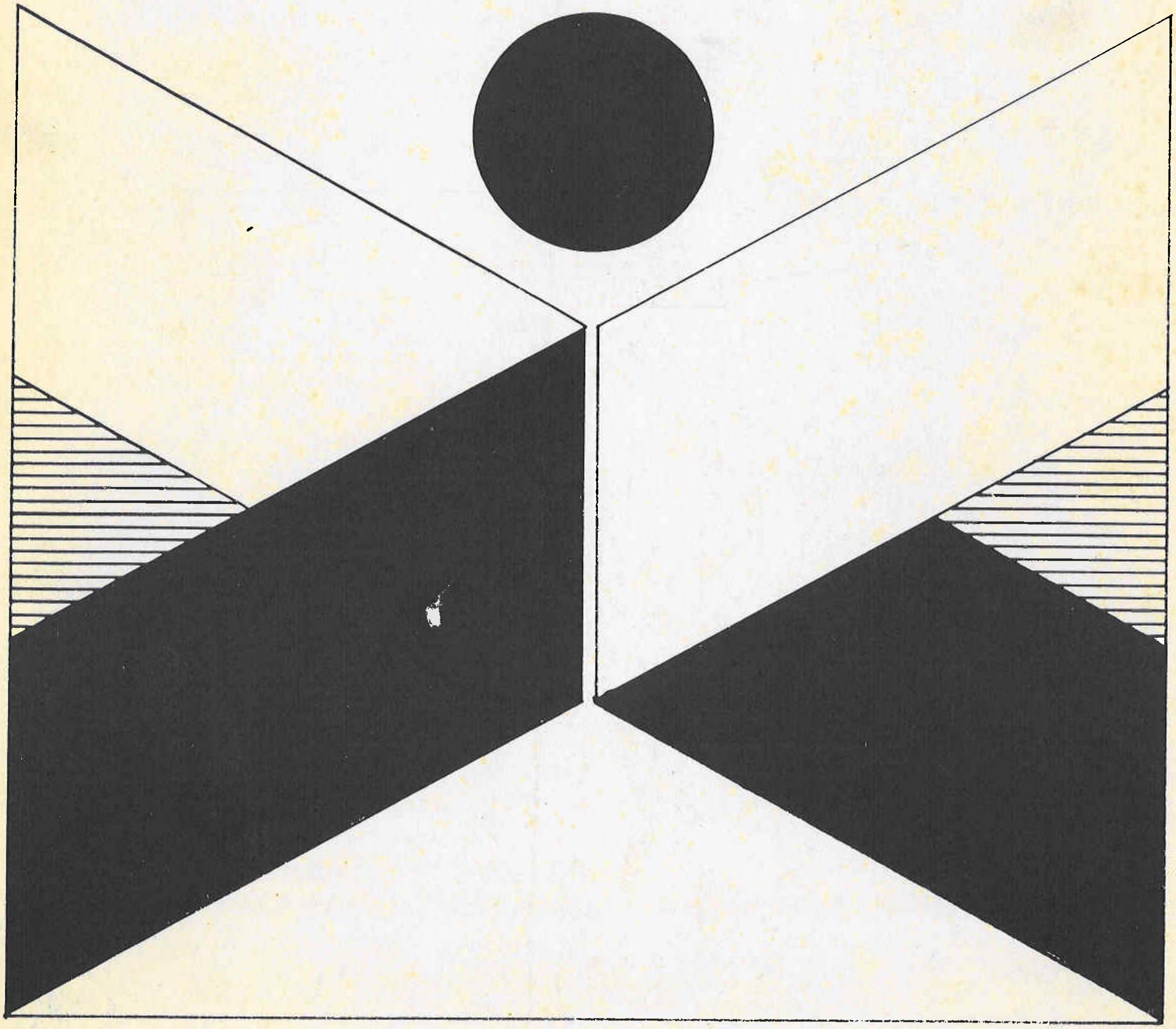
U.S. Department of Housing and Urban Development
Office of Policy Development and Research

Cooling and Heating Load Calculation Manual



Cooling and Heating Load Calculation Manual

Prepared by the
American Society of Heating, Refrigerating
and Air-Conditioning Engineers, Inc.

Under contract No. H-2303 for the
U.S. Department of Housing and Urban Development
Office of Policy Development and Research

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FOREWORD

Everyone involved in calculating heating loads will appreciate this manual because it details procedures for more accurate estimations. The more accurate and refined the procedures, the more certain it is that energy will be conserved. But energy-saving is not the only good; safety is equally essential. The introduction to Chapter 1 speaks emphatically to the safety issue, and I urge you to read it before proceeding to use the manual with confidence and success.

Donna E. Shalala
Assistant Secretary
for Policy Development
and Research

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ACKNOWLEDGMENTS

The development of this Load Calculation Manual is the result of many years of effort, primarily by the members of TC 4.1 Load Calculations and Data Committee of ASHRAE.

Jack Davis and Al Vener originated the idea for the Manual and their dedication brought the Manual to publication.

The present and past TC 4.1 Committee Chairmen, Ben Liebtag and Bob Roberson, guided the Manual project to completion.

The formal review by TC 4.1 was aided by Walt Bishop, Bill Holladay, Jim Grinnan, John Lamb and Dean Finn Carlson, with additional help from Dick Firsching, Don Gatley and Jim Carpenter.

Deeply appreciated are the understanding and encouragement of the Program Managers, J. F. Cuba of ASHRAE and K. Craedle of HUD.

The efforts of Carl MacPhee and Steve Comstock of ASHRAE, who converted the rough manuscript to printed form, are also appreciated.

Particular credit for completion of this Manual must go to the following Project staff members:

Dr. B.I. Leidy, Associate Project Director
Dr. J.E. Peterson, Associate Project Director
Kim Romanko
Lee Wilson
Jim Gaynor
Gary Solomon
Annette Grechen

Lastly, so many others contributed helpful suggestions, comments and criticisms that it is impossible to show a complete list. However, their assistance is acknowledged and appreciated.

In spite of all our efforts, omissions and errors are certain to occur; these, of course, are attributed to the authors alone. If a Manual user discovers an error or has a suggestion, we ask that he bring it to the attention of TC 4.1 Load Calculations and Data Committee of ASHRAE.

W. RUDOY
Project Director

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Reference 1. ASHRAE Handbook—1977 Fundamentals

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DEFINITIONS

absorptance: the capacity of a material to absorb radiant energy. Absorptance is the ratio of the radiant flux absorbed by a body to that incident to it.

air, dry: air without contained water vapor; air only.

air, outside: external air; atmosphere exterior to conditioned space; ambient (surrounding) air.

air, recirculated: return air passed through the conditioner before being again supplied to the conditioned space.

air, reheating of: in an air-conditioning system the final step in treatment, in the event the temperature is too low.

air, return: air returned from conditioned space.

air, saturated: moist air in which the partial pressure of the water vapor is equal to the vapor pressure of water at the existing temperature. This occurs when dry air and saturated water vapor coexist at the same dry-bulb temperature.

air, standard: air with a specific volume of 13.33 ft^3/lb.

air changes: a method of expressing the amount of air leakage into or out of a building or room in terms of the number of building volumes or room volumes exchanged.

air circulation: natural or imparted motion of air

air conditioning: the process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.

barometer: instrument for measuring atmospheric pressure.

blower: a fan used to force air under pressure.

boiler: a closed vessel in which a liquid is heated or vaporized.

boiling point: the temperature at which the vapor pressure of a liquid equals the absolute external pressure at the liquid-vapor interface.

British thermal unit (Btu): the Btu is defined as 778.177 foot-pounds if it is related to the IT calorie in such a way that 1 IT calorie per (kg) (C deg) = 1 Btu per (lb) (F deg), with 1 lb = 453.5924 g. Approximately, it is the heat required to raise the temperature of a pound of water from 59 F to 60 F.

bypass: a pipe or duct, usually controlled by valve or damper, for conveying a fluid around an element of a system.

bypass factor (BF): the fraction of air moving through a conditioning apparatus which is considered to pass through completely unaltered. (1 - BF) is frequently called the contact factor and is considered to be that portion of the air leaving the apparatus at the apparatus dewpoint.

capacity, air-conditioner, useful latent (dehumidifying): the available refrigerating capacity of an air conditioner for removing latent heat from the space to be conditioned.

capacity, air-conditioner, useful sensible: the available refrigerating capacity of an air conditioner for removing sensible heat from the space to be conditioned.

capacity, air-conditioner, useful total: the available refrigerating capacity of an air conditioner for removing sensible and latent heat from the space to be conditioned.

change of state: change from one phase, such as solid, liquid, or gas to another.

chilling (cooling): the lowering of the temperature of a substance by the removal of heat in the temperature range above freezing.

coil: a cooling or heating element made of pipe or tubing.

condensate: the liquid formed by condensation of a vapor. In steam heating, water condensed from steam; in air conditioning, water extracted from air, as by condensation on the cooling coil of a refrigeration machine.

condensation: the process of changing a vapor into liquid by the extraction of heat. Condensation of steam or water vapor is effected in either steam condensers or dehumidifying coils and the resulting water is called condensate.

conductance, thermal: the time rate of heat flow through a body (frequently per unit area) from one of its bounding surfaces to the other for a unit temperature difference between the two surfaces, under steady conditions.

conduction, thermal: the process of heat transfer through a material medium in which kinetic energy is transmitted by particles of the material from particle to particle without gross displacement of the particles.

conductivity, thermal: the time rate of heat flow through unit area and unit thickness of a homogeneous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to area. Materials are considered homogeneous when the value of the thermal conductivity is not affected by variation in thickness or in size of sample within the range normally used in construction.

conservation of energy: the principle which assumes that energy can be neither created nor destroyed.

convection: transfer of heat by movement of fluid.

convection, forced: convection resulting from forced circulation of a fluid, as by a fan, jet or pump.

convection, natural: circulation of gas or liquid (usually air or water) due to differences in density resulting from temperature changes.

cooling, direct method of: a system in which the evaporator is in direct contact with the material or space refrigerated or is located in air circulating passages communicating with such spaces.

cooling, evaporative: involves the adiabatic exchange of heat between air and a water spray or wetted surface. The water assumes the wet-bulb temperature of the air, which remains constant during its traverse of the exchanger.

cooling, indirect method of: a system in which a liquid, such as brine or water, cooled by the refrigerant, is circulated to the material or space refrigerated or is used to cool air so circulated.

cooling, surface: a method of cooling air or other gas by passing over cold surfaces.

cooling coil: an arrangement of pipe or tubing which transfers heat from air to a refrigerant or brine.

cooling effect, sensible, air cooler: the difference between the total effect and the dehumidifying effect.

cooling effect, total: the difference between total enthalpy of the dry air and water vapor mixture entering a unit per hr and the total enthalpy of the dry air and water vapor (and water) mixture leaving the unit per hr, expressed in Btu per hr.

cooling element: heat transfer surface containing refrigerating fluid in location where refrigerating effect is desired.

cooling load: the rate at which heat must be extracted from a space to maintain a desired room condition.

Cooling Load Temperature Difference (CLTD): an equivalent temperature difference used for calculating the instantaneous external cooling loads across a wall or roof ($CLTD = q/UA$). When used for glass, the CLTD calculates only the conduction cooling load; that is $q = q_{conduction}$ rather than q_{total}.

cooling medium: any substance whose temperature is such that it is used, with or without a change of state, to lower the temperature of other bodies or substances.

cooling range: in a water cooling device, the difference between the average temperature of the water entering the device and the average temperature of the water leaving it.

cooling water: water used for condensation of refrigerant; condenser water.

cooling of air: reduction in air temperature due to the abstraction of heat as a result of contact with a medium held at a temperature lower than that of the air. Cooling may be accompanied by moisture addition (evaporation), by moisture extraction (dehumidification), or by no change whatever of moisture content.

curtain wall: exterior wall construction of a building which does not contribute to the structural support.

cycle: a complete course of operation of working fluid back to a starting point, measured in thermodynamic terms (functions). Also used in general for any repeated process on any system.

damper: a device used to vary the volume of air passing through an air outlet, inlet, or duct.

declination of sun: the angle above or below the equatorial plane. It is plus if north of the plane, and minus if below. Celestial objects are located by declination.

degree day: a unit, based upon temperature difference and time, used in estimating fuel consumption and specifying nominal heating load of a building in winter. For any one day, when the mean temperature is less than 65 F, there exist as many degree days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65 F.

dehumidification: the condensation of water vapor from air by cooling below the dewpoint or removal of water vapor from air by chemical or physical methods.

dehumidifier: (1) an air cooler or washer used for lowering the moisture content of the air passing through it; (2) an absorption or adsorption device for removing moisture from air.

dehumidifier, surface: an air-conditioning unit, designed primarily for cooling and dehumidifying air through the action of passing the air over wet cooling coils.

dehumidifying effect: the heat removed in reducing the moisture content of air, passing through a dehumidifier, from its entering to its leaving condition.

dehumidifying effect, air cooler: the product of the weight of moisture condensed in the cooler by the constant 1060.

density: the ratio of the mass of a specimen of a substance to the volume of the specimen. The mass of a unit volume of a substance. When weight can be used without confusion, as synonymous with mass, density is the weight per unit volume.

design day: day for which load calculations are made.

dewpoint, apparatus: that temperature which would result if the psychometric process occurring in a dehumidifier, humidifier or surface-cooler were carried to the saturation condition of the leaving air while maintaining the same ratio of sensible to total heat load in the process.

dewpoint rise: increase in moisture content (specific humidity) of air expressed in terms of rise in dewpoint temperature.

dewpoint, room: the temperature at which condensation of water vapor in the room (space) begins for a given state of humidity and pressure as the vapor temperature is reduced; the temperature corresponding to saturation (100% relative humidity) for a given absolute humidity at constant pressure.

dimensions, overall: the projected dimensions of a device, usually on horizontal and vertical planes, that can be used to determine whether the device will fit in an assigned space or can be moved through a designated passageway.

draft: a current of air, when referring to the pressure difference which causes a current of air or gases to flow through a flue, chimney, heater, or space; or to a localized effect caused by one or more factors of high air velocity, low ambient temperature, or direction of air flow, whereby more heat is withdrawn from a person's skin than is normally dissipated.

duct: a passageway made of sheet metal or other suitable material, not necessarily leaktight, used for conveying air or other gas at low pressures.

duct air leakage: air which leaks out of supply air ducts.

duct heat gain or loss: heat transfer from or to the air flowing inside supply or return ducts.

duct system: a series of ducts, elbows and connectors to convey air from one location to another.

duct, warm air: in heating, ventilating, and air conditioning: pipes or ducts for conveying warm air into or out of a space or room.

effective area: the net area of an outlet or inlet device through which air can pass; it is equal to the free area of the device times the coefficient of discharge.

effective surface temperature (t_{es}): the assumed uniform surface temperature which would produce the same leaving air conditions as the non-uniform surface temperature that actually occurs on an air conditioning apparatus in operation. (See apparatus dewpoint).

emittance: the capacity of a material to emit radiant energy. Emittance is the ratio of the total radiant flux emitted by a body to that emitted by an ideal black body at the same temperature.

energy: the capacity for doing work; taking a number of forms, which may be transformed from one into another, such as thermal (heat), mechanical (work), electrical and chemical; in customary units, measured in kilowatt-hours (kWh) or British thermal units (Btu).

energy, internal: the sum of all the kinetic and potential energies contained in a substance due to the states of motion and separation of its several molecules, atoms and electrons. It includes sensible heat (vibration energy) and that part of the latent heat that is represented by the increase in energy during evaporation.

enthalpy: thermodynamic property of a substance defined as the sum of its internal energy plus the quantity Pv/J, where P = pressure of the substance, v = its volume, and J = the mechanical equivalent of heat. Formerly called *total heat* and *heat content*.

enthalpy, specific: enthalpy per unit mass of a substance.

enthalpy deviation: difference between the enthalpy of an air-water mixture and the enthalpy of an air-water mixture at saturation, at the same wet bulb temperature - measured in Btu per pound of dry air.

entropy: the ratio of the heat added to a substance to the absolute temperature at which it is added.

entropy, specific: entropy per unit mass of a substance.

evaporation: change of state from liquid to vapor.

evaporative equilibrium (of a wet-bulb instrument): the condition attained when the wetted wick has reached a stable and constant temperature (when the instrument is exposed to air at velocities over 900 fpm, this temperature may be considered to approach the true wet-bulb temperature.)

exfiltration: air flow outward through a wall, leak, membrane, etc.

Fahrenheit: a thermometric scale in which 32 deg denotes freezing and 212 deg the boiling point of water under normal pressure at sea level (14.696 psi).

fan: an air-moving device comprising a wheel or blade, and housing or orifice plate.

fan, attic: an exhaust fan to discharge air near the top of a building while cooler air is forced (drawn) in at a lower level.

film coefficient: the time rate of heat flow per unit area under steady conditions between a surface and a fluid for unit temperature difference between the surface and the fluid.

filter: a device to remove solid material from a fluid.

floor area, gross: the sum of the areas of the several floors of the building including basements, mezzanine and intermediate-floored tiers and penthouses of headroom height, measured from the exterior faces of exterior walls as from the centerline of walls separating buildings.

- Covered walkways, open roofed-over areas, porches and similar spaces shall be excluded.
- The gross floor area does not include such features as pipe trenches, exterior terraces or steps, chimneys, roof overhangs, etc.

fluid: gas, vapor, or liquid.

fluid, heat transfer: any gas, vapor, or liquid used to absorb heat from a source at a high temperature and reject it to a lower temperature substance.

fog: suspended liquid droplets generated by condensation from the gaseous to the liquid state, or by breaking up a liquid into a dispersed state, such as by splashing, foaming, and atomizing.

forced circulation air cooler: a cooler which includes a fan or a blower for positive air circulation.

free area: the total minimum area of the openings in an air inlet or outlet through which air can pass.

freezing point: temperature at which a given liquid substance will solidify or freeze upon removal of heat. Freezing point for water is 32 F.

furnace: that part of a boiler or warm air heating plant in which combustion takes place. Also a complete heating unit for transferring heat from fuel being burned to the air supplied to a heating system.

heat: the form of energy that is transferred by virtue of a temperature difference.

heat gain: rate at which heat is added to or generated within a space.

heat, latent: change of enthalpy during a change of state, usually expressed in Btu per lb. With pure substances, latent heat is absorbed or rejected at constant pressure.

heat, sensible: heat which is associated with a change in temperature; specific heat exchange of temperature; in contrast to a heat interchange in which a change of state (latent heat) occurs.

heat, specific: the ratio of the quantity of heat required to raise the temperature of a given mass of any substance one deg to the quantity required to raise the temperature of an equal mass of a standard substance (usually water at 59 F) one deg.

heat capacity: the amount of heat necessary to raise the temperature of a given mass one degree. Numerically, the mass multiplied by the specific heat.

heat conductor: a material capable of readily conducting heat. The opposite of an insulator or insulation.

heat exchanger: a device specifically designed to transfer heat between two physically separated fluids.

heat transfer, transient: the rate of heat flow in a system varies with time i.e., the temperature at any point changes.

heat transmission: any time-rate of heat flow; usually refers to conduction, convection and radiation combined.

heat transmission, steady-state: the rate of heat flow in a system is constant i.e., the temperature at any point does not change.

heat transmission coefficient: any one of a number of coefficients used in the calculation of heat transmission by conduction, convection, and radiation, through various materials and structures. (See *thermal conductance, thermal conductivity, thermal resistance, thermal resistivity, thermal transmittance,* etc.)

humidifier: a device to add moisture to air.

humidify: to add water vapor to the atmosphere; to add water vapor or moisture to any material.

humidifying effect: the latent heat of vaporization of water at the average evaporating temperature times the number of pounds of water evaporated per hour, in Btu per hr.

humidity: water vapor within a given space.

humidity, absolute: the weight of water vapor per unit volume.

humidity, percentage: the ratio of the specific humidity of humid air to that of saturated air at the same temperature and pressure, usually expressed as a percentage (degree of saturation; saturation ratio).

humidity ratio: see *humidity, specific.*

humidity, relative: the ratio of the mol fraction of water vapor present in the air, to the mol fraction of water vapor present in saturated air at the same temperature, and barometric pressure; approximately, it equals the ratio of the partial pressure or density of the water vapor in the air, to the saturation pressure or density, respectively, of water vapor at the same temperature.

humidity, specific: the ratio of the mass of the water vapor to the mass of dry air contained in the sample.

HVAC: heating, ventilating and air conditioning.

ice point: temperature at which water freezes under normal atmospheric pressure (14.696 psig), 32 F; 0 C.

inch of water: a unit of pressure equal to the pressure exerted by a column of liquid water 1 in. high at a temperature of 4 C or 39.2 F.

infiltration: air flowing inward as through a wall, crack, etc.

insulation, fill: granulated, shredded, or powdered material, prepared from vegetable, animal, or mineral origin. It can come in bulk or batt form.

insulation (thermal): a material having a relatively high resistance to heat flow, and used principally to retard the flow of heat.

internal load: any load due to sources contained in the space such as machinery waste heat, lighting, or people.

irradiation: quantity of radiant energy incident on a surface per unit time and unit area.

isobaric: an adjective used to indicate a change taking place at constant pressure.

isothermal: an adjective used to indicate a change taking place at constant temperature.

load: the amount of heat per unit time imposed on a system, or the required rate of heat removal.

load, external source: any load due to sources external to the space such as conduction through walls or radiation through glass.

load factor: ratio of actual mean load to a maximum load or maximum production capacity in a given period.

louver: an assembly of sloping vanes intended to permit air to pass through and to inhibit transfer of water droplets.

manometer: an instrument for measuring pressures: essentially a U-tube partially filled with a liquid, usually water, mercury, or a light oil, so constructed that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

melting point: for a given pressure, the temperature at which the solid and liquid phases of a substance are in equilibrium.

millimetre of mercury: a unit of pressure equal to the pressure exerted by a column of mercury 1 mm high at a temperature of 0 C.

on-center (o.c.): average distance between the centers of two adjacent members in any type of repetitive network such as the distance between the centers of two studs in the internal framework of a wall or roof.

outlet, ceiling: a round, square, rectangular, or linear air diffuser located in the ceiling, which provides a horizontal distribution pattern of primary and secondary air over the occupied zone and induces low velocity secondary air motion through the occupied zone.

outside air opening: any opening used as an entry for air from outdoors.

overall coefficient of heat transfer: see transmittance, thermal.

plenum chamber: an air compartment connected to one or more distributing ducts.

pounds of dry-air: the basis for all psychrometric calculations; remains constant during most psychrometric processes. The amount of water vapor associated with each pound of dry air is variable for general processes.

preheating: in air conditioning, to heat the air in advance of other processes.

pressure: the normal force exerted by a homogeneous liquid or gas, per unit of area, on the wall of its container.

pressure, atmospheric: the pressure due to the weight of the atmosphere. It is the pressure indicated by a barometer. Standard Atmospheric Pressure or Standard Atmosphere is the pressure of 76 cm of mercury having a density of 13.5951 grams per cu cm, under standard gravity of 980.665 cm per (sec) (sec). It is equivalent to 14.696 psi or 29.921 in. of mercury at 32 F.

pressure, gage: pressure above atmospheric.

pressure, saturation: the saturation pressure for a pure substance for any given temperature is that pressure at which vapor and liquid, or vapor and solid, can coexist in stable equilibrium.

pressure, static: (1) the pressure with respect to a stationary surface tangent to the mass flow velocity vector; (2) the pressure with respect to a surface at rest in relation to the surrounding fluid.

pressure, total: in the theory of the flow of fluids, the sum of the static pressure and the velocity pressure at the point of measurement. Also called *dynamic pressure.*

pressure, vapor: the pressure exerted by a vapor. If a vapor is kept in confinement over its liquid so that the vapor can accumulate above the liquid, the temperature being held constant, the vapor pressure approaches a fixed limit called the maximum, or saturated, vapor pressure, dependent only on the temperature and the liquid. The term *vapor pressure* is sometimes used as synonymous with *saturated vapor pressure.*

pressure, velocity: in moving fluid, the pressure capable of causing an equivalent velocity, if applied to move the same fluid through an orifice such that all pressure energy expended is converted into kinetic energy.

pressure drop: static pressure loss in fluid pressure, as from one end of duct to the other, due to friction, etc.

properties, thermodynamic: basic qualities used in defining the condition of a substance, such as temperature, pressure, volume, enthalpy, entropy.

psychrometer: an instrument for ascertaining the humidity or hygrometric state of the atmosphere.

psychrometric chart: a graphical representation of the thermodynamic properties of moist air.

psychometry: the branch of physics relating to the measurement or determination of atmospheric conditions, particularly regarding the moisture mixed with the air.

radiation, thermal: the transmission of heat through space by wave motion; the passage of heat from one object to another without warming the space between.

range (cooling range): in a water cooling device, the difference between the average temperature of the water entering the device, and the average temperature of the water leaving it.

reflectance: the ratio of the light reflected by a surface to the light falling upon it.

refrigerant: the fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects heat at a higher temperature and a higher pressure of the fluid, usually involving changes of phase of the fluid.

resistance, thermal: the reciprocal of thermal conductance.

resistivity, thermal: the reciprocal of thermal conductivity.

return air: air returned from conditioned space.

saturation: the condition for coexistence in stable equilibrium of a vapor and liquid or a vapor and solid phase of the same substance. Example: Steam over the water from which it is being generated.

saturation efficiency: a measure of the effectiveness of a spray chamber - sometimes called contact or performance factor. (Not to be confused with degree of saturation.) It can be considered to represent that portion of the air passing through the spray chamber which contacts the spray water surface; that is, a complement of a bypass factor. This "contacted" air is considered to leave the spray chamber at the effective temperature of the spray water; that is, the temperature at complete saturation of the air.

saturation temperature: for a fluid, the boiling point corresponding to a given pressure; evaporation temperature; condensation temperature.

sensible heat ratio: the ratio of sensible cooling effect to total cooling effect of an air cooler.

shading coefficient (SC): is the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar heat gain through a single light of double strength sheet glass under the same set of conditions.

solar constant: the solar radiation intensity incident on a surface normal to the sun's rays outside the earth's atmosphere at a distance from the sun equal to the mean distance between the earth and the sun. Its value is 428.8 Btuh/ft^2 (1353 $W \cdot m^{-2}$).

spray-type air-cooler: a forced circulation air cooler wherein the coil surface capacity is augmented by a liquid spray during period of operation.

stack effect: the tendency of air or gas in a duct or other vertical passage to rise when heated due to its lower density compared with that of the surrounding air or gas. In buildings, the tendency toward displacement (caused by the difference in temperature) of internal heated air by unheated outside air due to the difference in density of outside and inside air.

stack height: the height of a gravity convector between the bottom of the heating unit and top of the outlet opening.

sun effect: solar energy transmitted into space through windows and building materials.

surface, heating: the exterior surface of a heating unit. *Extended heating surface* (*or extended surface*): Heating surface consisting of fins, pins, or ribs which receive heat by conduction from the prime surface. *Prime surface*: Heating surface having the heating medium on one side and air (or extended surface) on the other.

system: a heating or refrigerating scheme or machine, usually confined to those parts in contact with heating or refrigerating medium.

system, year-round air-conditioning: one which ventilates, heats and humidifies in winter and cools and dehumidifies in summer the spaces under consideration, and provides the desired degree of air motion and cleanliness.

system efficiency, overall: the ratio of the useful energy (at the point of use) to the thermal energy input for a designated time period, expressed in percent.

temperature, dewpoint: The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 percent relative humidity) for a given absolute humidity at a constant pressure.

temperature, dry-bulb: the temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

temperature, room: temperature of any room, as for example (1) a room in which a refrigerator is being operated or tested; (2) a room being conditioned for the comfort of occupants. Used colloquially to mean ordinary temperature one is accustomed to find in dwellings.

temperature, wet-bulb: thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications.

temperature difference, mean: mean of differences between temperatures of a fluid receiving and a fluid yielding heat.

thermometer: an instrument for measuring temperature.

ton of refrigeration: a useful refrigerating effect equal to 12,000 Btu per hr; 200 Btu per min.

tower, water-cooling: an enclosed device for evaporatively cooling water by contact with air.

transmission: in thermodynamics, a general term for heat travel; properly, heat transferred per unit of time.

transmittance: the capacity of a material to transmit radiant energy. Transmittance is the ratio of the radiant flux transmitted through a body to that incident to it.

transmittance, thermal (*U* factor): the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids.

vapor: a gas, particularly one near to equilibrium with the liquid phase of the substance and which does not follow the gas laws. Usually used instead of gas for a refrigerant, and in general, for any gas below the critical temperature.

vapor, saturated: vapor in equilibrium with its liquid; that is, when the numbers, per unit time, of molecules passing in two directions through the surface dividing the two phases are equal.

vapor, superheated: vapor at a temperature which is higher than the saturation temperature (*i.e.* boiling point) at the existing pressure.

vapor, water: used commonly in air conditioning parlance to refer to steam in the atmosphere.

vapor barrier: a moisture-impervious layer applied to the surfaces enclosing a humid space to prevent moisture travel to a point where it may condense due to lower temperature.

velocity: a vector quantity which denotes at once the time rate and the direction of a linear motion.

velocity, outlet: the average discharge velocity of primary air being discharged from the outlet, normally measured in the plane of the opening.

velocity, room: the average sustained residual air velocity level in the occupied zone of the conditioned space, e.g., 65, 50, 35 fpm.

ventilation: the process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned. Often refers to outside air supplied to space.

volume, specific: the volume of a substance per unit mass; the reciprocal of density.

wall area, gross: the vertical projection of the exterior wall area bounding interior space which is conditioned by an energy-using system; includes opaque wall, window and door areas.

zone, comfort: *(average)*: the range of effective temperatures over which the majority (50 percent or more) of adults feel comfortable; (*extreme*): the range of effective temperatures over which one or more adults feel comfortable.

zone: a space or group of spaces within a building with heating and or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device.

CHAPTER 1

INTRODUCTION AND OVERVIEW

This Manual is for the use of both the experienced practicing engineer and the person new to the field of the calculation of heating and cooling loads.

The primary objective is to provide a convenient, consistent, and accurate method of calculating these loads and to enable the designer to select systems that meet the requirements for efficient energy utilization and are also responsive to environmental needs. Wherever possible, the references and recommendations of ASHRAE Standard 90 and HUD Minimum Property Standards have been included in the Manual.

Although ASHRAE continually has improved the accuracy of the load calculations procedure, many engineers and designers have found a need for a more detailed explanation of the procedure to go along with that increased technical accuracy. The procedure as described in the 1977 edition of the ASHRAE Handbook of Fundamentals shows a substantive change from that in the 1972 edition; therefore, this Manual is to supplement, but not replace, the ASHRAE Handbook, other handbooks, and other ASHRAE publications.

The cooling load obtained by the procedure described herein will generally agree within 5 percent of the results of the Transfer Function Method outlined in the 1977 ASHRAE Handbook of Fundamentals.

One note of caution: the ability to estimate loads more accurately due to changes in the calculation procedure provides a lessened margin of error. Therefore, it becomes increasingly important to survey and check more carefully the load sources, each item in the load, and the effects of system type on the load. This tightening up on the hidden safety factors occurs for a number of reasons. There is greater emphasis, by standards and codes, on sizing equipment closer to the expected loads, as determined by outside design weather conditions at the 2½% summer value and the 97½% winter value. Also, the suggested indoor design temperatures are now usually 78 F for cooling and 72 F for heating. Installed lighting levels are being reduced and the calculations are using lighting loads closer to the actual loads. **All of these factors require that the designer introduce any margin of safety by a positive action, rather than rely on an assumed hidden margin.**

The first part of the Manual contains the bulk of technical data, tables and graphs required for making calculations. It contains relatively little descriptive material.

The Appendix provides more detailed information, as well as supplementary technical data. In particular the titles of Chapters 3 through 6 are repeated in the Appendix. Appearing only in the first part are Chapters 2 and 7 and any other material which needs no further elaboration. Examples of the use of the material in the first part are inserted as closely as possible to the appropriate table or graph. The examples are numbered sequentially within each chapter. For instance, Example 4.3 is the third problem in Chapter 4. These examples illustrate the typical uses of the tables, including any variations in the use of the tables for corrections or adjustments.

Any suggestions or corrections in the Manual text should be brought to the attention of ASHRAE TC 4.1 — Load Calculations and Data.

1.1 PURPOSE OF LOAD CALCULATIONS

Load calculations can be used to accomplish one or more of the following objectives:

- Provide information for equipment selection and HVAC system design
- Provide data for evaluation of the optimum possibilities for load reduction
- Permit analysis of partial loads as required for system design, operation and control

These objectives can be obtained not only by making accurate load calculations but also by understanding the basis for the loads. Therefore, a brief description of cooling and heating loads is included.

1.2 PRINCIPLES OF COOLING LOADS (REFER TO FIG. 1.1)

In air conditioning design there are three distinct but related heat flow rates, each of which varies with time:

1. Heat Gain or Loss
2. Cooling Load or Heating Load
3. Heat Extraction or Heat Addition Rate

Heat Gain, or perhaps more correctly, instantaneous rate of heat gain, is the rate at which heat enters or is generated within a space at a given instant of time. There are two ways that heat gain is classified. They are the manner in which heat enters the space and the type of heat gain.

The manner in which a load source enters a space is indicated as follows:

1. Solar radiation through transparent surfaces such as windows
2. Heat conduction through exterior walls and roofs
3. Heat conduction through interior partitions, ceilings and floors
4. Heat generated within the space by occupants, lights, appliances, equipment and processes
5. Loads as a result of ventilation and infiltration of outdoor air
6. Other miscellaneous heat gains

The types of heat gain are sensible and latent. Proper selection of cooling and humidifying equipment is made by determining whether the heat gain is sensible or latent. Sensible heat gain is the direct addition of heat to an enclosure, apart from any change in the moisture content, by any or all of the mechanisms of conduction, convection and radiation. When moisture is

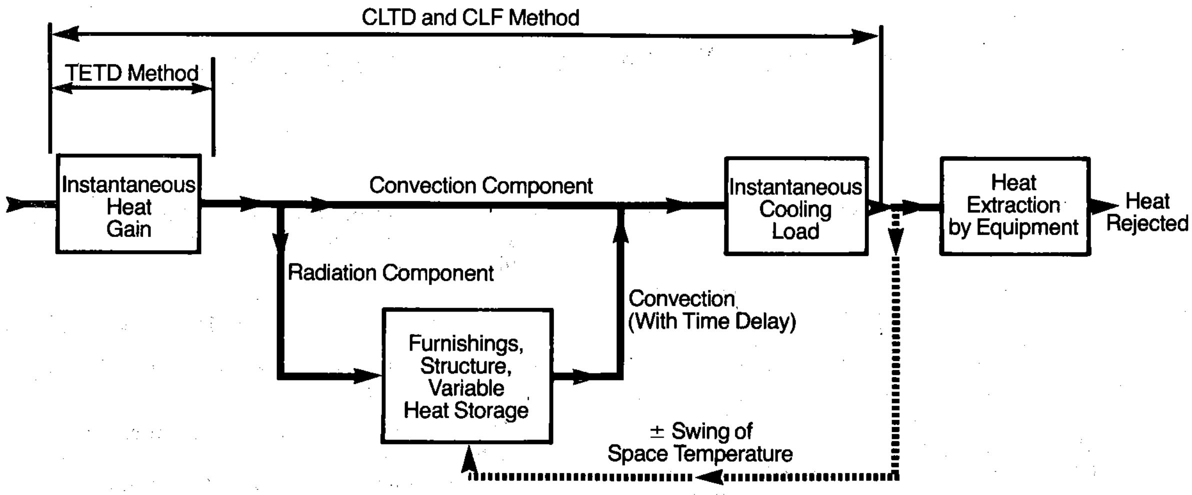

Fig. 1.1 Schematic of Load Transfer

added to the space, for example, by vapor emitted by the occupants, there is an energy quantity associated with that moisture which must be accounted for.

If a constant humidity ratio is to be maintained in the enclosure, then water vapor must be condensed out in the cooling apparatus at a rate equal to its rate of addition in the space. The amount of energy required to do this is essentially equal to the product of the rate of condensation per hour and the latent heat of condensation. This product is called the latent heat gain.

As a further example, the infiltration of outdoor air with a high dry-bulb temperature and a high humidity ratio, and the corresponding escape of room air at a lower dry-bulb temperature and a lower humidity ratio, would increase both the sensible heat gain and the latent heat gain of the space.

The proper design of an air conditioning system requires the determination of the sensible heat gain in the space, the latent heat gain in the space, and a value for the total load, sensible plus latent, of the outdoor air used for ventilation.

The sensible cooling load is defined as the rate at which heat must be removed from the space to maintain the room air temperature at a constant value. The summation of all instantaneous sensible heat gains at a specific time does not necessarily equal the sensible cooling load for the space at that time. The latent load, however, is essentially an instantaneous cooling load. That part of the sensible heat gain which occurs by radiation is partially absorbed by the surfaces and contents of the space and is not felt by the room air until some time later. The radiant energy must first be absorbed by the surfaces that enclose the space, such as walls and floor, and by furniture and other objects. As soon as these surfaces and objects become warmer than the air, some heat will be transferred to the air in the room by convection. The heat storage capacity of the building components and items, such as walls, floors and furniture, governs the rate at which their surface temperatures increase for a given radiant input. Thus, the interior heat storage capacity governs the relationship between the radiant portion of the sensible heat gain and how it contributes to the cooling load. The thermal storage effect can be important in determining the cooling equipment capacity.

The actual total cooling load is, generally, less than the peak total instantaneous heat gain, thus requiring smaller equipment than would be indicated by the heat gain. If the design is based on the instantaneous heat gain, the rest of the system may be oversized as well.

Heat extraction rate is the rate at which heat is removed from the conditioned space. Normal control systems operating in conjunction with the intermittent operation of the cooling equipment will cause a "swing" in room temperature. Therefore, the room air temperature is constant only at those rare times when the heat extraction rate equals the cooling load. Consequently, the computation of the heat extraction rate gives a more realistic value of energy removal at the cooling equipment than does just the instantaneous value of the cooling load provided the control system is simulated properly. The determination of the heat extraction rate must include the characteristics of the cooling equipment and the operating schedule of the equipment, in addition to the various sources of cooling load.

If the equipment is operated somewhat longer before and after the peak load periods, and/or the temperature in the space is allowed to rise a few degrees at the peak periods during the cooling operation (floating temperature), a reduction in the design equipment capacity may be made. A smaller system, operating for longer periods at times of peak loads will produce a lower first cost to the customer with commensurate lower demand charges and lower operating costs. Generally, equipment sized to more nearly meet the cooling requirements results in a more efficient, better operating system particularly when it is at a partially loaded condition.

Usually a fraction of the sensible heat gain does not appear as a cooling load, but instead is shifted to the surroundings. This fraction, F_c, depends upon the thermal conductance between the room air and the surroundings. It may also be considered as an adjustment factor which results when the load components are superimposed.

The adjustment factor, F_c, is calculated by the following equation:

$$F_c = 1 - 0.02\, K_T$$

where K_T, the unit length conductance between the room air and surroundings in Btu/(hr · ft^2 · F), is given by:

$$K_T = \frac{1}{L_F}(U_w A_w + U_{ow} A_{ow} + U_c A_c)$$

where

L_F = length of the exterior walls of the room, ft.

U = U-value of the room enclosure element (subscript w for window, ow for outside wall, and c for corridor), Btu/(hr · ft^2 · F).

A = area of the specific element, ft^2.

If the cooling load component has already been obtained by the technique used in this Manual, multiply that result by the calculated F_c factor.

Diversity of Cooling Loads

Diversity of cooling load results from not using part of the load on a design day. Therefore, diversity factors are factors of usage and are applied to the refrigeration capacity of large air conditioning systems. These factors vary with location, type, and size of application, and are based entirely on the judgment and experience of the engineer.

Generally, diversity factors can be applied to loads from people and lights; there is neither 100% occupancy nor total lighting at the time of such other peak loads as peak solar and transmission loads. The reductions in cooling loads from nonuse are real and should be accounted for.

Table 1.1 lists some typical diversity factors for large buildings. In addition to the factors for people and lights, a factor should also be applied to the machinery load in industrial buildings. For instance, electric motors may operate at a continuous overload, or may operate continuously at less than the rated capacity, or may operate intermittently. It is advisable to measure the power input whenever possible; this will provide a diversity factor. It is also possible to determine a diversity factor for a large existing building by reviewing the maximum electrical demand and monthly energy consumption obtained from the utility bills.

Table 1.1 Typical Diversity Factors For Large Buildings (Apply to Refrigeration Capacity)

Type of Application	Diversity Factor	
	People	Lights
Office	0.75 to 0.90	0.70 to 0.85
Apartment, Hotel	0.40 to 0.60	0.30 to 0.50
Department Store	0.80 to 0.90	0.90 to 1.0
Industrial*	0.85 to 0.95	0.80 to 0.90

Equation:

Cooling Load (for people and lights), Btu/hr
= (Heat Gain, Btu/hr)
× (Cooling Load Factor) × (Diversity Factor, above table)

*A diversity factor should also be applied to the machinery load.

Supply Air Calculations

Calculations for the design supply air quantities, the design refrigeration load and the reheat capacity, if any, are dependent upon the type of system used. In common use are variable air volume systems, induction systems, double duct systems or fan coil systems. However, some generalizations can be made that may assist in the use of the cooling load calculations for equipment design and selection. The design supply air quantities required are based on the peak load requirements for each space. The peak load on an air conditioning unit serving several zones is rarely equal to the sum of the peak loads of each zone. Therefore, if the system selection allows the air flow to each zone to vary, then the total volume of air necessary for the system will only be that amount necessary to handle the maximum coincident load on the system. This may require additional load calculations to determine the maximum coincident load. The total load on the unit is that imposed by the maximum coincident load plus ventilation, mixing losses, and perhaps reheat. These additional loads will need to be calculated separately.

Peak Load — Time of Day and Month of Year

The first approximation to be made, after dividing the conditioned areas into zones, is to estimate the time of the peak load for each zone and for the entire conditioned area for each zone. Most residential single family and multifamily applications and similar low internal load applications are more sensitive to the loads on the building envelope. Therefore, they generally will peak when the solar effect through the glass and the load through the roof are at their highest, usually in the late afternoon. For other types of applications where lights, people and other internal loads are more dominant, the hour of the peak load generally will depend on the relative magnitude and peak hours of the following loads.

LOAD	REFERENCE FOR PEAK TIME
1. Solar load through glass.	1. Check Table 3.25 for the peak hour for the orientation of the major glass area.
2. Lighting load.	2. Check Table 4.4 for appropriate lighting schedule and profile
3. Ventilation load, if imposed on this system.	3. Peaks at 1500 hr (3:00 PM) solar time. (Assuming a constant ventilation rate).
4. Roof load, if present.	4. Check Table 3.8 for appropriate type of roof and peak time.

Most conditioned areas with more than one glass exposure and with normal daytime occupancies will peak between 1300 and 1800 hours solar time. Exceptions generally are due to glass exposures on the northeast to southeast orientations or due to occupancy schedules such as those for restaurants or theaters. The load calculation forms are designed to permit calculations to be made conveniently for three different times. This should be sufficient to bracket the peak load.

The month in which the peak load occurs will depend upon the changes in solar loads each month and the changes in design weather conditions. Possible seasonal variation of internal loads, such as people, are also important.

The solar load, indicated in Table 3.25, is lowest in the summer months for the southeast through southwest exposures and greatest in the summer months for the west through north to east exposures.

The design outside dry bulb temperature, as shown in Table 2.2, drops off from the summer months. If the combination of solar load on the southern quadrant orientations and a seasonal increase in internal loads is greater than the effects of lower design outdoor conditions, then the peak load may occur in September, October or even during the Christmas season in December. For example, for Birmingham, Alabama, a

comparison between July and October shows the solar load on the south glass is three times greater in October. The east and west glass solar loads remain almost constant. The solar load on the north glass is cut in half, but it is small in magnitude. The outside design dry bulb temperature drops from 94 to 84 F. Consequently, it is easy to visualize a building with its largest glass area facing south having its maximum cooling load occurring in October for example.

Fig. 1.2 shows the profile of a cooling load for an office with a west exposure. The solid curve, Fig. 1.2A, is the cooling load with a constant space temperature maintained over a 24-hour operation. If the maximum cooling capacity available is represented by A, and if the capacity is controlled to maintain a constant temperature at partial loads below capacity, "A", when the actual cooling load exceeds the available cooling capacity, the temperature will swing as shown in the dashed curve. The cooling load with temperature swing is shown by the dashed curve (Fig. 1.2A). If no temperature swing can be allowed, then the air conditioning equipment must have the greater capacity indicated by point "B" on Fig. 1.2A. The additional energy required for that one condition can be approximated by the area between the two curves of Fig. 1.2A.

When a system is designed to allow a temperature swing, the maximum swing occurs only at the peak on design days. Under normal operating conditions, the temperature remains constant or close to constant. Engineers are not unanimous on the maximum acceptable temperature swing, but 3 deg F is viewed as a practical value for most comfort applications.

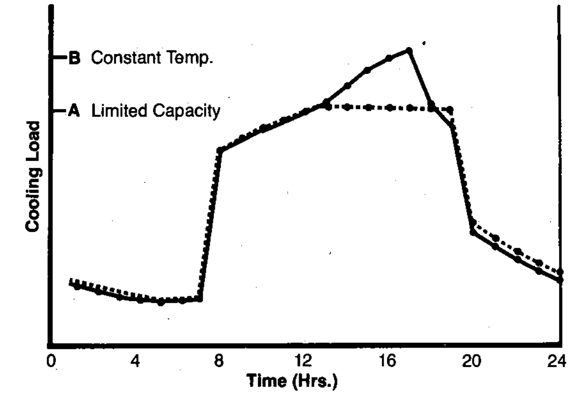

Fig. 1.2A Load Profile

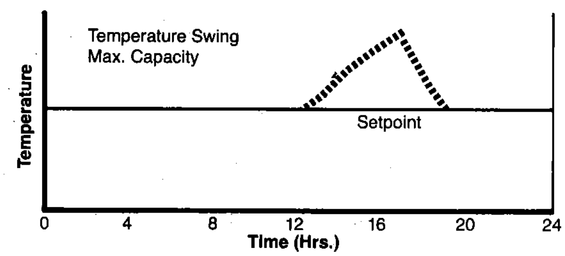

Fig. 1.2B Temperature Profile

Obtaining Cooling Load Components From Load Sources

The sensible cooling load component resulting from a specific sensible load source is calculated for a given time by use of a conversion factor from tables of "Cooling Load Temperature Differences" (CLTD) or "Cooling Load Factors" (CLF). The cooling loads for external roofs, external walls, and conduction through external glass (fenestration) are calculated in a one step process using CLTD factors. This one step process replaces the former Total Equivalent Temperature Difference (TETD) Method of calculating the heat gain and then converting it to a cooling load. The cooling load from any other sensible heat source, such as the glass solar load or lights, for example, is calculated by multiplying the instantaneous heat gain by a CLF factor. Thus, both the CLTD and CLF procedures include the effect of the time lag between the sensible heat gain and the cooling load due to temporary storage of the radiation component in interior furnishings and structure. (Fig. 1.1, CLTD and CLF Method.)

1.3 PRINCIPLES AND PROCEDURES FOR CALCULATING HEATING LOAD

The peak heating requirements may occur either at night during unoccupied hours or in the morning pickup period following a shutdown. Therefore, a number of calculations are helpful in making a proper equipment selection and system design.

Unoccupied Period

The most common heating load calculation is made for steady-state conditions at night or on the weekend with the building unoccupied and using the design winter temperatures. No credit is normally taken for internal gains or for solar heat gains. The design heat loss calculation is therefore the sum of all transmission losses plus the additional load due to infiltration.

Occupied Periods

Since the load due to ventilation with outside air may be significant and the normally higher inside design temperature may occur at the same time as the winter design conditions, the heating load is calculated with the ventilation load included for occupied periods. An indication of the load during occupied periods is the estimate of the internal heat gain available to offset the heating load. The approximate balance point for an entire building, when the internal gains offset a portion of the heat losses, can be calculated by the following equation:

$$t = t_i - \text{(Heat Gains, Btu/hr) divided by } ((U \times A) + 1.08 \times \text{SCFM of OA})$$

where

t = outside db temperature at balance point
t_i = inside db temperature
SCFM = standard CFM of outside air (OA)

If the balance point of the space is desired, then only the load due to infiltration air is used when the ventilation air is conditioned by the HVAC system before it enters the space.

The effect of solar heat gains may be added to the internal heat gains to evaluate operation on a cold but sunny day.

1.4 TYPES OF CALCULATIONS

Separate heating and cooling load calculations are normally required since each system is designed and operated under different parameters. Besides classifying the loads by function, they are classified by type, sensible or latent. This is necessary for the proper selection of equipment.

Calculations for partial and peak loads may be necessary for each conditioned room or area, as well as each group of areas (zones), and possibly for each group of zones. The number and type of calculations are determined by the type of HVAC system

installed and the manner in which cooling and heating capacity is shifted from area to area. More complete information is available in the latest edition of the Systems Volume of the ASHRAE Handbook.

While accurate results are the ultimate objective, it is often necessary and desirable to estimate loads using incomplete or preliminary data. A simplified form of the calculations procedure, using conservative load values, is useful. Check figures, such as square feet of floor area per ton of air conditioning, can be helpful in some cases. Reference tables of check figures are listed in Tables A1.1 and A1.2. They should be used with discretion since they were developed some years ago and need updating. However, in lieu of other data, they do provide some guidelines until a set of local check figures can be developed based on the reader's experience.

1.5 INFORMATION DESIRED (OUTPUT)

The result of the calculations is the total cooling or heating load for a space, a zone, or a group of zones. This load must be sufficiently accurate to allow for confidence in the selection of heating or cooling equipment and supply air. Table 1.2 and the Load Calculation Form show the individual outputs needed to determine the total cooling load output. These subloads are categorized as:

1. External Loads (due to external factors)
2. Internal loads
3. Infiltration and Ventilation Loads

External Loads — Cooling

The sensible heat loads from the outdoors are:

1. The combined effect of the outdoor air temperature and the incident solar radiation that causes heat flow through the roof and external walls.
2. The temperature of adjoining spaces that causes heat conduction into or out of the conditioned space through interior partitions, ceilings, floors, and windows.
3. Solar heat gain by direct or indirect solar radiation through windows or other fenestration materials.

Internal Loads — Cooling

The internal loads developed within the conditioned space usually include some or all of the following sources:

1. Lights — The electricity which is supplied produces heat along with the generation of light. Some energy is convected to the air in the conditioned space and some is radiated to surrounding surfaces to be convected to the space air at a later time. All of this load is sensible heat.
2. People — The human body generates heat through the process of metabolism and releases it by radiation from the skin or clothing and by convection and evaporation from the skin, clothing and the breathing process. That portion of the load due to evaporation of moisture is latent and the rest is sensible.
3. Internal Equipment:

   a) Electrical, gas, or steam appliances for such things as cooking, drying or humidifying release heat into the space. This could result in both a latent and sensible load.
   b) Electrical machines, such as calculators, typewriters, duplicators, and electric motors, may represent a significant part of the internal loads in commercial applications. All of these loads generate sensible heat.
   c) Miscellaneous sources of sensible heat and moisture gain directly within the space are, for example, escaping steam, air circulation fans, ductwork, and other heat sources occurring within the conditioned space but not included in any category above.

Infiltration and Ventilation Loads — Cooling

Outside air in the form of infiltration and ventilation provides a special type of load which is imposed on the conditioned space or the system. Ventilation is supplied to meet air purity and odor standards, while infiltration arises from controlled or uncontrolled leakage around doors and windows or through walls.

Heating Load

The design heating load calculation is usually based on a constant winter design temperature. These design temperatures normally occur at night, and no credit to the heating load is generally made for the heat given off by internal sources such as people, lights, and appliances. The heating load estimate must take into account heat loss through the building structure and heat required to offset the cold outdoor air which may infiltrate and/or may be introduced for ventilation. Solar heat gain during the day is not usually credited to a reduction in heat load because the heating equipment must have adequate capacity to meet the most adverse conditions normally expected, which generally occur at night.

The storage of heat is a useful consideration in the selection of capacity for cooling equipment. Credit for storage in reducing the heating load for the purpose of equipment selection must be used with care. Such credit for storage will allow reduction in heating capacity requirements when a temperature swing is permitted for continuous operation only. Temperature swing allows the space temperature to drop a few degrees during periods of design load.

The practice of "turning down the heat" and allowing large drops in space temperature when a building is not occupied does not allow a reduction in heating capacity because of its non-continuous nature. Although this practice may lead to energy savings based on total average heat requirements, it leads to an increase in heating equipment capacity to provide the pickup needed when heating operation is resumed. It may be desirable to provide additional capacity when intermittent operation is planned, because of the additional load that pickup imposes.

Table 1.3 and the Load Calculation Form show the individual outputs needed to determine the total heating load output.

1.6 INFORMATION REQUIRED (INPUT)

Before a cooling or heating load can be properly estimated, a complete survey must be made of the physical data. The more exact the information that can be obtained about space characteristics, heat load sources, location of equipment and services, weather data, etc., the more accurate will be the load estimate. Table 1.4 gives a survey check list.

Required Input — External Loads — Cooling

For calculation of the outdoor loads, the input information should include:

1. Orientation and dimensions of building components.
2. Construction materials for roof, walls, ceiling, interior partitions, floors and fenestration.
3. Size and use of space to be conditioned.
4. Surrounding conditions outdoors and in adjoining spaces.

Table 1.2 Procedure for Calculating Space Design Cooling Load—Summary of Load Sources and Equations

Load Source	Equation	Reference, Table, Description
External Roof	$q = U \times A \times CLTD$	→ Design Heat Transmission Coefficients—Tables 3.1-3.5, A3.1 and A3.2 → Areas calculated from Architectural Plans → Cooling Load Temperature Difference Base Conditions for Roofs—Table 3. 8 and Notes Note 2—Correction for Color of Exterior Surface Note 2—Correction for Outside Dry Bulb Temperature and Daily Range—Table 3.13 Note 2—Correction for Inside Dry Bulb Temperature—Table 3.13 Note 2—Application for Latitude and Month—Table 3.12
Walls	$q = U \times A \times CLTD$	→ Design Heat Transmission Coefficients—Tables 3.1-3.4, A3.1 and A3.2 → Area Calculated from Architectural Plans Wall Construction Group Description—Table 3.9 → Cooling Load Temperature Difference at Base Conditions for Wall Group—Table 3.10 and Notes Note 2—Correction for Color of Exterior Surface Note 2—Correction for Outside Dry Bulb Temperature and Daily Range—Table 3.13 Note 2—Correction for Inside Dry Bulb Temperature—Table 3.13 Note 2—Application for Latitude and Month—Table 3.12
Glass Conduction	$q = U \times A \times CLTD$	→ Type of Glass and Interior Shading, if Used—Tables 3.14-3.16 and A3.4 → Area—Glass Area Calculated from Plans → Cooling Load Temperature Difference for Conduction Load Through Glass—Table 3.23 Correction for Outside Dry Bulb Temperature and Daily Range—Table 3.13 Correction for Inside Dry Bulb Temperature—Table 3.13
Solar	$q = A \times SC \times SHGF \times CLF$	→ Area—Net Glass Area Calculated from Plans → Shading Coefficients for Combination of Type of Glass and Type of Shading—Tables 3.17-3.22 → Maximum Solar Heat Gain Factor for Specific Orientation of Surface, Latitude and Month—Table 3.25 for no external shading Externally shaded Location less than 24 deg N Lat.—Table 3.26 Location at or more than 24 deg N Lat.—Table 3.25, N orientation → Cooling Load Factor with No Interior Shading—Table 3.27 Cooling Load Factor if Interior Shading is Used—Table 3.28 For glass areas shaded externally—use north orientation with either Table 3.27 or 3.28
Partitions, Ceilings, Floors	$q = U \times A \times TD$	→ Design Heat Transmission Coefficients—Tables 3.1-3.5 and A3.1 → Area Calculated from Architectural Plans → Design Temperature Difference
Internal Lights	$q = INPUT \times CLF$	→ Input Rating from Electrical Plans or Lighting Fixture Data—Chapter 4 and Table 4.1 Coefficients "a" and classification "b" for Type of Fixture, Installation, Air Supply and Return and Room Furnishings and Construction—Tables 4.2 and 4.3 → Cooling Load Factor Based on Total Hours of Operation and Time—Table 4.4 Note 1 Correction for Schedule of Operation of Lights and Cooling System, CLF = 1.0 when cooling system is operated only when lights are on, or when lights are on 24 hr/day.
People Sensible	$q_s = No \times Sens.\ H.G. \times CLF$	→ Number of People in Space—From survey or Table 5.3 → Sensible Heat Gain from Occupants—Table 4.5 → Cooling Load Factor for People—Based on Duration of Occupancy and Time from Entry—Table 4.6 Note 1 Correction for Space Temperature and/or Density of Occupants, CLF = 1.0 if there is variable space temperature and/or high people density.
Latent	$q_l = No \times Lat.\ H.G.$	→ Latent Heat Gain from Occupants—Table 4.5
Appliances Sensible	$q_s = HEAT\ GAIN \times CLF$	→ Recommended Rate of Heat Gain-Sensible Heat—Tables 4.8 and 4.9 → For Use with Hood—Table 4.10 For Use without Hood—Table 4.11
Latent	$q_l = HEAT\ GAIN$	→ Recommended Rate of Heat Gain—Latent Heat (Without Hood)—Tables 4.8 and 4.9 Set Equal to Zero When Hood is Used Over Appliances
Power	$q = HEAT\ GAIN \times CLF$	→ Manufacturer's Data or Tables 4.12 and 4.13 → Table 4.11 or CLF = 1.0 if cooling system is not operated continuously
Ventilation & Infiltration Air Sensible Latent Total	$q_s = 1.10 \times CFM \times \Delta t$ $q_l = 4840 \times CFM \times \Delta W$ $q = 4.5 \times CFM \times \Delta h$	→ Ventilation and Infiltration Air, Standard CFM—Chapter 5 → Inside-Outside Air Temperature Difference, deg F—Table 2.1 → Inside-Outside Air Humidity Ratio Difference, lb H_2O/lb Dry Air—Tables 2.1 and 2.3 → Inside-Outside Air Enthalpy Difference, Btu/lb of Dry Air—Psychrometric Chart
Adjustment Factor	$F_c = 1\text{-}0.02\ K_1$	→ Fraction of Input Energy Lost to the Surroundings; Applied to all External and Internal Loads Except Ventilation and Infiltration Air. → K_1 = sum of $U \times A$ for all exterior wall surfaces and fenestration and then divided by length of exterior wall

Table 1.3 Summary of Loads, Equations and Reference for Calculating Design Heating Loads

Heating Load	Equation	Reference, Table, Description
Roofs, Walls, Glass	$q = U \times A \times TD$	→ Tables 3.1-3.5 and A3.1 → Areas calculated from plans or obtained by survey → Temperature Difference between inside design db and design outside db. Table 2.1
Floors over exterior space	$q = U \times A \times TD$	Same as above.
Floors on or below grade	$q = U \times A \times TD$ and/or $q = F \times P$	→ Temperature difference between inside design db and ground temperature. Table 7.1 and Fig. 7.2 → Table 7.9 Perimeter heat loas factor → Perimeter of slab measured in feet
Walls below grade	$q = U \times A \times TD$	→ Table 7.4 → Table 7.1 and Fig. 7.2 → Area calculated from plans or survey
Infiltration Sensible Latent	$q = 1.08 \times SCFM \times TD$ $q = 4840 \times SCFM \times \Delta W$	→ Sensible heating load, Btu/hr → Btu/hr per standard cfm per degree F → Standard cfm of infiltration air Chapter 5 → Design temperature difference between inside and outside db Table 2.1 → Design humidity ratio difference
Ventilation	$q = 1.08 \times SCFM \times TD$	→ Sensible heating load, Btu/hr. This load is imposed where the ventilation air is conditioned. It does not necessarily become part of the space load. → Btu/hr per standard cfm per degree F → Ventilation air, standard cfm Chapter 5 → Temperature difference between inside and outside air db temperature Table 2.1
Balance Point Temperature	$t = t_i - \dfrac{\text{Heat Gain}}{\text{Heat Loss Factor}}$	→ Approximate balance point temperature, outside → Design inside db temperature → Sum of heat gains Internal Heat Gains or Internal Gains plus Solar Heat Gain calculated according to procedure of cooling load → Heat Loss Factor = Unoccupied Design Heat Load divided by Design Temperature Difference

Required Input — Internal Loads — Cooling

For calculation of the internal loads, the input information should include:

1. Lighting — connected wattage, incandescent or fluorescent, schedule of use, recessed or exposed, vented fixture air flow or water flow.
2. People — number, activity, length of occupancy, occupancy schedule.
3. Internal Equipment — nameplate data, location, schedule of use, fuel or power consumption, hooded or unhooded, air quantity exhausted or required. When possible, use the information from metered data such as KWH from utility bills.

Required Input — Infiltration and Ventilation — Cooling

For calculation of infiltration and ventilation loads, the input information should include:

1. Cfm per person and/or per sq ft, minimums required by codes or to the level these are increased by building owner.
2. Exhaust fans - type, size, speed, cfm delivery.
3. Doors and windows - location, type, size, frequency of opening.

Additional Input — Needed for All Types of Cooling Load Components

General information:

1. Thermal storage characteristics - system operating schedule in hours per day during peak outdoor conditions, permissible temperature swing in space during a design day, construction of walls enclosing the space and construction of floors, and the storage capabilities of furniture and equipment.
2. Continuous or intermittent operation - that is, whether the conditioning system operates every business day for the same fixed number of hours during the cooling season, or only on occasions, such as for churches. If intermittent operation, determine the duration of time available for precooling or pulldown.

Table 1.4 Cooling and Heating Load Calculation Survey — Check List

Data Required for Calculations	Information Needed to Obtain Data
Latitude	What is the location of this site to the nearest one degree of latitude, north or south of the equator?
Elevation	Elevation may be used to adjust weather data.
Cooling Outside db Temp. Daily Range wb Temp. Heating Outside db Temp. Wind speed	Is cooling required? What is the estimated peak month? Location of building or space? Is this at a location with weather data published in ASHRAE Handbook? If not, obtain data from the weather station closest to location. Are there sufficient differences in the local weather to warrant checking with a local meteorologist? How critical is the application? Is the 2-1 2% weather data applicable as in most general comfort applications?
Physical Data Roof area for each type of roof construction	Are drawings available? Can a complete on-site survey be made?
Skylight areas and construction	Are construction details available from drawings or specifications
Ceiling construction	What type of construction is used? Suspended ceiling? Plenum above ceiling? Is plenum used for return air? Is return air or supply air ducted through space? What type of construction is used above suspended ceiling? Is space enclosed at all sides and how? Insulation?
Gross wall areas for each orientation and space	Use compass to determine orientation
Glass areas for each type of glass, shading and orientation	Is a window schedule available with unit size, sash opening and visible glass opening? Are manufacturer's data available? Are windows tight in sash and well caulked? Are data available regarding shading by overhangs, side fins, reveals, balconies or other external construction?
Location and size of elevator shafts, venting.	
Door areas, type and construction on each orientation	Are doors weatherstripped?
Net wall area for each orientation and construction	
Partition areas and constructions next to unconditioned spaces	Is sufficient information available to estimate the temperature of the unconditioned spaces? Are there any heat sources located there?
Floor areas, type and construction, and type of space below floor	
Thermal Conductance, *U*-values, for each surface: Roof Skylight Wall Window Door Partition Floor	Are complete details available for each type of construction? What information is available regarding interior shading devices such as drapes or blinds for windows? Will supply air be introduced in such a manner as to affect the U-factor of windows by the velocity on the inside surface?
Internal Loads and Schedule of Use People Lights Equipment Computers Miscellaneous Photocopy equipment Kitchen equipment	What number of people are in the space and during what periods of the day? How active are the people? Is smoking permitted? What types of lights are used? Fluorescent, incandescent, recessed, vented? How much electric power is used and how are the lights scheduled? Can you obtain copies of the utility bills? What type of equipment is operated and on what schedule? Is information available on the heat released from the equipment during normal operation? Is any of the equipment hooded? Are motors or other equipment operated at full load, overload, light load? Are there metered data or other information available on the average load?
Exhaust Makeup Air	Are exhaust air systems used? Continuous or intermittent operation? What quantity of air is exhausted? How is makeup air supplied — separately or by ventilation air?

Required Input — Heating Load

The input for calculation of heating load is essentially the same as that for the cooling load. However, it may not be necessary to calculate the internal sources and solar heat gain.

1.7 SUGGESTIONS FOR USER MODIFICATION OF THIS MANUAL

Any general purpose manual must be rather all-inclusive. If the majority of your work is in one location with one set of conditions, it may be desirable to collect that data only once and prepare forms which include the repetitive data on them. Some suggestions are listed below:

- Latitude, elevation
- Outside design conditions for summer and winter db, wb, daily range, wind speed
- Inside design db
- Design differences - db and humidity ratio
- Design day outside temperatures at each hour
- Design cooling conditions for months other than summer
- Corrections to CLTD tables for outside temperature and for latitude and month
- Maximum solar heat gain factors

A sample format is included with Example 1.1 for Birmingham, Ala.

Another possible time saver for those working with the same design parameters may be to incorporate all of the corrections into the CLTD tables for roofs and walls. Generate, for your own use, a new set of tables specifically adjusted for your location.

It is not possible to include in the Manual each and every type of wall and roof construction. Therefore, it would be helpful for you to add these data to the Manual as your work requires calculation of unique wall or roof *U*-factors, weights, etc.

LOAD CALCULATIONS FOR:

Date ____________ 19 ______ Sheet No ____________ of ______

Client ______________________ Job No ______________________

______________________ Drawing No ______________________

Computed By ____________ Checked By ____________ Approved By ______

DESIGN CONDITIONS FOR ____________

LATITUDE ________ DB DAILY RANGE ______ F

	SUMMER MONTH ______			WINTER	
	DB	WB	W	DB	W
OUTSIDE					
INSIDE					
DIFFER.					

LATENT LOAD

ITEM | Q/ITEM | NUMBER OF EACH ITEM: __ HR, __ HR, __ HR

PEOPLE

EQUIPMENT

EQUIPMENT

INFILT. AIR: 4840 | FACTOR × | SCFM | × | ΔW

VENTILATION AIR | ______ SCFM × 1.10 | ΔT

HEAT TO RETURN AIR[A] | 3.41 BTU/HR PER WATT × ______ WATTS × ______ FRACTION TO RETURN AIR

F–FACTOR=1–.02×(SUM OF U×A OF EXT. WALL AND GLASS)/EXT. PERIMETER= ______

INFILT. AIR | ______ SCFM × 1.10 | ΔT

INTERNAL COOLING LOADS

MISC. | EQUIPT. | PEOPLE | LIGHTS

EQUIPT.: HRS. ON | START TIME | HOODED YES/NO | Q_s | CLF

PEOPLE: HRS. IN SPACE | TIME ENTER | NO. OF PEOPLE | Q_s BTU/HR-P | NO. × Q_s × | CLF

LIGHTS: TYPE | TOTAL HOURS ON | START TIME | WATTS TO BTU/HR 3.41 3.41 × | BALLAST AND USE FACTOR × | TOTAL WATTAGE × | __ HR | __ HR | __ HR | CLF

EXTERNAL COOLING LOADS

SOLAR

ITEM: GLASS UNSHADED, SHADED; GLASS UNSHADED, SHADED; GLASS UNSHADED, SHADED; GLASS UNSHADED, SHADED

ORIENTATION | TOTAL AREA | SHADE COEFF. × | MAX SHG BTU/(HR-FT²) × | __ HR AREA × CLF | __ HR AREA × CLF | __ HR AREA × CLF

CONDUCTION

ITEM: FLOOR, FLOOR, CEILING, PARTITION | U | AREA | U×A × | ΔT

SUM.

ITEM: ROOF, ROOF, WALL, WALL, WALL, WALL, GLASS, GLASS | ORIENTATION BTU | U BTU (HR-FT²-F) | AREA FT² | U×A BTU/(HR-F) | CLTD TABLE VALUES __ HR __ HR __ HR | ADJUST FOR LATIT. & MONTH | COLOR CORR. K | ADJUST FOR INSIDE OUTSIDE TEMP | CLTD. CORRECTED __ HR __ HR __ HR

COOLING Q-SENSIBLE, BTU/HR: __ HR | __ HR | __ HR

SUBTOTAL

SUBTOTAL ROOM Q-SENSIBLE

SUBTOTAL × F–FACTOR

SUPPLY DUCT __% LEAKAGE + __% HEAT GAIN

ROOM SUBTOTAL

DEDUCT FROM ROOM

NET ROOM SENSIBLE

VENTILATION AIR

Q-LATENT, BTU/HR: __ HR | __ HR | __ HR

Q-LATENT SUBTOTAL

__% DUCT LEAKAGE

ROOM Q-LATENT

ROOM SENSIBLE + ROOM LAT.

ROOM SENSIBLE HEAT RATIO

SUPPLY AIR CFM BASED ON A SUPPLY TEMP. OF __ F IS: (ROOM Q-SENSIBLE) / 1.10 × (T_{ROOM} – T_{SUPPLY})

COOLING LOAD SUMMARY

Q-SENSIBLE | Q-LATENT

VENTILATION LOAD

ROOM SUBTOTAL

ADD HEAT TO RETURN AIR[A]

RETURN DUCT GAIN __%

COOLING EQUIPMENT LOAD

SAFETY FACTOR __%

TOTAL: QS | QL

GRAND TOTAL = QS + QL

HEATING

U BTU (HR-FT²–F) | U×A BTU/(HR–F) | Q-SENSIBLE BTU/HR (@ ΔT = __)

INFILT/VENT AIR | CFM

SAFETY FACTOR ______ % | TOTAL

PICK-UP FACTOR

GRAND TOTAL

INTERNAL LOADS SUBTOTAL

RATIO OF INTERNAL TO GRAND TOTAL

HUMIDIFICATION @ ΔW= ____ | CFM | BTU/HR

RESIDENTIAL COOLING & HEATING
LOAD CALCULATIONS

Prepared For ______________________ Job No. ________ Date ____________

______________________ Prepared by ______________________

Location ______________________

Latitude ______________________

Summary of Load Calculations for Entire House	
Cooling	**Heating**
________ Btu/hr Sensible	________ Btu/hr
________ Btu/hr Total	________ Btu/hr -F
____ Tons ______ ft^2/ton	________ Btu/hr -ft^2

Design Conditions		
	Summer	Winter
Outside Temp. db, F		
Inside Temp. db, F		
Difference		

Daily Range, Deg. F ____________

Temperature Swing ________ Deg. F.

Window Schedule

Type	Description	
	of Window	of Shades & Shading
A		
B		
C		
D		

Exterior Shading Calculation

Type							
Orientation							
Shade Line Factor							
Overhang, ft							
Shade Length, ft							
Distance to Top of Window ft							
Shaded ht. of Window, ft							
Width of Window, ft							
Shaded Area, ft^2							
Unshaded Area, ft^2							

Work Sheet

		Living Room	Dining Room	Kitchen	Bedroom No. 1	Bedroom No. 2	Bedroom No. 3	Bath No. 1						UA Calculations: Entire House	UA Calculations: U-Value	UA Calculations: UxA	Load Factors: Heating UxΔT	Load Factors: Cooling
WINDOW	Type____ Facing____, ft^2																	
WINDOW	, ft^2																	
WINDOW	, ft^2																	
WINDOW	, ft^2																	
WINDOW	, ft^2																	
WINDOW	, ft^2																	
DOOR	, ft^2																	
DOOR	, ft^2																	
DOOR	, ft^2																	
Subtotal Area, ft^2																		
WALL	Exposed, Running ft.																	
WALL	Gross Area, ft^2																	
WALL	Above grade, ft^2																	
WALL	, ft^2																	
WALL	, ft^2																	
WALL	Below Grade, ft^2																	
WALL	, ft^2																	
Subtotals																		
U_0-Value $= \frac{\text{Sum of } U \times A}{\text{Sum of } A}$																		
Roof/Ceiling, ft^2																		
, ft^2																		
Floor, ft^2																		
, ft^2																		
Totals																		
Overall $U = \frac{\text{Sum of } U \times A}{\text{Ref. Area}}$																		

RESIDENTIAL HEATING AND COOLING LOAD CALCULATIONS

COOLING LOAD CALCULATION

Description/ Orientation	Type	U-Value	Load Factor	Entire House		Living Room		Dining Room		Kitchen		Bedroom No. 1		Bedroom No. 2		Bedroom No. 3		Bath No. 1											
				Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr
WINDOWS																													
DOORS																													
WALLS																													
ROOF																													
FLOOR																													
People			225																										
Lights & Appliances					1200						1200																		
Infilt./Ventil.																													
Subtotal																													
Duct Heat Gain @___%																													
Room Sensible Cooling Load																													

HEATING LOAD CALCULATION

WINDOW																													
DOOR																													
WALL																													
ROOF																													
FLOOR																													
Infilt./Ventil.																													
Subtotal																													
Duct (Piping) Heat Loss @___%																													
Room Sensible Heat Loss																													

CHAPTER 2

WEATHER DATA AND DESIGN CONDITIONS

INDOOR DESIGN CONDITIONS

The indoor conditions to be maintained within a building are the dry-bulb temperature and relative humidity of the air at the breathing line, 3 to 5 ft above the floor in an area that would indicate average conditions at that level and which would not be affected by abnormal or unusual heat gains or losses from the interior or exterior. The design indoor air temperature will vary in accordance with activity and with the intended use of the building. Recommended indoor design conditions for specific applications are discussed in various chapters of the Application volume of ASHRAE HANDBOOK & Product Directory.

For many applications, such as in various areas of a hospital facility, the design conditions are undergoing substantive review and change. Therefore, it is recommended that the latest codes or recommendations be referred to before designing a system. A general discussion on thermal comfort conditions is provided in ASHRAE Standard 55-74, Thermal Environmental Conditions for Human Occupancy. For load calculations, for general comfort applications, ASHRAE Standard 90-75 recommends that the indoor design temperature be 78 F for summer and 72 F for winter. The actual design relative humidity for summer shall be selected for minimum energy use but shall be within the comfort envelope as defined in ASHRAE Standard 55-74.

OUTDOOR DESIGN CONDITIONS

Winter

Recommended design temperatures are presented in Column 5 of Tables 2.1A and 2.1B, and Column 4 of Table 2.1C. Two temperature levels are offered for each station. The 99% and 97.5% values represent the temperatures which equalled or exceeded these portions of the total hours in the months of December, January, and February (a total of 2160 hr) in the northern hemisphere, and the months of June, July, and August in the southern hemisphere, with a total hour count of 2208 hr. In a normal winter, there would be approximately 22 hr at or below the 99% design value and approximately 54 hr at or below the 97.5% design value. For Canadian stations, the 99% and 97.5% design values are based on only the month of January, because January in Canada is characteristically an extremely cold month as compared to December and February. The Canadian design temperatures are a few degrees lower than if they were based on the three winter months.

Summer

Recommended design dry-bulb and wet-bulb temperatures and outdoor daily temperature ranges are presented in Columns 6, 7, and 8 of Tables 2.1A and 2.1B and in Column 5 of Table 2.1C.

Column 6 of Tables 2.1A and 2.1B, and Columns 5, 6, and 7 of Table 2.1C provides dry-bulb temperature design data with their corresponding coincident wet-bulb temperatures. The dry-bulb temperatures presented represent values which have equalled or exceeded by 1, 2.5 and 5% of the total hours during the summer months of June through September (a total of 2928 hr) in the northern hemisphere and the months of December, January, February and March in the southern hemisphere with a total hour count of 2904 hr. The coincident wet-bulb temperature listed with each design dry-bulb temperature is the mean of all wet-bulb temperatures occurring at the specific dry-bulb design temperature. Hereafter, reference will be only to Tables 2.1A and 2.1B.

The outdoor daily range of dry-bulb temperatures shown in Column 7 gives the difference between the average daily maximum and average daily minimum temperatures during the warmest month at each station. Large daily ranges are associated with inland stations far removed from large bodies of water and stations at high elevations above sea level. Wet-bulb temperatures presented in Column 8 represent values which have been equalled or exceeded by 1, 2.5, and 5% of the hours during the summer months. These wet-bulb design temperature values were selected independently of the dry-bulb design temperature values and should not be considered as coincident with the dry-bulb design listed in Column 6.

In a normal summer, there would be approximately 30 hr at or above a 1% design value, and approximately 150 hr at or above a 5% design value. For Canadian stations the 1, 2.5, and 5% design values are based on only the month of July because July in Canada is characteristically considerably warmer than the month preceding it or the month following it. The Canadian summer design values are a few degrees higher than if they were based on four summer months.

For building cooling load calculations, values of dry-bulb should be selected from Column 6. Values of wet-bulb temperature from Column 8 should be selected when sizing cooling towers or other equipment dependent mainly upon wet-bulb temperature.

The outdoor humidity ratios listed in Column 9 are determined from the 2.5 values of the summer dry bulb and coincident wet bulb. The barometric pressure for the elevation of each weather station is used in the calculation.

INTERPOLATION BETWEEN STATIONS

Data from many weather stations at specific locations and elevations furnish a network from which, by interpolation, good estimates can be made of the expected conditions at locations without weather stations.

When design requirements are extremely important it may be advisable to retain a competent Applied Meteorologist to develop data that can show a comparative relationship with the nearest official station having a long-period record. If this is not feasible, the following general rules will apply in adjusting the design data supplied for the weather stations listed in Tables 2.1A and 2.1B to fit some other location:

1. Adjustment for Elevation. For a lower elevation, the de-

sign values from Table 2.1A should be increased, while for a higher elevation, the values should be decreased. The increments used in these adjustments are generally:

Dry-bulb temperature	1 degree F per 200 ft
Wet-bulb temperature	1 degree F per 500 ft

In the winter where cold air drainage (mainly in hilly or mountainous areas) or considerable radiational cooling occurs at a site, these adjustments do not apply.

2. Adjustment for Air Mass Modification. Short distance variations are most extreme near large bodies of water where air moves from the water over the land in summer. Along the West Coast, both dry-bulb and wet-bulb temperatures increase with distance from the ocean. In the region north of the Gulf of Mexico, dry-bulb temperatures increase for the first 200 or 300 miles, with a slight decrease in wet-bulb temperatures due to mixing with drier air inland. Beyond this 200 to 300 mile belt, both dry-bulb and wet-bulb values tend to decrease at a somewhat regular rate.

3. Adjustment for Vegetation. The difference between large areas of dry surfaces and large areas of dense foliage upwind from the site can account for variations of up to 2 F wet-bulb and 5 F dry-bulb. The warmer temperatures are associated with the dry surfaces. Adjustments for vegetation require the assistance of a consulting Applied Meteorologist.

The data presented are representative of the site at the latitudes, longitudes, and elevations listed in the table.

These statistics are presented here as a guide only, and extreme caution should be exercised in using them for any location other than that for which they intended. Assistance in their interpretation and extrapolation should be obtained from a consulting Applied Meteorologist particularly with regard to heat sinks in urban locations.

WEATHER-ORIENTED DESIGN FACTORS

The rational approach in air-conditioning system design involves computation of a peak design load at a condition established using one of the frequency of occurrence levels (Tables 2.1A and 2.1B, Column 6) of dry-bulb and wet-bulb temperatures published herein.

As previously noted, the maximum dry-bulb and maximum wet-bulb temperatures are usually not coincident. This is particularly true throughout the continental or inland mass of the United States. As a matter of fact, the 1% level values rarely occur at the same time in such areas. *In maritime areas they tend to be coincident.* Typically, the maximum dry-bulb is coincident with a wet-bulb slightly below the maximum wet-bulb temperature and vice-versa. The assumption of maximum dry- and maximum wet-bulb coincidence can result in weather-oriented loads up to 1/3 greater than might otherwise be expected. *When calculating building cooling loads, it is advisable to determine whether the structure is most sensitive to dry-bulb, i.e., extensive exterior, or wet-bulb, i.e., outside ventilation.* Then the appropriate maximum dry-bulb temperature could be used for design with its corresponding coincident wet-bulb value. If the dry-bulb values with mean coincident wet-bulb values listed in Column 6 of Tables 2.1A and 2.1B are not satisfactory, the following method of analysis is recommended for ascertaining appropriate maximum values. The method usually involves only a day or two of hand computations. From at least 5 years of hourly or 3-hourly weather reports, select the 15 days when the daily maximum dry-bulb reading was highest. For each hour (or third hour) of the day, find the average dry-bulb and average wet-bulb. These averages will define a typical hot design day. Similarly, the 15 days when the daily maximum wet bulb reading was highest should be selected and the hourly dry-bulb and wet-bulb temperatures averaged to give a typical humid design day. This is certainly within the capability of any engineering office that is involved on several local projects. Where projects of greater significance are involved, there are several alternatives. A longer period of record, say 10 years, can be studied. Hourly data instead of the usual three-hour interval can be used. Machine tabulations can be made on any desired criteria. Consulting Applied Meteorologists are available to analyze both the raw data and the statistical compilations.

As more complicated and sophisticated applications are utilized to meet critical demands, these design maximums based on peak values will not suffice. The engineers will have to consider off-peak values. Some types of days that must be accommodated are more frequent in occurrence than maximum or minimum design days. Examples of these are cloudy, small temperature change, windy, warm a.m. and cool p.m., and, of course, fair and warm, and fair and cool. Quite often these days, due to the temperature control implication, must be studied before a final design can be implemented.

Since the advent of machine computations, many system designers are making calculations of dry-bulb with its corresponding wet-bulb maximum, and vice versa, for several hours daily on both a room by room basis and on a zone or a building basis. This can result in more compatible systems in operation.

Further, the trend of the industry to attempt energy consumption estimates in order to establish system design is making some progress. The weather data required for calculation of these estimates are not included in this chapter, but Air Force Manual 88-8, Chapter 6, has published some of this information, and many local Chapters of ASHRAE have attempted similar work both through the Chapters and through individuals.

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[b]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
ALABAMA																
Alexander City	33	0	86	0	660	18	22	96/77	93/76	91/76	21	79	78	78	.0158	
Anniston AP	33	4	85	5	599	18	22	97/77	94/76	92/76	21	79	78	78	.0155	
Auburn	32	4	85	3	730	18	22	96/77	93/76	91/76	21	79	78	78	.0158	
Birmingham AP	33	3	86	5	610	17	21	96/74	94/75	92/74	21	78	77	76	.0146	54.2
Decatur	34	4	87	0	580	11	16	95/75	93/74	91/74	22	78	77	76	.0140	
Dothan AP	31	2	85	2	321	23	27	94/76	92/76	91/76	20	80	79	78	.0160	
Florence AP	34	5	87	4	528	17	21	97/74	94/74	92/74	22	78	77	76	.0138	
Gadsden	34	0	86	0	570	16	20	96/75	94/75	92/74	22	78	77	76	.0146	
Huntsville AP	34	4	86	4	619	11	16	95/75	93/74	91/74	23	78	77	76	.0140	51.3
Mobile AP	30	4	88	2	211	25	29	95/77	93/77	91/76	18	80	79	78	.0163	59.9
Mobile CO	30	4	88	1	119	25	29	95/77	93/77	91/76	16	80	79	78	.0163	
Montgomery AP	32	2	86	2	195	22	25	96/76	95/76	93/76	21	79	79	78	.0149	55.4
Selma-Craig AFB	32	2	87	0	207	22	26	97/78	95/77	93/77	21	81	80	79	.0158	
Talladega	33	3	86	1	565	18	22	97/77	94/76	92/76	21	79	78	78	.0155	
Tuscaloosa AP	33	1	87	4	170r	20	23	98/75	96/76	94/76	22	79	78	77	.0147	
ALASKA																
Anchorage AP	61	1	150	0	90	−23	−18	71/59	68/58	66/56	15	60	59	57	.0104	23.0
Barrow (S)	71	2	156	5	22	−45	−41	57/53	53/50	49/47	12	54	50	47	.0070	
Fairbanks AP (S)	64	5	147	5	436	−51	−47	82/62	78/60	75/59	24	64	62	60	.0071	6.7
Juneau AP	58	2	134	4	17	−4	1	74/60	70/58	67/57	15	61	59	58	.0075	32.1
Kodiak	57	3	152	3	21	10	13	69/58	65/56	62/55	10	60	58	56	.0074	
Nome AP	64	3	165	3	13	−31	−27	66/57	62/55	59/54	10	58	56	55	.0076	13.1
ARIZONA																
Douglas AP	31	3	109	3	4098	27	31	98/63	95/63	93/63	31	70	69	68	.0069	
Flagstaff AP	35	1	111	4	6973	−2	4	84/55	82/55	80/54	31	61	60	59	. . .	35.6
Fort Huachuca AP (S)	31	3	110	2	4664	24	28	95/62	92/62	90/62	27	69	68	67	.0071	
Kingman AP	35	2	114	0	3446	18	25	103/65	100/64	97/64	30	70	69	69	.0062	
Nogales	31	2	111	0	3800	28	32	99/64	96/64	94/64	31	71	70	69	.0074	
Phoenix AP(S)	33	3	112	0	1117	31	34	109/71	107/71	105/71	27	76	75	75	.0086	58.5
Prescott AP	34	4	112	3	5014	4	9	96/61	94/60	92/60	30	66	65	64	.0055	
Tuscon AP (S)	32	1	111	0	2584	28	32	104/66	102/66	100/66	26	72	71	71	.0067	58.1
Winslow AP	35	0	110	4	4880	5	10	97/61	95/60	93/60	32	66	65	64	.0053	43.0
Yuma AP	32	4	114	4	199	36	39	111/72	109/72	107/71	27	79	78	77	.0083	64.2
ARKANSAS																
Blytheville AFB	36	0	90	0	264	10	15	96/78	94/77	91/76	21	81	80	78	.0164	
Camden	33	4	92	5	116	18	23	98/76	96/76	94/76	21	80	79	78	.0147	
El Dorado AP	33	1	92	5	252	18	23	98/76	96/76	94/76	21	80	79	78	.0148	
Fayetteville AP	36	0	94	1	1253	7	12	97/72	94/73	92/73	23	77	76	75	.0132	
Fort Smith AP	35	2	94	2	449	12	17	101/75	98/76	95/76	24	80	79	78	.0146	50.3
Hot Springs	34	3	93	1	535	17	23	101/77	97/77	94/77	22	80	79	78	.0157	
Jonesboro	35	5	90	4	345	10	15	96/78	94/77	91/76	21	81	80	78	.0164	
Little Rock AP (S)	34	4	92	1	257	15	20	99/76	96/77	94/77	22	80	79	78	.0160	50.5
Pine Bluff AP	34	1	92	0	204	16	22	100/78	97/77	95/78	22	81	80	80	.0154	
Texarkana AP	33	3	94	0	361	18	23	98/76	96/77	93/76	21	80	79	78	.0160	54.2
CALIFORNIA																
Bakersfield AP	35	2	119	0	495	30	32	104/70	101/69	98/68	32	73	71	70	.0081	55.4
Barstow AP	34	5	116	5	2142	26	29	106/68	104/68	102/67	37	73	71	70	.0075	
Blythe AP	33	4	114	3	390	30	33	112/71	110/71	108/70	28	75	75	74	.0076	
Burbank AP	34	1	118	2	699	37	39	95/68	91/68	88/67	25	71	70	69	.0069	58.6
Chico	39	5	121	5	205	28	30	103/69	101/68	98/67	36	71	70	68	.0071	

***Oct through April, inclusive, 1976 ASHRAE SYSTEMS HANDBOOK & PRODUCT DIRECTORY, CHART 43.**

[a] Table 1 was prepared by ASHRAE Technical Committee 4.2, Weather Data, from data compiled from official weather stations where hourly weather observations are made by trained observers.

[b] Latitude, for use in calculating solar loads, and longitude are given to the nearest 10 minutes. For example, the latitude and longitude for Anniston, Alabama are given as 33 34 and 85 55 respectively, or 33° 40, and 85° 50.

[c] Elevations are ground elevations for each station. Temperature readings are generally made at an elevation of 5 ft above ground, except for locations marked r, indicating roof exposure of thermometer.

[d] Percentage of winter design data shows the percent of the 3-month period, December through February.

[e] Percentage of summer design data shows the percent of 4-month period, June through September.

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[b]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb			Humidity Ratio	Ave. Winter Temp*
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%	
Concord	38	0	122	0	195	24	27	100/69	97/68	94/67	32	71	70	68	.0080	
Covina	34	0	117	5	575	32	35	98/69	95/68	92/67	31	73	71	70	.0087	
Crescent City AP	41	5	124	0	50	31	33	68/60	65/59	63/58	18	62	60	59	.0092	
Downey	34	0	118	1	116	37	40	93/70	89/70	86/69	22	72	71	70	.0113	
El Cajon	32	4	117	0	525	42	44	83/69	80/69	78/68	30	71	70	68	.0129	
El Centro AP (S)	32	5	115	4	−30	35	38	112/74	110/74	108/74	34	81	80	78	.0097	
Escondido	33	0	117	1	660	39	41	89/68	85/68	82/68	30	71	70	69	.0110	
Eureaka/ Arcata AP	41	0	124	1	217	31	33	68/60	65/59	63/58	11	62	60	59	.0092	49.9
Fairfield- Travis AFB	38	2	122	0	72	29	32	99/68	95/67	91/66	34	70	68	67	.0077	
Fresno AP (S)	36	5	119	4	326	28	30	102/70	100/69	97/68	34	72	71	70	.0083	53.3
Hamilton AFB	38	0	122	3	3	30	32	89/68	84/66	80/65	28	72	69	67	.0096	
Laguna Beach	33	3	117	5	35	41	43	83/68	80/68	77/67	18	70	69	68	.0100	
Livermore	37	4	122	0	545	24	27	100/69	97/68	93/67	24	71	70	68	.0083	
Lompoc, Vandenburg AFB	34	4	120	3	552	35	38	75/61	70/61	67/60	20	63	61	60	.0096	
Long Beach AP	33	5	118	1	34	41	43	83/68	80/68	77/67	22	70	69	68	.0119	57.8
Los Angeles AP (S)	34	0	118	2	99	41	43	83/68	80/68	77/67	15	70	69	68	.0119	57.4
Los Angeles CO (S)	34	0	118	1	312	37	40	93/70	89/70	86/69	20	72	71	70	.0116	60.3
Merced-Castle AFB	37	2	120	3	178	29	31	102/70	99/69	96/68	36	72	71	70	.0083	
Modesto	37	4	121	0	91	28	30	101/69	98/68	95/67	36	71	70	69	.0087	
Monterey	36	4	121	5	38	35	38	75/63	71/61	68/61	20	64	62	61	.0091	
Napa	38	2	122	2	16	30	32	100/69	96/68	92/67	30	71	69	68	.0082	
Needles AP	34	5	114	4	913	30	33	112/71	110/71	108/70	27	75	75	74	.0079	
Oakland AP	37	4	122	1	3	34	36	85/64	80/63	75/62	19	66	64	63	.0088	53.5
Oceanside	33	1	117	2	30	41	43	83/68	80/68	77/67	13	70	69	68	.0119	
Ontario	34	0	117	36	995	31	33	102/70	99/69	96/67	36	74	72	71	.0088	
Oxnard	34	1	119	1	43	34	36	83/66	80/64	77/63	19	70	68	67	.0090	
Palmdale AP	34	4	118	1	2517	18	22	103/65	101/65	98/64	35	69	67	66	.0062	
Palm Springs	33	5	116	4	411	33	35	112/71	110/70	108/70	35	76	74	73	.0068	
Pasadena	34	1	118	1	864	32	35	98/69	95/68	92/67	29	73	71	70	.0090	
Petaluma	38	1	122	4	27	26	29	94/68	90/66	87/65	31	72	70	68	.0081	
Pomona CO	34	0	117	5	871	28	30	102/70	99/69	95/68	36	74	72	71	.0081	
Redding AP	40	3	122	1	495	29	31	105/68	102/67	100/66	32	71	69	68	.0064	
Redlands	34	0	117	1	1318	31	33	102/70	99/69	96/68	33	74	72	71	.0091	
Richmond	38	0	122	2	55	34	36	85/64	80/63	75/62	17	66	64	63	.0084	
Riverside- March AFB (S)	33	5	117	2	1511	29	32	100/68	98/68	95/67	37	72	71	70	.0086	
Sacramento AP	38	3	121	3	17	30	32	101/70	98/70	94/69	36	72	71	70	.0093	53.9
Salinas AP	36	4	121	4	74	30	32	74/61	70/60	67/59	24	62	61	59	.0087	
San Bernardino, Norton AFB	34	1	117	1	1125	31	33	102/70	99/69	96/68	38	74	72	71	.0088	
San Diego AP	32	4	117	1	19	42	44	83/69	80/69	78/68	12	71	70	68	.0126	59.5
San Fernando	34	1	118	3	977	37	39	95/68	91/68	88/67	38	71	70	69	.0099	
San Francisco AP	37	4	122	2	8	35	38	82/64	77/63	73/62	20	65	64	62	.0091	53.4
San Francisco CO	37	5	122	3	52	38	40	74/63	71/62	69/61	14	64	62	61	.0098	55.1
San Jose AP	37	2	122	0	70r	34	36	85/66	81/65	77/64	26	68	67	65	.0095	
San Luis Obispo	35	2	120	4	315	33	35	92/69	88/70	84/69	26	73	71	70	.0119	
Santa Ana AP	33	4	117	5	115r	37	39	89/69	85/68	82/68	28	71	70	69	.0107	
Santa Barbara MAP	34	3	119	5	10	34	36	81/67	77/66	75/65	24	68	67	66	.0111	
Santa Cruz	37	0	122	0	125	35	38	75/63	71/61	68/61	28	64	62	61	.0091	
Santa Maria AP (S)	34	5	120	3	238	31	33	81/64	76/63	73/62	23	65	64	63	.0093	54.3
Santa Monica CO	34	0	118	3	57	41	43	83/68	80/68	77/67	16	70	69	68	.0119	
Santa Paula	34	2	119	0	263	33	35	90/68	86/67	84/66	36	71	69	68	.0100	
Santa Rosa	38	3	122	5	167	27	29	99/68	95/67	91/66	34	70	68	67	.0077	
Stockton AP	37	5	121	2	28	28	30	100/69	97/68	94/67	37	71	70	68	.0080	
Ukiah	39	1	122	4	620	27	29	99/69	95/68	91/67	40	70	68	67	.0087	
Visalia	36	2	119	1	354	28	30	102/70	100/69	97/68	38	72	71	70	.0083	
Yreka	41	4	122	4	2625	13	17	95/65	92/64	89/63	38	67	65	64	.0075	
Yuba City	39	1	121	4	70	29	31	104/68	101/67	99/66	36	71	69	68	.0064	
COLORADO																
Alamosa AP	37	3	105	5	7536	−11	−6	84/57	82/57	80/57	35	62	61	60	.0074	29.7
Boulder	40	0	105	2	5385	−6	0	93/59	91/59	89/59	27	64	63	62	.0058	
Colorado Springs AP	38	5	104	4	6173	−3	2	91/58	88/57	86/57	30	63	62	61	.0053	37.3
Denver AP	39	5	104	5	5283	−5	1	93/59	91/59	89/59	28	64	63	62	.0058	37.6
Durango	37	1	107	5	6550	−6	−1	89/59	87/59	85/59	30	64	63	62	.0072	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b] °	′	Longitude[b] °	′	Elevation[c] Ft	Design Dry-Bulb 99%	97.5%	Design Dry-Bulb and Mean Coincident Wet-Bulb 1%	2.5%	5%	Mean Daily Range	Design Wet-Bulb 1%	2.5%	5%	Humidity Ratio 2.5%	Ave. Winter Temp.*
Fort Collins	40	4	105	0	5001	−5	1	93/59	91/59	89/59	28	64	63	62	.0055	
Grand Junction AP (S)	39	1	108	3	4849	2	7	96/59	94/59	92/59	29	64	63	62	.0048	
Greeley	40	3	104	4	4648	−2	4	96/60	94/60	92/60	29	65	64	63	.0053	
La Junta AP	38	0	103	3	4188	−3	3	100/68	98/68	95/67	31	72	70	69	.0101	
Leadville	39	2	106	2	10177	−18	−14	84/52	81/51	78/50	30	56	55	54	——	
Pueblo AP	38	2	104	2	4639	−7	0	97/61	95/61	92/61	31	67	66	65	.0057	
Sterling	40	4	103	1	3939	−7	−2	95/62	93/62	90/62	30	67	66	65	.0067	
Trinidad AP	37	2	104	2	5746	−2	3	93/61	91/61	89/61	32	66	65	64	.0069	
CONNECTICUT																
Bridgeport AP	41	1	73	1	7	6	9	86/73	84/71	81/70	18	75	74	73	.0132	39.9
Hartford, Brainard Field	41	5	72	4	15	3	7	91/74	88/73	85/72	22	77	75	74	.0140	37.3
New Haven AP	41	2	73	0	6	3	7	88/75	84/73	82/72	17	76	75	74	.0150	39.0
New London	41	2	72	1	60	5	9	88/73	85/72	83/71	16	76	75	74	.0139	
Norwalk	41	1	73	3	37	6	9	86/73	84/71	81/70	19	75	74	73	.0132	
Norwich	41	3	72	0	20	3	7	89/75	86/73	83/72	18	76	75	74	.0144	
Waterbury	41	3	73	0	605	−4	2	88/73	85/71	82/70	21	75	74	72	.0134	
Windsor Locks, Bradley Field (S)	42	0	72	4	169	0	4	91/74	88/72	85/71	22	76	75	73	.0132	
DELAWARE																
Dover AFB	39	0	75	3	38	11	15	92/75	90/75	87/74	18	79	77	76	.0152	
Wilmington AP	39	4	75	3	78	10	14	92/74	89/74	87/73	20	77	76	75	.0146	42.5
DISTRICT OF COLUMBIA																
Andrews AFB	38	5	76	5	279	10	14	92/75	90/74	87/73	18	78	76	75	.0147	
Washington National AP	38	5	77	0	14	14	17	93/75	91/74	89/74	18	78	77	76	.0141	45.7
FLORIDA																
Belle Glade	26	4	80	4	16	41	44	92/76	91/76	89/76	16	79	78	78	.0159	
Cape Kennedy AP	28	3	80	3	16	35	38	90/78	88/78	87/78	15	80	79	79	.0184	
Daytona Beach AP	29	1	81	0	31	32	35	92/78	90/77	88/77	15	80	79	78	.0170	64.5
Fort Lauderdale	26	0	80	1	13	42	46	92/78	91/78	90/78	15	80	79	79	.0177	
Fort Myers AP	26	4	81	5	13	41	44	93/78	92/78	91/77	18	80	79	79	.0175	68.6
Fort Pierce	27	3	80	2	10	38	42	91/78	90/78	89/78	15	80	79	79	.0179	
Gainesville AP (S)	29	4	82	2	155	28	31	95/77	93/77	92/77	18	80	79	78	.0163	
Jacksonville AP	30	3	81	4	24	29	32	96/77	94/77	92/76	19	79	79	78	.0161	61.9
Key West AP	24	3	81	5	6	55	57	90/78	90/78	89/78	9	80	79	79	.0179	73.1
Lakeland CO (S)	28	0	82	0	214	39	41	93/76	91/76	89/76	17	79	78	78	.0159	66.7
Miami AP (S)	25	5	80	2	7	44	47	91/77	90/77	89/77	15	79	79	78	.0170	77.1
Miami Beach CO	25	5	80	1	9	45	48	90/77	89/77	88/77	10	79	79	78	.0172	72.5
Ocala	29	1	82	1	86	31	34	95/77	93/77	92/76	18	80	79	78	.0163	
Orlando AP	28	3	81	2	106r	35	38	94/76	93/76	91/76	17	79	78	78	.0154	65.7
Panama City, Tyndall AFB	30	0	85	4	22	29	33	92/78	90/77	89/77	14	81	80	79	.0170	
Pensacola CO	30	3	87	1	13	25	29	94/77	93/77	91/77	14	80	79	79	.0163	60.4
St. Augustine	29	5	81	2	15	31	35	92/78	89/78	87/78	16	80	79	79	.0182	
St. Petersburg	28	0	82	4	35	36	40	92/77	91/77	90/76	16	79	79	78	.0168	
Sanford	28	5	81	2	14	35	38	94/76	93/76	91/76	17	79	78	78	.0154	
Sarasota	27	2	82	3	30	39	42	93/77	92/77	90/76	17	79	79	78	.0165	
Tallahassee AP (S)	30	2	84	2	58	27	30	94/77	92/76	90/76	19	79	78	78	.0156	60.1
Tampa AP (S)	28	0	82	3	19	36	40	92/77	91/77	90/76	17	79	79	78	.0168	66.4
West Palm Beach AP	26	4	80	1	15	41	45	92/78	91/78	90/78	16	80	79	79	.0177	68.4
GEORGIA																
Albany, Turner AFB	31	3	84	1	224	25	29	97/77	95/76	93/76	20	80	79	78	.0149	
Americus	32	0	84	2	476	21	25	97/77	94/76	92/75	20	79	78	77	.0155	
Athens	34	0	83	2	700	18	22	94/74	92/74	90/74	21	78	77	76	.0138	51.8
Atlanta AP (S)	33	4	84	3	1005	17	22	94/74	92/74	90/73	19	77	76	75	.0146	51.7
Augusta AP	33	2	82	0	143	20	23	97/77	95/76	93/76	19	80	79	78	.0149	54.5
Brunswick	31	1	81	3	14	29	32	92/78	89/78	87/78	18	80	79	79	.0182	
Columbus, Lawson AFB	32	3	85	0	242	21	24	95/76	93/76	91/75	21	79	78	77	.0154	54.8
Dalton	34	5	85	0	720	17	22	94/76	93/76	91/76	22	79	78	77	.0158	
Dublin	32	3	83	0	215	21	25	96/77	93/76	91/75	20	79	78	77	.0154	
Gainesville	34	2	83	5	1254	16	21	93/74	91/74	89/73	21	77	76	75	.0152	
Griffin (S)	33	1	84	2	980	18	22	93/76	90/75	88/74	21	78	77	76	.0159	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[b]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
La Grange	33	0	85	0	715	19	23	94/76	91/75	89/74	21	78	77	76	.0153	
Macon AP	32	4	83	4	356	21	25	96/77	93/76	91/75	22	79	78	77	.0158	56.2
Marietta, Dobbins AFB	34	0	84	3	1016	17	21	94/74	92/74	90/74	21	78	77	76	.0146	
Moultrie	31	1	83	4	340	27	30	97/77	95/77	92/76	20	80	79	78	.0162	
Rome AP	34	2	85	1	637	17	22	94/76	93/76	91/76	23	79	78	77	.0158	49.9
Savannah-Travis AP	32	1	81	1	52	24	27	96/77	93/77	91/77	20	80	79	78	.0163	57.8
Valdosta-Moody AFB	31	0	83	1	239	28	31	96/77	94/77	92/76	20	80	79	78	.0161	
Waycross	31	2	82	2	140	26	29	96/77	94/77	91/76	20	80	79	78	.0161	
HAWAII																
Hilo AP (S)	19	4	155	1	31	61	62	84/73	83/72	82/72	15	75	74	74	.0143	71.9
Honolulu AP	21	2	158	0	7	62	63	87/73	86/73	85/72	12	76	75	74	.0144	74.2
Kaneohe Bay MCAS	21	2	157	5	18	65	66	85/75	84/74	83/74	12	76	76	75	.0157	
Wahiawa	21	3	158	0	900	58	59	86/73	85/72	84/72	14	75	74	73	.0145	
IDAHO																
Boise AP(S)	43	3	116	1	2842	3	10	96/65	94/64	91/64	31	68	66	65	.0073	39.7
Burley	42	3	113	5	4180	−3	2	99/62	95/61	92/66	35	64	63	61	.0055	
Coeur d'Alene AP	47	5	116	5	2973	−8	−1	89/62	86/61	83/60	31	64	63	61	.0070	
Idaho Falls AP	43	3	112	0	4730r	−11	−6	89/61	87/61	84/59	38	65	63	61	.0076	
Lewiston AP	46	2	117	0	1413	−1	6	96/65	93/64	90/63	32	67	66	64	.0068	41.0
Moscow	46	4	117	0	2660	−7	0	90/63	87/62	84/61	32	65	64	62	.0073	
Mountain Home AFB	43	0	115	5	2992	6	12	99/64	97/63	94/62	36	66	65	63	.0059	
Pocatello AP	43	0	112	4	4444	−8	−1	94/61	91/60	89/59	35	64	63	61	.0060	34.8
Twin Falls (AP (S)	42	3	114	3	4148	−3	2	99/62	95/61	92/60	34	64	63	61	.0055	
ILLINOIS																
Aurora	41	5	88	2	744	−6	−1	93/76	91/76	88/75	20	79	78	76	.0162	
Belleville, Scott AFB	38	3	89	5	447	1	6	94/76	92/76	89/75	21	79	78	76	.0160	
Bloomington	40	3	89	0	775	−6	−2	92/75	90/74	88/73	21	78	76	75	.0150	
Carbondale	37	5	89	1	380	2	7	95/77	93/77	90/76	21	80	79	77	.0167	
Champaign/Urbana	40	0	88	2	743	−3	2	95/75	92/74	90/73	21	78	77	75	.0142	
Chicago, Midway AP	41	5	87	5	610	−5	0	94/74	91/73	88/72	20	77	75	74	.0136	37.5
Chicago, O'Hare AP	42	0	87	5	658	−8	−4	91/74	89/74	86/72	20	77	76	74	.0149	35.8
Chicago CO	41	5	87	4	594	−3	2	94/75	91/74	88/73	15	79	77	75	.0145	38.9
Danville	40	1	87	4	558	−4	1	93/75	90/74	88/73	21	78	77	75	.0147	
Decatur	39	5	88	5	670	−3	2	94/75	91/74	88/73	21	78	77	75	.0145	
Dixon	41	5	89	3	696	−7	−2	93/75	90/74	88/73	23	78	77	75	.0147	
Elgin	42	0	88	2	820	−7	−2	91/75	88/74	86/73	21	78	77	75	.0155	
Freeport	42	2	89	4	780	−9	−4	91/74	89/73	87/72	24	77	76	74	.0144	
Galesburg	41	0	90	3	771	−7	−2	93/75	91/75	88/74	22	78	77	75	.0157	
Greenville	39	0	89	2	563	−1	4	94/76	92/75	89/74	21	79	78	76	.0151	
Joliet	41	3	88	1	588	−5	0	93/75	90/74	88/73	20	78	77	75	.0147	
Kankakee	41	1	87	5	625	−4	1	93/75	90/74	88/73	21	78	77	75	.0147	
La Salle/Peru	41	2	89	1	520	−7	−2	93/75	91/75	88/74	22	78	77	75	.0153	
Macomb	40	3	90	4	702	−5	0	95/76	92/76	89/75	22	79	78	76	.0160	
Moline AP	41	3	90	3	582	−9	−4	93/75	91/75	88/74	23	78	77	75	.0153	36.4
Mt Vernon	38	2	88	5	500	0	5	95/76	92/75	89/74	21	79	78	76	.0151	
Peoria AP	40	4	89	4	652	−8	−4	91/75	89/74	87/73	22	78	76	75	.0149	38.1
Quincy AP	40	0	91	1	762	−2	3	96/76	93/76	90/76	22	80	78	77	.0161	
Rantoul, Chanute AFB	40	2	88	1	740	−4	1	94/75	91/74	89/73	21	78	77	75	.0145	
Rockford	42	1	89	0	724	−9	−4	91/74	89/73	87/72	24	77	76	74	.0141	34.8
Springfield AP	39	5	89	4	587	−3	2	94/75	92/74	89/74	21	79	77	76	.0142	40.6
Waukegan	42	2	87	5	680	−6	−3	92/76	89/74	87/73	21	78	76	75	.0149	
INDIANA																
Anderson	40	0	85	4	847	0	6	95/76	92/75	89/74	22	79	78	76	.0155	
Bedford	38	5	86	3	670	0	5	95/76	92/75	89/74	22	79	78	76	.0151	
Bloomington	39	1	86	4	820	0	5	95/76	92/75	89/74	22	79	78	76	.0155	
Columbus, Bakalar AFB	39	2	85	5	661	3	7	95/76	92/75	90/74	22	79	78	76	.0151	
Crawfordsville	40	0	86	5	752	−2	3	94/75	91/74	88/73	22	79	77	76	.0148	
Evansville AP	38	0	87	3	381	4	9	95/76	93/75	91/75	22	79	78	77	.0149	45.0
Fort Wayne AP	41	0	85	1	791	−4	1	92/73	89/72	87/72	24	77	75	74	.0136	37.3
Goshen AP	41	3	85	5	823	−3	1	91/73	89/73	86/72	23	77	75	74	.0144	
Hobart	41	3	87	2	600	−4	2	91/73	88/73	85/72	21	77	75	74	.0143	
Huntington	40	4	85	3	802	−4	1	92/73	89/72	87/72	23	77	75	74	.0136	
Indianapolis AP (S)	39	4	86	2	793	−2	2	92/74	90/74	87/73	22	78	76	75	.0150	39.6
Jeffersonville	38	2	85	5	455	5	10	95/74	93/74	90/74	23	79	77	76	.0140	
Kokomo	40	3	86	1	790	−4	0	91/74	90/73	88/73	22	77	75	74	.0142	
Lafayette	40	2	86	5	600	−3	3	94/74	91/73	88/73	22	78	76	75	.0136	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
La Porte	41	3	86	4	810	−3	3	93/74	90/74	87/73	22	78	76	75	.0150	
Marion	40	3	85	4	791	−4	0	91/74	90/73	88/73	23	77	75	74	.0142	
Muncie	40	1	85	2	955	−3	2	92/74	90/73	87/73	22	76	76	75	.0142	
Peru, Bunker Hill AFB	40	4	86	1	804	−6	−1	90/74	88/73	86/73	22	77	75	74	.0146	
Richmond AP	39	5	84	5	1138	−2	2	92/74	90/74	87/73	22	78	76	75	.0150	
Shelbyville	39	3	85	5	765	−1	3	93/74	91/74	88/73	22	78	76	75	.0148	
South Bend AP	41	4	86	2	773	−3	1	91/73	89/73	86/72	22	77	75	74	.0144	36.6
Terre Haute AP	39	3	87	2	601	−2	4	95/75	92/74	89/73	22	79	77	76	.0142	
Valparaise	41	2	87	0	801	−3	3	93/74	90/74	87/73	22	78	76	75	.0150	
Vincennes	38	4	87	3	420	1	6	95/75	92/74	90/73	22	79	77	76	.0142	
IOWA																
Ames (S)	42	0	93	4	1004	−11	−6	93/75	90/74	87/73	23	78	76	75	.0150	
Burlington AP	40	5	91	1	694	−7	−3	94/74	91/75	88/73	22	78	77	75	.0153	37.6
Cedar Rapids AP	41	5	91	4	863	−10	−5	91/76	88/75	86/74	23	78	77	75	.0164	
Clinton	41	5	90	1	595	−8	−3	92/75	90/75	87/74	23	78	77	75	.0156	
Council Bluffs	41	2	95	5	1210	−8	−3	94/76	91/75	88/74	22	78	77	75	.0157	
Des Moines AP	41	3	93	4	948r	−10	−5	94/75	91/74	88/73	23	78	77	75	.0148	35.5
Dubuque	42	2	90	4	1065	−12	−7	90/74	88/73	86/72	22	77	75	74	.0146	32.7
Fort Dodge	42	3	94	1	1111	−12	−7	91/74	88/74	86/72	23	77	75	74	.0155	
Iowa City	41	4	91	3	645	−11	−6	92/76	89/76	87/74	22	80	78	76	.0167	
Keokuk	40	2	91	2	526	−5	0	95/75	92/75	89/74	22	79	77	76	.0151	
Marshalltown	42	0	92	5	898	−12	−7	92/76	90/75	88/74	23	78	77	75	.0159	
Mason City AP	43	1	93	2	1194	−15	−11	90/74	88/74	85/72	24	77	75	74	.0155	
Newton	41	4	93	0	946	−10	−5	94/75	91/74	88/73	23	78	77	75	.0148	
Ottumwa AP	41	1	92	2	842	−8	−4	94/75	91/74	88/73	22	78	77	75	.0148	
Sioux City AP	42	2	96	2	1095	−11	−7	95/74	92/74	89/73	24	78	77	75	.0146	34.0
Waterloo	42	3	92	2	868	−15	−10	91/76	89/75	86/74	23	78	77	75	.0153	32.6
KANSAS																
Atchison	39	3	95	1	945	−2	2	96/77	93/76	91/76	23	81	79	77	.0161	
Chanute AP	34	4	95	3	977	3	7	100/74	97/74	94/74	23	78	77	76	.0134	
Dodge City AP (S)	37	5	100	0	2594	0	5	100/69	97/69	95/69	25	74	73	71	.0102	42.5
El Dorado	37	5	96	5	1282	3	7	101/72	98/73	96/73	24	77	76	75	.0123	
Emporia	38	2	96	1	1209	1	5	100/74	97/74	94/73	25	78	77	76	.0134	
Garden City AP	38	0	101	0	2882	−1	4	99/69	96/69	94/69	28	74	73	71	.0107	
Goodland AP	39	2	101	4	3645	−5	0	99/66	96/65	93/66	31	71	70	68	.0079	37.8
Great Bend	38	2	98	5	1940	0	4	101/73	98/73	95/73	28	78	76	75	.0130	
Hutchinson AP	38	0	97	5	1524	4	8	102/72	99/72	97/72	28	77	75	74	.0116	
Liberal	37	0	101	0	2838	2	7	99/68	96/68	94/68	28	73	72	71	——	
Manhattan, Fort Riley (S)	39	0	96	5	1076	−1	3	99/75	95/75	92/74	24	78	77	76	.0148	
Parsons	37	2	95	3	908	5	9	100/74	97/74	94/74	23	79	77	76	.0134	
Russell AP	38	5	98	5	1864	0	4	101/73	98/73	95/73	29	78	76	75	.0130	
Salina	38	5	97	4	1271	0	5	103/74	100/74	97/73	26	78	77	75	.0131	
Topeka AP	39	0	95	4	877	0	4	99/75	96/75	93/74	24	79	78	76	.0145	41.7
Wichita AP	37	4	97	3	1321	3	7	101/72	98/73	96/73	23	77	76	75	.0127	44.2
KENTUCKY																
Ashland	38	3	82	4	551	5	10	94/76	91/74	89/73	22	78	77	75	.0145	
Bowling Green AP	37	0	86	3	535	4	10	94/77	92/75	89/74	21	79	77	76	.0151	
Corbin AP	37	0	84	1	1175	4	9	94/73	92/73	89/72	23	77	76	75	.0137	
Covington AP	39	0	84	4	869	1	6	92/73	90/72	88/72	22	77	75	74	.0133	41.4
Hopkinsville, Campbell AFB	36	4	87	3	540	4	10	94/77	92/75	89/74	21	79	77	76	.0133	
Lexington AP (S)	38	0	84	4	979	3	8	93/73	91/73	88/72	22	77	76	75	.0139	43.8
Louisville AP	38	1	85	4	474	5	10	95/74	93/74	90/74	23	79	77	76	.0140	44.0
Madisonville	37	2	87	3	439	5	10	96/76	93/75	90/75	22	79	78	77	.0149	
Owensboro	37	5	87	1	420	5	10	97/76	94/75	91/75	23	79	78	77	.0146	
Paducah AP	37	0	88	4	398	7	12	98/76	95/75	92/75	20	79	78	77	.0144	
LOUISIANA																
Alexandria AP	31	2	92	2	92	23	27	95/77	94/77	92/77	20	80	79	78	.0161	57.5
Baton Rouge AP	30	3	91	1	64	25	29	95/77	93/77	92/77	19	80	80	79	.0163	59.8
Bogalusa	30	5	89	5	103	24	28	95/77	93/77	92/77	19	80	80	79	.0163	
Houma	29	3	90	4	13	31	35	95/78	93/78	92/77	15	81	80	79	.0172	
Lafayette AP	30	1	92	0	38	26	30	95/78	94/78	92/78	18	81	80	79	.0170	
Lake Charles AP (S)	30	1	93	1	14	27	31	95/77	93/77	92/77	17	80	79	79	.0163	60.5
Minden	32	4	93	2	250	20	25	99/77	96/76	94/76	20	79	79	78	.0151	
Monroe AP	32	3	92	0	78	20	25	99/77	96/76	94/76	20	79	79	78	.0147	
Natchitoches	31	5	93	0	120	22	26	97/77	95/77	93/77	20	80	79	78	.0158	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
New Orleans AP	30	0	90	2	3	29	33	93/78	92/78	90/77	16	81	80	79	.0175	61.0
Shreveport AP(S)	32	3	93	5	252	20	25	99/77	96/76	94/76	20	79	79	78	.0151	56.2
MAINE																
Augusta AP	44	2	69	5	350	−7	−3	88/73	85/70	82/68	22	74	72	70	0.0126	
Bangor, Dow AFB	44	5	68	5	162	−11	−6	86/70	83/68	80/67	22	73	71	69	.0112	
Caribou AP (S)	46	5	68	0	624	−18	−13	84/69	81/67	78/66	21	71	69	67	.0112	24.4
Lewiston	44	0	70	1	182	−7	−2	88/73	85/70	82/68	22	74	72	70	.0123	
Millinocket AP	45	4	68	4	405	−13	−9	87/69	83/68	80/66	22	72	70	68	.0115	
Portland (S)	43	4	70	2	61	−6	−1	87/72	84/71	81/69	22	74	72	70	.0133	33.0
Waterville	44	3	69	4	89	−8	−4	87/72	84/69	81/68	22	74	72	70	.0117	
MARYLAND																
Baltimore AP	39	1	76	4	146	10	13	94/75	91/75	89/74	21	78	77	76	.0150	43.7
Baltimore CO	39	2	76	3	14	14	17	92/77	89/76	87/75	17	80	78	76	.0163	46.2
Cumberland	39	4	78	5	945	6	10	92/75	89/74	87/74	22	77	76	75	.0153	
Frederick AP	39	3	77	3	294	8	12	94/76	91/75	88/74	22	78	77	76	.0153	42.0
Hagerstown	39	4	77	4	660	8	12	94/75	91/74	89/74	22	77	76	75	.0145	
Salisbury (S)	38	2	75	3	52	12	16	93/75	91/75	88/74	18	79	77	76	.0150	
MASSACHUSETTS																
Boston AP (S)	42	2	71	0	15	6	9	91/73	88/71	85/70	16	75	74	72	.0124	40.0
Clinton	42	2	71	4	398	−2	2	90/72	87/71	84/69	17	75	73	72	.0129	
Fall River	41	4	71	1	190	5	9	87/72	84/71	81/69	18	74	73	72	.0133	
Framingham	42	2	71	3	170	3	6	89/72	86/71	83/69	17	74	73	71	.0128	
Gloucester	42	3	70	4	10	2	5	89/73	86/71	83/70	15	75	74	72	.0128	
Greenfield	42	3	72	4	205	−7	−2	88/72	85/71	82/69	23	74	73	71	.0130	
Lawrence	42	4	71	1	57	−6	0	90/73	87/72	84/70	22	76	74	73	.0134	
Lowell	42	3	71	2	90	−4	1	91/73	88/72	85/70	21	76	74	73	.0132	
New Bedford	41	4	71	0	70	5	9	85/72	82/71	80/69	19	74	73	72	.0137	
Pittsfield AP	42	3	73	2	1170	−8	−3	87/71	84/70	81/68	23	73	72	70	.0131	36.2
Springfield, Westover AFB	42	1	72	3	247	−5	0	90/72	87/71	84/69	19	75	73	72	.0126	
Taunton	41	5	71	1	20	5	9	89/73	86/72	83/70	18	75	74	73	.0136	
Worcester AP	42	2	71	5	986	0	4	87/71	84/70	81/68	18	73	72	70	.0131	34.7
MICHIGAN																
Adrian	41	5	84	0	754	−1	3	91/73	88/72	85/71	23	76	75	73	.0138	
Alpena AP	45	0	83	3	689	−11	−6	89/70	85/70	83/69	27	73	72	70	.0126	29.7
Battle Creek AP	42	2	85	2	939	1	5	92/74	88/72	85/70	23	76	74	73	.0138	
Benton Harbor AP	42	1	86	3	649	1	5	91/72	88/72	85/70	20	75	74	72	.0135	
Detroit	42	2	83	0	633	3	6	91/73	88/72	86/71	20	76	74	73	.0135	37.2
Escanaba	45	4	87	0	594	−11	−7	87/70	83/69	80/68	17	73	71	69	0.0122	29.6
Flint AP	42	0	83	4	766	−4	1	90/73	87/72	85/71	25	76	74	72	.0140	33.1
Grand Rapids AP	42	5	85	3	681	1	5	91/72	88/72	85/70	24	75	74	72	.0135	34.9
Holland	42	5	86	1	612	2	6	88/72	86/71	83/70	22	75	73	72	.0131	
Jackson AP	42	2	84	2	1003	1	5	92/74	88/72	85/70	23	76	74	73	.0138	
Kalamazoo	42	1	85	3	930	1	5	92/74	88/72	85/70	23	76	74	73	.0138	
Lansing AP	42	5	84	4	852	−3	1	90/73	87/72	84/70	24	75	74	72	.0140	34.8
Marquette CO	46	3	87	3	677	−12	−8	84/70	81/69	77/66	18	72	70	68	——	30.2
Mt Pleasant	43	4	84	5	796	0	4	91/73	87/72	84/71	24	76	74	72	.0140	
Muskegon AP	43	1	86	1	627	2	6	86/72	84/70	82/70	21	75	73	72	.0128	36.0
Pontiac	42	4	83	2	974	0	4	90/73	87/72	85/71	21	76	74	73	.0140	
Port Huron	43	0	82	3	586	0	4	90/73	87/72	83/71	21	76	74	73	.0145	
Saginaw AP	43	3	84	1	662	0	4	91/73	87/72	84/71	23	76	74	72	.0137	
Sault Ste. Marie AP (S)	46	3	84	2	721	−12	−8	84/70	81/69	77/66	23	72	70	68	.0127	27.7
Traverse City AP	44	4	85	4	618	−3	1	89/72	86/71	83/69	22	75	73	71	.0131	
Yipsilanti	42	1	83	3	777	1	5	92/72	89/71	86/70	22	75	74	72	.0127	
MINNESOTA																
Albert Lea	43	4	93	2	1235	−17	−12	90/74	87/72	84/71	24	77	75	73	.0140	
Alexandria AP	45	5	95	2	1421	−22	−16	91/72	88/72	85/70	24	76	74	72	.0141	
Bemidji AP	47	3	95	0	1392	−31	−26	88/69	85/69	81/67	24	73	71	69	.0124	
Brainerd	46	2	94	2	1214	−20	−16	90/73	87/71	84/69	24	75	73	71	.0132	
Duluth AP	46	5	92	1	1426	−21	−16	85/70	82/68	79/66	22	72	70	68	.0123	23.4
Fairbault	44	2	93	2	1190	−17	−12	91/74	88/72	85/71	24	77	75	73	.0138	
Fergus Falls	46	1	96	0	1210	−21	−17	91/72	88/72	85/70	24	76	74	72	.0138	
International Falls AP	48	3	93	2	1179	−29	−25	85/68	83/68	80/66	26	71	70	68	.0118	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

						Winter[d]		Summer[e]								
Col. 1	Col. 2		Col. 3		Col. 4	Col. 5		Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
Mankato	44	1	94	0	785	−17	−12	91/72	88/72	85/70	24	77	75	73	.0138	
Minneapolis/																
St Paul AP	44	5	93	1	822	−16	−12	92/75	89/73	86/71	22	77	75	73	.0144	28.3
Rochester AP	44	0	92	3	1297	−17	−12	90/74	87/72	84/71	24	77	75	73	.0143	28.8
St Cloud AP (S)	45	4	94	1	1034	−15	−11	91/74	88/72	85/70	24	76	74	72	.0138	
Virginia	47	3	92	3	1435	−25	−21	85/69	83/68	80/66	23	71	70	68	.0120	
Willmar	45	1	95	0	1133	−15	−11	91/74	88/72	85/71	24	76	74	72	.0138	
Winona	44	1	91	4	652	−14	−10	91/75	88/73	85/72	24	77	75	74	.0143	
MISSISSIPPI																
Biloxi,																
Keesler AFB	30	2	89	0	25	28	31	94/79	92/79	90/78	16	82	81	80	.0184	
Clarksdale	34	1	90	3	178	14	19	96/77	94/77	92/76	21	80	79	78	.0161	
Columbus AFB	33	4	88	3	224	15	20	95/77	93/77	91/76	22	80	79	78	.0163	
Greenville AFB	33	3	91	1	139	15	20	95/77	93/77	91/76	21	80	79	78	.0163	
Greenwood	33	3	90	1	128	15	20	95/77	93/77	91/76	21	80	79	78	.0163	
Hattiesburg	31	2	89	2	200	24	27	96/78	94/77	92/77	21	81	80	79	.0165	
Jackson AP	32	2	90	1	330	21	25	97/76	95/76	93/76	21	79	78	78	.0153	55.7
Laurel	31	4	89	1	264	24	27	96/78	94/77	92/77	21	81	80	79	.0164	
McComb AP	31	2	90	3	458	21	26	96/77	94/76	92/76	18	80	79	78	.0160	
Meridian AP	32	2	88	5	294	19	23	97/77	95/76	93/76	22	80	79	78	.0153	55.4
Natchez	31	4	91	3	168	23	27	96/78	94/78	92/77	21	81	80	79	.0170	
Tupelo	34	2	88	4	289	14	19	96/77	94/77	92/76	22	80	79	78	.0164	
Vicksburg CO	32	2	91	0	234	22	26	97/78	95/78	93/77	21	81	80	79	.0167	56.9
MISSOURI																
Cape Girardeau	37	1	89	3	330	8	13	98/76	95/75	92/75	21	79	78	77	.0144	42.3
Columbia AP (S)	39	0	92	2	778	−1	4	97/74	94/74	91/73	22	78	77	76	.0141	
Farmington AP	37	5	90	3	928	3	8	96/76	93/75	90/74	22	78	77	75	.0152	
Hannibal	39	4	91	2	489	−2	3	96/76	93/76	90/76	22	80	78	77	.0158	
Jefferson City	38	4	92	1	640	2	7	98/75	95/74	92/74	23	78	77	76	.0135	
Joplin AP	37	1	94	3	982	6	10	100/73	97/73	94/73	24	78	77	76	.0125	
Kansas City AP	39	1	94	4	742	2	6	99/75	96/74	93/74	20	78	77	76	.0136	43.9
Kirksville AP	40	1	92	4	966	−5	0	96/74	93/74	90/73	24	78	77	76	.0143	
Mexico	39	1	92	0	775	−1	4	97/74	94/74	91/73	22	78	77	76	.0141	
Moberly	39	3	92	3	850	−2	3	97/74	94/74	91/73	23	78	77	76	.0141	
Poplar Bluff	36	5	90	3	322	11	16	98/78	95/76	92/76	22	81	79	78	.0153	
Rolla	38	0	91	5	1202	3	9	94/77	91/75	89/74	22	78	77	76	.0157	
St Joseph AP	39	5	95	0	809	−3	2	96/77	93/76	91/76	23	81	79	77	.0161	40.3
St Louis AP	38	5	90	2	535	2	6	97/75	94/75	91/74	21	78	77	76	.0146	43.1
St Louis CO	38	4	90	2	465	3	8	98/75	94/75	91/74	18	78	77	76	.0146	
Sedalia,																
Whiteman AFB	38	4	93	3	838	−1	4	95/76	92/76	90/75	22	79	78	76	.0164	
Sikeston	36	5	89	3	318	9	15	98/77	95/76	92/75	21	80	78	77	.0153	
Springfield AP	37	1	93	2	1265	3	9	96/73	93/74	91/74	23	78	77	75	——	44.5
MONTANA																
Billings AP	45	5	108	3	3567	−15	−10	94/64	91/64	88/63	31	67	66	64	.0083	34.5
Bozeman	45	5	111	0	4856	−20	−14	90/61	87/60	84/59	32	63	62	60	.0071	
Butte AP	46	0	112	3	5526r	−24	−17	86/58	83/56	80/56	35	60	58	57	——	
Cut Bank AP	48	4	112	2	3838r	−25	−20	88/61	85/61	82/60	35	64	62	61	.0062	
Glasgow AP (S)	48	1	106	4	2277	−22	−18	92/64	89/63	85/62	29	68	66	64	.0075	26.4
Glendive	47	1	104	4	2076	−18	−13	95/66	92/64	89/62	29	69	67	65	.0073	
Great Falls AP (S)	47	3	111	2	3664r	−21	−15	91/60	88/60	85/59	28	64	62	60	.0062	32.8
Havre	48	3	109	4	2488	−18	−11	94/65	90/64	87/63	33	68	66	65	.0080	28.1
Helena AP	46	4	112	0	3893	−21	−16	91/60	88/60	85/59	32	64	62	61	.0064	31.1
Kalispell AP	48	2	114	2	2965	−14	−7	91/62	87/61	84/60	34	65	63	62	.0068	31.4
Lewiston AP	47	0	109	3	4132	−22	−16	90/62	87/61	83/60	30	65	63	62	.0073	
Livingston AP	45	4	110	3	4653	−20	−14	90/61	87/60	84/59	32	63	62	60	.0069	
Miles City AP	46	3	105	5	2629	−20	−15	98/66	95/66	92/65	30	70	68	67	.0083	31.2
Missoula AP	46	5	114	1	3200	−13	−6	92/62	88/61	85/60	36	65	63	62	.0066	31.5
NEBRASKA																
Beatrice	40	2	96	5	1235	−5	−2	99/75	95/74	92/74	24	78	77	76	.0139	
Chadron AP	42	5	103	0	3300	−8	−3	97/66	94/65	91/65	30	71	69	68	.0084	
Columbus	41	3	97	2	1442	−6	−2	98/74	95/73	92/73	25	77	76	75	.0133	
Fremont	41	3	96	3	1203	−6	−2	98/75	95/74	92/74	22	78	77	76	.0139	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet-Bulb			Humidity Ratio	Ave. Winter
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%	Temp.*
Grand Island AP	41	0	98	2	1841	−8	−3	97/72	94/71	91/71	28	75	74	73	.0122	36.0
Hastings	40	4	98	3	1932	−7	−3	97/72	94/71	91/71	27	75	74	73	.0122	
Kearney	40	4	99	1	2146	−9	−4	96/71	93/70	90/70	28	74	73	72	.0116	
Lincoln CO (S)	40	5	96	5	1150	−5	−2	99/75	95/74	92/74	24	78	77	76	.0139	38.8
McCook	40	1	100	4	2565	−6	−2	98/69	95/69	91/69	28	74	72	71	.0107	
Norfolk	42	0	97	3	1532	−8	−4	97/74	93/74	90/73	30	78	77	75	.0147	34.0
North Platte AP (S)	41	1	100	4	2779	−8	−4	97/69	94/69	90/69	28	74	72	71	.0112	35.5
Omaha AP	41	2	95	5	978	−8	−3	94/76	91/75	88/74	22	78	77	75	.0157	35.6
Scottsbluff AP	41	5	103	4	3950	−8	−3	95/65	92/65	90/64	31	70	68	67	.0091	35.9
Sidney AP	41	1	103	0	4292	−8	−3	95/65	92/65	90/64	31	70	68	67	.0094	
NEVADA																
Carson City	39	1	119	5	4675	4	9	94/60	91/59	89/58	42	63	61	60	.0053	
Elko AP	40	5	115	5	5075	−8	−2	94/59	92/59	90/58	42	63	62	60	.0053	34.0
Ely AP (S)	39	1	114	5	6257	−10	−4	89/57	87/56	85/55	39	60	59	58	.0051	33.1
Las Vegas AP (S)	36	1	115	1	2162	25	28	108/66	106/65	104/65	30	71	70	69	.0048	53.5
Lovelock AP	40	0	118	3	3900	8	12	98/63	96/63	93/62	42	66	65	64	.0067	
Reno AP (S)	39	3	119	5	4404	5	10	95/61	92/60	90/59	45	64	62	61	.0057	
Reno CO	39	3	119	5	4490	6	11	96/61	93/60	91/59	45	64	62	61	.0055	
Tonopah AP	38	0	117	1	5426	5	10	94/60	92/59	90/58	40	64	62	61	.0055	39.3
Winnemucca AP	40	5	117	5	4299	−1	3	96/60	94/60	92/60	42	64	62	61	.0053	36.7
NEW HAMPSHIRE																
Berlin	44	3	71	1	1110	−14	−9	87/71	84/69	81/68	22	73	71	70	.0123	
Claremont	43	2	72	2	420	−9	−4	89/72	86/70	83/69	24	74	73	71	.0123	
Concord AP	43	1	71	3	339	−8	−3	90/72	87/70	84/69	26	74	73	71	.0121	33.0
Keene	43	0	72	2	490	−12	−7	90/72	87/70	83/69	24	74	73	71	.0121	
Laconia	43	3	71	3	505	−10	−5	89/72	86/70	83/69	25	74	73	71	.0123	
Manchester, Grenier AFB	43	0	71	3	253	−8	−3	91/72	88/71	85/70	24	75	74	72	.0127	
Portsmouth, Pease AFB	43	1	70	5	127	−2	2	89/73	85/71	83/70	22	75	74	72	.0130	
NEW JERSEY																
Atlantic City CO	39	3	74	3	11	10	13	92/74	89/74	86/72	18	78	77	75	.0146	43.2
Long Branch	40	2	74	0	20	10	13	93/74	90/73	87/72	18	78	77	75	.0135	
Newark AP	40	4	74	1	11	10	14	94/74	91/73	88/72	20	77	76	75	.0133	42.8
New Brunswick	40	3	74	3	86	6	10	92/74	89/73	86/72	19	77	76	75	.0137	
Paterson	40	5	74	1	100	6	10	94/74	91/73	88/72	21	77	76	75	.0133	
Phillipsburg	40	4	75	1	180	1	6	92/73	89/72	86/71	21	76	75	74	.0129	
Trenton CO	40	1	74	5	144	11	14	91/75	88/74	85/73	19	78	76	75	.0148	42.4
Vineland	39	3	75	0	95	8	11	91/75	89/74	86/73	19	78	76	75	.0146	
NEW MEXICO																
Alamagordo, Holloman AFB	32	5	106	1	4070	14	19	98/64	96/64	94/64	30	69	68	67	.0074	
Albuquerque AP (S)	35	0	106	4	5310	12	16	96/61	94/61	92/61	27	66	65	64	.0065	45.0
Artesia	32	5	104	2	3375	13	19	103/67	100/67	97/67	30	72	71	70	.0085	
Carlsbad AP	32	2	104	2	3234	13	19	103/67	100/67	97/67	28	72	71	70	.0082	
Clovis AP	34	3	103	1	4279	8	13	95/65	93/65	91/65	28	69	68	67	.0092	
Farmington AP	36	5	108	1	5495	1	6	95/63	93/62	91/61	30	67	65	64	.0075	
Gallup	35	3	108	5	6465	0	5	90/59	89/58	86/58	32	64	62	61	0.0062	
Grants	35	1	107	5	6520	−1	4	89/59	88/58	85/57	32	64	62	61	.0061	
Hobbs AP	32	4	103	1	3664	13	18	101/66	99/66	97/66	29	71	70	69	.0080	
Las Cruces	32	2	107	0	3900	15	20	99/64	96/64	94/64	30	69	68	67	.0074	
Los Alamos	35	5	106	2	7410	5	9	89/60	87/60	85/60	32	62	61	60	.0084	
Raton AP	36	5	104	3	6379	−4	1	91/60	89/60	87/60	34	65	64	63	.0074	38.1
Roswell, Walker AFB	33	2	104	3	3643	13	18	100/66	98/66	96/66	33	71	70	69	.0082	47.5
Santa Fe CO	35	4	106	0	7045	6	10	90/61	88/61	86/61	28	63	62	61	.0087	
Silver City AP	32	4	108	2	5373	5	10	95/61	94/60	91/60	30	66	64	63	.0058	48.0
Socorro AP	34	0	106	5	4617	13	17	97/62	95/62	93/62	30	67	66	65	.0065	
Tucumcari AP	35	1	103	4	4053	8	13	99/66	97/66	95/65	28	70	69	68	.0087	
NEW YORK																
Albany AP (S)	42	5	73	5	277	−6	−1	91/73	88/72	85/70	23	75	74	72	.0135	34.6
Albany CO	42	5	73	5	19	−4	1	91/73	88/72	85/70	20	75	74	72	.0132	37.2
Auburn	43	0	76	3	715	−3	2	90/73	87/71	84/70	22	75	73	72	.0129	
Batavia	43	0	78	1	900	1	5	90/72	87/71	84/70	22	75	73	72	.0132	
Binghamton AP	42	1	76	0	1590	−2	1	86/71	83/69	81/68	20	73	72	70	.0128	33.9
Buffalo AP	43	0	78	4	705r	2	6	88/71	85/70	83/69	21	74	73	72	.0126	34.5
Cortland	42	4	76	1	1129	−5	0	88/71	85/71	82/70	23	74	73	71	.0137	
Dunkirk	42	3	79	2	590	4	9	88/73	85/72	83/71	18	75	74	72	.0142	
Elmira AP	42	1	76	5	860	−4	1	89/71	86/71	83/70	24	74	73	71	.0134	
Geneva (S)	42	5	77	0	590	−3	2	90/73	87/71	84/70	22	75	73	72	.0129	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb			Humidity Ratio	Ave. Winter Temp.*
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%	
Glen Falls	42	2	73	4	321	−11	−5	88/72	85/71	82/69	23	74	73	71	.0134	
Gloversville	43	1	74	2	790	−8	−2	89/72	86/71	83/69	23	75	74	72	.0134	
Hornell	42	2	77	4	1325	−4	0	88/71	85/70	82/69	24	74	73	72	.0132	
Ithaca (S)	42	3	76	3	950	−5	0	88/71	85/71	82/70	24	74	73	71	.0137	
Jamestown	42	1	79	2	1390	−1	3	88/70	86/70	83/69	20	74	72	71	0.0129	
Kingston	42	0	74	0	279	−3	2	91/73	88/72	85/70	22	76	74	73	.0135	
Lockport	43	1	78	4	520	4	7	89/74	86/72	84/71	21	76	74	73	.0139	
Massena AP	45	0	75	0	202r	−13	−8	86/70	83/69	80/68	20	73	72	70	.0120	
Newburg-Stewart AFB	41	3	74	1	460	−1	4	90/73	88/72	85/70	21	76	74	73	.0135	
NYC-Central Park (S)	40	5	74	0	132	11	15	92/74	89/73	87/72	17	76	75	74	.0137	42.8
NYC-Kennedy AP	40	4	73	5	16	12	15	90/73	87/72	84/71	16	76	75	74	.0134	41.4
NYC-La Guardia AP	40	5	73	5	19	11	15	92/74	89/73	87/72	16	76	75	74	.0137	43.1
Niagra Falls AP	43	1	79	0	596	4	7	89/74	86/72	84/71	20	76	74	73	.0139	
Olean	42	1	78	3	1420	−2	2	87/71	84/71	81/70	23	74	73	71	.0142	
Oneonta	42	3	75	0	1150	−7	−4	86/71	83/69	80/68	24	73	72	70	.0125	
Oswego CO	43	3	76	3	300	1	7	86/73	83/71	80/70	20	75	73	72	.0138	
Plattsburg AFB	44	4	73	3	165	−13	−8	86/70	83/69	80/68	22	73	72	70	.0120	
Poughkeepsie	41	4	73	5	103	0	6	92/74	89/74	86/72	21	77	75	74	.0146	
Rochester AP	43	1	77	4	543	1	5	91/73	88/71	85/70	22	75	73	72	.0127	35.4
Rome-Griffiss AFB	43	1	75	3	515	−11	−5	88/71	85/70	83/69	22	75	73	71	.0126	
Schenectady (S)	42	5	74	0	217	−4	1	90/73	87/72	84/70	22	75	74	72	.0134	35.4
Suffolk County AFB	40	5			57	7	10	86/72	83/71	80/70	16	76	74	73	.0129	
Syracuse AP	43	1	76	1	424	−3	2	90/73	87/71	84/70	20	75	73	72	.0129	35.2
Utica	43	1	75	2	714	−12	−6	88/73	85/71	82/70	22	75	73	71	.0134	
Watertown	44	0	76	0	497	−11	−6	86/73	83/71	81/70	20	75	73	72	.0138	
NORTH CAROLINA																
Ashville AP	35	3	82	3	217r	10	14	89/73	87/72	85/71	21	75	74	72	.0134	46.7
Charlotte AP	35	0	81	0	735	18	22	95/74	93/74	91/74	20	77	76	76	.0140	50.4
Durham	36	0	78	5	406	16	20	94/75	92/75	90/75	20	78	77	76	.0151	
Elizabeth City AP	36	2	76	1	10	12	19	93/78	91/77	89/76	18	80	78	78	.0168	
Fayetteville, Pope AFB	35	1	79	0	95	17	20	95/76	92/76	90/75	20	79	78	77	.0156	
Goldsboro, Seymour-Johnson AFB	35	2	78	0	88	18	21	94/77	91/76	89/75	18	79	78	77	.0159	
Greensboro AP (S)	36	1	80	0	887	14	18	93/74	91/73	89/73	21	77	76	75	.0139	47.5
Greenville	35	4	77	2	25	18	21	93/77	91/76	89/75	19	79	78	77	.0159	
Henderson	36	2	78	2	510	12	15	95/77	92/76	90/76	20	79	78	77	.0160	
Hickory	35	4	81	2	1165	14	18	92/73	90/72	88/72	21	75	74	73	.0133	
Jacksonville	34	5	77	3	24	20	24	92/78	90/78	88/77	18	80	79	78	.0179	
Lumberton	34	4	79	0	132	18	21	95/76	92/76	90/75	20	79	78	77	.0156	
New Bern AP	35	1	77	0	17	20	24	92/78	90/78	88/77	18	80	79	78	.0179	
Raleigh/Durham AP (S)	35	5	78	5	433	16	20	94/75	92/75	90/75	20	78	77	76	.0151	49.4
Rocky Mount	36	0	77	5	81	18	21	94/77	91/76	89/75	19	79	78	77	.0159	
Wilmington AP	34	2	78	0	30	23	26	93/79	91/78	89/77	18	81	80	79	.0177	54.6
Winston-Salem AP	36	1	80	1	967	16	20	94/74	91/73	89/73	20	76	75	74	.0139	48.4
NORTH DAKOTA																
Bismark AP (S)	46	5	100	5	1647	−23	−19	95/68	91/68	88/67	27	73	71	70	.0102	26.6
Devil's Lake	48	1	98	5	1471	−25	−21	91/69	88/68	85/66	25	73	71	69	.0109	22.4
Dickinson AP	46	5	102	5	2595	−21	−17	94/68	90/66	87/65	25	71	69	68	.0110	
Fargo AP	46	5	96	5	900	−22	−18	92/73	89/71	85/69	25	76	74	72	.0127	24.8
Grands Forks AP	48	0	97	2	832	−26	−22	91/70	87/70	84/68	25	74	72	70	.0124	
Jamestown AP	47	0	98	4	1492	−22	−18	94/70	90/69	87/68	26	74	74	71	.0112	
Minot AP	48	2	101	2	1713	−24	−20	92/68	89/67	86/65	25	72	70	68	.0099	
Williston	48	1	103	4	1877	−25	−21	91/68	88/67	85/65	25	72	70	68	.0104	25.2
OHIO																
Akron-Canton AP	41	0	81	3	1210	1	6	89/72	86/71	84/70	21	75	73	72	.0134	38.1
Ashtabula	42	0	80	5	690	4	9	88/73	85/72	83/71	18	75	74	72	.0142	
Athens	39	2	82	1	700	0	6	95/75	92/74	90/73	22	78	76	74	.0142	
Bowling Green	41	3	83	4	675	−2	2	92/73	89/73	86/71	23	76	75	73	.0141	
Cambridge	40	0	81	4	800	1	7	93/75	90/74	87/73	23	78	76	75	.0150	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Winter[d] Col. 5		Summer[e] Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb			Humidity Ratio	Ave. Winter Temp.*
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%	
Chillicothe	39	2	83	0	638	0	6	95/75	92/74	90/73	22	78	76	74	.0142	
Cincinnati CO	39	1	84	4	761	1	6	92/73	90/72	88/72	21	77	75	74	.0133	45.1
Cleveland AP (S)	41	2	81	5	777r	1	5	91/73	88/72	86/71	22	76	74	73	.0138	37.2
Columbus AP (S)	40	0	82	5	812	0	5	92/73	90/73	87/72	24	77	75	74	.0142	39.7
Dayton AP	39	5	84	1	997	−1	4	91/73	89/72	86/71	20	76	75	73	.0136	39.8
Defiance	41	2	84	2	700	−1	4	94/74	91/73	88/72	24	77	76	74	.0136	
Findlay AP	41	0	83	4	797	2	3	92/74	90/73	87/72	24	77	76	74	.0142	
Fremont	41	2	83	1	600	−3	1	90/73	88/73	85/71	24	76	75	73	.0143	
Hamilton	39	2	84	3	650	0	5	92/73	90/72	87/71	22	76	75	73	.0130	
Lancaster	39	4	82	4	920	0	5	93/74	91/73	88/72	23	77	75	74	.0139	
Lima	40	4	84	0	860	−1	4	94/74	91/73	88/72	24	77	76	74	.0139	
Mansfield AP	40	5	82	3	1297	0	5	90/73	87/72	85/72	22	76	74	73	.0143	36.9
Marion	40	4	83	1	920	0	5	93/74	91/73	88/72	23	77	76	74	.0139	
Middletown	39	3	84	3	635	0	5	92/73	90/72	87/71	22	76	75	73	.0130	
Newark	40	1	82	3	825	−1	5	94/73	92/73	89/72	23	77	75	74	.0137	
Norwalk	41	1	82	4	720	−3	1	90/73	88/73	85/71	22	76	75	73	.0143	
Portsmouth	38	5	83	0	530	5	10	95/76	92/74	89/73	22	78	77	75	.0142	
Sandusky CO	41	3	82	4	606	1	6	93/73	91/72	88/71	21	76	74	73	.0128	39.1
Springfield	40	0	83	5	1020	−1	3	91/74	89/73	87/72	21	77	76	74	.0144	
Steubenville	40	2	80	4	992	1	5	89/72	86/71	84/70	22	74	73	72	.0134	
Toledo AP	41	4	83	5	676r	−3	1	90/73	88/73	85/71	25	76	75	73	.0143	36.4
Warren	41	2	80	5	900	0	5	89/71	87/71	85/70	23	74	73	71	.0132	
Wooster	40	5	82	0	1030	1	6	89/72	86/71	84/70	22	75	73	72	.0134	
Youngstown AP	41	2	80	4	1178	−1	4	88/71	86/71	84/70	23	74	73	71	.0134	36.8
Zanesville AP	40	0	81	5	881	1	7	93/75	90/74	87/73	23	78	76	75	.0150	
OKLAHOMA																
Ada	34	5	96	4	1015	10	14	100/74	97/74	95/74	23	77	76	75	.0134	
Altus AFB	34	4	99	2	1390	11	16	102/73	100/73	98/73	25	77	76	75	.0122	
Ardmore	34	2	97	1	880	13	17	100/74	98/74	95/74	23	77	77	76	.0132	
Bartlesville	36	5	96	0	715	6	10	101/73	98/74	95/74	23	77	77	76	.0128	
Chickasha	35	0	98	0	1085	10	14	101/74	98/74	95/74	24	78	77	76	.0132	
Enid-Vance AFB	36	2	98	0	1287	9	13	103/74	100/74	97/74	24	79	77	76	.0131	
Lawton AP	34	3	98	2	1108	12	16	101/74	99/74	96/74	24	78	77	76	.0133	
Mc Alester	34	5	95	5	760	14	19	99/74	96/74	93/74	23	77	76	75	.0136	
Muskogee AP	35	4	95	2	610	10	15	101/74	98/75	95/75	23	79	78	77	.0137	
Norman	35	1	97	3	1109	9	13	99/74	96/74	94/74	24	77	76	75	.0136	
Oklahoma City AP (S)	35	2	97	4	1280	9	13	100/74	97/74	95/73	23	78	77	76	.0138	48.3
Ponca City	36	4	97	0	996	5	9	100/74	97/74	94/74	24	77	76	76	.0134	
Seminole	35	2	96	4	865	11	15	99/74	96/74	94/73	23	77	76	75	.0136	
Stillwater (S)	36	1	97	1	884	8	13	100/74	96/74	93/74	24	77	76	75	.0136	
Tulsa AP	36	1	95	5	650	8	13	101/74	98/75	95/75	22	79	78	77	.0137	47.7
Woodward	36	3	99	3	1900	6	10	100/73	97/73	94/73	26	78	76	75	.0132	
OREGON																
Albany	44	4	123	1	224	18	22	92/67	89/66	86/65	31	69	67	66	.0084	
Astoria AP (S)	46	1	123	5	8	25	29	75/65	71/62	68/61	16	65	63	62	.0098	45.6
Baker AP	44	5	117	5	3368	−1	6	92/63	89/61	86/60	30	65	63	61	.0066	
Bend	44	0	121	2	3599	−3	4	90/62	87/60	84/59	33	64	62	60	.0115	
Corvallis (S)	44	3	123	2	221	18	22	92/67	89/66	86/65	31	69	67	66	.0084	
Eugene AP	44	1	123	1	364	17	22	92/67	89/66	86/65	31	69	67	66	.0086	45.6
Grants Pass	42	3	123	2	925	20	24	99/69	96/68	93/67	33	71	69	68	.0088	
Klamath Falls AP	42	1	121	4	4091	4	9	90/61	87/60	84/59	36	63	61	60	.0066	
Medford AP (S)	42	2	122	5	1298	19	23	98/68	94/67	91/66	35	70	68	67	.0087	43.2
Pendleton AP	45	4	118	5	1492	−2	5	97/65	93/64	90/62	29	66	65	63	.0068	42.6
Portland AP	45	4	122	4	21	17	23	89/68	85/67	81/65	23	69	67	66	.0100	45.6
Portland CO	45	3	122	4	57	18	24	90/68	86/67	82/65	21	69	67	66	0.0098	47.4
Roseburg AP	43	1	123	2	505	18	23	93/67	90/66	87/65	30	69	67	66	.0084	46.3
Salem AP	45	0	123	0	195	18	23	92/68	88/66	84/65	31	69	68	66	.0086	45.4
The Dalles	45	4	121	1	102	13	19	93/69	89/68	85/66	28	70	68	67	-----	
PENNSYLVANIA																
Allentown AP	40	4	75	3	376	4	9	92/73	88/72	86/72	22	76	75	73	.0135	38.9
Altoona CO	40	2	78	2	1468	0	5	90/72	87/71	84/70	23	74	73	72	.0135	
Butler	40	4	80	0	1100	1	6	90/73	87/72	85/71	22	75	74	73	.0140	
Chambersburg	40	0	77	4	640	4	8	93/75	90/74	87/73	23	77	76	75	.0147	
Erie AP	42	1	80	1	732	4	9	88/73	85/72	83/71	18	75	74	72	.0142	36.8
Harrisburg AP	40	1	76	5	335	7	11	94/75	91/74	88/73	21	77	76	75	.0145	41.2
Johnstown	40	2	78	5	1214	−3	2	86/70	83/70	80/68	23	72	71	70	.0133	
Lancaster	40	1	76	2	255	4	8	93/75	90/74	87/73	22	77	76	75	.0147	
Meadville	41	4	80	1	1065	0	4	88/71	85/70	83/69	21	73	72	71	.0128	
New Castle	41	0	80	2	825	2	7	91/73	88/72	86/71	23	75	74	73	.0138	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

Col. 1 State and Station	Col. 2 Latitude[b] °	′	Col. 3 Longitude[c] °	′	Col. 4 Elevation[c] Ft	Winter[d] Col. 5 Design Dry-Bulb 99%	97.5%	Summer[e] Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb 1%	2.5%	5%	Col. 7 Mean Daily Range	Col. 8 Design Wet-Bulb 1%	2.5%	5%	Col. 9 Humidity Ratio 2.5%	Col. 10 Ave. Winter Temp.*
Philadelphia AP	39	5	75	2	7	10	14	93/75	90/74	87/72	21	77	76	75	.0144	41.8
Pittsburgh AP	40	3	80	1	1137	1	5	89/72	86/71	84/70	22	74	73	72	0.0134	38.4
Pittsburgh CO	40	3	80	0	749r	3	7	91/72	88/71	86/70	19	74	73	72	.0127	42.2
Reading CO	40	2	76	0	226	9	13	92/73	89/72	86/72	19	76	75	73	.0129	42.4
Scranton/ Wilkes-Barre	41	2	75	4	940	1	5	90/72	87/71	84/70	19	74	73	72	.0132	37.2
State College (S)	40	5	77	5	1175	3	7	90/72	87/71	84/70	23	74	73	72	.0132	
Sunbury	40	5	76	5	480	2	7	92/73	89/72	86/70	22	75	74	73	.0132	
Uniontown	39	5	79	4	1040	5	9	91/74	88/73	85/72	22	76	75	74	.0146	
Warren	41	5	79	1	1280	−2	4	89/71	86/71	83/70	24	74	73	72	.0137	
West Chester	40	0	75	4	440	9	13	92/75	89/74	86/72	20	77	76	75	.0149	
Williamsport AP	41	1	77	0	527	2	7	92/73	89/72	86/70	23	75	74	73	.0132	38.5
York	40	0	76	4	390	8	12	94/75	91/74	88/73	22	77	76	75	.0145	
RHODE ISLAND																
Newport (S)	41	3	71	2	20	5	9	88/73	85/72	82/70	16	76	75	73	.0136	
Providence AP	41	4	71	3	55	5	9	89/73	86/72	83/70	19	75	74	73	.0136	38.8
SOUTH CAROLINA																
Anderson	34	3	82	4	764	19	23	94/74	92/74	90/74	21	77	76	75	.0146	
Charleston AFB (S)	32	5	80	0	41	24	27	93/78	91/78	89/77	18	81	80	79	.0177	56.4
Charleston CO	32	5	80	0	9	25	28	94/78	92/78	90/77	13	81	80	79	.0175	57.9
Columbia AP	34	0	81	1	217	20	24	97/76	95/75	93/75	22	79	78	77	.0141	54.0
Florence AP	34	1	79	4	146	22	25	94/77	92/77	90/76	21	80	79	78	.0165	54.5
Georgetown	33	2	79	2	14	23	26	92/79	90/78	88/77	18	81	80	79	.0179	
Greenville AP	34	5	82	1	957	18	22	93/74	91/74	89/74	21	77	76	75	.0148	51.6
Greenwood	34	1	82	1	671	18	22	95/75	93/74	91/74	21	78	77	76	.0140	
Orangeburg	33	3	80	5	244	20	24	97/76	95/75	93/75	20	79	78	77	.0141	
Rock Hill	35	0	81	0	470	19	23	96/75	94/74	92/74	20	78	77	76	.0138	
Spartanburg AP	35	0	82	0	816	18	22	93/74	91/74	89/74	20	77	76	75	.0148	
Sumter-Shaw AFB	34	0	80	3	291	22	25	95/77	92/76	90/75	21	79	78	77	.0160	
SOUTH DAKOTA																
Aberdeen AP	45	3	98	3	1296	−19	−15	94/73	91/72	88/70	27	77	75	73	.0134	
Brookings	44	2	96	5	1642	−17	−13	95/73	92/72	89/71	25	77	75	73	.0132	
Huron AP	44	3	98	1	1282	−18	−14	96/73	93/72	90/71	28	77	75	73	.0130	28.8
Mitchel	43	5	98	0	1346	−15	−10	96/72	93/71	90/70	28	76	75	73	.0120	
Pierre AP	44	2	100	2	1718r	−15	−10	99/71	95/71	92/69	29	75	74	72	.0117	
Rapid City AP (S)	44	0	103	0	3165	−11	−7	95/66	92/65	89/65	28	71	69	67	.0085	33.4
Sioux Falls AP	43	4	96	4	1420	−15	−11	94/73	91/72	88/71	24	76	75	73	.0134	30.6
Watertown AP	45	0	97	0	1746	−19	−15	94/73	91/72	88/71	26	76	75	73	.0134	
Yankton	43	0	97	2	1280	−13	−7	94/73	91/72	88/71	25	77	76	74	.0134	
TENNESSEE																
Athens	33	3	84	4	940	13	18	95/74	92/73	90/73	22	77	76	75	.0137	
Bristol- Tri City AP	36	3	82	2	1519	9	14	91/72	89/72	87/71	22	75	75	73	.0139	46.2
Chattanooga AP	35	0	85	1	670	13	18	96/75	93/74	91/74	22	78	77	76	.0140	50.3
Clarksville	36	4	87	2	470	6	12	95/76	93/74	90/74	21	78	77	76	.0140	
Columbia	35	4	87	0	690	10	15	97/75	94/74	91/74	21	78	77	76	.0138	
Dyersburg	36	0	89	3	334	10	15	96/78	94/77	91/76	21	81	80	78	.0164	
Greenville	35	5	82	5	1320	11	16	92/73	90/72	88/72	22	76	75	74	.0137	
Jackson AP	35	4	88	5	413	11	16	98/76	95/75	92/75	21	79	78	77	.0144	
Knoxville AP	35	5	84	0	980	13	19	94/74	92/73	90/73	21	77	76	75	.0137	49.2
Memphis AP	35	0	90	0	263	13	18	98/77	95/76	93/76	21	80	79	78	.0153	50.5
Murfreesboro	35	5	86	2	608	9	14	97/75	94/74	91/74	22	78	77	76	.0138	
Nashville AP (S)	36	1	86	4	577	9	14	97/75	94/74	91/74	21	78	77	76	.0138	48.9
Tullahoma	35	2	86	1	1075	8	13	96/74	93/73	91/73	22	77	76	75	.0135	
TEXAS																
Abilene AP	32	3	99	4	1759	15	20	101/71	99/71	97/71	22	75	74	74	.0111	53.9
Alice AP	27	4	98	0	180	31	34	100/78	98/77	95/77	20	82	81	79	.0151	
Amarillo AP	35	1	101	4	3607	6	11	98/67	95/67	93/67	26	71	70	70	.0097	47.0
Austin AP	30	2	97	4	597	24	28	100/74	98/74	97/74	22	78	77	77	.0162	59.1
Bay City	29	0	96	0	52	29	33	96/77	94/77	92/77	16	80	79	79	.0161	
Beaumont	30	0	94	0	18	27	31	95/79	93/78	91/78	19	81	80	80	.0172	
Beeville	28	2	97	4	225	30	33	99/78	97/77	95/77	18	82	81	79	.0154	
Big Springs AP (S)	32	2	101	3	2537	16	20	100/69	97/69	95/69	26	74	73	72	.0102	
Brownsville AP (S)	25	5	97	3	16	35	39	94/77	93/77	92/77	18	80	79	79	.0163	67.7
Brownwood	31	5	99	0	1435	18	22	101/73	99/73	96/73	22	77	76	75	.0124	
Bryan AP	30	4	96	2	275	24	29	98/76	96/76	94/76	20	79	78	78	.0154	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES

						Winter[d]		Summer[e]								
Col. 1	Col. 2		Col. 3		Col. 4	Col. 5		Col. 6			Col. 7	Col. 8			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb			Humidity Ratio	Ave. Winter Temp.*
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%	
Corpus Christi AP	27	5	97	3	43	31	35	95/78	94/78	92/78	19	80	80	79	.0170	64.6
Corsicana	32	0	96	3	425	20	25	100/75	98/75	96/75	21	79	78	77	.0137	
Dallas AP	32	5	96	5	481	18	22	102/75	100/75	97/75	20	78	78	77	.0132	55.3
Del Rio, Laughlin AFB	29	2	101	0	1072	26	31	100/73	98/73	97/73	24	79	77	76	.0123	
Denton	33	1	97	1	655	17	22	101/74	99/74	97/74	22	78	77	76	.0126	
Eagle Pass	28	5	100	3	743	27	32	101/73	99/73	98/73	24	78	78	77	.0118	
El Paso AP (S)	31	5	106	2	3918	20	24	100/64	98/64	96/64	27	69	68	68	.0070	52.9
Fort Worth AP (S)	32	5	97	0	544r	17	22	101/74	99/74	97/74	22	78	77	76	.0126	55.1
Galveston AP	29	2	94	5	5	31	36	90/79	89/79	88/78	10	81	80	80	.0191	62.2
Greenville	33	0	96	1	575	17	22	101/74	99/74	97/74	21	78	77	76	.0126	
Harlingen	26	1	97	4	37	35	39	96/77	94/77	93/77	19	80	79	79	.0161	
Houston AP	29	4	95	2	50	27	32	96/77	94/77	92/77	18	80	79	79	.0161	61.0
Houston CO	29	5	95	2	158r	28	33	97/77	95/77	93/77	18	80	79	79	.0158	62.0
Huntsville	30	4	95	3	494	22	27	100/75	98/75	96/75	20	78	78	77	.0137	
Killeen-Gray AFB	31	0	97	4	1021	20	25	99/73	97/73	95/73	22	77	76	75	.0125	
Lamesa	32	5	102	0	2965	13	17	99/69	96/69	94/69	26	73	72	71	.0107	
Laredo AFB	27	3	99	3	503	32	36	102/73	101/73	99/74	23	78	78	77	.0113	66.0
Longview	32	2	94	4	345	19	24	99/76	97/76	95/76	20	80	79	78	.0148	
Lubbock AP	33	4	101	5	3243	10	15	98/69	96/69	94/69	26	73	72	71	.0107	48.8
Lufkin AP	31	1	94	5	286	25	29	99/76	97/76	94/76	20	80	79	78	.0148	
Mc Allen	26	1	98	1	122	35	39	97/77	95/77	94/77	21	80	79	79	.0158	
Midland AP (S)	32	0	102	1	2815r	16	21	100/69	98/69	96/69	26	73	72	71	.0103	53.8
Mineral Wells AP	32	5	98	0	934	17	22	101/74	99/74	97/74	22	78	77	76	.0129	
Palestine CO	31	5	95	4	580	23	27	100/76	98/76	96/76	20	79	79	78	.0150	
Pampa	35	3	101	0	3230	7	12	99/67	96/67	94/67	26	71	70	70	.0091	
Pecos	31	2	103	3	2580	16	21	100/69	98/69	96/69	27	73	72	71	.0100	
Plainview	34	1	101	4	3400	8	13	98/68	96/68	94/68	26	72	71	70	.0102	
Port Arthur AP	30	0	94	0	16	27	31	95/79	93/78	91/78	19	81	80	80	.0172	60.5
San Angelo, Goodfellow AFB	31	2	100	2	1878	18	22	101/71	99/71	97/70	24	75	74	73	.0111	
San Antonio AP (S)	29	3	98	3	792	25	30	99/72	97/73	96/73	19	77	76	76	.0125	50.6
Sherman Perrin AFB	33	4	96	4	763	15	20	100/75	98/75	95/74	22	78	77	76	.0141	60.1
Snyder	32	4	101	0	2325	13	18	100/70	98/70	96/70	26	74	73	72	.0108	
Temple	31	1	97	2	675	22	27	100/74	99/74	97/74	22	78	77	77	.0126	
Tyler AP	32	2	95	2	527	19	24	99/76	97/76	95/76	21	80	79	78	.0148	
Vernon	34	1	99	2	1225	13	17	102/73	100/73	97/73	24	77	76	75	.0119	
Victoria AP	28	5	97	0	104	29	32	98/78	96/77	94/77	18	82	81	79	.0156	62.1
Waco AP	31	4	97	0	500	21	26	101/75	99/75	97/75	22	78	78	77	.0135	57.2
Wichita Falls AP	34	0	98	3	994	14	18	103/73	101/73	98/73	24	77	76	75	.0116	53.0
UTAH																
Cedar City AP	37	4	113	1	5613	−2	5	93/60	91/60	89/59	32	65	63	62	.0065	
Logan	41	4	111	5	4775	−3	2	93/62	91/61	88/60	33	65	64	63	.0069	
Moab	38	5	109	3	3965	6	11	100/60	98/60	96/60	30	65	64	63	.0041	
Ogden AP	41	1	112	0	4455	1	5	93/63	91/61	88/61	33	66	65	64	.0067	
Price	39	4	110	5	5580	−2	5	93/60	91/60	89/59	33	65	63	62	.0065	
Provo	40	1	111	4	4470	1	6	98/62	96/62	94/61	32	66	65	64	.0062	
Richfield	38	5	112	0	5300	−2	5	93/60	91/60	89/59	34	65	63	62	.0065	
St George CO	37	1	113	4	2899	14	21	103/65	101/65	99/64	33	70	68	67	.0065	
Salt Lake City AP (S)	40	5	112	0	4220	3	8	97/62	95/62	92/61	32	66	65	64	.0065	38.4
Vernal AP	40	3	109	3	5280	−5	0	91/61	89/60	86/59	32	64	63	62	.0069	
VERMONT																
Barre	44	1	72	3	1120	−16	−11	84/71	81/69	78/68	23	73	71	70	.0130	
Burlington AP (S)	44	3	73	1	331	−12	−7	88/72	85/70	82/69	23	74	72	71	.0126	29.4
Rutland	43	3	73	0	620	−13	−8	87/72	84/70	81/69	23	74	72	71	.0128	
VIRGINIA																
Charlottsville	38	1	78	3	870	14	18	94/74	91/74	88/73	23	77	76	75	.0148	
Danville AP	36	3	79	2	590	14	16	94/74	92/73	90/73	21	77	76	75	.0134	
Fredericksburg	38	2	77	3	50	10	14	96/76	93/75	90/74	21	78	77	76	.0145	
Harrisonburg	38	3	78	5	1340	12	16	93/72	91/72	88/71	23	75	74	73	.0134	
Lynchburg AP	37	2	79	1	947	12	16	93/74	90/74	88/73	21	77	76	75	.0150	46.0
Norfolk AP	36	5	76	1	26	20	22	93/77	91/76	89/76	18	79	78	77	.0159	49.2
Petersburg	37	1	77	3	194	14	17	95/76	92/76	90/75	20	79	78	77	.0156	

TABLE 2.1A CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

Col. 1	Col. 2		Col. 3		Col. 4	Col. 5 (Winter[d])		Col. 6 (Summer[e])			Col. 7 (Summer[e])	Col. 8 (Summer[e])			Col. 9	Col. 10
State and Station	Latitude[b]		Longitude[c]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb			Humidity Ratio	Ave. Winter Temp.*
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%	
Richmond AP	37	3	77	2	162	14	17	95/76	92/76	90/75	21	79	78	77	.0156	47.3
Roanoke AP	37	2	80	0	1174r	12	16	93/72	91/72	88/71	23	75	74	73	.0131	46.1
Staunton	38	2	78	5	1480	12	16	93/72	91/72	88/71	23	75	74	73	.0143	
Winchester	39	1	78	1	750	6	10	93/75	90/74	88/74	21	77	76	75	.0150	
WASHINGTON																
Aberdeen	47	0	123	5	12	25	28	80/65	77/62	73/61	16	65	63	62	.0084	
Bellingham AP	48	5	122	3	150	10	15	81/67	77/65	74/63	19	68	65	63	.0104	
Bremerton	47	3	122	4	162	21	25	82/65	78/64	75/62	20	66	64	63	.0095	
Ellensburg AP	47	0	120	3	1729	2	6	94/65	91/64	87/62	34	66	65	63	.0070	
Everett-Paine AFB	47	5	122	2	598	21	25	80/65	76/64	73/62	20	67	64	63	.0102	
Kennewick	46	0	119	1	392	5	11	99/68	96/67	92/66	30	70	68	67	.0078	
Longview	46	1	123	0	12	19	24	88/68	85/67	81/65	30	69	67	66	.0100	
Moses Lake, Larson AFB	47	1	119	2	1183	1	7	97/66	94/65	90/63	32	67	66	64	.0070	
Olympia AP	47	0	122	5	190	16	22	87/66	83/65	79/64	32	67	66	64	.0090	44.2
Port Angeles	48	1	123	3	99	24	27	72/62	69/61	67/60	18	64	62	61	.0096	
Seattle-Boeing Fld	47	3	122	2	14	21	26	84/68	81/66	77/65	24	69	67	65	.0102	
Seattle CO (S)	47	4	122	2	14	22	27	85/68	82/66	78/65	19	69	67	65	.0113	46.9
Seattle-Tacoma AP (S)	47	3	122	2	386	21	26	84/65	80/64	76/62	22	66	64	63	.0093	44.2
Spokane AP (S)	47	4	117	3	2357	−6	2	93/64	90/63	87/62	28	65	64	62	.0073	36.5
Tacoma-Mc Chord AFB	47	1	122	3	350	19	24	86/66	82/65	79/63	22	68	66	64	.0095	
Walla Walla AP	46	1	118	2	1185	0	7	97/67	94/66	90/65	27	69	67	66	.0077	43.8
Wenatchee	47	2	120	2	634	7	11	99/67	96/66	92/64	32	68	67	65	.0070	
Yakima AP	46	3	120	3	1061	−2	5	96/65	93/65	89/63	36	68	66	65	.0073	39.1
WEST VIRGINIA																
Beckley	37	5	81	1	2330	−2	4	83/71	81/69	79/69	22	73	71	70	.0139	
Bluefield AP	37	2	81	2	2850	−2	4	83/71	81/69	79/69	22	73	71	70	.0142	
Charleston AP	38	2	81	4	939	7	11	92/74	90/73	87/72	20	76	75	74	.0142	44.8
Clarksburg	39	2	80	2	977	6	10	92/74	90/73	87/72	21	76	75	74	.0142	
Elkins AP	38	5	79	5	1970	1	6	86/72	84/70	82/70	22	74	72	71	.0137	40.1
Huntington CO	38	2	82	3	565r	5	10	94/76	91/74	89/73	22	78	77	75	.0145	45.0
Martinsburg AP	39	2	78	0	537	6	10	93/75	90/74	88/74	21	77	76	75	.0147	
Morgantown AP	39	4	80	0	1245	4	8	90/74	87/73	85/73	22	76	75	74	.0149	
Parkersburg CO	39	2	81	3	615r	7	11	93/75	90/74	88/73	21	77	76	75	.0147	43.5
Wheeling	40	1	80	4	659	1	5	89/72	86/71	84/70	21	74	73	72	.0131	
WISCONSIN																
Appleton	44	2	88	2	742	−14	−9	89/74	86/72	83/71	23	76	74	72	.0139	
Ashland	46	3	90	5	650	−21	−16	85/70	82/68	79/66	23	72	70	68	.0112	
Beloit	42	3	89	0	780	−7	−3	92/75	90/75	88/74	24	78	77	75	.0159	
Eau Claire AP	44	5	91	3	888	−15	−11	92/75	89/73	86/71	23	77	75	73	.0144	
Fond du Lac	43	5	88	3	760	−12	−8	89/74	86/72	84/71	23	76	74	72	.0143	
Green Bay AP	44	3	88	1	683	−13	−9	88/74	85/72	83/71	23	76	74	72	.0142	30.3
La Crosse AP	43	5	91	2	652	−13	−9	91/75	88/73	85/72	22	77	75	74	.0143	31.5
Madison AP (S)	43	1	89	2	858	−11	−7	91/74	88/73	85/71	22	77	75	73	.0146	30.9
Manitowoc	44	1	87	4	660	−11	−7	89/74	86/72	83/71	21	76	74	72	0.0139	
Marinette	45	0	87	4	605	−15	−11	87/73	84/71	82/70	20	75	73	71	.0136	
Milwaukee AP	43	0	87	5	672	−8	−4	90/74	87/73	84/71	21	76	74	73	.0145	32.6
Racine	42	4	87	4	640	−6	−2	91/75	88/73	85/72	21	77	75	74	.0143	
Sheboygan	43	4	87	4	648	−10	−6	89/75	86/73	83/72	20	77	75	74	.0148	
Stevens Point	43	0	89	3	1079	−15	−11	92/75	89/73	86/71	23	77	75	73	.0144	
Waukesha	43	0	88	1	860	−9	−5	90/74	87/73	84/71	22	76	74	73	.0149	
Wausau AP	44	6	89	4	1196	−16	−12	91/74	88/72	85/70	23	76	74	72	.0138	
WYOMING																
Casper AP	42	5	106	3	5319	−11	−5	92/58	90/57	87/57	31	63	61	60	.0046	33.4
Cheyene AP	41	1	104	5	6126	−9	−1	89/58	86/58	84/57	30	63	62	60	.0064	34.2
Cody AP	44	3	109	0	5090	−19	−13	89/60	86/60	83/59	32	64	63	61	.0073	
Evanston	41	2	111	0	6860	−9	−3	86/55	84/55	82/54	32	59	58	57	.0053	
Lander AP (S)	42	5	108	4	5563	−16	−11	91/61	88/61	85/60	32	64	63	61	.0077	31.4
Laramie AP (S)	41	2	105	3	7266	−14	−6	84/56	81/56	79/55	28	61	60	59	.0067	
Newcastle	43	5	104	1	4480	−17	−12	91/64	87/63	84/63	30	69	68	66	.0090	
Rawlins	41	5	107	1	6736	−12	−4	86/57	83/57	81/56	40	62	61	60	.0144	
Rock Springs AP	41	4	109	0	6741	−9	−3	86/55	84/55	82/54	32	59	58	57	.0051	
Sheridan AP	44	5	107	0	3942	−14	−8	94/62	91/62	88/61	32	66	65	63	.0071	32.5
Torrington	42	0	104	1	4098	−14	−8	94/62	91/62	88/61	30	66	65	63	.0071	

TABLE 2.1B CLIMATIC CONDITIONS FOR CANADA

Col. 1	Col. 2		Col. 3.		Col. 4.	WINTER[e] Col. 5.		SUMMER[f] Col. 6			Col. 7	Col. 8			Col. 9
Province and Station[b]	Latitude[c]		Longitude[c]		Elevation[d]	Design Dry-Bulb		Design Dry Bulb and Mean Coincident Wet-Bulb			Mean Daily	Design Wet Bulb			Humidity Ratio
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%	2.5%
ALBERTA															
Calgary AP	51	6	114	1	3540	−27	−23	84/63	81/61	79/60	25	65	63	62	.0084
Edmonton AP	53	34	113	31	2219	−29	−25	85/66	82/65	79/63	23	68	66	65	.0103
Grande Prairie AP	55	11	118	53	2190	−39	−33	83/64	80/63	78/61	23	66	64	62	.0093
Jasper	52	53	118	4	3480	−31	−26	83/64	80/62	77/61	28	66	64	63	.0094
Lethbridge AP (S)	49	38	112	48	3018	−27	−22	90/65	87/64	84/63	28	68	66	65	.0089
McMurray AP	56	39	111	13	1216	−41	−38	86/67	82/65	79/64	26	69	67	65	.0098
Medicine Hat AP	50	1	110	43	2365	−29	−24	93/66	90/65	87/64	28	70	68	66	.0087
Red Deer AP	52	11	113	54	2965	−31	−26	84/65	81/64	78/62	25	67	66	64	.0103
BRITISH COLUMBIA															
Dawson Creek	55	44	120	11	2164	−37	−33	82/64	79/63	76/61	26	66	64	62	.0095
Fort Nelson AP (S)	58	50	122	35	1230	−43	−40	84/64	81/63	78/62	23	67	65	64	.0086
Kamloops CO	50	43	120	25	1133	−21	−15	94/66	91/65	88/64	29	68	66	65	.0077
Nanaimo (S)	49	11	123	58	230	16	20	83/67	80/65	77/64	21	68	66	65	.0095
New Westminster	49	13	122	54	50	14	18	84/68	81/67	78/66	19	69	68	66	.0109
Penticton AP	49	28	119	36	1121	0	4	92/68	89/67	87/66	31	70	68	67	.0096
Prince George AP(S)	53	53	122	41	2218	−33	−28	84/64	80/62	77/61	26	66	64	62	.0086
Prince Rupert CO	54	17	130	23	170	− 2	2	64/59	63/57	61/56	12	60	58	57	.0086
Trail	49	8	117	44	1400	− 5	0	92/66	89/65	86/64	33	68	67	65	.0084
Vancouver AP (S)	49	11	123	10	16	15	19	79/67	77/66	74/65	17	68	67	66	.0111
Victoria CO	48	25	123	19	228	20	23	77/64	73/62	70/60	16	64	62	60	.0093
MANITOBA															
Brandon	49	52	99	59	1200	−30	−27	89/72	86/70	83/68	25	74	72	70	.0126
Churchill AP (S)	58	45	94	4	155	−41	−39	81/66	77/64	74/62	18	67	65	63	.0097
Dauphin AP	51	6	100	3	999	−31	−28	87/71	84/70	81/68	23	74	72	70	.0131
Flin Flon	54	46	101	51	1098	−41	−37	84/68	81/66	79/65	19	70	68	67	.0107
Portage la Prairie AP	49	54	98	16	867	−28	−24	88/73	86/72	83/70	22	76	74	71	.0143
The Pas AP (S)	53	58	101	6	894	−37	−33	85/68	82/67	79/66	20	71	69	68	.0112
Winnipeg AP (S)	49	54	97	14	786	−30	−27	89/73	86/71	84/70	22	75	73	71	.0134
NEW BRUNSWICK															
Campbellton CO	48	0	66	40	25	−18	−14	85/68	82/67	79/66	21	72	70	68	.0107
Chatham AP	47	1	65	27	112	−15	−10	89/69	85/68	82/67	22	72	71	69	.0107
Edmundston CO	47	22	68	20	500	−21	−16	87/70	83/68	80/67	21	73	71	69	.0107
Fredericton AP (S)	45	52	66	32	74	−16	−11	89/71	85/69	82/68	23	73	71	70	.0115
Moncton AP (S)	46	7	64	41	248	−12	− 8	85/70	82/69	79/67	23	72	71	69	.0122
Saint John AP	45	19	65	53	352	−12	− 8	80/67	77/65	75/64	19	70	68	66	.0107
NEWFOUNDLAND															
Corner Brook	48	58	57	57	15	− 5	0	76/64	73/63	71/62	17	67	66	65	.0100
Gander AP	48	57	54	34	482	− 5	− 1	82/66	79/65	77/64	19	69	67	66	.0102
Goose Bay AP (S)	53	19	60	25	144	−27	−24	85/66	81/64	77/63	19	68	66	64	.0088
St. John's AP (S)	47	37	52	45	463	3	7	77/66	75/65	73/64	18	69	67	66	.0111
Stephenville AP	48	32	58	33	44	− 3	4	76/65	74/64	71/63	14	67	66	65	.0104
NORTHWEST TERR.															
Fort Smith AP (S)	60	1	111	58	665	−49	−45	85/66	81/64	78/63	24	68	66	65	.0091
Frobisher AP (S)	63	45	68	33	68	−43	−41	66/53	63/51	59/50	14	54	52	51	.0052
Inuvik (S)	68	18	133	29	200	−56	−53	79/62	77/60	75/59	21	64	62	61	.0071
Resolute AP (S)	74	43	94	59	209	−50	−47	57/48	54/46	51/45	10	50	48	46	.0048
Yellowknife AP	62	28	114	27	682	−49	−46	79/62	77/61	74/60	16	64	63	62	.0080
NOVA SCOTIA															
Amherst	45	49	64	13	65	−11	− 6	84/69	81/68	79/67	21	72	70	68	.0117
Halifax AP (S)	44	39	63	34	83	1	5	79/66	76/65	74/64	16	69	67	66	.0107
Kentville (S)	45	3	64	36	40	− 3	1	85/69	83/68	80/67	22	72	71	69	.0112
New Glasgow	45	37	62	37	317	− 9	− 5	81/69	79/68	77/67	20	72	70	69	.0124
Sydney AP	46	10	60	3	197	− 1	3	82/69	80/68	77/66	19	71	70	68	.0119
Truro CO	45	22	63	16	131	− 8	− 5	82/70	80/69	78/68	22	73	71	70	.0126
Yarmouth AP	43	50	66	5	136	5	9	74/65	72/64	70/63	15	68	66	65	.0109
ONTARIO															
Belleville	44	9	77	24	250	−11	− 7	86/73	84/72	82/71	20	75	74	73	.0144
Chatham	42	24	82	12	600	0	3	89/74	87/73	85/72	19	76	75	74	.0145
Cornwall	45	1	74	45	210	−13	− 9	89/73	87/72	84/71	21	75	74	72	.0134
Hamilton	43	16	79	54	303	− 3	1	88/73	86/72	83/71	21	76	74	73	.0139
Kapuskasing AP (S)	49	25	82	28	752	−31	−28	86/70	83/69	80/67	23	72	70	69	.0125
Kenora AP	49	48	94	22	1345	−32	−28	84/70	82/69	80/68	19	73	71	70	.0131
Kingston	44	16	76	30	300	−11	− 7	87/73	84/72	82/71	20	75	74	73	.0144

TABLE 2.1B CLIMATIC CONDITIONS FOR CANADA

Col. 1	Col. 2		Col. 3.		Col. 4.	Col. 5. WINTER[e]		Col. 6 SUMMER[f]			Col. 7	Col. 8			Col. 9
Province and Station[b]	Latitude[c]		Longitude[c]		Elevation[d]	Design Dry-Bulb		Design Dry Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet Bulb			Humidity Ratio
	°	′	°	′	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%	2.5%
Kitchener	43	26	80	30	1125	−6	−2	88/73	85/72	83/71	23	75	74	72	.0145
London AP	43	2	81	9	912	−4	0	87/74	85/73	83/72	21	76	74	73	.0153
North Bay AP	46	22	79	25	1210	−22	−18	84/68	81/67	79/66	20	71	70	68	.0115
Oshawa	43	54	78	52	370	−6	−3	88/73	86/72	84/71	20	75	74	73	.0139
Ottawa AP (S)	45	19	75	40	413	−17	−13	90/72	87/71	84/70	21	75	73	72	.0129
Owen Sound	44	34	80	55	597	−6	−2	84/71	82/70	80/69	21	73	72	70	.0133
Peterborough	44	17	78	19	635	−13	−9	87/72	85/71	83/70	21	75	73	72	.0134
St. Catharines	43	11	79	14	325	−1	3	87/73	85/72	83/71	20	76	74	73	.0142
Sarnia	42	58	82	22	625	0	3	88/73	86/72	84/71	19	76	74	73	.0139
Sault Ste. Marie AP	46	32	84	30	675	−17	−13	85/71	82/69	79/68	22	73	71	70	.0125
Sudbury AP	46	37	80	48	1121	−22	−19	86/69	83/67	81/66	22	72	70	68	.0110
Thunder Bay AP	48	22	89	19	644	−27	−24	85/70	83/68	80/67	24	72	70	68	.0115
Timmins AP	48	34	81	22	965	−33	−29	87/69	84/68	81/66	25	72	70	68	.0115
Toronto AP (S)	43	41	79	38	578	−5	−1	90/73	87/72	85/71	20	75	74	73	.0137
Windsor AP	42	16	82	58	637	0	4	90/74	88/73	86/72	20	77	75	74	.0143
PRINCE EDWARD ISLAND															
Charlottetown AP (S)	46	17	63	8	186	−7	−4	80/69	78/68	76/67	16	71	70	68	.0124
Summerside AP	46	26	63	50	78	−8	−4	81/69	79/68	77/67	16	72	70	68	.0121
QUEBEC															
BagotvilleAP	48	20	71	0	536	−28	−23	87/70	83/68	80/67	21	72	70	68	.0112
Chicoutimi	48	25	71	5	150	−26	−22	86/70	83/68	80/67	20	72	70	68	.0115
Drummondville	45	53	72	29	270	−18	−14	88/72	85/71	82/69	21	75	73	71	.0134
Granby	45	23	72	42	550	−19	−14	88/72	85/71	83/70	21	75	73	72	.——
Hull	45	26	75	44	200	−18	−14	90/72	87/71	84/70	21	75	73	72	.0126
Mégantic AP	45	35	70	52	1362	−20	−16	86/71	83/70	81/69	20	74	72	71	.0136
Montréal AP (S)	45	28	73	45	98	−16	−10	88/73	85/72	83/71	17	75	74	72	.0139
Québec AP	46	48	71	23	245	−19	−14	87/72	84/70	81/68	20	74	72	70	.0125
Rimouski	48	27	68	32	117	−16	−12	83/68	79/66	76/65	18	71	69	67	.0107
St. Jean	45	18	73	16	129	−15	−11	88/73	86/72	84/71	20	75	74	72	.0136
St. Jèirome	45	48	74	1	556	−17	−13	88/72	86/71	83/70	23	75	73	72	.0131
Sept. Iles AP (S)	50	13	66	16	190	−26	−21	76/63	73/61	70/60	17	67	65	63	.0087
Shawinigan	46	34	72	43	306	−18	−14	86/72	84/70	82/69	21	74	72	71	.0131
Sherbrooke CO	45	24	71	54	595	−25	−21	86/72	84/71	81/69	20	74	73	71	.0129
Thetford Mines	46	4	71	19	1020	−19	−14	87/71	84/70	81/69	21	74	72	71	.0131
Trois Rivières	46	21	72	35	50	−17	−13	88/72	85/70	82/69	23	74	72	71	.0123
Val d'Or AP	48	3	77	47	1108	−32	−27	85/70	83/68	80/67	22	72	70	68	.0118
Valleyfield	45	16	74	6	150	−14	−10	89/73	86/72	84/71	20	75	74	72	.0136
SASKATCHEWAN															
Estevan AP	49	4	103	0	1884	−30	−25	92/70	89/68	86/67	26	72	70	69	.0109
Moose Jaw AP	50	20	105	33	1857	−29	−25	93/69	89/67	86/66	27	71	69	68	.0102
North Battleford AP	52	46	108	15	1796	−33	−30	88/67	85/66	82/65	23	69	68	66	.0103
Prince Albert AP	53	13	105	41	1414	−42	−35	87/67	84/66	81/65	25	70	68	67	.0103
Regina AP	50	26	104	40	1884	−33	−29	91/69	88/68	84/67	26	72	70	68	.0100
Saskatoon AP (S)	52	10	106	41	1645	−35	−31	89/68	86/66	83/65	26	70	68	67	.0098
Swift Current (AP (S)	50	17	107	41	2677	−28	−25	93/68	90/66	87/65	25	70	69	67	.0095
Yorkton AP	51	16	102	28	1653	−35	−30	87/69	84/68	80/66	23	72	70	68	.0118
YUKON TERRITORY															
Whitehorse AP (S)	60	43	135	4	2289	−46	−43	80/59	77/58	74/56	22	61	59	58	.0069

[a] Table 2.1B was based on work by ASHRAE Technical Committee 4.2 using data compiled from official weather stations where hourly weather observations are made by trained observers.
[b] When airport temperature observations were used to develop design data, "AP" follows the station name. Data for stations followed by "CO" come from office locations within an u area and generally reflect an influence of the surroundings area. Stations without designation can be considered semirural and can be directly compared to most airport data.
[c] Latitude, for use in calculating solar loads, and longitude are given to the nearest minute.
[d] Elevations are ground elevations for each station as of 1964. Temperature readings are generally made at an elevation of 5 ft above ground.
[e] The winter design data are based on the month of January only.
[f] The summer design data are based on the month of July only.

Table 2.1C Climatic Conditions for Other Countries

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter			Summer						
			Col. 4			Col. 5 Design Dry-Bulb			Col. 6 Outdoor Daily Range F deg	Col. 7 Design Wet-Bulb		
			Mean of Annual Extremes	99%	97½%	1%	2½%	5%		1%	2½%	5%
ADEN												
Aden	12 50N/45 02E	10	63	68	70	102	100	98	11	83	82	82
AFGHANISTAN												
Kabul	34 35N/69 12E	5955	2	6	9	98	96	93	32	66	65	64
ALGERIA												
Algiers	36 46N/3 03E	194	38	43	45	95	92	89	14	77	76	75
ARGENTINA												
Buenos Aires	34 35S/58 29W	89	27	32	34	91	89	86	22	77	76	75
Córdoba	31 22S/64 15W	1388	21	28	32	100	96	93	27	76	75	74
Tucuman	26 50S/65 10W	1401	24	32	36	102	99	96	23	76	75	74
AUSTRALIA												
Adelaide	34 56S/138 35E	140	36	38	40	98	94	91	25	72	70	68
Alice Springs	23 48S/133 53E	1795	28	34	37	104	102	100	27	75	74	72
Brisbane	27 28S/153 02E	137	39	44	47	91	88	86	18	77	76	75
Darwin	12 28S/130 51E	88	60	64	66	94	93	91	16	82	81	81
Melbourne	37 49S/144 58E	114	31	35	38	95	91	86	21	71	69	68
Perth	31 57S/115 51E	210	38	40	42	100	96	93	22	76	74	73
Sydney	33 52S/151 12E	138	38	40	42	89	84	80	13	74	73	72
AUSTRIA												
Vienna	48 15N/16 22E	644	−2	6	11	88	86	83	16	71	69	67
AZORES												
Lajes (Terceira)	38 45N/27 05W	170	42	46	49	80	78	77	11	73	72	71
BAHAMAS												
Nassau	25 05N/77 21W	11	55	61	63	90	89	88	13	80	80	79
BELGIUM												
Brussels	50 48N/4 21E	328	13	15	19	83	79	77	19	70	68	67
BERMUDA												
Kindley AFB	33 22N/64 41W	129	47	53	55	87	86	85	12	79	78	78
BOLIVIA												
La Paz	16 30S/68 09W	12001	28	31	33	71	69	68	24	58	57	56
BRAZIL												
Belem	1 27S/48 29W	42	67	70	71	90	89	87	19	80	79	78
Belo Horizonte	19 56S/43 57W	3002	42	47	50	86	84	83	18	76	75	75
Brasilia	15 52S/47 55W	3442	46	49	51	89	88	86	17	76	75	75
Curitiba	25 25S/49 17W	3114	28	34	37	86	84	82	21	75	74	74
Fortaleza	3 46S/38 33W	89	66	69	70	91	90	89	17	79	78	78
Porto Alegre	30 02S/51 13W	33	32	37	40	95	92	89	20	76	76	75
Recife	8 04S/34 53W	97	67	69	70	88	87	86	10	78	77	77
Rio de Janeiro	22 55S/43 12W	201	56	58	60	94	92	90	11	80	79	78
Salvador	13 00S/38 30W	154	65	67	68	88	87	86	12	79	79	78
São Paulo	23 33S/46 38W	2608	36	42	46	86	84	82	18	75	74	74
BRITISH HONDURAS												
Belize	17 31N/88 11W	17	55	60	62	90	90	89	13	82	82	81
BULGARIA												
Sofia	42 42N/23 20E	1805	−2	3	8	89	86	84	26	71	70	69
BURMA												
Mandalay	21 59N/96 06E	252	50	54	56	104	102	101	30	81	80	80
Rangoon	16 47N/96 09E	18	59	62	63	100	98	95	25	83	82	82
CAMBODIA												
Phnom Penh	11 33N/104 51E	36	62	66	68	98	96	94	19	83	82	82
CEYLON												
Colombo	6 54N/79 52E	24	65	69	70	90	89	88	15	81	80	80
CHILE												
Punta Arenas	53 10S/70 54W	26	22	25	27	68	66	64	14	56	55	54
Santiago	33 27S/70 42W	1706	27	32	35	90	89	88	32	71	70	69
Valparaiso	33 01S/71 38W	135	39	43	46	81	79	77	16	67	66	65
CHINA												
Chungking	29 33N/106 33E	755	34	37	39	99	97	95	18	81	80	79
Shanghai	31 12N/121 26E	23	16	23	26	94	92	90	16	81	81	80
COLOMBIA												
Baranquilla	10 59N/74 48W	44	66	70	72	95	94	93	17	83	82	82
Bogotá	4 36N/74 05W	8406	42	45	46	72	70	69	19	60	59	58
Cali	3 25N/76 30W	3189	53	57	58	84	82	79	15	70	69	68
Medellin	6 13N/75 36W	4650	48	53	55	87	85	84	25	73	72	72
CONGO												
Brazzaville	4 15S/15 15E	1043	54	60	62	93	92	91	21	81	81	80
Kinasha (Leopoldville)	4 20S/15 18E	1066	54	60	62	92	91	90	19	81	80	80
Stanleyville	0 26N/15 14E	1370	65	67	68	92	91	90	19	81	80	80

Table 2.1C Climatic Conditions for Other Countries

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter: Col. 4 Mean of Annual Extremes	Winter: Col. 4 99%	Winter: Col. 4 97½%	Summer: Col. 5 Design Dry-Bulb 1%	Summer: Col. 5 Design Dry-Bulb 2½%	Summer: Col. 5 Design Dry-Bulb 5%	Summer: Col. 6 Outdoor Daily Range F deg	Summer: Col. 7 Design Wet-Bulb 1%	Summer: Col. 7 Design Wet-Bulb 2½%	Summer: Col. 7 Design Wet-Bulb 5%
CUBA												
Guantanamo Bay	19 54N/75 09W	21	60	64	66	94	93	92	16	82	81	80
Havana	23 08N/82 21W	80	54	59	62	92	91	89	14	81	81	80
CZECHOSLOVAKIA												
Prague	50 05N/14 25E	662	3	4	9	88	85	83	16	66	65	64
DENMARK												
Copenhagen	55 41N/12 33E	43	11	16	19	79	76	74	17	68	66	64
DOMINICAN REPUBLIC												
Santo Domingo	18 29N/69 54W	57	61	63	65	92	90	88	16	81	80	80
ECUADOR												
Guayaquil	2 10S/79 53W	20	61	64	65	92	91	89	20	80	80	79
Quito	0 13S/78 32W	9446	30	36	39	73	72	71	32	63	62	62
EL SALVADOR												
San Salvador	13 42N/89 13W	2238	51	54	56	98	96	95	32	77	76	75
ETHIOPIA												
Addis Ababa	9 02N/38 45E	7753	35	39	41	84	82	81	28	66	65	64
Asmara	15 17N/38 55E	7628	36	40	42	83	81	80	27	65	64	63
FINLAND												
Helsinki	60 10N/24 57E	30	−11	− 7	− 1	77	74	72	14	66	65	63
FRANCE												
Lyon	45 42N/4 47E	938	− 1	10	14	91	89	86	23	71	70	69
Marseilles	43 18N/5 23E	246	23	25	28	90	87	84	22	72	71	69
Nantes	47 15N/1 34W	121	17	22	26	86	83	80	21	70	69	67
Nice	43 42N/7 16E	39	31	34	37	87	85	83	15	73	72	72
Paris	48 49N/2 29E	164	16	22	25	89	86	83	21	70	68	67
Strasbourg	48 35N/7 46E	465	9	11	16	86	83	80	20	70	69	67
FRENCH GUIANA												
Cayenne	4 56N/52 27W	20	69	71	72	92	91	90	17	83	83	82
GERMANY												
Berlin	52 27N/13 18E	187	6	7	12	84	81	78	19	68	67	66
Hamburg	53 33N/9 58E	66	10	12	16	80	76	73	13	68	66	65
Hannover	52 24N/9 40E	561	7	16	20	82	78	75	17	68	67	65
Mannheim	49 34N/8 28E	359	2	8	11	87	85	82	18	71	69	68
Munich	48 09N/11 34E	1729	− 1	5	9	86	83	80	18	68	66	64
GHANA												
Accra	5 33N/0 12W	88	65	68	69	91	90	89	13	80	79	79
GIBRALTAR												
Gibraltar	36 09N/5 22W	11	38	42	45	92	89	86	14	76	75	74
GREECE												
Athens	37 58N/23 43E	351	29	33	36	96	93	91	18	72	71	71
Thessaloniki	40 37N/22 57E	78	23	28	32	95	93	91	20	77	76	75
GREENLAND												
Narssarssuaq	61 11N/45 25W	85	−23	−12	− 8	66	63	61	20	56	54	52
GUATEMALA												
Guatemala City	14 37N/90 31W	4855	45	48	51	83	82	81	24	69	68	67
GUYANA												
Georgetown	6 50N/58 12W	6	70	72	73	89	88	87	11	80	79	79
HAITI												
Port au Prince	18 33N/72 20W	121	63	65	67	97	95	93	20	82	81	80
HONDURAS												
Tegucigalpa	14 06N/87 13W	3094	44	47	50	89	87	85	28	73	72	71
HONG KONG												
Hong Kong	22 18N/114 10E	109	43	48	50	92	91	90	10	81	80	80
HUNGARY												
Budapest	47 31N/19 02E	394	8	10	14	90	86	84	21	72	71	70
ICELAND												
Reykjavik	64 08N/21 56E	59	8	14	17	59	58	56	16	54	53	53
INDIA												
Ahmenabad	23 02N/72 35E	163	49	53	56	109	107	105	28	80	79	78
Bangalore	12 57N/77 37E	3021	53	56	58	96	94	93	26	75	74	74
Bombay	18 54N/72 49E	37	62	65	67	96	94	92	13	82	81	81
Calcutta	22 32N/88 20E	21	49	52	54	98	97	96	22	83	82	82
Madras	13 04N/80 15E	51	61	64	66	104	102	101	19	84	83	83
Nagpur	21 09N/79 07E	1017	45	51	54	110	108	107	30	79	79	78
New Delhi	28 35N/77 12E	703	35	39	41	110	107	105	26	83	82	82
INDONESIA												
Djakarta	6 11S/106 50E	26	69	71	72	90	89	88	14	80	79	78
Kupang	10 10S/123 34E	148	63	66	68	94	93	92	20	81	80	80
Makassar	5 08S/119 28E	61	64	66	68	90	89	88	17	80	80	79
Medan	3 35N/98 41E	77	66	69	71	92	91	90	17	81	80	79
Palembang	3 00S/104 46E	20	67	70	71	92	91	90	17	80	79	79
Surabaya	7 13S/112 43E	10	64	66	68	91	90	89	18	80	79	79

Table 2.1C Climatic Conditions for Other Countries

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IRAN												
Abadan	30 21N/48 16E	7	32	39	41	116	113	110	32	82	81	81
Meshed	36 17N/59 36E	3104	3	10	14	99	96	93	29	68	67	66
Tehran	35 41N/51 25E	4002	15	20	24	102	100	98	27	75	74	73
IRAQ												
Baghdad	33 20N/44 24E	111	27	32	35	113	111	108	34	73	72	72
Mosul	36 19N/43 09E	730	23	29	32	114	112	110	40	73	72	72
IRELAND												
Dublin	53 22N/6 21W	155	19	24	27	74	72	70	16	65	64	62
Shannon	52 41N/8 55W	8	19	25	28	76	73	71	14	65	64	63
ISRAEL												
Jerusalem	31 47N/35 13E	2485	31	36	38	95	94	92	24	70	69	69
Tel Aviv	32 06N/34 47E	36	33	39	41	96	93	91	16	74	73	72
ITALY												
Milan	45 27N/09 17E	341	12	18	22	89	87	84	20	76	75	74
Naples	40 53N/14 18E	220	28	34	36	91	88	86	19	74	73	72
Rome	41 48N/12 36E	377	25	30	33	94	92	89	24	74	73	72
IVORY COAST												
Abidjan	5 19N/4 01W	65	64	67	69	91	90	88	15	83	82	81
JAPAN												
Fukuoka	33 35N/130 27E	22	26	29	31	92	90	89	20	82	80	79
Sapporo	43 04N/141 21E	56	−7	1	5	86	83	80	20	76	74	72
Tokyo	35 41N/139 46E	19	21	26	28	91	89	87	14	81	80	79
JORDAN												
Amman	31 57N/35 57E	2548	29	33	36	97	94	92	25	70	69	68
KENYA												
Nairobi	1 16S/36 48E	5971	45	48	50	81	80	78	24	66	65	65
KOREA												
Pyongyang	39 02N/125 41E	186	−10	−2	3	89	87	85	21	77	76	76
Seoul	37 34N/126 58E	285	−1	7	9	91	89	87	16	81	79	78
LEBANON												
Beirut	33 54N/35 28E	111	40	42	45	93	91	90	15	78	77	76
LIBERIA												
Monrovia	6 18N/10 48W	75	64	68	69	90	89	88	19	82	82	81
LIBYA												
Bengasi	32 06N/20 04E	82	41	46	48	97	94	91	13	77	76	75
MADAGASCAR												
Tananarive	18 55S/47 33E	4531	39	43	46	86	84	83	23	73	72	71
MALAYSIA												
Kuala Lumpur	3 07N/101 42E	127	67	70	71	94	93	92	20	82	82	81
Penang	5 25N/100 19E	17	69	72	73	93	93	92	18	82	81	80
Singapore	1 18N/103 50E	33	69	71	72	92	91	90	14	82	81	80
MARTINIQUE												
Fort de France	14 37N/61 05W	13	62	64	66	90	89	88	14	81	81	80
MEXICO												
Guadalajara	20 41N/103 20W	5105	35	39	42	93	91	89	29	68	67	66
Mérida	20 58N/89 38W	72	56	59	61	97	95	94	21	80	79	77
Mexico City	19 24N/99 12W	7575	33	37	39	83	81	79	25	61	60	59
Monterrey	25 40N/100 18W	1732	31	38	41	98	95	93	20	79	78	77
Vera Cruz	19 12N/96 08W	184	55	60	62	91	89	88	12	83	83	82
MOROCCO												
Casablanca	33 35N/7 39W	164	36	40	42	94	90	86	50	73	72	70
NEPAL												
Katmandu	27 42N/85 12E	4388	30	33	35	89	87	86	25	78	77	76
NETHERLANDS												
Amsterdam	52 23N/4 55E	5	17	20	23	79	76	73	10	65	64	63
NEW GUINEA												
Manokwari	0 52S/134 05E	62	70	71	72	89	88	87	12	82	81	81
Point Moresby	9 29S/147 09E	126	62	67	69	92	91	90	14	80	80	79
NEW ZEALAND												
Auckland	36 51S/174 46E	140	37	40	42	78	77	76	14	67	66	65
Christ Church	43 32S/172 37E	32	25	28	31	82	79	76	17	68	67	66
Wellington	41 17S/174 46E	394	32	35	37	76	74	72	14	66	65	64
NICARAGUA												
Managua	12 10N/86 15W	135	62	65	67	94	93	92	21	81	80	79
NIGERIA												
Lagos	6 27N/3 24E	10	67	70	71	92	91	90	12	82	82	81
NORWAY												
Bergen	60 24N/5 19E	141	14	17	20	75	74	73	21	67	66	65
Oslo	59 56N/10 44E	308	−2	0	4	79	77	74	17	67	66	64

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PAKISTAN												
Chittagong	22 21N/91 50E	87	48	52	54	93	91	89	20	82	81	81
Karachi	24 48N/66 59E	13	45	49	51	100	98	95	14	82	82	81
Lahore	31 35N/74 20E	702	32	35	37	109	107	105	27	83	82	81
Peshwar	34 01N/71 35E	1164	31	35	37	109	106	103	29	81	80	79
PANAMA AND CANAL ZONE												
Panama City	8 58N/79 33W	21	69	72	73	93	92	91	18	81	81	80
PARAGUAY												
Asunción	25 17S/57 30W	456	35	43	46	100	98	96	24	81	81	80
PERU												
Lima	12 05S/77 03W	394	51	53	55	86	85	84	17	76	75	74
PHILIPPINES												
Manila	14 35N/120 59E	47	69	73	74	94	92	91	20	82	81	81
POLAND												
Kraków	50 04N/19 57E	723	− 2	2	6	84	81	78	19	68	67	66
Warsaw	52 13N/21 02E	394	− 3	3	8	84	81	78	19	71	70	68
PORTUGAL												
Lisbon	38 43N/9 08W	313	32	37	39	89	86	83	16	69	68	67
PUERTO RICO												
San Juan	18 29N/66 07W	82	65	67	68	89	88	87	11	81	80	79
RUMANIA												
Bucharest	44 25N/26 06E	269	− 2	3	8	93	91	89	26	72	71	70
SAUDI ARABIA												
Dhahran	26 17N/50 09E	80	39	45	48	111	110	108	32	86	85	84
Jedda	21 28N/39 10E	20	52	57	60	106	103	100	22	85	84	83
Riyadh	24 39N/46 42E	1938	29	37	40	110	108	106	32	78	77	76
SENEGAL												
Dakar	14 42N/17 29W	131	58	61	62	95	93	91	13	81	80	80
SOMALIA												
Mogadiscio	2 02N/49 19E	39	67	69	70	91	90	89	12	82	82	81
SOUTH AFRICA												
Capetown	33 56S/18 29E	55	36	40	42	93	90	86	20	72	71	70
Johannesburg	26 11S/78 03E	5463	26	31	34	85	83	81	24	70	69	69
Pretoria	25 45S/28 14E	4491	27	32	35	90	87	85	23	70	69	68
SOVIET UNION												
Alma Ata	43 14N/76 53E	2543	−18	−10	− 6	88	86	83	21	69	68	67
Archangel	64 33N/40 32E	22	−29	−23	−18	75	71	68	13	60	58	57
Kaliningrad	54 43N/20 30E	23	− 3	+ 1	6	83	80	77	17	67	66	65
Krasnoyarsk	56 01N/92 57E	498	−41	−32	−27	84	80	76	12	64	62	60
Kiev	50 27N/30 30E	600	−12	− 5	+ 1	87	84	81	22	69	68	67
Kharkov	50 00N/36 14E	472	−19	−10	− 3	87	84	82	23	69	68	67
Kuibyshev	53 11N/50 06E	190	−23	−19	−13	89	85	81	20	69	67	66
Leningrad	59 56N/30 16E	16	−14	− 9	− 5	78	75	72	15	65	64	63
Minsk	53 54N/27 33E	738	−19	−11	− 4	80	77	74	16	67	66	65
Moscow	55 46N/37 40E	505	−19	−11	− 6	84	81	78	21	69	67	65
Odessa	46 29N/30 44E	214	− 1	4	8	87	84	82	14	70	69	68
Petropavlovsk	52 53N/158 42E	286	− 9	− 3	0	70	68	65	13	58	57	56
Rostov on Don	47 13N/39 43E	159	− 9	− 2	4	90	87	84	20	70	69	68
Sverdlovsk	56 49N/60 38E	894	−34	−25	−20	80	76	72	16	63	62	60
Tashkent	41 20N/69 18E	1569	− 4	3	8	95	93	90	29	71	70	69
Tbilisi	41 43N/44 48E	1325	12	18	22	87	85	83	18	68	67	66
Vladivostok	43 07N/131 55E	94	−15	−10	− 7	80	77	74	11	70	69	68
Volgograd	48 42N/44 31E	136	−21	−13	− 7	93	89	86	19	71	70	69
SPAIN												
Barcelona	41 24N/2 09E	312	31	33	36	88	86	84	13	75	74	73
Madrid	40 25N/3 41W	2188	22	25	28	93	91	89	25	71	69	67
Valencia	39 28N/0 23W	79	31	33	37	92	90	88	14	75	74	73
SUDAN												
Khartoum	15 37N/32 33E	1279	47	53	56	109	107	104	30	77	76	75
SURINAM												
Paramaribo	5 49N/55 09W	12	66	68	70	93	92	90	18	82	82	81
SWEDEN												
Stockholm	59 21N/18 04E	146	3	5	8	78	74	72	15	64	62	60
SWITZERLAND												
Zurich	47 23N/8 33E	1617	4	9	14	84	81	78	21	68	67	66
SYRIA												
Damascus	33 30N/36 20E	2362	25	29	32	102	100	98	35	72	71	70
TAIWAN												
Tainan	22 57N/120 12E	70	40	46	49	92	91	90	14	84	83	82
Taipei	25 02N/121 31E	30	41	44	47	94	92	90	16	83	82	81

Table 2.1C Climatic Conditions for Other Countries

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter Col. 4 Mean of Annual Extremes	Winter Col. 4 99%	Winter Col. 4 97½%	Summer Col. 5 Design Dry-Bulb 1%	Col. 5 2½%	Col. 5 5%	Col. 6 Outdoor Daily Range F deg	Col. 7 Design Wet-Bulb 1%	Col. 7 2½%	Col. 7 5%
TANZANIA												
Dar es Salaam	6 50S/39 18E	47	62	64	65	90	89	88	13	82	81	81
THAILAND												
Bangkok	13 44N/100 30E	39	57	61	63	97	95	93	18	82	82	81
TRINIDAD												
Port of Spain	10 40N/61 31W	67	61	64	66	91	90	89	16	80	80	79
TUNISIA												
Tunis	36 47N/10 12E	217	35	39	41	102	99	96	22	77	76	74
TURKEY												
Adana	36 59N/35 18E	82	25	33	35	100	97	95	22	79	78	77
Ankara	39 57N/32 53E	2825	2	9	12	94	92	89	28	68	67	66
Istanbul	40 58N/28 50E	59	23	28	30	91	88	86	16	75	74	73
Izmir	38 26N/27 10E	16	24	27	29	98	96	94	23	75	74	73
UNITED ARAB REPUBLIC												
Cairo	29 52N/31 20E	381	39	45	46	102	100	98	26	76	75	74
UNITED KINGDOM												
Belfast	54 36N/5 55W	24	19	23	26	74	72	69	16	65	64	62
Birmingham	52 29N/1 56W	535	21	24	27	79	76	73	15	66	64	63
Cardiff	51 28N/3 10W	203	21	24	27	79	76	73	14	64	63	62
Edinburgh	55 55N/3 11W	441	22	25	28	73	70	68	13	64	62	61
Glasgow	55 52N/4 17W	85	17	21	24	74	71	68	13	64	63	61
London	51 29N/00 00	149	20	24	26	82	79	76	16	68	66	65
URUGUAY												
Montevideo	34 51S/56 13W	72	34	37	39	90	88	85	21	73	72	71
VENEZUELA												
Caracas	10 30N/66 56W	3418	49	52	54	84	83	81	21	70	69	69
Maracaibo	10 39N/71 36W	20	69	72	73	97	96	95	17	84	83	83
VIET NAM												
Da Nang	16 04N/108 13E	23	56	60	62	97	95	93	14	86	86	85
Hanoi	21 02N/105 52E	53	46	50	53	99	97	95	16	85	85	84
Saigon	10 47N/106 42E	30	62	65	67	93	91	89	16	85	84	83
YUGOSLAVIA												
Belgrade	44 48N/20 28E	453	4	9	13	92	89	86	23	74	73	72

Table 2.2 Cooling Design Dry Bulb and Mean Coincident Wet Bulb

CITY	LAT DEG.	LAT MIN.	LONG DEG.	LONG MIN.	ELEV	DESIGN DB (2.5%) JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC	DESIGN COINCIDENT WB (2.5%) JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC
Birmingham, Al	33	34	86	45	630	67	72	76	83	91	84	74	68	62	63	64	67	71	69	64	60
Yuma, Az	32	40	114	36	206	76	82	87	96	99	99	85	75	54	57	58	61	63	66	58	54
Little Rock, Ar	34	44	92	14	265	68	70	76	83	89	84	74	67	63	61	64	67	72	71	65	61
Arcata, Ca	40	59	124	6	217	61	60	59	59	62	66	63	59	53	54	53	54	57	58	56	55
Bishop, Ca	37	22	118	22	4112	60	66	72	81	88	85	72	64	43	45	48	52	57	55	49	45
Los Angeles, Ca	33	56	118	23	122	72	71	72	74	74	80	79	74	54	55	55	61	61	63	56	53
San Diego, Ca	32	44	117	10	37	69	69	70	73	72	79	74	71	53	56	56	60	60	64	55	54
Colorado Springs	38	49	104	42	6170	56	61	63	73	79	77	64	59	39	43	43	47	52	50	44	40
Wilmington, De	39	40	75	36	78	50	55	63	78	84	78	65	55	48	52	54	64	70	69	60	51
Jacksonville, Fl	30	25	81	39	24	75	80	83	86	93	86	81	75	66	68	68	69	73	74	69	67
Augusta, Ga	33	22	81	58	182	70	73	78	85	91	84	77	71	62	63	66	68	73	71	65	63
Boise, Id	43	34	116	13	2857	51	53	62	72	83	74	59	48	44	46	49	53	62	55	48	43
Chicago-OHare, Il	41	59	87	54	667	40	49	58	74	83	78	64	50	45	47	52	63	68	66	56	49
Fort Wayne, In	41	0	85	12	828	47	52	60	76	82	78	63	53	47	50	53	62	68	63	58	51
Indianapolis, In	39	44	86	16	793	53	57	64	78	82	79	66	55	52	54	57	64	68	65	59	53
Des Moines, Ia	41	32	93	39	963	42	49	59	76	84	79	63	52	39	44	49	62	69	64	55	48
Dodge City, Ks	37	46	99	58	2592	58	64	72	82	89	83	68	59	46	49	51	58	64	60	52	45
Covington, Ky	39	4	84	40	888	55	61	65	79	84	79	68	58	53	56	55	64	70	64	59	53
Louisville, Ky	38	11	85	44	488	58	63	69	82	88	81	71	61	56	57	59	66	72	67	61	57
Lake Charles, La	30	13	93	9	32	72	75	78	84	89	88	79	74	67	68	69	70	75	74	73	68
New Orleans, La	29	59	90	15	20	74	77	79	84	89	86	79	74	69	70	70	72	74	75	72	69
Portland, Me	43	39	70	19	61	41	44	49	62	77	69	58	48	33	43	44	53	64	60	55	47
Battle Creek, Mi	42	18	85	14	939	49	48	64	72	86	77	62	49	50	45	57	59	66	64	55	49
Minneapolis, Mn	44	53	93	15	838	36	42	52	73	83	76	57	43	34	39	45	58	65	62	52	43
Jackson, Ms	32	20	90	13	332	70	74	78	84	89	87	77	70	64	65	67	70	73	72	68	63
Kansas City, Mo	39	7	94	35	750	54	60	69	81	87	83	69	58	49	51	55	65	71	67	57	52
Springfield, Mo	37	14	93	23	1270	59	62	72	80	84	83	69	59	54	54	59	65	70	66	60	53
Billings, Mt	45	48	108	32	3583	51	54	62	70	80	77	59	52	41	44	47	52	59	56	47	41
North Platte, Ne	41	8	100	42	2787	52	58	64	77	83	80	64	54	42	45	49	56	63	57	49	43
Tonopah, Ne	38	4	117	8	5422	53	58	65	75	81	78	64	55	40	43	45	49	54	52	46	41
Albuquerque, NM	35	3	106	37	5314	55	63	69	79	87	79	64	56	42	45	47	51	56	55	46	42
Albany, NY	42	45	73	48	277	43	47	54	73	81	73	60	49	42	45	49	59	67	65	58	46
Greensboro, NC	36	5	79	57	891	63	64	70	83	87	81	71	63	57	56	59	65	70	68	59	58
Bismarck, ND	46	46	100	45	1660	41	42	56	70	82	77	53	43	37	39	46	53	62	57	43	38
Akron-Canton, Oh	40	55	81	26	1236	49	53	60	74	79	75	64	54	48	50	53	63	67	62	57	52
Toledo, Oh	41	36	83	48	692	44	48	59	76	84	77	64	52	42	46	53	63	69	63	58	51
Tulsa, Ok	36	11	95	54	674	63	69	75	83	88	86	73	63	57	58	60	66	73	69	61	53
Medford, Or	42	23	122	52	1329	55	59	66	75	84	78	63	53	48	50	53	58	64	60	52	49
Portland, Or	45	36	122	36	24	54	57	60	69	79	73	59	54	50	51	51	56	63	59	54	53
Pittsburgh, Pa	40	30	80	13	1151	49	53	63	78	82	77	64	55	46	50	53	63	68	64	57	51
Sioux Falls, SD	43	34	96	44	1422	41	45	57	75	84	78	58	47	37	41	48	58	65	60	49	43
Bristol, Tn	36	30	82	21	1566	59	64	69	81	86	79	70	60	54	55	58	64	70	66	61	54
Amarillo, Tx	35	14	101	46	3700	63	69	75	84	90	84	70	65	46	50	51	56	61	59	50	47
Midland, Tx	31	56	102	12	2858	72	74	81	88	94	88	77	71	53	54	55	59	65	63	56	52
Wichita Falls, Tx	33	59	98	31	1039	66	74	82	88	93	89	76	67	56	58	61	66	71	67	60	54
Cedar City, Ut	37	42	113	6	5616	53	56	63	73	81	78	63	54	41	44	46	50	55	53	46	42
Burlington, Vt	44	28	73	9	331	39	40	49	68	79	70	58	46	38	38	44	56	66	61	55	44
Blackstone, Va	37	4	77	58	438	65	64	71	83	87	82	72	65	59	56	61	67	72	70	61	60
Roanoke, Va	37	19	79	58	1174	60	63	69	82	87	81	69	62	54	52	56	63	69	66	56	55
Everett, Wa	47	54	122	17	596	50	54	61	64	72	64	54	53	47	49	49	55	61	58	52	49
Charleston, WV	38	22	81	36	989	62	64	70	83	86	80	72	64	55	55	56	63	67	66	60	55
Huntington, WV	38	25	82	27	565	65	65	72	83	87	84	71	63	58	56	60	66	70	69	60	57
Green Bay, Wi	44	29	88	8	699	36	39	48	70	77	69	58	42	36	39	44	57	65	60	54	41
Madison, Wi	43	8	89	20	866	38	44	53	73	81	74	61	44	37	42	47	60	68	62	55	43
Cheyenne, Wy	41	9	104	49	6144	51	56	58	69	76	74	60	54	37	41	41	48	52	50	43	41

Table 2.3 Indoor Design Humidity Ratio (Lb/Lb) at Design Dry Bulb of 78 F and Relative Humidity as Listed

RH	Elevation (ft) 0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500
30	.0061	.0062	.0063	.0064	.0066	.0067	.0068	.0069	.0071	.0072	.0073	.0075	.0076	.0078	.0079	.0081
35	.0071	.0072	.0074	.0075	.0077	.0078	.0079	.0081	.0083	.0084	.0086	.0087	.0089	.0091	.0092	.0094
40	.0081	.0083	.0084	.0086	.0088	.0089	.0091	.0093	.0094	.0096	.0098	.0100	.0102	.0104	.0106	.0108
45	.0092	.0093	.0095	.0097	.0099	.0101	.0103	.0104	.0107	.0109	.0111	.0113	.0115	.0117	.0119	.0122
50	.0102	.0104	.0106	.0108	.0110	.0112	.0114	.0116	.0119	.0121	.0123	.0125	.0128	.0130	.0133	.0136
55	.0113	.0115	.0117	.0119	.0121	.0123	.0126	.0128	.0131	.0134	.0136	.0138	.0141	.0144	.0147	.0149
60	.0123	.0125	.0128	.0130	.0132	.0135	.0137	.0140	.0143	.0145	.0148	.0151	.0154	.0157	.0160	.0163

CHAPTER 3

EXTERNAL LOAD FACTORS

External load factors are those involved in the calculation of components of the cooling load which arise from influences external to the space being cooled. These components of cooling load come from:

1. Heat conduction through exterior walls and roofs and overhangs.
2. Heat conduction through interior partitions, ceilings, and floors.
3. Heat conduction through fenestration
4. Solar radiation effects which may be:
   (a) Converted to conduction and convection effects through walls and roofs or glass.
   (b) Transmitted directly through glass from the outside into the space.

3.1 CONDUCTION EFFECTS AND U-VALUES

The steady-state conduction heat flow through a roof or a wall or glass is given by:

$$q = (UA) \times \Delta t \text{ or } \left(\frac{A}{R_t}\right) \times \Delta t \qquad (3.1)$$

where

q = rate of heat transfer, Btu/hr

Δt = total temperature difference, air to air, deg F

R_t = sum of individual thermal resistances, $(\text{hr} \cdot \text{ft}^2 \cdot \text{F})/\text{Btu}$; $R_t = R_1 + R_2 = \ldots = 1/U$

U = coefficient of transmission, $\text{Btu}/(\text{hr} \cdot \text{ft}^2 \cdot \text{F}) = 1/R_t$

A = cross-sectional wall area, ft^2, measured perpendicularly to the direction of flow and is constant for a flat wall or roof or glass.

The unsteady-state equation for cooling load is written in similar format to Eq. (3.1):

$$q = U \times A \times \text{CLTD} \qquad (3.2)$$

where

q = the cooling load, Btu/hr

CLTD = the Cooling Load Temperature Difference, deg F

Eqs. (3.1) and (3.2) are explained in more detail in Sections A3.1 and A3.2. Eq. (3.2) will be used for all the components of external cooling load named above, except for the solar radiation through glass. The solar load through glass or fenestration is discussed in Sections 3.3 and A3.3. Eq. (3.1) is used for heating loads.

Calculation of U-Values

For a flat wall or roof composed of layers of construction materials and including surface air films and internal air spaces, the area A is constant. When one or more non-uniform layers exist, parallel heat flow must be considered. The area, A, is still taken as a total constant area and is calculated from architectural plans. U for parallel flow is taken as U_{av}, the weighted average value for the entire area based on the area of each of the non-uniform sections.

Load Source	Equation	Reference, Table, Description
External Roof	$q = U \times A \times \text{CLTD}$	→ Design Heat Transmission Coefficients – Tables 3.1-3.5, A3.1 and A3.2 → Areas calculated from Architectural Plans → Cooling Load Temperature Difference Base Conditions for Roofs – Table 3.8 and Notes Note 2 – Correction for Color of Exterior Surface Note 2 – Correction for Outside Dry Bulb Temperature and Daily Range – Table 3.13 Note 2 – Correction for Inside Dry Bulb Temperature – Table 3.13 Note 2 – Application for Latitude and Month – Table 3.12
Walls	$q = U \times A \times \text{CLTD}$	→ Design Heat Transmission Coefficients – Tables 3.1-3.4, A3.1 and A3.2 → Area Calculated from Architectural Plans Wall Construction Group Description – Table 3.9 → Cooling Load Temperature Difference at Base Conditions for Wall Group – Table 3.10 and Notes Note 2 – Correction for Color of Exterior Surface Note 2 – Correction for Outside Dry Bulb Temperature and Daily Range – Table 3.13 Note 2 – Correction for Inside Dry Bulb Temperature – Table 3.13 Note 2 – Application for Latitude and Month – Table 3.12
Glass Conduction	$q = U \times A \times \text{CLTD}$	→ Type of Glass and Interior Shading, if Used – Tables 3.14-3.16 and A3.4 → Area – Glass Area Calculated from Plans → Cooling Load Temperature Difference for Conduction Load Through Glass – Table 3.23 Correction for Outside Dry Bulb Temperature and Daily Range – Table 3.13 Correction for Inside Dry Bulb Temperature – Table 3.13

EXAMPLE 3.1

Obtain both the winter and summer U-values for a flat masonry roof with 3/8 in. built-up roofing on 6 in. of concrete slab (6 in. gravel agg.; 140 lb/ft³) with a suspended ceiling of 1/2 in. acoustical tile (18 lb/ft³) Determine the value of U if 1 in. of preformed roof insulation is added. How much added R other than from the first 1 in. of insulation is necessary if it is to meet code standard of U = 0.08?

Item	Table	Explanation and Notes
$q = U \times A \times CLTD$ $q = U \times A \times TD$	Table 1.2 Table 1.3	Cooling Load Equation for Roof; Obtain U Heating Load Equation
U (Winter, 15 mph wind)	Table 3.2H (Heat flow up)	For guidelines in procedure only. Substitute values which apply to this construction
U (Winter)		**Construction (Heat Flow Up)** — **Resistance (R)**
	Table 3.3	1. Inside surface film (still air) — 0.61
	Table 3.1	2. 1/2 in. acoustic tile (wood fiber) — 1.25
	Table 3.4	3. Air space (Non-reflective E_S = 0.82; greater than 3.5 in. 50 F mean; 10 deg F difference) — 0.93
	Table 3.1	4. 6 in. concrete, gravel aggregate, not dried; 140 lb/ft³; 0.08/in. × 6 in. — 0.48
	Table 3.1	5. Built-up roofing (3/8 in.) — 0.33
	Table 3.3	6. Outside surface film (15 mph wind) — 0.17
		Total Thermal Resistance (R) $R_t = 3.77$ $U = 1/R_t = 1/3.77 = 0.26$ Btu/(hr · ft² · F)
Add roof deck insulation (Winter)	Table 3.1 (also see Note h)	The additional insulation for a 1 in. preformed slab is R = 2.78 as obtained from manufacturer's data or from specs.
	Table A3.1	The value of U obtained by interpolating in Table A3.1 with U = 0.26 and additional R = 2.78 is U = 0.15, approximated between 0.171 and 0.146 **Alternate Method (Preferred)** New R = 3.77 + 2.78 = 6.55 U = 1/6.55 = 0.153 Btu/(hr · ft² · F)

Item	Table	Explanation and Notes
Additional R required to meet specification of U = 0.08 (Winter)		For U = 0.08, R = 1/0.08 = 12.5 Existing R = 6.55 Additional R = 12.5 − 6.55 = 5.95
U (Summer)		The difference in U-values for the summer and the winter for roofs is due to the air film resistances on the outside, on the inside and in any air space such as a suspended ceiling. This is caused by the wind speed, by the direction of heat flow and by the average temperature.
Inside air film (Summer)	Table 3.3	Horiz. (still air) with E = 0.90 for most construction materials & Heat Flow Down R = 0.92
Outside air film (Summer)		Any position (7.5 mph wind) R = 0.25 Any direction of heat flow
Horizontal Air Space (Summer)	Table 3.3	E_S for both surfaces of air space with normal building materials E_S = 0.82
	Table 3.4	Horiz. Air Space Heat Flow Down & E_S = 0.82 R = 1.00 (Greater than 3 1/2 in. with 90 F mean)
U (Summer)		**Construction (Heat Flow Down)** — **Resistance (R)** 1. Inside surface film (still air) — 0.92 2. (As above) — 1.25 3. Air Space — 1.00 4. (As above) — 0.48 5. (As above) — 0.33 6. Outside surface film (7.5 mph wind) — 0.25 Total Thermal Resistance (R) (add) $R_t = 4.23$ $U = 1/R_t = 1/4.23 = 0.24$ Btu/(hr · ft² · F)
Additional R to meet condition of U = 0.08 (Summer)		With R = 2.78 added: R_t = 4.23 + 2.78 = 7.01 $U = 1/R_t$ = 0.143 Btu/(hr · ft² · F) For summer U = 0.08, the added R necessary is R = 12.5 − 7.01 = 5.49 (hr · ft² · F)/Btu

EXAMPLE 3.2

An outside wall is constructed of 6 in. concrete, 140 lb/ft³ density, and 1/2 in. gypsum board furred out 2 in. on metal furring strips. The winter and summer U values are needed for this wall. Determine additional resistance of insulation required for U = 0.08.

Item	Table	Explanation and Notes
$q = U \times A \times CLTD$ $q = U \times A \times TD$	Table 1.2 Table 1.3	Cooling Load Equation for Walls obtain U Heating Load Equation
U (Winter, 15 mph wind)	Table 3.2B	For guidelines in procedure only. Check on the density of the concrete for such a wall, since a lighter density concrete wall, 80 lb/ft² for example, has greater resistance resulting in lower U.
U (Winter) (2 in. air space; neglect effect of metal furring strips)	Table 3.1 Table 3.3 Table 3.1 Table 3.4 Table 3.1 Table 3.3	Total $R = R_1 + R_2 + \ldots$ Outside air film $R = 0.17$ 6 in. concrete $R = 0.48$ 2 in. air space $R = 0.90$ 1/2 in. gypsum board $R = 0.45$ Inside air film $R = 0.68$ Total $R_t = 2.68$ $U = \frac{1}{R_t} = 0.37$ Btu/(hr·ft²·F)
U (Summer)	Table 3.3	If a summer wind velocity is between 5 and 10 mph, the approximate value of U will be about 0.36. This is close enough for most applications to use 0.37 for both summer and winter. Generally, this is true for most exterior wall and roof constructions. **Alternate Calculation** Summer (7 1/2 mph wind) outside air film $R = 0.25$ $R_t = (2.68 - .17) + 0.25 = 2.76$ $U = 1/2.76 = 0.36$ Btu/(hr·ft²·F)
Add R-6.25 Urethane (1 in.)	Table 3.1 Table 3.2	Urethane with a resistance of 6.25 for 1 in. is added in air space. However an air space of 1 in. is maintained between insulation and gypsum board. Assume 1 in. air space has same resistance as previous 2 in. air space. With U = 0.37 and R added = 6.25 the new U = 0.11 approx.
U (Winter, summer) (1 in. air space; 1 in. urethane) R = 6.25 Alternate		Replace 2 in. air space with 1 in. urethane and 1 in. air space Previous Total $R = 2.68$ Subtract 2 in. air space $R = 0.90$ $R = 1.78$ Add urethane $R = 6.25$ Add 1 in. air space (Table 3.4) $R = 0.94$ New Total $R_t = 8.97$ $U = \frac{1}{R_t} = 0.11$ Btu/(hr·ft²·F)
Given Code or Standard Requirement U = 0.08	Table 3.1	The original U = 0.37 requires an additional resistance of $R = 1/0.08 - 2.68 = 12.5 - 2.68$ $R = 9.8$ (hr·ft²·F)/Btu This is equivalent to (9.8/6.25) = 1.6 in. of urethane

EXAMPLE 3.3

Obtain the winter and summer U-values for a 4 in. concrete floor covered with floor tile (1/8 in.) over an unconditioned space. Assume the concrete is 4 in. sand aggregate.

Item	Table	Explanation and Notes
$q = U \times A \times CLTD$ $q = U \times A \times TD$	Table 1.2 Table 1.3	Cooling Load Equation for Floor; obtain U Heating Load Equation; obtain U
U (Winter) Still air both sides.	Table 3.2G Heat flow up	For guidelines in procedure only.
U (Winter)	 Table 3.3 Table 3.1 Table 3.1 Table 3.3	**Construction (Heat Flow Up)** — **Resistance (R)** 1. Bottom surface film (still air) 0.61 2. 4 in. concrete 0.08/in. × 4 in. (sand agg., not dried) 140 lb/ft³ 0.32 3. 1/8 in. floor tile 0.05 4. Top surface film (still air) 0.61 Total Thermal Resistance $R_t = 1.59$ $U = 1/R_t$ $= 1/1.59 = 0.62$ Btu/(hr·ft²·F)
U (Summer) Still air both sides	Table 3.3	Only change from winter is for resistances of air films on top and bottom. Now heat flow is down. For normal construction materials $E = 0.90$ Horiz. (still air) Heat Flow Down $R = 0.92$ **Construction (Heat Flow Down)** — **Resistance (R)** 1. Bottom surface film (still air) 0.92 2. (As above) 0.32 3. (As above) 0.05 4. Top surface film (still air) 0.92 Total Thermal Resistance $R_t = 2.21$ $U = 1/R_t$ $= 1/2.21 = 0.45$ Btu/(hr·ft²·F)
Comment		In both winter and summer the major resistances are due to the air films on top and bottom, for this type of construction. There is a significant difference in this case.

Table 3.1A Thermal Properties of Typical Building and Insulating Materials — (Design Values)[a]

Description	Customary Unit: Density (lb/ft³)	Conductivity (k)	Conductance (C)	Resistance[b] (R): Per inch thickness (1/k)	Resistance[b] (R): For thickness listed (1/C)	Specific Heat, Btu/(lb)(deg F)	Wt lb/ft²	Heat Capacity: Btu/ft² · F	Heat Capacity: Btu/ft³ · F
BUILDING BOARD									
Boards, Panels, Subflooring, Sheathing									
Woodboard Panel Products							—	—	28.8
Asbestos-cement board	120	4.0	—	0.25	—	0.24	1.25	0.30	28.8
Asbestos-cement board 0.125 in.	120	—	33.00	—	0.03		2.50	0.60	28.8
Asbestos-cement board 0.25 in.	120	—	16.50	—	0.06		1.56	0.41	13.0
Gypsum or plaster board 0.375 in.	50	—	3.10	—	0.32	0.26	2.08	0.54	13.0
Gypsum or plaster board 0.5 in.	50	—	2.22	—	0.45		2.60	0.68	13.0
Gypsum or plaster board 0.625 in.	50	—	1.78	—	0.56		—	—	9.86
Plywood (Douglas Fir)	34	0.80	—	1.25	—	0.29	0.71	0.21	9.86
Plywood (Douglas Fir) 0.25 in.	34	—	3.20	—	0.31		1.06	0.31	9.86
Plywood (Douglas Fir) 0.375 in.	34	—	2.13	—	0.47		1.42	0.41	9.86
Plywood (Douglas Fir) 0.5 in.	34	—	1.60	—	0.62		1.77	0.51	9.86
Plywood (Douglas Fir) 0.625 in.	34	—	1.29	—	0.77				
Plywood or wood panels 0.75 in.	34	—	1.07	—	0.93	0.29	2.13	0.62	9.86
Vegetable Fiber Board									
Sheathing, regular density 0.5 in.	18	—	0.76	—	1.32	0.31	0.75	0.23	5.58
0.78125 in.	18	—	0.49	—	2.06		1.17	0.36	5.58
Sheathing intermediate density 0.5 in.	22	—	0.82	—	1.22	0.31	0.92	0.28	6.82
Nail-base sheathing 0.5 in.	25	—	0.88	—	1.14	0.31	1.04	0.32	7.75
Shingle backer 0.375 in.	18	—	1.06	—	0.94	0.31	0.56	0.17	5.58
Shingle backer 0.3125 in.	18	—	1.28	—	0.78		0.47	0.15	5.58
Sound deadening board 0.5 in.	15	—	0.74	—	1.35	0.30	0.62	0.19	4.50
Tile and lay-in panels, plain or acoustic	18	0.40	—	2.50	—	0.14	—	—	2.52
0.5 in.	18	—	0.80	—	1.25		0.75	0.11	2.52
0.75 in.	18	—	0.53	—	1.89		1.13	0.16	2.52
Laminated paperboard	30	0.50	—	2.00	—	0.33	—	—	9.90
Homogeneous board from repulped paper	30	0.50	—	2.00	—	0.28	—	—	8.40
Hardboard									
Medium density	50	0.73	—	1.37	—	0.31	—	—	17.60
High density, service temp. service underlay	55	0.82	—	1.22	—	0.32	—	—	17.60
High density, std. tempered	63	1.00	—	1.00	—	0.32	—	—	20.16
Particleboard									
Low density	37	0.54	—	1.85	—	0.31			11.47
Medium density	50	0.94	—	1.06	—	0.31			15.50
High density	62.5	1.18	—	0.85	—	0.31			19.38
Underlayment 0.625 in.	40	—	1.22	—	0.82	0.29	2.08	0.6	11.60
Wood subfloor 0.75 in.		—	1.06	—	0.94	0.33	2.00	0.6	9.60
BUILDING MEMBRANE									
Vapor—permeable felt	—	—	16.70	—	0.06		—	—	—
Vapor—seal, 2 layers of mopped 15-lb felt	—	—	8.35	—	0.12		—	—	—
Vapor—seal, plastic film	—	—	—	—	Negl.		—	—	—
FINISH FLOORING MATERIALS									
Carpet and fibrous pad	—	—	0.48	—	2.08	0.34	—	—	—
Carpet and rubber pad	—	—	0.81	—	1.23	0.33	—	—	—
Cork tile 0.125 in.	—	—	3.60	—	0.28	0.48	—	—	—
Terrazzo 1 in.	—	—	12.50	—	0.08	0.19	11.7	2.22	26.60
Tile—asphalt, linoleum, vinyl, rubber	—	—	20.00	—	0.05	0.30	—	—	—
vinyl asbestos						0.24	—	—	—
ceramic						0.19	—	—	—
Wood, hardwood finish 0.75 in.			1.47		0.68		2.81	0.84	13.50
INSULATING MATERIALS									
Blanket and Batt									
Mineral Fiber, fibrous form processed from rock, slag, or glass									
approx.[e] 2–2.75 in.	0.3–2.0	—	0.143	—	7[d]	0.17–0.23	.12-.40	.02-.09	0.1-0.46
approx.[e] 3–3.5 in.	0.3–2.0	—	0.091	—	11[d]		.16-.54	.03-.12	0.1-0.46
approx.[e] 3.50–6.5	0.3–2.0	—	0.053	—	19[d]		.30-.98	.05-.23	0.1-0.46
approx.[e] 6–7 in.	0.3–2.0		0.045		22[d]		.30-1.10	.05-.25	0.1-0.46
approx.[d] 8.5 in.	0.3–2.0		0.033		30[d]		.40-1.42	.07-.32	0.1-0.46
Board and Slabs									
Cellular glass	8.5	0.38	—	2.63	—	0.24	—	—	2.64
Glass fiber, organic bonded	4-9	0.25	—	4.00	—	0.23	—	—	.9-2.1
Expanded rubber (rigid)	4.5	0.22	—	4.55	—	0.40	—	—	1.8
Expanded polystyrene extruded Cut cell surface	1.8	0.25	—	4.00	—	0.29	—	—	0.52
Expanded polystyrene extruded Smooth skin surface	2.2	0.20	—	5.00	—	0.29	—	—	0.64
Expanded polystyrene extruded Smooth skin surface	3.5	0.19	—	5.26	—		—	—	1.02
Expanded polystyrene, molded beads	1.0	0.28	—	3.57	—	0.29	—	—	0.29
Expanded polyurethane[f] (R-11 exp.)	1.5	0.16	—	6.25	—	0.38	—	—	0.57
(Thickness 1 in. or greater)	2.5								

Table 3.1A Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a] (continued)

Description	Customary Unit: Density (lb/ft³)	Conductivity (k)	Conductance (C)	Resistance[b] (R): Per inch thickness (1/k)	Resistance[b] (R): For thickness listed (1/C)	Specific Heat, Btu/(lb) (deg F)	Heat Capacity: Wt lb/ft²	Heat Capacity: Btu/ft²·F	Heat Capacity: Btu/ft³·F
Mineral fiber with resin binder	15	0.29	—	3.45	—	0.17	—	—	9.15
Mineral fiberboard, wet felted									
Core or roof insulation	16-17	0.34	—	2.94	—		—	—	2.2-2.4
Acoustical tile	18	0.35	—	2.86	—	0.19	—	—	3.42
Acoustical tile	21	0.37	—	2.70	—		—	—	2.94
Mineral fiberboard, wet molded									
Acoustical tile[g]	23	0.42	—	2.38	—	0.14	—	—	3.22
Wood or cane fiberboard									
Acoustical tile[g] 0.5 in.	—	—	0.80	—	1.25	0.31	—	—	—
Acoustical tile[g] 0.75 in.	—	—	0.53	—	1.89		—	—	—
Interior finish (plank, tile)	15	0.35	—	2.86	—	0.32	—	—	4.80
Wood shredded (cemented in preformed slabs)	22	0.60	—	1.67	—	0.31	—	—	6.82
LOOSE FILL									
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.13-3.70	—	0.33	—	—	.76-1.06
Sawdust or shavings	8.0-15.0	0.45	—	2.22	—	0.33	—	—	2.64-4.45
Wood fiber, softwoods	2.0-3.5	0.30	—	3.33	—	0.33	—	—	.66-1.16
Perlite, expanded	5.0-8.0	0.37	—	2.70	—	0.26	—	—	1.3 -2.08
Mineral fiber (rock, slag or glass)									
approx.[e] 3.75-5 in.	0.6-2.0	—	—		11	0.17	0.2 - .71	.04-.12	0.1
approx.[e] 6.5-8.75 in.	0.6-2.0	—	—		19		.51-1.27	.06-.22	0.1- .34
approx.[e] 7.5-10 in.	0.6-2.0	—	—		22		.45-1.46	.07-.25	0.1- .34
approx.[e] 10.25-13.75 in.	0.6-2.0	—	—		30		.60-2.02	.1 -.34	0.1- .34
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	3.20	—	—	1.4-1.64
	4.0-6.0	0.44	—	2.27	—		—	—	0.8-1.2
ROOF INSULATION[h]									
Preformed, for use above deck									
Different roof insulations are available in different thicknesses to provide the design C values listed.[h] Consult individual manufacturers for actual *thickness of their material.*			0.72 to 0.12		1.39 to 8.33		—	—	—
MASONRY MATERIALS									
CONCRETES									
Cement mortar	116	5.0	—	0.20	—		—	—	23.2
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	51	1.66	—	0.60	—	0.21	—	—	10.71
Lightweight aggregates including expanded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes	120	5.2	—	0.19	—		—	—	24.0
	100	3.6	—	0.28	—		—	—	20.0
	80	2.5	—	0.40	—		—	—	16.0
	60	1.7	—	0.59	—		—	—	12.0
	40	1.15	—	0.86	—		—	—	8.0
	30	0.90	—	1.11	—		—	—	6.0
	20	0.70		1.43			—	—	4.0
Perlite, expanded	40	0.93		1.08			—	—	12.8
	30	0.71		1.41			—	—	9.6
	20	0.50		2.00		0.32	—	—	6.4
Sand and gravel or stone aggregate (oven dried)	140	9.0	—	0.11		0.22	—	—	30.8
Sand and gravel or stone aggregate (not dried)	140	12.0	—	0.08			—	—	28.0
Stucco	116	5.0	—	0.20			—	—	23.2
MASONRY UNITS									
Brick, common[i]	120	5.0	—	0.20	—	0.19	—	—	22.8
Brick, face[i]	130	9.0	—	0.11	—		—	—	24.7
Clay tile, hollow:									
1 cell deep 3 in.	—	—	1.25	—	0.80	0.21	15.0	3.2	12.6
1 cell deep 4 in.	—	—	0.90	—	1.11		16.0	3.4	10.1
2 cells deep 6 in.	—	—	0.66	—	1.52		25.0	5.25	10.5
2 cells deep 8 in.	—	—	0.54	—	1.85		30.0	6.3	9.5
2 cells deep 10 in.	—	—	0.45	—	2.22		35.0	7.4	8.8
3 cells deep 12 in.	—	—	0.40	—	2.50		40.0	8.4	8.4
Concrete blocks, three oval core:									
Sand and gravel aggregate 4 in.	—	—	1.40	—	0.71	0.22	23.0	5.1	15.2
8 in.	—	—	0.90	—	1.11		43.0	9.4	14.1
12 in.	—	—	0.78	—	1.28		63.0	13.9	13.9
Cinder aggregate 3 in.	—	—	1.16	—	0.86	0.21	17.0	3.6	14.3
4 in.	—	—	0.90	—	1.11		20.0	4.2	12.6
8 in.	—	—	0.58	—	1.72		37.0	7.9	11.8
12 in.	—	—	0.53	—	1.89		53.0	11.1	11.1
Lightweight aggregate 3 in.	—	—	0.79	—	1.27	0.21	15.0	2.6	12.6
(expanded shale, clay, slate 4 in.	—	—	0.67	—	1.50		17.0	3.6	10.9
or slag; pumice) 8 in.	—	—	0.50	—	2.00		32.0	6.7	10.1
12 in.	—	—	0.44	—	2.27		43.0	9.0	9.0
Concrete blocks, rectangular core.*[j]									
Sand and gravel aggregate									
2 core, 8 in. 36 lb.[k]*	—	—	0.96	—	1.04	0.22	43.1	9.5	14.2
Same with filled cores[j]*	—	—	0.52	—	1.93	0.22	—	—	—

Table 3.1A Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a] (concluded)

Description	Customary Unit: Density (lb/ft³)	Conductivity (k)	Conductance (C)	Resistance[b] (R): Per inch thickness (1/k)	Resistance[b] (R): For thickness listed (1/C)	Specific Heat, Btu/(lb) (deg F)	Wt lb/ft²	Heat Capacity: Btu/ft²·F	Heat Capacity: Btu/ft³·F
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):									
3 core, 6 in. 19 lb.[k]*	—	—	0.61	—	*1.65*	0.21	22.8	4.8	9.6
Same with filled cores[l]*	—	—	0.33	—	*2.99*		—	—	—
2 core, 8 in. 24 lb.[k]*	—	—	0.46	—	*2.18*		28.8	6.0	9.1
Same with filled cores[l]*	—	—	0.20	—	*5.03*		—	—	—
3 core, 12 in. 38 lb.[k]*	—	—	0.40	—	*2.48*		45.6	9.6	9.6
Same with filled cores[l]*	—	—	0.17	—	*5.82*		—	—	—
Stone, lime or sand	—	12.50	—	*0.08*	—	0.19	—	—	28.5
Gypsum partition tile:									
3 × 12 × 30 in. solid	—	—	0.79	—	*1.26*	*0.19*	11.0	2.1	8.6
3 × 12 × 30 in. 4-cell	—	—	0.74	—	*1.35*		9.0	1.7	6.7
4 × 12 × 30 in. 3-cell	—	—	0.60	—	*1.67*		13.0	2.5	7.2
PLASTERING MATERIALS									
Cement plaster, sand aggregate	116	5.0	—	*0.20*	—	0.20	—	—	23.2
Sand aggregate ... 0.375 in.	—	—	13.3	—	*0.08*	0.20	3.63	0.72	23.2
Sand aggregate ... 0.75 in.	—	—	6.66	—	*0.15*	0.20	7.25	1.45	23.2
Gypsum plaster:									
Lightweight aggregate ... 0.5 in.	45	—	3.12	—	*0.32*		1.88	0.38	9.0
Lightweight aggregate ... 0.625 in.	45	—	2.67	—	*0.39*		2.34	0.47	9.0
Lightweight agg. on metal lath ... 0.75 in.	—	—	2.13	—	*0.47*		—	0.57	—
Perlite aggregate	45	1.5	—	*0.67*	—	0.32	—	—	14.4
Sand aggregate	105	5.6	—	*0.18*	—	0.20	—	—	21.0
Sand aggregate ... 0.5 in.	105	—	11.10	—	*0.09*		4.38	0.88	21.0
Sand aggregate ... 0.625 in.	105	—	9.10	—	*0.11*		5.47	1.09	21.0
Sand aggregate on metal lath ... 0.75 in.	—	—	7.70	—	*0.13*		—	1.32	—
Vermiculite aggregate	45	1.7	—	*0.59*	—		—	—	9.0
ROOFING									
Asbestos-cement shingles	120	—	4.76	—	*0.21*	0.24	—	—	28.8
Asphalt roll roofing	70	—	6.50	—	*0.15*	0.36	—	—	25.2
Asphalt shingles	70	—	2.27	—	*0.44*	0.30	—	—	25.2
Built-up roofing ... 0.375 in.	70	—	3.00	—	*0.33*	0.35	2.19	0.73	24.5
Slate ... 0.5 in.	—	—	20.00	—	*0.05*	0.30	—	—	—
Wood shingles, plain and plastic film faced	—	—	1.06	—	*0.94*	0.31	—	—	—
SIDING MATERIALS (ON FLAT SURFACE)									
Shingles									
Asbestos-cement	120	—	4.75	—	*0.21*		—	—	28.8
Wood, 16 in., 7.5 exposure	—	—	1.15	—	*0.87*	0.31	—	—	—
Wood, double, 16-in., 12-in. exposure	—	—	0.84	—	*1.19*	0.28	—	—	—
Wood, plus insul. backer board, 0.3125 in.	—	—	0.71	—	*1.40*	0.31	—	—	—
Siding									
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	*0.21*	0.24	—	—	29.5
Asphalt roll siding	—	—	6.50	—	*0.15*	0.35	—	—	24.5
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	*1.46*	0.35	—	—	—
Wood, drop, 1 × 8 in.	—	—	1.27	—	*0.79*	0.28	—	—	—
Wood, bevel, 0.5 × 8 in., lapped	—	—	1.23	—	*0.81*	0.28	—	—	—
Wood, bevel, 0.75 × 10 in., lapped	—	—	0.95	—	*1.05*	0.28	—	—	—
Wood, plywood, 0.375 in., lapped	—	—	1.59	—	*0.59*	0.29	—	—	—
Wood, medium density siding, 0.4375 in.	40	1.49	—	*0.67*	—	0.28	—	—	11.5
Aluminum or Steel[m], over sheathing									
Hollow-backed	—	—	1.61	—	*0.61*	0.29	—	—	—
Insulating-board backed nominal 0.375 in.	—	—	0.55	—	*1.82*	0.32	—	—	—
Insulating-board backed nominal 0.375 in., foil backed			0.34		*2.96*		—	—	—
Architectural glass	—	—	10.00	—	*0.10*	0.20	—	—	—
WOODS									
Maple, oak, and similar hardwoods	45	1.10	—	*0.91*	—	0.30	—	—	13.5
Fir, pine, and similar softwoods	32	0.80	—	*1.25*	—	0.33	—	—	10.6
Fir, pine, and similar softwoods ... 0.75 in.	32	—	1.06	—	*0.94*	0.33	2.0	0.66	10.6
... 1.5 in.		—	0.53	—	*1.89*		4.0	1.32	10.6
... 2.5 in.		—	0.32	—	*3.12*		6.7	2.20	10.6
... 3.5 in.		—	0.23	—	*4.35*		9.3	3.08	10.6

[a]Representative values for dry materials were selected by ASHRAE TC4.4, Insulation and Moisture Barriers. They are intended as design (not specification) values for materials in normal use. For properties of a particular product, use the value supplied by the manufacturer or by unbiased tests

[b]Resistance values are the reciprocals of C before rounding off C to two decimal places.

[c]Also see Insulating Materials, Board.

[d] Does not include paper backing and facing, if any. Where insulation forms a boundary (reflective or otherwise) of an air space, see Tables 3.3 and 3.4 for the insulating value of air space for the appropriate effective emittance and temperature conditions of the space.

[e] Conductivity varies with fiber diameter. Insulation is produced by different densities; therefore, there is a wide variation in thickness for the same R-value among manufacturers. No effort should be made to relate any specific R-value to any specific thickness.

[f] Values are for aged board stock. For change in conductivity with age of expanded urethane, see Chapter 19, Factors Affecting Thermal Conductivity, 1977 Fundamentals Volume.

[g]Insulating values of acoustical tile vary, depending on density of the board and on type, size, and depth of perforations.

[h]The U. S. Department of Commerce, *Simplified Practice Recommendation for Thermal Conductance Factors for Preformed Above-Deck Roof Insulation*, No. R 257-55, recognizes the specification of roof insulation on the basis of the C-values shown. Roof insulation is made in thicknesses to meet these values.

[i]Face brick and common brick do not always have these specific densities. When density is different from that shown, there will be a change in thermal conductivity.

[j]Data on rectangular core concrete blocks differ from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.

[k]Weights of units approximately 7.625 in. high and 15.75 in. long. These weights are given as a means of describing the blocks tested, but conductance values are all for 1 ft² of area.

[l]Vermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barriers or other precautions must be considered to keep insulation dry.

[m]Values for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air space is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values given are averages for use as design guides, and were obtained from several guarded hotbox tests (ASTM C236) or calibrated hotbox (BSS 77) on hollow-backed types and types made using backing-boards of wood fiber, foamed plastic, and glass fiber. Departures of ±50% or more from the values given may occur.

Table 3.1B Thermal Conductivity (k) of Industrial Insulation (Design Values)[a] (For Mean Temperatures Indicated)

Expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature difference per inch)

Form / Material Composition	Accepted Max Temp for Use, F*	Typical Density (lb/ft³)	Typical Conductivity k at Mean Temp F													
			−100	−75	−50	−25	0	25	50	75	100	200	300	500	700	900
BLANKETS & FELTS																
MINERAL FIBER																
(Rock, slag or glass)																
Blanket, metal reinforced	1200	6–12									0.26	0.32	0.39	0.54		
	1000	2.5–6									0.24	0.31	0.40	0.61		
Mineral fiber, glass																
Blanket, flexible, fine-fiber	350	0.65				0.25	0.26	0.28	0.30	0.33	0.36	0.53				
organic bonded		0.75				0.24	0.25	0.27	0.29	0.32	0.34	0.48				
		1.0				0.23	0.24	0.25	0.27	0.29	0.32	0.43				
		1.5				0.21	0.22	0.23	0.25	0.27	0.28	0.37				
		2.0				0.20	0.21	0.22	0.23	0.25	0.26	0.33				
		3.0				0.19	0.20	0.21	0.22	0.23	0.24	0.31				
Blanket, flexible, textile-fiber	350	0.65				0.27	0.28	0.29	0.30	0.31	0.32	0.50	0.68			
organic bonded		0.75				0.26	0.27	0.28	0.29	0.31	0.32	0.48	0.66			
		1.0				0.24	0.25	0.26	0.27	0.29	0.31	0.45	0.60			
		1.5				0.22	0.23	0.24	0.25	0.27	0.29	0.39	0.51			
		3.0				0.20	0.21	0.22	0.23	0.24	0.25	0.32	0.41			
Felt, semirigid organic bonded	400	3–8						0.24	0.25	0.26	0.27	0.35	0.44			
	850	3	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.35	0.55			
Laminated & felted	1200	7.5											0.35	0.45	0.60	
Without binder																
VEGETABLE & ANIMAL FIBER																
Hair Felt or Hair Felt plus Jute	180	10						0.26	0.28	0.29	0.30					
BLOCKS, BOARDS & PIPE INSULATION																
ASBESTOS																
Laminated asbestos paper	700	30									0.40	0.45	0.50	0.60		
Corrugated & laminated asbestos																
Paper																
4-ply	300	11–13								0.54	0.57	0.68				
6-ply	300	15–17								0.49	0.51	0.59				
8-ply	300	18–20								0.47	0.49	0.57				
MOLDED AMOSITE & BINDER	1500	15–18									0.32	0.37	0.42	0.52	0.62	0.72
85% MAGNESIA	600	11–12									0.35	0.38	0.42			
CALCIUM SILICATE	1200	11–13									0.38	0.41	0.44	0.52	0.62	0.72
	1800	12–15												0.63	0.74	0.95
CELLULAR GLASS	800	9			0.32	0.33	0.35	0.36	0.38	0.40	0.42	0.48	0.55			
DIATOMACEOUS SILICA	1600	21–22												0.64	0.68	0.72
	1900	23–25												0.70	0.75	0.80
MINERAL FIBER																
Glass,																
Organic bonded, block and boards	400	3–10	0.16	0.17	0.18	0.19	0.20	0.22	0.24	0.25	0.26	0.33	0.40			
Nonpunking binder	1000	3–10									0.26	0.31	0.38	0.52		
Pipe insulation, slag or glass	350	3–4					0.20	0.21	0.22	0.23	0.24	0.29				
	500	3–10					0.20	0.22	0.24	0.25	0.26	0.33	0.40			
Inorganic bonded-block	1000	10–15									0.33	0.38	0.45	0.55		
	1800	15–24									0.32	0.37	0.42	0.52	0.62	0.74
Pipe insulation slag or glass	1000	10–15									0.33	0.38	0.45	0.55		
MINERAL FIBER																
Resin binder		15			0.23	0.24	0.25	0.26	0.28	0.29						
RIGID POLYSTYRENE																
Extruded, Refrigerant 12 exp	170	3.5	0.16	0.16	0.15	0.16	0.16	0.17	0.18	0.19	0.20					
Extruded, Refrigerant 12 exp	170	2.2	0.16	0.16	0.17	0.16	0.17	0.18	0.19	0.20						
Extruded	170	1.8	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27					
Molded beads	170	1	0.18	0.20	0.21	0.23	0.24	0.25	0.26	0.28						
POLYURETHANE**																
Refrigerant 11 exp	210	1.5–2.5	0.16	0.17	0.18	0.18	0.18	0.17	0.16	0.16	0.17					
RUBBER, Rigid Foamed	150	4.5						0.20	0.21	0.22	0.23					
VEGETABLE & ANIMAL FIBER																
Wool felt (pipe insulation)	180	20						0.28	0.30	0.31	0.33					
INSULATING CEMENTS																
MINERAL FIBER																
(Rock, slag, or glass)																
With colloidal clay binder	1800	24–30									0.49	0.55	0.61	0.73	0.85	
With hydraulic setting binder	1200	30–40									0.75	0.80	0.85	0.95		
LOOSE FILL																
Cellulose insulation (milled pulverized																
paper or wood pulp)		2.5–3							0.26	0.27	0.29					
Mineral fiber, slag, rock or glass		2–5			0.19	0.21	0.23	0.25	0.26	0.28	0.31					
Perlite (expanded)		5–8	0.25	0.27	0.29	0.30	0.32	0.34	0.35	0.37	0.39					
Silica aerogel		7.6			0.13	0.14	0.15	0.15	0.16	0.17	0.18					
Vermiculite (expanded)		7–8.2			0.39	0.40	0.42	0.44	0.45	0.47	0.49					
		4–6			0.34	0.35	0.38	0.40	0.42	0.44	0.46					

[a]Representative values for dry materials as selected by ASHRAE TC 4.4, Insulation and Moisture Barriers. They are intended as design (not specification) values for materials of building construction for normal use. For thermal resistance of a particular product, use the value supplied by the manufacturer or by unbiased tests.

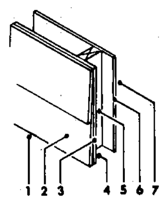
*These temperatures are generally accepted as maximum. When operating temperature approaches these limits follow the manufacturer's recommendations.

**Values are for aged board stock. For change in conductivity with age of refrigerant-blown expanded urethane see section on Thermal Conductivity, Chapter 19, 1977 Fundamentals Volume.

Note: Some polyurethane foams are formed by means which produce a stable product (with respect to k), but most are blown with refrigerant and will change with time.

Table 3.2A Coefficients of Transmission (*U*) and Heat Capacities of Frame Walls

These U-coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²· F.



Replace Air Space with 3.5-in. R-11 Blanket Insulation (New Item 4)

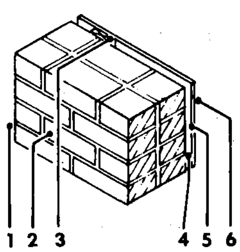
Construction	Resistance (R) 1 Between Framing	1 At Framing	2 Between Framing	2 At Framing	Heat Capacity 1 Between Framing	Heat Capacity 2 Between Framing
1. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17	—	—
2. Siding, wood, 0.5 in.× 8 in. lapped (average)	0.81	0.81	0.81	0.81	0.47	0.47
3. Sheathing, 0.5-in. asphalt impregnated	1.32	1.32	1.32	1.32	0.23	0.23
4. Nonreflective air space, 3.5 in. (50 Fmean; 10 deg F temperature difference)	1.01	—	11.00	—	—	.08
5. Nominal 2-in. × 4-in. wood stud	—	4.38	—	4.38	—	—
6. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
7. Inside surface (still air)	0.68	0.68	0.68	0.68		
Total Thermal Resistance (R)	R_i=4.44	R_s=7.81	R_i=14.43	R_s=7.81	1.24	1.32

Construction No. 1: $U_i = 1/4.44 = 0.225$; $U_s = 1/7.81 = 0.128$. With 20% framing (typical of 2-in. × 4-in. studs @ 16-in. o.c.), $U_{av} = 0.8 (0.225) + 0.2 (0.128) = 0.206$ (See Eq 9)

Construction No. 2: $U_i = 1/14.43 = 0.069$; $U_s = 0.128$. With framing unchanged, $U_{av} = 0.8(0.069) + 0.2(0.128) = 0.081$

Table 3.2B Coefficients of Transmission (*U*) and Heat Capacities of Solid Masonry Walls

Coefficients are expressed in Btu/per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²· F.



Replace Furring Strips and Air Space with 1-in. Extruded Polystyrene (New Item 4)

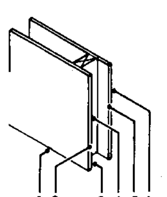
Construction	Resistance (*R*) 1 Between Furring	1 At Furring	2	Heat Capacity 1 Between Furring	Heat Capacity 2 Between Furring
1. Outside surface (15 mph wind)	0.17	0.17	0.17	—	—
2. Common brick, 8 in.	1.60	1.60	1.60	15.2	15.2
3. Nominal 1-in. ×3-in. vertical furring	—	0.94	—	—	—
4. Nonreflective air space, 0.75 in. (50 F mean; 10 deg F temperature difference)	1.01	—	5.00	—	0.05
5. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.54	0.54
6. Inside surface (still air)	0.68	0.68	0.68	—	—
Total Thermal Resistance (R)	R_i = 3.91	R_s = 3.84	R_i = 7.90 = R_s	15.74	15.79

Construction No. 1: $U_i = 1/3.91 = 0.256$; $U_s = 1/3.84 = 0.260$. With 20% framing (typical of 1-in. × 3-in. vertical furring on masonry @ 16-in. o.c.) $U_{av} = 0.8 (0.256) + 0.2 (0.260) = 0.257$

Construction No. 2: $U_i = U_s = U_{av} = 1/7.90 = 0.127$

Table 3.2C Coefficients of Transmission (*U*) and Heat Capacities of Frame Partitions or Interior Walls

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides. The Heat Capacity Units are Btu/ft²· F.



Replace Air Space with 3.5-in. R-11 Blanket Insulation (New Item 3)

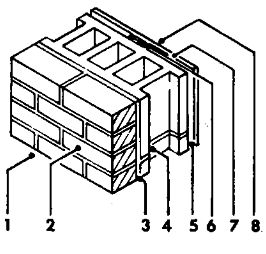
Construction	Resistance (R) 1 Between Framing	1 At Framing	2 Between Framing	2 At Framing	Heat Capacity 1 Between Framing	Heat Capacity 2 Between Framing
1. Inside surface (still air)	0.68	0.68	0.68	0.68	—	—
2. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
3. Nonreflective air space, 3.5 in. (50 F mean; 10 deg F temperature difference)	1.01	—	11.00	—	—	0.08
4. Nominal 2-in. × 4-in. wood stud	—	4.38	—	4.38		
5. Gypsum wallboard0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
6. Inside surface (still air)	0.68	0.68	0.68	0.68		
Total Thermal Resistance (R)	R_i= 3.27	R_s= 6.64	R_i=13.26	R_s= 6.64	1.08	1.16

Construction No. 1: $U_i = 1/3.27 = 0.306$; $U_s = 1/6.64 = 0.151$. With 10% framing (typical of 2-in. × 4-in. studs @ 24-in. o.c.), $U_{av} = 0.9 (0.306) + 0.1 (0.151) = 0.290$

Construction No. 2: $U_i = 1/13.26 = 0.075$, $U_s = 1/6.64 = 0.151$. With framing unchanged, $U_{av} = 0.9(0.075) + 0.1(0.151) = 0.083$

Table 3.2D Coefficients of Transmission (*U*) and Heat Capacities of Masonry Walls

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F.



Replace Cinder Aggregate Block with 6-in. Light-weight Aggregate Block with Cores Filled (New Item 4)

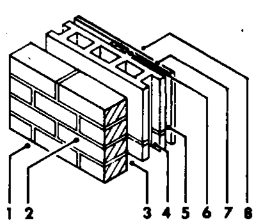
Construction	Resistance (R) 1: Between Furring	1: At Furring	2: Between Furring	2: At Furring	Heat Capacity 1: Between Furring	Heat Capacity 2: Between Furring
1. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17	—	—
2. Face brick, 4 in.	0.44	0.44	0.44	0.44	8.23	8.23
3. Cement mortar, 0.5 in.	0.10	0.10	0.10	0.10	0.97	0.97
4. Concrete block, cinder aggregate, 8 in.	1.72	1.72	2.99	2.99	7.90	7.36
5. Reflective air space, 0.75 in. (50 F mean; 30 deg F temperature difference)	2.77	—	2.77	—		
6. Nominal 1-in. × 3-in. vertical furring	—	0.94	—	0.94		
7. Gypsum wallboard, 0.5 in., foil backed	0.45	0.45	0.45	0.45	0.54	0.54
8. Inside surface (still air)	0.68	0.68	0.68	0.68		
Total Thermal Resistance (R)	R_i = 6.33	R_s = 4.50	R_i = 7.60	R_s = 5.77	17.64	17.64

Construction No. 1: $U_i = 1/6.33 = 0.158$; $U_s = 1/4.50 = 0.222$. With 20% framing (typical of 1-in. × 3-in. vertical furring on masonry @ 16-in. o.c.), $U_{av} = 0.8\,(0.158) + 0.2\,(0.222) = 0.171$

Construction No. 2: $U_i = 1/7.60 = 0.132$, $U_s = 1/5.77 = 0.173$. With framing unchanged, $U_{av} = 0.8(0.132) + 0.2(0.173) = 1.40$

Table 3.2E Coefficients of Transmission (*U*) and Heat Capacities of Masonry Cavity Walls

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F.



Replace Furring Strips and Gypsum Wallboard with 0.625-in. Plaster (Sand Aggregate) Applied Directly to Concrete Block-Fill 2.5-in. Air Space with Vermiculite Insulation (New Items 3 and 7.

Construction	Resistance (R) 1: Between Furring	1: At Furring	2	Heat Capacity 1: Between Furring	Heat Capacity 2: Between Furring
1. Outside surface (15 mph wind)	0.17	0.17	0.17		
2. Common brick, 8 in.	0.80	0.80	0.80	15.2	15.2
3. Nonreflective air space, 2.5 in. (30 F mean; 10 deg F temperature difference)	1.10*	1.10*	5.32**	—	0.32
4. Concrete block, stone aggregate, 4 in.	0.71	0.71	0.71	5.1	5.1
5. Nonreflective air space 0.75 in. (50 F mean; 10 deg F temperature difference)	1.01	—	—		
6. Nominal 1-in. × 3-in. vertical furring	—	0.94	—		
7. Gypsum wallboard, 0.5 in.	0.45	0.45	0.11	0.54	1.09
8. Inside surface (still air)	0.68	0.68	0.68	—	—
Total Thermal Resistance (R)	R_i = 4.92	R_s = 4.85	$R_i = R_s$ = 7.79	20.8	21.7

Construction No. 1: $U_i = 1/4.92 = 0.203$; $U_s = 1/4.85 = 0.206$. With 20% framing (typical of 1-in. × 3-in. vertical furring on masonry @16-in. o.c.), $U_{av} = 0.8(0.203) + 0.2(0.206) = 0.204$

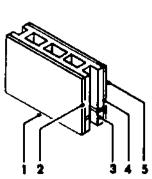
Construction No. 2: $U_i = U_s = U_{av} = 1.79 = 0.128$

*Interpolated value from Table 3.4

**Calculated value from Table 3.1.

Table 3.2F Coefficients of Transmission (*U*) and Heat Capacities of Masonry Partitions

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides. The Heat Capacity Units are Btu/ft²·F.



Replace Concrete Block with 4-in. Gypsum Tile (New Item 3)

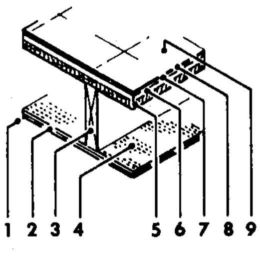
Construction	Resistance (R) 1	Resistance (R) 2	Heat Capacity 1	Heat Capacity 2
1. Inside surface (still air)	0.68	0.68	—	—
2. Plaster, lightweight aggregate, 0.625 in.	0.39	0.39	0.47	0.47
3. Concrete block, cinder aggregate, 4 in.	1.11	1.67	4.20	2.47
4. Plaster, lightweight aggregate, 0.625 in.	0.39	0.39	0.47	0.47
5. Inside surface (still air)	0.68	0.68	—	—
Total Thermal Resistance(R)	3.25	3.81	5.14	3.41

Construction No. 1: $U = 1/3.25 = 0.308$

Construction No. 2: $U = 1/3.81 = 0.262$

Table 3.2G Coefficients of Transmission (*U*) and Heat Capacities of Frame Construction Ceilings and Floors

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference between the air on the two sides), and are based on still air (no wind) on both sides. The Heat Capacity Units are Btu/ft²·F.



Assume Unheated Attic Space above Heated Room with Heat Flow Up—Remove Tile, Felt, Plywood, Subfloor and Air Space—Replace with R-19 Blanket Insulation (New Item 4)

Heated Room Below / Unheated Space

Construction (Heat Flow Up)	1 Resistance (R) Between Floor Joists	1 Resistance (R) At Floor Joist	2 Resistance (R) Between Floor Joists	2 Resistance (R) At Floor Joists	1 Heat Capacity Between Floor Joists	2 Heat Capacity Between Floor Joists
1. Bottom surface (still air)	0.61	0.61	0.61	0.61	—	—
2. Metal lath and lightweight aggregate, plaster, 0.75 in.	0.47	0.47	0.47	0.47	0.57	0.57
3. Nominal 2-in. × 8-in. floor joist	—	9.06	—	9.06	—	—
4. Nonreflective airspace, 7.25-in.	0.93*	—	19.00	—	—	0.14
5. Wood subfloor, 0.75 in.	0.94	0.94	—	—	0.60	—
6. Plywood, 0.625 in.	0.78	0.78	—	—	0.51	—
7. Felt building membrane	0.06	0.06	—	—	—	—
8. Resilient tile	0.05	0.05	—	—	0.34	—
9. Top surface (still air)	0.61	0.61	0.61	0.61	—	—
Total Thermal Resistance (R)	R_i= 4.45	R_s= 12.58	R_i= 20.69	R_s=10.75	2.02	0.71

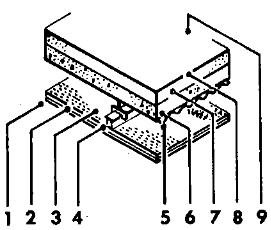
Construction No. 1 U_i= 1/4.45= 0.225; U_s= 1/12.58= 0.079. With 10% framing (typical of 2-in. joists @ 16-in. o.c.), U_{av} = 0.9 (0.225) + 0.1 (0.079)= 0.210

Construction No. 2 U_i = 1/20.69 = 0.048; U_s = 1/10.75 = 0.093. With framing unchanged, U_{av} = 0.9 (0.048) + 0.1 (0.093) = 0.053

*Use largest air space (3.5 in.) value shown in Table 3.4

Table 3.2H Coefficients of Transmission (*U*) and Heat Capacities of Flat Masonry Roofs with Built-up Roofing, with and without Suspended Ceilings (Winter Conditions, Upward Flow)

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based upon an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F.



Add Rigid Roof Deck Insulation, *C* = 0.24 (*R* = 1/*C*) (New Item 7)

Construction (Heat Flow Up)	1 Resistance (R)	2 Resistance (R)	1 Heat Capacity	2 Heat Capacity
1. Inside surface (still air)	0.61	0.61	—	—
1. Metal lath and lightweight aggregate plaster, 0.75 in.	0.47	0.47	0.57	0.57
3. Nonreflective air space, greater than 3.5 in. (50 F mean; 10 deg F temperature difference)	0.93*	0.93*	—	—
4. Metal ceiling suspension system with metal hanger rods	0**	0**	—	—
5. Corrugated metal deck	0	0	0.24	0.24
6. Concrete slab, lightweight aggregate, 2 in.	2.22	2.22	1.00	1.00
7. Rigid roof deck insulation (none)	—	4.17	—	NA
8. Built-up roofing, 0.375 in.	0.33	0.33	0.77	0.77
9. Outside surface (15 mph wind)	0.17	0.17	—	—
Total Thermal Resistance (R)	4.73	8.90	2.58	2.58 +

Construction No. 1: U_{av} = 1/4.73 = 0.211

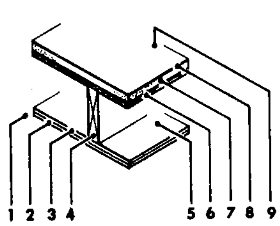
Construction No. 2: U_{av} = 1/8.90= 0.112

*Use largest air space (3.5 in.) value shown in Table 3.4

**Area of hanger rods is negligible in relation to ceiling area.

Table 3.2I Coefficients of Transmission (*U*) and Heat Capacities of Wood Construction Flat Roofs and Ceilings (Winter Conditions, Upward Flow)

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based upon an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F.



Replace Roof Deck Insulation and 7.25-in. Air Space with 6-in. R-19 Blanket Insulation and 1.25-in. Air Space (New Items 5 and 7)

Construction (Heat Flow Up)	1 Resistance (R) Between Joists	1 Resistance (R) At Joists	2 Resistance (R) Between Joists	2 Resistance (R) At Joists	1 Heat Capacity Between Joists	2 Heat Capacity Between Joists
1. Inside surface (still air)	0.61	0.61	0.61	0.61	—	—
2. Acoustical tile, fiberboard, glued, 0.5 in.	1.25	1.25	1.25	1.25	0.31	0.31
3. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
4. Nominal 2-in. × 8-in. ceiling joists	—	9.06	—	9.06	—	—
5. Nonreflective air space, 7.25 in. (50 F mean; 10 deg F temperature difference)	0.93*	—	1.05**	—	—	0.14
6. Plywood deck, 0.625 in.	0.78	0.78	0.78	0.78	0.51	0.51
7. Rigid roof deck insulation, C = 0.72, (*R* = 1/C)	1.39	1.39	19.00	—	—	NA
8. Built-up roof	0.33	0.33	0.33	0.33	0.77	0.77
9. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17	—	—
Total Thermal Resistance (R)	R_i=5.91	R_s=14.04	R_i=23.64	R_s=12.65	2.13	2.27+

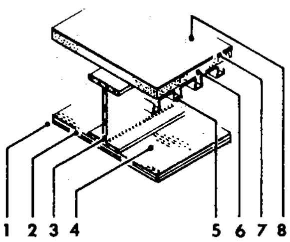
Construction No. 1 U_i = 1/5.91 = 0.169; U_s = 1/14.04 = 0.071. With 10% framing (typical of 2-in. joists @ 16-in. o.c.), U_{av} = 0.9 (0.169) + 0.1 (0.071) = 0.159

Construction No. 2 U_i = 1/23.64 = 0.042; U_s = 1/12.65 = 0.079. With framing unchanged, U_{av} = 0.9 (0.042) + 0.1 (0.079) = 0.046

*Use largest air space (3.5 in.) value shown in Table 3.4.

Table 3.2J Coefficients of Transmission (U) and Heat Capacities of Metal Construction Flat Roofs and Ceilings (Winter Conditions, Upward Flow)

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on upon outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F.



Replace Rigid Roof Deck Insulation (C = 0.24) and Sand Aggregate Plaster with Rigid Roof Deck Insulation, C = 0.36 and Lightweight Aggregate Plaster (New Items 2 and 6)

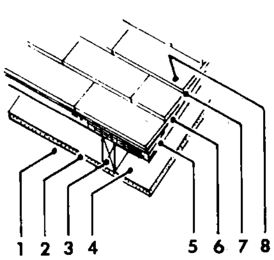
Construction (Heat Flow Up)	Resistance (R) 1	Resistance (R) 2	Heat Capacity 1	Heat Capacity 2
1. Inside surface (still air)	0.61	0.61		
2. Metal lath and sand aggregate plaster, 0.75 in	0.13	0.47	1.31	0.56
3. Structural beam	0.00*	0.00*	—	—
4. Nonreflective air space (50 F mean; 10 deg F temperature difference	0.93**	0.93**	—	—
5. Metal deck	0.00*	0.00*	0.24	0.24
6. Rigid roof deck insulation, $C = 0.24 (R = 1/c)$	4.17	2.78	NA	NA
7. Built-up roofing, 0.375 in.	0.33	0.33	0.77	0.77
8. Outside surface (15 mph wind)	0.17	0.17	—	—
Total Thermal Resistance (R)	6.34	5.29	2.32	1.57

Construction No. 1: $U = 1/6.34 = 0.158$
Construction No. 2: $U = 1/5.29 = 0.189$

*If structural beams and metal deck are to be considered, the technique shown in Example A3.1 and Fig. A3. may be used to estimate total R. Full scale testing of a suitable portion of the construction is, however, preferable.
**Use largest air space (3.5 in.) value shown in Table 3.4.

Table 3.2K Coefficients of Transmission (U) and Heat Capacities of Pitched Roofs[a]

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph for heat heat flow upward and 7.5 mph for heat flow downward. The Heat Capacity Units are Btu/ft²·F.



Find U_{av} for same Construction 2 with Heat Flow Down (Summer Conditions)

Construction 1 (Heat Flow Up) (Reflective Air Space)	Resistance (R) 1 Between Rafters	1 At Rafters	2 Between Rafters	2 At Rafters	Heat Capacity 1 Between Rafters	Heat Capacity 2 Between Rafters
1. Inside surface (still air)	0.62	0.62	0.76	0.76	—	—
2. Gypsum wallboard 0.5 in., foil backed	0.45	0.45	0.45	0.45	0.54	0.54
3. Nominal 2-in. × 4-in. ceiling rafter	—	4.38	—	4.38	—	—
4. 45 deg slope reflective air space, 3.5 in. (50 F mean, 30 deg F temperature difference)	2.17	—	4.33	—	—	—
5. Plywood sheathing, 0.625 in.	0.78	0.78	0.78	0.78	0.51	0.51
6. Felt building membrane	0.06	0.06	0.06	0.06	Neg	Neg
7. Asphalt shingle roofing	0.44	0.44	0.44	0.44	0.33	0.33
8. Outside surface (15 mph wind)	0.17	0.17	0.25**	0.25**	—	—
Total Thermal Resistance (R)	R_i=4.69	R_s=6.90	R_i=7.07	R_s=7.12	1.38	1.38

Construction No. 1: $U_i = 1/4.69 = 0.213$; $U_s = 1/6.90 = 0.145$. With 10% framing (typical of 2-in. rafters @16-in. o.c.), $U_{av} = 0.9\ (0.213) + 0.1\ (0.145) = 0.206$
Construction No. 2: $U_i = 1/7.07 = 0.141$; $U_s = 1/7.12 = 0.140$. With framing unchanged, $U_{av} = 0.9\ (0.141) + 0.1\ (0.140) = 0.141$

Find U_{av} for same Construction 2 with Heat Flow Down (Summer Conditions)

Construction 1 (Heat Flow Up) (Non-Reflective Air Space)	Resistance (R) 3 Between Rafters	3 At Rafters	4 Between Rafters	4 At Rafters	Heat Capacity 1 Between Rafters	Heat Capacity 2 Between Rafters
1. Inside surface (still air)	0.62	0.62	0.76	0.76	—	—
2. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
3. Nominal 2-in. × 4-in. ceiling rafter	—	4.38	—	4.38	—	—
4. 45 deg slope, nonreflective air space, 3.5 in. (50 F mean; 10 deg F temperature difference)	0.96	—	0.90*	—	—	—
5. Plywood sheathing, 0.625 in.	0.78	0.78	0.78	0.78	0.51	0.51
6. Felt building membrane	0.06	0.06	0.06	0.06	Neg	Neg
7. Asphalt shingle roofing	0.44	0.44	0.44	0.44	0.33	0.33
8. Outside surface (15-mph wind)	0.17	0.17	0.25**	0.25**	—	—
Total Thermal Resistance (R)	R_i=3.48	R_s=6.90	R_i=3.64	R_s=7.12	1.38	1.38

Construction No. 3: $U_i = 1/3.48 = 0.287$; $U_s = 1/6.90 = 0.145$. With 10% framing typical of 2-in. rafters @ 16-in. o.c.), $U_{av} = 0.9\ (0.287) + 0.1\ (0.145) = 0.273$
Construction No. 4: $U_i = 1/3.64 = 0.275$; $U_s = 1/7.12 = 0.140$. With framing unchanged, $U_{av} = 0.9\ (0.275) + 0.1\ (0.140) = 0.262$

Pitch of roof—45 deg. ns.
*Air space value at 90 F mean, 10 deg F temperature difference.
**7.5-mph wind.

Table 3.3 Surface Conductances and Resistances for Air

All conductance values expressed in Btu/(hr · ft² · F).
A surface cannot take credit for both an air space resistance value and a surface resistance value.
No credit for an air space value can be taken for any surface facing an air space of less than 0.5 in.

SECTION A. Surface Conductances and Resistances[a,b]

Position of Surface	Direction of Heat Flow	Surface Emittance: Non-reflective ε = 0.90		Reflective ε = 0.20		Reflective ε = 0.05	
		h_i	R	h_i	R	h_i	R
STILL AIR							
Horizontal	Upward	1.63	*0.61*	0.91	*1.10*	0.76	*1.32*
Sloping—45 deg	Upward	1.60	*0.62*	0.88	*1.14*	0.73	*1.37*
Vertical	Horizontal	1.46	*0.68*	0.74	*1.35*	0.59	*1.70*
Sloping—45 deg	Downward	1.32	*0.76*	0.60	*1.67*	0.45	*2.22*
Horizontal	Downward	1.08	*0.92*	0.37	*2.70*	0.22	*4.55*
MOVING AIR		h_o	R	h_o	R	h_o	R
(Any Position) 15-mph Wind (for winter)	Any	6.00	0.17				
7.5-mph Wind (for summer)	Any	4.00	0.25				

SECTION B. Reflectance and Emittance Values of Various Surfaces and Effective Emittances of Air Spaces

Surface	Reflectance in Percent	Average *Emittance* ε	Effective *Emittance E* of Air Space: One surface emittance ε; the other 0.90	Effective *Emittance E* of Air Space: Both surfaces emittances ε
Aluminum foil, bright	92 to 97	0.05	0.05	0.03
Aluminum sheet	80 to 95	0.12	0.12	0.06
Aluminum coated paper, polished	75 to 84	0.20	0.20	0.11
Steel, galvanized, bright	70 to 80	0.25	0.24	0.15
Aluminum paint	30 to 70	0.50	0.47	0.35
Building materials: wood, paper, masonry, nonmetallic paints	5 to 15	0.90	0.82	0.82
Regular glass	5 to 15	0.84	0.77	0.72

[a]For ventilated attics or spaces above ceilings under summer conditions (heat flow down) see Table 3.5.

[b]Conductances are for surfaces of the stated emmitance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 deg F and for surface temperature of 70 F.

Table 3.4 Thermal Resistances of Plane Air Spaces[c, d, e *]

All resistance values expressed in (hour) (square foot) (degree Fahrenheit temperature difference) per Btu
Values apply only to air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no leakage of air to or from the space. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp[a] (F)	Temp Diff.[a] (deg F)	0.5 in. Air Space, Value of E[a,b]: 0.03	0.05	0.2	0.5	0.82	0.75-in. Air Space[c], Value of E[a,b]: 0.03	0.05	0.2	0.5	0.82
Horiz.	Up	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		−50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		−50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
45° Slope	Up	90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		50	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
		−50	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		−50	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30
Vertical	Horiz.	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		−50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		−50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
45° Slope	Down	90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84
		50	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99
		50	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02
		0	20	2.91	2.80	2.19	1.52	1.15	3.75	3.57	2.63	1.72	1.26
		0	10	2.94	2.83	2.21	1.53	1.15	4.12	3,91	2.81	1.80	1.30
		−50	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57
		−50	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66
Horiz.	Down	90	10	2.48	2.34	1.67	1.06	0.77	3.55	3.29	2.10	1.22	0.85
		50	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02
		50	10	2.67	2.55	1.89	1.25	0.92	3.84	3.59	2.41	1.45	1.02
		0	20	2.94	2.83	2.20	1.53	1.15	4.18	3.96	2.83	1.81	1.30
		0	10	2.96	2.85	2.22	1.53	1.16	4.25	4.02	2.87	1.82	1.31
		−50	20	3.25	3.15	2.58	1.89	1.47	4.60	4.41	3.36	2.28	1.69
		−50	10	3.28	3.18	2.60	1.90	1.47	4.71	4.51	3.42	2.30	1.71

Table 3.4 Thermal Resistances of Plane[a] Air Spaces[d,e]* (concluded)

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp,[b] (F)	Air Space Temp Diff,[b] (deg F)	1.5-in. Air Space[d] Value of $E^{b,c}$ 0.03	0.05	0.2	0.5	0.82	3.5-in. Air Space[d] Value of $E^{b,c}$ 0.03	0.05	0.2	0.5	0.82
Horiz	Up	90	10	2.55	2.41	1.71	1.08	0.77	2.84	2.66	1.83	1.13	0.80
		50	30	1.87	1.81	1.45	1.04	0.80	2.09	2.01	1.58	1.10	0.84
		50	10	2.50	2.40	1.81	1.21	0.89	2.80	2.66	1.95	1.28	0.93
		0	20	2.01	1.95	1.63	1.23	0.97	2.25	2.18	1.79	1.32	1.03
		0	10	2.43	2.35	1.90	1.38	1.06	2.71	2.62	2.07	1.47	1.12
		−50	20	1.94	1.91	1.68	1.36	1.13	2.19	2.14	1.86	1.47	1.20
		−50	10	2.37	2.31	1.99	1.55	1.26	2.65	2.58	2.18	1.67	1.33
45° Slope	Up	90	10	2.92	2.73	1.86	1.14	0.80	3.18	2.96	1.97	1.18	0.82
		50	30	2.14	2.06	1.61	1.12	0.84	2.26	2.17	1.67	1.15	0.86
		50	10	2.88	2.74	1.99	1.29	0.94	3.12	2.95	2.10	1.34	0.96
		0	20	2.30	2.23	1.82	1.34	1.04	2.42	2.35	1.90	1.38	1.06
		0	10	2.79	2.69	2.12	1.49	1.13	2.98	2.87	2.23	1.54	1.16
		−50	20	2.22	2.17	1.88	1.49	1.21	2.34	2.29	1.97	1.54	1.25
		−50	10	2.71	2.64	2.23	1.69	1.35	2.87	2.79	2.33	1.75	1.39
Vertical	Horiz.	90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
		0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
		0	10	3.51	3.35	2.51	1.67	1.23	3.49	3.33	2.50	1.67	1.23
		−50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		−50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50
45° Slope	Down	90	10	5.07	4.55	2.56	1.36	0.91	4.81	4.33	2.49	1.34	0.90
		50	30	3.58	3.36	2.31	1.42	1.00	3.51	3.30	2.28	1.40	1.00
		50	10	5.10	4.66	2.85	1.60	1.09	4.74	4.36	2.73	1.57	1.08
		0	20	3.85	3.66	2.68	1.74	1.27	3.81	3.63	2.66	1.74	1.27
		0	10	4.92	4.62	3.16	1.94	1.37	4.59	4.32	3.02	1.88	1.34
		−50	20	3.62	3.50	2.80	2.01	1.54	3.77	3.64	2.90	2.05	1.57
		−50	10	4.67	4.47	3.40	2.29	1.70	4.50	4.32	3.31	2.25	1.68
Horiz.	Down	90	10	6.09	5.35	2.79	1.43	0.94	10.07	8.19	3.41	1.57	1.00
		50	30	6.27	5.63	3.18	1.70	1.14	9.60	8.17	3.86	1.88	1.22
		50	10	6.61	5.90	3.27	1.73	1.15	11.15	9.27	4.09	1.93	1.24
		0	20	7.03	6.43	3.91	2.19	1.49	10.90	9.52	4.87	2.47	1.62
		0	10	7.31	6.66	4.00	2.22	1.51	11.97	10.32	5.08	2.52	1.64
		−50	20	7.73	7.20	4.77	2.85	1.99	11.64	10.49	6.02	3.25	2.18
		−50	10	8.09	7.52	4.91	2.89	2.01	12.98	11.56	6.36	3.34	2.22

[a]Interpolation is permissable for other values of mean temperature, temperature differences, and effective emittance E. Interpolation and moderate extrapolation for air spaces greater than 3.5 in. are also permissable.

[b]Effective emittance of the space E is given by $1/E = 1/e_1 + 1/e_2 - 1$, *where* e_1 and e_2 are the emittances of the surfaces of the air space (See section B of Table 3.3)

[c]Credit for an air space resistance value cannot be taken more than once and only for the boundary conditions established.

[d]Resistances of horizontal spaces with heat flow downward are substantially independent of temperature difference.

[e]Thermal resistance values were determined from the relation $R = 1/C$, *where* $C = h_c + Eh_r$, h_c is the conduction-convection coefficient, Eh_r is the radiation coefficient $\cong 0.00686\, E\,[(460 + t_m)]^3$, and t_m, is the mean temperature of the air space. For interpolation from Table 3.4 to air space thicknesses less than 0.5 in. (as in insulating window glass), assume $h_c = 0.795\ (+\,0.0016)$ and compute R values from the above relations for an air space thickness of 0.2 in.

*Based on National Bureau of Standards data presented in Housing Research Paper No. 32, Housing and Home Finance Agency 1954, U. S. Government Printing Office, Washington 20402.

Table 3.5 Effective Resistance of Ventilated Attics[a]–(Summer Condition)[5]
PART A. NONREFLECTIVE SURFACES

	No. Vent.		Natural Vent.		Power Vent.					
	Ventilation Rate, cfm/ft²									
	0		0.1[b]		0.5		1.0		1.5	
	1/U Ceiling Resistance, R[c]									
Ventilation Air Temp., F	10	20	10	20	10	20	10	20	10	20
80	1.9	1.9	2.8	3.5	6.5	10	9.8	17	12	21
90	1.9	1.9	2.6	3.1	5.2	7.9	7.6	12	8.6	15
100	1.9	1.9	2.4	2.7	4.2	6.1	5.8	8.7	6.5	10
PART B. REFLECTIVE SURFACES[e]										
80	6.5	6.5	8.2	9.0	14	18	18	26	20	31
90	6.5	6.5	7.7	8.3	12	15	14	20	16	22
100	6.5	6.5	7.3	7.8	10	12	11	15	12	16

[a] The term *effective resistance is* used when there is attic ventilation. A value for no ventilation is also included. The effective resistance of the attic may be added to the resistance (1/U) of the ceiling to obtain the effective resistance of the combination. These values apply to wood frame construction with a roof deck and roofing having a conductance of 1.0 Btu/(hr · ft² · F).

[b] When attic ventilation meets the usual requirements, 0.1 cfm/ft² may be assumed as the natural summer ventilation rate for design purposes.

[c] *Resistance* is (hr · ft² · F)/Btu. Determine ceiling resistance and adjust for framing. Do not add the effect of a reflective surface facing the attic to the ceiling resistance, as it is accounted for in Part B.

[d] Based on air discharging outward from attic.

[e] Surfaces with effective emittance *E* of 0.05 between ceiling joists facing the attic space.

Table 3.6 Coefficients of Transmission (*U*) for Slab Doors
Btu per (hr · ft² · F)

	Winter			Summer
	Solid Wood,	Storm Door[b]		
Thickness[a]	No Storm Door	Wood	Metal	No Storm Door
1-in.	0.64	0.30	0.39	0.61
1.25-in.	0.55	0.28	0.34	0.53
1.5-in.	0.49	0.27	0.33	0.47
2-in.	0.43	0.24	0.29	0.42
	Steel Door			
1.75 in.				
A[c]	0.59	—	—	0.58
B[d]	0.19	—	—	0.18
C[e]	0.47	—	—	0.46

[a]Nominal thickness.
[b]Values for wood storm doors are for approximately 50% glass; for metal storm door values apply for any percent of glass.
[c]A = Mineral fiber core (2 lb/ft³).
[d]B = Solid urethane foam core with thermal break.
[e]C = Solid polystyrene core with thermal break.

3.2 COOLING LOAD TEMPERATURE DIFFERENCE (CLTD)

The Cooling Load Temperature Difference (CLTD), deg F, is defined by Eq. (3.2)

$$\text{CLTD} = q/UA \qquad (3.2)$$

The values of CLTD in Table 3.8 for flat roofs, Table 3.10 for sunlit walls, and Table 3.23 for conduction through glass were obtained for the following design conditions.

1) Dark surface for the roofs and walls with a ratio of the solar radiation absorptance to the convective film coefficient (α/h) of 0.30.
2) Indoor air temperature of 78 F, db.
3) Outdoor air maximum temperature of 95 F db with outdoor mean temperature of 85 F and an outdoor daily range of 21 deg F.
4) Solar radiation typical of 40 deg North latitude on July 21 with a clear sky.
5) For the roof and wall tables (Tables 3.8 and 3.10), outside surface film resistance is R = 0.33 (hr · ft² · F)/Btu and inside surface film resistance is R = 0.685 (hr · ft² · F)/Btu.

Adjustments to the tabulated CLTD are to be made by following the guidelines given in the form of notes attached to each of the CLTD tables.

- Table 3.7 gives the roof construction code for use with Table 3.8.
- Table 3.9 gives the wall construction group description for use with Table 3.10.
- Table 3.11 gives thermal properties and code numbers for Tables 3.8 and 3.10.
- Table 2.1 gives climatic conditions.
- Table 3.13 gives CLTD adjustments for inside and outside design conditions.
- Table 3.12 gives the CLTD adjustment for month and latitude based on a dark surface, $\alpha/h = 0.30$.

CLTD values for roof and wall constructions other than those used in Tables 3.8 and 3.10 can be approximated by using the following procedure.

1) Obtain for the roof or wall under consideration the *U*-value, the weight in lb/ft² which is the sum of density times thickness for each layer, and the thermal capacity in Btu/(ft² · F) which is the sum of the product of density, thickness and specific heat for each layer. These values are obtainable from Table 3.1 for typical building and insulating materials.
2) Compare the given construction to a construction in Table 3.8 or 3.10 on the basis of the three parameters: Heat capacity, weight, and *U*-value. These are listed in the order of consideration for equivalence in selection of CLTD values.
3) After establishing an acceptable thermal equivalence, use the CLTD table with necessary adjustments for the design conditions.
4) To calculate $q = U \times A \times \text{CLTD}$, use the *actual U-value* of the *actual construction* not the approximate reference values listed in the CLTD tables.

Examples for the Calculation of CLTD Factors for Roofs, Walls and Glass and the Use of the Related Tables

- Example 3.4 Calculation of CLTD and q/A for a typical flat roof construction of Table 3.8 with the adjustments for design conditions.
- Example 3.5 Calculation of CLTD and q/A for a flat roof not having a construction listed in Table 3.8 but with selection of a thermally equivalent roof of the table with adjustments for design conditions.
- Example 3.6 Calculation of CLTD and q/A for a pitched roof using Tables 3.3 and 3.5 to get *U*, Table 3.8 for CLTD and an adjustment of CLTD for design conditions from Table 3.12.
- Example 3.7 Calculation of cooling load through sunlit exterior walls, using one construction listed in Table 3.9 and another not listed in Table 3.9.
- Example 3.8 Calculation of CLTD and q/A for conduction through glass by use of Table 3.23 with adjustments for design conditions. This CLTD accounts for *only* the conduction part of the total cooling load. Solar radiation transmitted through glass is handled by the solar heat gain concept.

EXAMPLE 3.4 — Calculation of CLTD and q/A for a Typical Roof Construction Identical to One in Table 3.8 (Roof No. 12, Table 3.7) with Corrections as Required by Notes of Table 3.8.

Determine the CLTD and q/A for a 6 in. H.W. concrete flat roof with 1 in. insulation as used in Roof No. 12, Tables 3.7 and 3.8 and adjusted as necessary for the following conditions:

Time: 1900 (19 hr)
Inside Design: 75 F
Month: October
Roof: Light-colored (marble chips), without suspended ceiling
Location: Atlanta, Georgia (surburban area)

Item	Table	Explanation and Notes
$q = U \times A \times$ CLTD	Table 1.2	Cooling Load Roof
Climatic Conditions	Table 2.1	**Summer** **Col. 1** State & Station: Georgia, Atlanta AP — **Col. 2** Latitude: 33°40′ **Col. 6** Design db/wb 2 1/2%: 92/74 — **Col. 7** Daily Range: 19
Roof Construction and Thermal Properties	Table 3.8	Roof No. 12, 6 in. H.W. concrete with 1 in. insulation, layers A_0, E_2, E_3, B_5, C_{13}, E_0. Without suspended ceiling: wt = 75 lb/ft^2, heat capacity = 15.9 Btu/(ft$^2 \cdot$ F)
	Table 3.11	**Description / Code No. / Resistance (R)** Outside surface resistance — A_0 — 0.333 1/2 in. slag or stone — E_2 — 0.050 3/8 in. felt & membrane — E_3 — 0.285 1 in. insulation — B_5 — 3.330 6 in. H.W. concrete — C_{13} — 0.500 Inside surface resistance — E_0 — 0.685
U and R		R_t = Sum R = 5.18 $U_t = 1/5.18$ $= 0.193$ Btu/(hr $\cdot$ ft$^2 \cdot$ F)
CLTD Uncorrected	Table 3.8 Upper Section	For Roof No. 12 without a suspended ceiling at 19 hr, the CLTD is 45 deg F
Corrections to be made to CLTD?	Table 3.8 Notes	Note (1) explains general use of Table 3.8
Indoor Design?	Table 3.13 Part a)	Note (2a) Indoor temperature correction required; Table 3.13, Part a, gives correction = 3.0 deg F for an indoor db of 75 F
Outdoor Design?	Table 3.13 Part b)	Note (2b) Correction required for outdoor design; using climatic conditions of 92 F (2 1/2% db) and 19 F daily range, Table 3.13 Part b, gives correction = 2.5 deg F
Attic, f?	Table 3.8	Note (2) $f = 1.0$, no attic
Color, K?	Table 3.8	Note (2) $K = 0.5$, light-colored roof in suburban area and expected to maintain condition
Month-Latitude?	Table 3.8	Note (2) Use Table 3.12, hor. **Lat. / North Lat-Month / Hor.** 32 — October — −10 (33.7) — October — Approx. (−11) 40 — October — −14
CLTD Corrected	Table 3.8	$CLTD_{corr}$ = (CLTD + Lat. & Mo. Corr.) K + Inside Design Corr. + Outside Temp. Corr. $= (45 - 11)(0.5) + 3 - 2.5$ $= 17.5$ deg F
$q/A = U \times$ CLTD		$q/A = 0.193 \times 9.5$ $= 3.38$ Btu/(hr $\cdot$ ft^2)
Outside Design in October	Table 2.2	Design conditions for a month other than the summer (June, July, August, September) are indicated in Table 2.2. The nearest weather station listed is Augusta, Georgia. If this is sufficiently accurate, the design db is 84 F for October. The correction to the CLTD for average outside db would be $(84 - 19/2) - 85 = -10.5$ deg F. The previous correction for outside db was only −2.5 deg F. Therefore, an additional correction of −8 deg F should be made to the CLTD for July. CLTD = 17.5 − 8 = 9.5 deg F
October $q/A = U \times$ CLTD		$q/A = 9.193 \times 9.5$ $= 1.83$ Btu/(hr $\cdot$ ft^2)

EXAMPLE 3.5 — Calculation of CLTD and q/A for a Flat Roof Construction Not in Table 3.8.

Calculate the CLTD and q/A for a 6 in. L.W. concrete flat roof with 2 in. insulation, density = 5.7 lb/ft³. Similar to construction No. 6 with insulation added.

Location: Beatrice, Nebraska (rural area)
Time: 1700 (17 hr)
Inside Design: 78 F
Month: July
Roof: Dark-colored without suspended ceiling, no attic.

Item	Table	Explanation and Notes
$q = U \times A \times$ CLTD	Table 1.2	Cooling Load for Roof
Climatic Conditions	Table 2.1	**Summer** **Col. 1** State & Station: Nebraska, Beatrice — **Col. 2** Latitude: 40°20′ **Col. 6** Design db/wb 2 1/2%: 95/74 — **Col. 7** Daily Range: 24

Item	Table	Explanation and Notes
Roof Construction and Thermal Properties	Table 3.11	Roof not listed in Table 3.8 but using construction layers listed in Table 3.11

Description	Code No.	R	WT	WT × SH
Outside surface resistance	A_0	0.333		
1/2 in. slag or stone	E_2	0.050	2.29	0.92
3/8 in. felt and membrane	E_3	0.285	2.19	0.88
2 in. insulation ($\rho = 5.7$)	B_6	6.680	0.95	0.19
6 in. L. W. concrete	C_{15}	5.000	20.00	4.00
Inside surface resistance	E_0	0.685		
Totals =		13.033	25.43	5.99

Item	Table	Explanation and Notes
R_t and U		$U = 1/R_T = 1/13$ $= 0.077 \text{Btu/(hr} \cdot \text{ft}^2 \cdot \text{F)}$
Equivalent Roof	Table 3.8 Notes 3 & 4	This roof is similar to roof No. 6 with insulation $R = 6.68$ added. Notes 3 & 4 indicate that the thermally equivalent roof would be one that peaks 2 hr later than roof No. 6. Peak time = 18 + 2 = 20 hr. Roof No. 8 peaks at 20 hr although it does have a higher heat capacity and mass. It is also possible to use roof No. 6 with a suspended ceiling for it also peaks at 20 hr. Roof 8 without a suspended ceiling and Roof 6 with a suspended ceiling have almost identical CLTD characteristics.
CLTD	Table 3.8	Use Roof No. 8, without suspended ceiling CLTD @ 17 hr = 46 deg F
Corrections to be made to CLTD?	Table 3.8 Notes	Note (1) Explains general use
	(Table 3.13 Part a)	Note (2a) Indoor temperature correction, Table 3.13, Part a, gives a correction = 0 deg F at 78 F db indoor design
Outdoor Design?	(Table 3.13 Part b)	Note (2b) Correction for outdoor design. Using climatic data of 95 F and 24 deg F daily range, Table 3.13 gives a correction = −2 deg F
Attic, f?		Note (2) $f = 1.0$, no attic
Color, K?		Note (2) $K = 1.0$, dark-colored roof
Month-Latitude?		Note (2) No correction, month is July at 40 deg N lat
$CLTD_{corr}$		$CLTD_{corr} = 46 \text{ deg F} - 2 \text{ deg F} = 44 \text{ deg F}$
$q/A = U \times CLTD$		$q/A = 0.077^* \times 44$ $= 3.39 \text{ Btu/(hr} \cdot \text{ft}^2)$ *actual U of given roof

EXAMPLE 3.6

Determine the cooling load at 4:00 PM daylight savings time in August for a combination pitched roof over a ceiling for an apartment building in Charlotte, North Carolina.

Inside Design Temperature = 78 F
Roof Pitch Approx. 30°; with asphalt shingles and building paper on 5/8 in. plywood
Attic space with natural ventilation
Ceiling: metal lath and lightweight aggregate plaster on wood joists with *R*-19 insulation between joists.

Item	Table	Explanation and Notes
$q = U \times A \times CLTD$	Table 1.2	Cooling Load Equation for Roof
Climatic Conditions	Table 2.1	Outside design conditions for Charlotte are db/wb (Col. 6) 93/74 F with a daily range of 20 deg F (Col. 7) at a latitude of 35 deg N (Col. 2)
U-Ceiling	Table 3.2G and Table 3.4	U_{av} value from Table 3.2G is 0.053 Btu/(hr · ft² · F) based on air films for winter conditions of $R = 0.61$ for top and bottom surfaces. For summer, air film $R = 0.92$ $R_t = 1/0.053 = 18.9$ Summer $R_t = 18.9 - (2 \times 0.61) + (2 \times 0.92) = 19.5$ $U_{av} = 1/19.5$ $= 0.051 \text{ Btu/(hr} \cdot \text{ft}^2 \cdot \text{F)}$ The difference between summer and winter U-values is small, when there is a large resistance from insulation. Usually the difference is neglected.
Combined U for roof-ceiling	Table 3.5	For roof-attic effective resistance with no reflective surfaces in the attic, use Part a; with ceiling $R = 19.5$ and a design db of 93 F, estimate the effective resistance of the attic and roof equal to 3.0, about one third between 3.1 and 2.7 under natural ventilation. Total effective $R = 3.0 + 19.5 = 22.5$ $U = 1/22.5$ $= 0.044 \text{ Btu/(hr} \cdot \text{ft}^2 \cdot \text{F)}$ based on ceiling area
CLTD	Table 3.8 Note 4	This roof/ceiling construction can be approximated best by roof Number 2 with a suspended ceiling. $U = 0.115$ and $R = 8.7$. The resistance is greater than roof 2 by $22.5 - 8.7 = 13.8$. This represents $(13.8/7) \times 2 \text{ hr} = 4$ hr delay in the peak time over the tabulated peak time of 1700 solar time. The construction which is nearest to that description is Number 10. CLTD for roof Number 10 at 4:00 PM DST (1500 solar time) is 28 deg F.
	Table 3.12	The latitude and month correction for August and using an equivalent horizontal surface is −2 deg F at 35 deg N lat (halfway between 32 and 40 deg N lat values.)

Item	Table	Explanation and Notes
	Table 3.13	Correction for outside conditions with design db = 93 F and 20 deg F daily range is −2 deg F Net correction = (−2 − 2) = −4 deg F CLTD = 28 − 4 = 24 deg F
$q/A = U \times \text{CLTD}$		$q/A = 0.044$ Btu/(hr·ft²·F) × 24 deg F = 1.06 Btu/(hr·ft²) of ceiling area.

EXAMPLE 3.7 — Calculation of Cooling Load Through Sunlit Exterior Walls.

a. **4 in. L.W. concrete block wall with air space and 3/4 in. plaster finish on inside and stucco on outside. This is exactly similar to construction listed in Table 3.9.**

b. **6 in. H.W. concrete wall with 1 in. urethane insulation and air space and gypsum board, similar to construction in Example 3.2. This construction is not listed in Table 3.9.**

Location: Suburban area of Windsor, Ontario, Canada
Wall Surface: Light colored exterior surface
Inside Design: 74 F
Time and Month: 1900 (7:00 PM) in August

EXAMPLE 3.7a

Item	Table	Explanation and Notes
$q = U \times A \times \text{CLTD}$	Table 1.2	Cooling Load for External Wall
Climatic Conditions	Table 2.1	**Summer** **Col. 1** State & Station — **Col. 2** Latitude CANADA Ontario Windsor — 42° 16′ **Col. 6** Design db/wb 2 1/2% — **Col. 7** Daily Range, 88/73 — 20
(a) Wall Construction and Thermal Properties	Table 3.9	First wall under heading: L.W. & H.W. concrete block + (Finish)

Group No.	Description	WT	Heat Capacity	U
		lb/ft²	Btu/(ft²·F)	Btu/(hr·ft²·F)
F	4 in. Block + air space	29	5.7	0.263

Table 3.11 (Check on Listing of Table 3.9)

Description	Code No.	R	WT	WT X SH
Outside surface resistance	A_0	0.333	—	—
1 in. Stucco	A_1	0.208	9.66	1.93
4 in. L.W. concrete block	C_2	1.510	12.70	2.54
Air space resistance	B_1	0.910	—	—
0.75 in. plaster	E_1	0.149	6.25	1.25
Inside surface resistance	E_0	0.685	—	—
Totals =		3.795	28.61	5.72

$U = 1/R_T = 0.263$; Checks Table 3.9 exactly, which may not always be the case.

Item	Table	Explanation and Notes
CLTD Uncorrected	Table 3.10	For a wall facing West at 19 hr, a Group F wall has a CLTD = 60 deg F
Corrections to be made to CLTD?	Table 3.10 Notes	Note (1) Explains general use of Table 3.10
Indoor Design?	Table 3.13 Part a	Note (2) Indoor temperature correction required; Table 3.13, Part a, gives correction = 4.0 deg F
Outdoor Design?	Table 3.13 Part b	Note (2) Correction required for outdoor design; using climatic conditions of 88 F (2 1/2% db) and 20 deg F daily range, Table 3.13 Part b, gives correction = −7 deg F
Color, K?		Note (2) $K = 0.65$, light-colored wall in suburban area. If this is in the city or in an industrial area, the permanence of the light color would be questionable and K would be taken as 1.0
Month-Latitude?	Table 3.12	Note (2) Use Table 3.12 for correction
		Table 3.12 Latitude and Month Correction Lat. / North Lat. Month / E W 40 / August / 0 (42) / August / (0) 48 / August / −1
CLTD Corrected	Table 3.10 Note (2)	$\text{CLTD}_{corr} = (\text{CLTD} + \text{Lat. \& Month Corr.}) \times K + (78 - T_R) + (T_o - 85)$ $= (60 - 0)(0.65) + 4.0 - 7.0 = 36.0$ deg F
$q/A = U \times \text{CLTD}$		$q/A = 0.263\ (36.0)$ = 9.47 Btu/(hr·ft²)

EXAMPLE 3.7b

Item	Table	Explanation and Notes
U value	Example 3.2	$U = 0.11$ Btu/(hr·ft²·F)
CLTD	Table 3.9	H.W. concrete walls are listed for 4 in. and 8 in. but not 6 in. The 4 in. wall plus insulation is in Group D and the 8 in. wall plus insulation is Group B. Therefore, use Group C for 6 in. wall
	Table 3.9	A Group C wall facing west and at 19 hr shows CLTD = 29 F. The corrections will be the same as in Part a of this example $\text{CLTD}_{corr} = (\text{CLTD} + \text{LM}) \times K + (78 - T_o) + (T_O - 85)$ $= (29 + 0)(0.65) + 4 - 7$ = 15.9 deg F
Cooling Load		$q/A = 0.11$ Btu/(hr·ft²·F) × 15.9 deg F = 1.75 Btu/(hr·ft²)

EXAMPLE 3.8 — Calculation of CLTD and q for Conduction Through a Glass Window Unit.

Determine the CLTD and q for a window unit for summer wind conditions as below:

Summer conditions
Time: 1600 (16 h)
Inside Design: 76 F
Month: July
Location: Pampa, TX

a. Size 4 ft × 8 ft vertical window
Glass, single clear
Interior shading, by Venetian blinds

b. Size 4 ft × 8 ft wood sash - 80% glass
Insulating glass unit with a 1/4 in. clear outer light and 1/4 in. clear inner light
No interior shading
Air velocity sweeping inside surface of glass is approximately 200 fpm due to under-the-window supply air

EXAMPLE 3.8a

Item	Table	Explanation and Notes
$q = U \times A \times$ CLTD	Table 1.4	Glass Conduction Cooling Load
Climatic	Table 2.1	**Summer** **Col. 1** State & Station — **Col. 2** Latitude Texas Pampa — 35°30′ **Col. 6** Design Dry db/wb — **Col. 7** Daily Range 2 1/2% 96/67 — 26
U and UA	Table 3.14A	$U = 0.81$ Btu/(hr·ft²·F); $UA = 25.92$ Btu/(hr·F)
CLTD Uncorrected	Table 3.23	@ 16 hr CLTD = 14 deg F
Corrections to be made to CLTD?	Table 3.23 Notes	Inside temperature correction from Table 3.13 is 2 deg F
	Table 3.13	Using 96 deg F design db and 26 deg F daily range. Table 3.13 gives correction for outdoor design = −2 deg F Net correction = +2 − 2 = 0
CLTD corrected		$CLTD_{corr}$ = 14 deg F
$q = U \times A \times$ CLTD		$q = 25.92\ (14) = 363$ Btu/hr

EXAMPLE 3.8b

Item	Table	Explanation and Notes
U and UA	Table 3.14A	$U = 0.56$ for summer conditions with no interior shading. Note (e) indicates 1/4 in. glass with 1/2 in. air space
	Table 3.15	Adjusts for inside air velocity $U = 0.64$ at 185 fpm
	Table 3.14B	Adjustment factor for wood sash is 0.95 $U = 0.95 \times 0.64$ $= 0.61$ Btu/(hr·ft²·F) $UA = 0.61 \times 32$ $= 19.5$ Btu/(hr·F)
$CLTD_{corr}$		Same as Part a $CLTD_{corr}$ = 14 deg F
Conduction thru glass $q = U \times A \times$ CLTD		$q = 19.5 \times 14 = 273$ Btu/hr

Table 3.7 Roof Construction Code

Roof No.	Description	Code Number of Layers (see Table 3.11)
1	Steel Sheet with 1-in. insulation	A0, E2, E3, B5, A3, EO
2	1-in. wood with 1-in. insulation	A0, E2, E3, B5, B7, E0
3	4-in. l. w. concrete	A0, E2, E3, C14, E0
4	2-in. h.w. concrete with 1-in. insulation	A0, E2, E3, B5, C12, E0
5	1-in. wood with 2-in. insulation	A0, E2, E3, B6, B7, E0
6	6-in. l. w. concrete	A0, E2, E3, C15, E0
7	2.5-in. wood with 1-in. insulation	A0, E2, E3, B5, B8, E0
8	8-in. l. w. concrete	A0, E2, E3, C16, E0
9	4-in. h. w. concrete with 1-in. insulation	A0, E2, E3, B5, C5, E0
10	2.5-in. wood with 2-in. insulation	A0, E2, E3, B6, B8, E0
11	Roof terrace system	A0, C12, B1, B6, E2, E3, C5, E0
12	6-in h. w. concrete with 1-in. insulation	A0, E2, E3, B5, C13, E0
13	4-in. wood with 1-in. insulation	A0, E2, E3, B5, B9, E0

Table 3.8 Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs

Roof No	Description of Construction	Weight lb/ft²	U-value Btu/(h·ft²·F)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hour of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD	Heat Capacity Btu/(ft²·F)
	Without Suspended Ceiling																															
1	Steel sheet with 1-in. (or 2-in.) insulation	7 (8)	0.213 (0.124)	1	−2	−3	−3	−5	−3	6	19	34	49	61	71	78	79	77	70	59	45	30	18	12	8	5	3	14	−5	79	84	2.13
2	1-in. wood with 1-in. insulation	8	0.170	6	3	0	−1	−3	−3	−2	4	14	27	39	52	62	70	74	74	70	62	51	38	28	20	14	9	16	−3	74	77	3.73
3	4-in. l.w concrete	18	0.213	9	5	2	0	−2	−3	−3	1	9	20	32	44	55	64	70	73	71	66	57	45	34	25	18	13	16	−3	73	76	4.45
4	2-in. h.w. concrete with 1-in. (or 2-in.) insulation	29	0.206 (0.122)	12	8	5	3	0	−1	−1	3	11	20	30	41	51	59	65	66	66	62	54	45	36	29	22	17	16	−1	67	68	6.57
5	1-in. wood with 2-in. insulation	19	0.169	3	0	−3	−4	−5	−7	−6	−3	5	16	27	39	49	57	63	64	62	57	48	37	26	18	11	7	16	−7	64	71	3.83
6	6-in. l.w. concrete	24	0.158	22	17	13	9	6	3	1	1	3	7	15	23	33	43	51	58	62	64	62	57	50	42	35	28	18	1	54	63	5.79
7	2.5-in. wood with 1-insulation	13	0.130	29	24	20	16	13	10	7	6	6	9	13	20	27	34	42	48	53	55	56	54	49	44	39	34	19	6	56	50	6.51
8	8-in. l.w. concrete	31	0.126	35	30	26	22	18	14	11	9	7	7	9	13	19	25	33	39	46	50	53	54	53	49	45	40	20	7	54	47	7.13
9	4-in. h.w. concrete with 1-in. (or 2-in.) insulation	52 (52)	0.200 (0.120)	25	22	18	15	12	9	8	8	10	14	20	26	33	40	46	50	53	53	52	48	43	38	34	30	18	8	53	45	11.21
10	2.5-in. wood with 2-in. insu-insulation	13	0.093	30	26	23	19	16	13	10	9	8	9	13	17	23	29	36	41	46	49	51	50	47	43	39	35	19	8	51	43	6.61
11	Roof terrace system	(75)	0.106	34	31	28	25	22	19	16	14	13	13	15	18	22	26	31	36	40	44	45	46	45	43	40	37	20	13	46	33	15.98
12	6-in. h.w. concrete with 1-in. (or 2-in.) insulation	75 (75)	0.192 (0.117)	31	28	25	22	20	17	15	14	14	16	18	22	26	31	36	40	43	45	45	44	42	40	37	34	19	14	45	31	15.89
13	4-in. wood with 1-in. (or 2-in) insulation	17 (18)	0.106 (0.078)	38	36	33	30	28	25	22	20	18	17	16	17	18	21	24	28	32	36	39	41	43	43	42	40	22	16	43	27	9.27
	With Suspended Ceiling																															
1	Steel Sheet with 1-in. (or 2-in.) insulation	9 (10)	0.134 (0.092)	2	0	−2	−3	−4	−4	−1	9	23	37	50	62	71	77	78	74	67	56	42	28	18	12	8	5	15	−4	78	82	2.50
2	1-in. wood with 1-in. insulation	10	0.115	20	15	11	8	5	3	2	3	7	13	21	30	40	48	55	60	62	61	58	51	44	37	30	25	17	2	62	60	4.11
3	4-in. l.w. concrete	20	0.134	19	14	10	7	4	2	0	0	4	10	19	29	39	48	56	62	65	64	61	54	46	38	30	24	17	0	65	65	4.83
4	2-in. h.w. concrete with 1-in. insulation	30	0.131	28	25	23	20	17	15	13	13	14	16	20	25	30	35	39	43	46	47	46	44	41	38	35	32	18	13	47	34	6.94
5	1-in. wood with 2-in. insulation	10	0.083	25	20	16	13	10	7	5	5	7	12	18	25	33	41	48	53	57	57	56	52	46	40	34	29	18	5	57	52	4.21
6	6-in. l.w. concrete	26	0.109	32	28	23	19	16	13	10	8	7	8	11	16	22	29	36	42	48	52	54	54	51	47	42	37	20	7	54	47	6.17
7	2.5-in. wood with 1-in. insulation	15	0.096	34	31	29	26	23	21	18	16	15	15	16	18	21	25	30	34	38	41	43	44	44	42	40	37	21	15	44	29	6.89
8	8-in. l.w. concrete	33	0.093	39	36	33	29	26	23	20	18	15	14	14	15	17	20	25	29	34	38	42	45	46	45	44	42	21	14	46	32	7.51
9	4-in. h.w. concrete with 1-in. (or 2-in.) insulation	53 (54)	0.128 (0.090)	30	29	27	26	24	22	21	20	20	21	22	24	27	29	32	34	36	38	38	38	37	36	34	33	19	20	38	18	11.58
10	2.5-in. wood with 2-in. insulation	15	0.072	35	33	30	28	26	24	22	20	18	18	18	20	22	25	28	32	35	38	40	41	41	40	39	37	21	18	41	23	6.98
11	Roof terrace system	77	0.082	30	29	28	27	26	25	24	23	22	22	22	23	23	25	26	28	29	31	32	33	33	33	33	32	22	22	33	11	16.36
12	6-in. h.w. concrete with 1-in. (or 2-in) insulation	77 (77)	0.125 (0.088)	29	28	27	26	25	24	23	22	21	21	22	23	25	26	28	30	32	33	34	34	34	33	32	31	20	21	34	13	16.26
13	4-in. wood with 1-in (or 2-in.) insulation	19 (20)	0.082 (0.064)	35	34	33	32	31	29	27	26	24	23	22	21	22	22	24	25	27	30	32	34	35	36	37	36	23	21	37	16	9.64

(1) *Direct Application of Table 3.8 Without Adjustments:*

Values in Table 3.8 were calculated using the following conditions:

- Dark flat surface roof ("dark" for solar radiation absorption)
- Indoor temperature of 78 F
- Outdoor maximum temperature of 95 F with outdoor mean temperature of 85 F and an outdoor daily range of 21 deg F
- Solar radiation typical of 40 deg North latitude on July 21
- Outside surface resistance, $R_o = 0.333$ (hr·ft²·F)/Btu
- Without and with suspended ceiling, but no attic fans or return air ducts in suspended ceiling space
- Inside surface resistance, $R_i = 0.685$ (hr·ft²·F)/Btu

(2) *Adjustments to Table 3.8 Values:*

The following equation makes adjustments for deviations of design and solar conditions from those listed in (1) above.

$$CLTD_{corr} = [(CLTD + LM) \times K + (78 - T_R) + (T_o - 85)] \times f$$

where CLTD is from this table

(a) LM is latitude-month correction from Table 3.12 for a horizontal surface.

(b) K is a color adjustment factor and is applied after first making month-latitude adjustments. Credit should not be taken for light-colored roof except where permanence of light color is established by experience, as in rural areas or where there is little smoke.
$K = 1.0$ if dark colored or light in an industrial area
$K = 0.5$ if permanently light-colored (rural area)

(c) $(78 - T_R)$ is indoor design temperature correction.
Table 3.13 can be used when indoor design is other than 78 F.

(d) $(T_o - 85)$ is outdoor design temperature correction, where T_o is the average outside temperature on design day.
Table 3.13 is based on the local design outside dry-bulb temperature and daily range, as given in Column 6 (2 1/2%) and 7, Table 2.1, Climatic Conditions.

(e) f is a factor for attic fan and/or ducts above ceiling and is applied after all other adjustments have been made.
$f = 1.0$ no attic or ducts
$f = 0.75$, positive ventilation
Values in Table 3.8 were calculated without and with a suspended ceiling, but made no allowance for positive ventilation or return ducts thru the space. If ceiling is insulated and a fan is used between ceiling and roof, CLTD may be reduced by 25% ($f = .75$). Use of the suspended ceiling space for a return air plenum or with return air ducts should be analyzed separately.

(3) *Roof Constructions Not Listed In Table:*

The U-Values listed are to be used only as guides. The actual value of U as obtained from tables such as Table 3.2 or as calculated for the actual roof construction should be used.

An actual roof construction not in this table would be thermally similar to a roof in the table, if it has similar mass, m lb/ft², and similar heat capacity Btu/(ft²·F). In such a case, use the CLTD from this table as corrected by Note (2) above.

Example: A flat roof without a suspended ceiling has properties m = 18.0 lb/ft². $U = 0.20$ Btu/(hr·ft²·F), and heat capacity = 9.5 Btu/(ft²·F). Use $CLTD_{uncorr}$ from Roof No. 13, to obtain $CLTD_{corr}$ and use the actual U value to calculate $q/A = U\,(CLTD)_{corr} = 0.20\,(CLTD_{corr})$.

(4) *Additional Insulation*

For each R-7 increase in R-value due to insulation added to the roof structure (Table 3.7), use a CLTD for a roof whose weight and heat capacity are approximately the same, but whose CLTD has a maximum value 2 hr later. If this is not possible, because a roof with the longest time lag has already been selected, use an effective CLTD in the cooling load calculation equal to 29 deg F.

Table 3.9 Wall Construction Group Description

Group No.	Description of Construction	Weight (lb/ft²)	*U*-Value Btu/(hr·ft²·F)	Heat Capacity Btu/(ft²·F)	Code Numbers of Layers (See Table 3.11)
4-in. Face Brick+(*Brick*)					
C	Air Space+4-in. Face Brick	83	0.358	18.3	A0, A2, B1, A2, E0
D	4-in. Common Brick	90	0.415	18.4	A0, A2, C4, E1, E0
C	1-in. Insulation or Air space+4-in. Common Brick	90	0.174-0.301	18.4	A0, A2, C4, B1/B2, E1, E0
B	2-in. Insulation+4-in. Common Brick	88	0.111	18.5	A0, A2, B3, C4, E1, E0
B	8-in. Common Brick	130	0.302	26.4	A0, A2, C9, E1, E0
A	Insulation or Air space+8-in. Common Brick	130	0.154-0.243	26.4	A0, A2, C9, B1/B2, E1, E0
4-in. Face Brick+(*H.W. Concrete*)					
C	Air Space+2-in. Concrete	94	0.350	19.7	A0, A2, B1, C5, E1, E0
B	2-in. Insulation+4-in. concrete	97	0.116	19.8	A0, A2, B3, C5, E1, E0
A	Air Space or Insulation+8-in. or more Concrete	143-190	0.110-0.112	29.1-38.4	A0, A2, B1, C10/11, E1, E0
4-in. Face Brick+(*L.W. or H.W. Concrete Block*)					
E	4-in. Block	62	0.319	12.9	A0, A2, C2, E1, E0
D	Air Space or Insulation+4-in. Block	62	0.153-0.246	12.9	A0, A2, C2, B1/B2, E1, E0
D	8-in. Block	70	0.274	15.1	A0, A2, C7, A6, E0
C	Air Space or 1-in. Insulation+6-in. or 8-in. Block	73-89	0.221-0.275	15.5-18.5	A0, A2, B1, C7/C8, E1, E0
B	2-in. Insulation+8-in. Block	89	0.096-0.107	15.5-18.6	A0, A2, B3, C7/C8, E1, E0
4-in Face Brick+(*Clay Tile*)					
D	4-in. Tile	71	0.381	15.1	A0, A2, C1, E1, E0
D	Air Space+4-in. Tile	71	0.281	15.1	A0, A2, C1, B1, E1, E0
C	Insulation+4-in. Tile	71	0.169	15.1	A0, A2, C1, B2, E1, E0
C	8-in. Tile	96	0.275	19.7	A0, A2, C6, E1, E0
B	Air Space or 1-in. Insulation+8-in. Tile	96	0.142-0.221	19.7	A0, A2, C6, B1/B2, E1, E0
A	2-in. Insulation+8-in. Tile	97	0.097	19.8	A0, A2, B3, C6, E1, E0
H.W. Concrete Wall+(*Finish*)					
E	4-in. Concrete	63	0.585	12.5	A0, A1, C5, E1, E0
D	4-in. Concrete+1-in. or 2-in. Insulation	63	0.119-0.200	12.5	A0, A1, C5, B2/B3, E1, E0
C	2-in. Insulation+4-in. Concrete	63	0.119	12.7	A0, A1, B6, C5, E1, E0
C	8-in. Concrete	109	0.490	21.9	A0, A1, C10, E1, E0
B	8-in. Concrete+1-in. or 2-in. Insulation	110	0.115-0.187	22.0	A0, A1, C10, B5/B6, E1, E0
A	2-in. Insulation+8-in. Concrete	110	0.115	21.9	A0, A1, B3, C10, E1, E0
B	12-in. Concrete	156	0.421	31.2	A0, A1, C11, E1, E0
A	12-in. Concrete+Insulation	156	0.113	31.3	A0, C11, B6, A6, E0
L.W. and H.W. Concrete Block+(*Finish*)					
F	4-in. Block+Air Space/Insulation	29-36	0.161-0.263	5.7-7.2	A0, A1, C2, B1/B2, E1, E0
E	2-in. Insulation+4-in. Block	29-37	0.105-0.114	5.8-7.3	A0, A1, B1, C2/C3, E1, E0
E	8-in. Block	41-57	0.294-0.402	6.3-11.3	A0, A1, C7/C8, E1, E0
D	8-in. Block+Air Space/Insulation	41-57	0.149-0.173	8.3-11.3	A0, A1, C7/C8, B2, E1, E0
Clay *Tile+(Finish)*					
F	4-in. Tile	39	0.419	7.8	A0, A1, C1, E1, E0
F	4-in. Tile+Air space	39	0.303	7.8	A0, A1, C1, B1, E1, E0
E	4-in. Tile+1-in. Insulation	39	0.175	7.9	A0, A1, C1, B2, E1, E0
D	2-in. Insulation+4-in. Tile	40	0.110	7.9	A0, A1, B3, C1, E1, E0
D	8-in. Tile	63	0.296	12.5	A0, A1, C6, E1, E0
C	8-in. Tile+Air Space/1-in. Insulation	63	0.151-0.231	12.6	A0, A1, C6, B1/B2, E1, E0
B	2-in. Insulation+8-in. Tile	63	0.099	12.6	A0, A1, B3, C6, E1, E0
Metal Curtain Wall					
G	With/without Air Space+1-in./2-in./3-in. Insulation	5-6	0.091-0.230	0.7	A0, A3, B5/B6/B12, A3, E0
Frame Wall					
G	1-in. to 3-in. Insulation	16	0.081-0.178	3.2	A0, A1, B1, B2/B3/B4, E1, E0

Table 3.10 Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls

North Latitude Wall Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hr of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
	Solar Time, hr																											
Group A Walls																												
N	14	14	14	13	13	13	12	12	11	11	10	10	10	10	10	10	11	11	12	12	13	13	14	14	2	10	14	4
NE	19	19	19	18	17	17	16	15	15	15	15	15	16	16	17	18	18	18	19	19	20	20	20	20	22	15	20	5
E	24	24	23	23	22	21	20	19	19	18	19	19	20	21	22	23	24	24	25	25	25	25	25	25	22	18	25	7
SE	24	23	23	22	21	20	20	19	18	18	18	18	18	19	20	21	22	23	23	24	24	24	24	24	22	18	24	6
S	20	20	19	19	18	18	17	16	16	15	14	14	14	14	14	15	16	17	18	19	19	20	20	20	23	14	20	6
SW	25	25	25	24	24	23	22	21	20	19	19	18	17	17	17	17	18	19	20	22	23	24	25	25	24	17	25	8
W	27	27	26	26	25	24	24	23	22	21	20	19	19	18	18	18	18	19	20	22	23	25	26	26	1	18	27	9
NW	21	21	21	20	20	19	19	18	17	16	16	15	15	14	14	14	15	15	16	17	18	19	20	21	1	14	21	7
Group B Walls																												
N	15	14	14	13	12	11	11	10	9	9	9	8	9	9	9	10	11	12	13	14	14	15	15	15	24	8	15	7
NE	19	18	17	16	15	14	13	12	12	13	14	15	16	17	18	19	19	20	20	21	21	21	20	20	21	12	21	9
E	23	22	21	20	18	17	16	15	15	15	17	19	21	22	24	25	26	26	27	27	26	26	25	24	20	15	27	12
SE	23	22	21	20	18	17	16	15	14	14	15	16	18	20	21	23	24	25	26	26	26	26	25	24	21	14	26	12
S	21	20	19	18	17	15	14	13	12	11	11	11	11	12	14	15	17	19	20	21	22	22	22	21	23	11	22	11
SW	27	26	25	24	22	21	19	18	16	15	14	14	13	13	14	15	17	20	22	25	27	28	28	28	24	13	28	15
W	29	28	27	26	24	23	21	19	18	17	16	15	14	14	14	15	17	19	22	25	27	29	29	30	24	14	30	16
NW	23	22	21	20	19	18	17	15	14	13	12	12	12	11	12	12	13	15	17	19	21	22	23	23	24	11	23	9
Group C Walls																												
N	15	14	13	12	11	10	9	8	8	7	7	8	8	9	10	12	13	14	15	16	17	17	17	16	22	7	17	10
NE	19	17	16	14	13	11	10	10	11	13	15	17	19	20	21	22	22	23	23	23	23	22	21	20	20	10	23	13
E	22	21	19	17	15	14	12	12	14	16	19	22	25	27	29	29	30	30	30	29	28	27	26	24	18	12	30	18
SE	22	21	19	17	15	14	12	12	12	13	16	19	22	24	26	28	29	29	29	29	28	27	26	24	19	12	29	17
S	21	19	18	16	15	13	12	10	9	9	9	10	11	14	17	20	22	24	25	26	25	25	24	22	20	9	26	17
SW	29	27	25	22	20	18	16	15	13	12	11	11	11	13	15	18	22	26	29	32	33	33	32	31	22	11	33	22
W	31	29	27	25	22	20	18	16	14	13	12	12	12	13	14	16	20	24	29	32	35	35	35	33	22	12	35	23
NW	25	23	21	20	18	16	14	13	11	10	10	10	10	11	12	13	15	18	22	25	27	27	27	26	22	10	27	17
Group D Walls																												
N	15	13	12	10	9	7	6	6	6	6	6	7	8	10	12	13	15	17	18	19	19	19	18	16	21	6	19	13
NE	17	15	13	11	10	8	7	8	10	14	17	20	22	23	23	24	24	25	25	24	23	22	20	18	19	7	25	18
E	19	17	15	13	11	9	8	9	12	17	22	27	30	32	33	33	32	32	31	30	28	26	24	22	16	8	33	25
SE	20	17	15	13	11	10	8	8	10	13	17	22	26	29	31	32	32	32	31	30	28	26	24	22	17	8	32	24
S	19	17	15	13	11	9	8	7	6	6	7	9	12	16	20	24	27	29	29	29	27	26	24	22	19	6	29	23
SW	28	25	22	19	16	14	12	10	9	8	8	8	10	12	16	21	27	32	36	38	38	37	34	31	21	8	38	30
W	31	27	24	21	18	15	13	11	10	9	9	9	10	11	14	18	24	30	36	40	41	40	38	34	21	9	41	32
NW	25	22	19	17	14	12	10	9	8	7	7	8	9	10	12	14	18	22	27	31	32	32	30	27	22	7	32	25
Group E Walls																												
N	12	10	8	7	5	4	3	4	5	6	7	9	11	13	15	17	19	20	21	23	20	18	16	14	20	3	22	19
NE	13	11	9	7	6	4	5	9	15	20	24	25	25	26	26	26	26	26	25	24	22	19	17	15	16	4	26	22
E	14	12	10	8	6	5	6	11	18	26	33	36	38	37	36	34	33	32	30	28	25	22	20	17	13	5	38	33
SE	15	12	10	8	7	5	5	8	12	19	25	31	35	37	37	36	34	33	31	28	26	23	20	17	15	5	37	32
S	15	12	10	8	7	5	4	3	4	5	9	13	19	24	29	32	34	33	31	29	26	23	20	17	17	3	34	31
SW	22	18	15	12	10	8	6	5	5	6	7	9	12	18	24	32	38	43	45	44	40	35	30	26	19	5	45	40
W	25	21	17	14	11	9	7	6	6	6	7	9	11	14	20	27	36	43	49	49	45	40	34	29	20	6	49	43
NW	20	17	14	11	9	7	6	5	5	5	6	8	10	13	16	20	26	32	37	38	36	32	28	24	20	5	38	33
Group F Walls																												
N	8	6	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	20	16	13	11	19	1	24	23
NE	9	7	5	3	2	1	5	14	23	28	30	29	28	27	27	27	27	26	24	22	19	16	13	11	11	1	30	29
E	10	7	6	4	3	2	6	17	28	38	44	45	43	39	36	34	32	30	27	24	21	17	15	12	12	2	45	43
SE	10	7	6	4	3	2	4	10	19	28	36	41	43	42	39	36	34	31	28	25	21	18	15	12	13	2	43	41
S	10	8	6	4	3	2	1	1	3	7	13	20	27	34	38	39	38	35	31	26	22	18	15	12	16	1	39	38
SW	15	11	9	6	5	3	2	2	4	5	8	11	17	26	35	44	50	53	52	45	37	28	23	18	18	2	53	51
W	17	13	10	7	5	4	3	3	4	6	8	11	14	20	28	39	49	57	60	54	43	34	27	21	19	3	60	57
NW	14	10	8	6	4	3	2	2	3	5	8	10	13	15	21	27	35	42	46	43	35	28	22	18	19	2	46	44
Group G Walls																												
N	3	2	1	0	−1	2	7	8	9	12	15	18	21	23	24	24	25	26	22	15	11	9	7	5	18	−1	26	27
NE	3	2	1	0	−1	9	27	36	39	35	30	26	26	27	27	26	25	22	18	14	11	9	7	5	9	−1	39	40
E	4	2	1	0	−1	11	31	47	54	55	50	40	33	31	30	29	27	24	19	15	12	10	8	6	10	−1	55	56
SE	4	2	1	0	−1	5	18	32	42	49	51	48	42	36	32	30	27	24	19	15	12	10	8	6	11	−1	51	52
S	4	2	1	0	−1	0	1	5	12	22	31	39	45	46	43	37	31	25	20	15	12	10	8	5	14	−1	46	47
SW	5	4	3	1	0	0	2	5	8	12	16	26	38	50	59	63	61	52	37	24	17	13	10	8	16	0	63	63
W	6	5	3	2	1	1	2	5	8	11	15	19	27	41	56	67	72	67	48	29	20	15	11	8	17	1	72	71
NW	5	3	2	1	0	0	2	5	8	11	15	18	21	27	37	47	55	55	41	25	17	13	10	7	18	0	55	55

(1) *Direct Application of the Table Without Adjustments:*

Values in the table were calculated using the same conditions for walls as outlined for the roof CLTD table, Table 3.8. These values may be used for all normal air conditioning estimates usually without correction (except as noted below) when the load is calculated for the hottest weather.

For totally shaded walls use the North orientation values.

(2) *Adjustments to Table Values:*

The following equation makes adjustment for conditions other than those listed in Note (1).

$$CLTD_{corr} = (CLTD + LM) \times K + (78 - T_R) + (T_o - 85)$$

where CLTD is from Table 3.10 at the wall orientation.

(a) LM is the latitude-month correction from Table 3.12

(b) K is a color adjustment factor and is applied after first making latitude-month adjustment

$K = 1.0$ is dark colored or light in an industrial area

$K = 0.83$ if permanently medium colored (rural area)

$K = 0.65$ if permanently light colored (rural area)

Credit should not be taken for wall color other than dark except where permanence of color is established by experience, as in rural areas or where there is little smoke.

Colors: Light — Cream

Medium — Medium blue, medium green, bright red, light brown, unpainted wood, and natural color concrete

Dark — Dark blue, red, brown and green

(c) $(78 - T_R)$ is indoor design temperature correction

Table 3.13 may also be used when indoor design is specified as other than 78 F.

(d) $(T_o - 85)$ is outdoor design temperature correction where T_o is the average outside temperature on a design day.

Table 3.13 is based on the local design outside dry-bulb temperature and daily range, as given in Column 6 (2 1/2%) and 7, Table 2.1, Climatic Conditions.

(3) *Wall Construction Not Listed:*

The U-values listed are to be used only as guides. The value of U as obtained from tables such as Table 3.2 or as calculated for the actual wall structure should be used.

An actual wall construction not listed in this table (or Table 3.9) would be thermally similar to a wall in the table, if it has similar mass, lb/ft^2, and similar heat capacity, Btu/(ft^2·F). In that case, use CLTD from this table as corrected by Note (2) above.

(4) *Additional Insulation:*

For each 7 increase in R-value due to insulation added to the wall structures in Table 3.9, use the CLTD for the wall group with the next higher letter in the alphabet. When the insulation is added to the exterior of the construction rather than the interior, use the CLTD for the wall group two letters higher. If this is not possible, due to having already selected a wall in Group A, use an effective CLTD in the load calculation as given in the following table.

CLTD, Uncorrected, When Vertical Wall Structure is "Thermally" Heavier than Group A due to Added Insulation

N	NE	E	SE	S	SW	W	NW
11	17	22	21	17	21	22	17

Table 3.11 Thermal Properties and Code Numbers of Layers Used in Calculations of Coefficients for Roof and Wall

Description	Code Number	Thickness and Thermal Properties L	K	D	SH	R	WT	WT × SH
Outside surface resistance	A0					0.333		
1-in. Stucco (asbestos cement or wood siding plaster, etc.)	A1	0.0833	0.4	116	0.20	0.208	9.66	1.93
4-in. face brick (dense concrete)	A2	0.333	0.75	130	0.22	0.444	43.3	9.53
Steel siding (aluminum or other lightweight cladding)	A3	0.005	26.0	480	0.10	0.0002	2.40	0.24
Finish	A6	0.0417	0.24	78	0.26	0.174	3.25	0.85
Air space resistance	B1					0.91		
1-in. insulation	B2	0.083	0.025	2.0	0.2	3.32	0.17	0.03
2-in. insulation	B3	0.167	0.025	2.0	0.2	6.68	0.33	0.07
3-in. insulation	B4	0.25	0.025	2.0	0.2	10.03	0.50	0.10
1-in. insulation	B5	0.0833	0.025	5.7	0.2	3.33	0.47	0.10
2-in. insulation	B6	0.167	0.025	5.7	0.2	6.68	0.95	0.19
1-in. wood	B7	0.0833	0.07	37.0	0.6	1.19	3.08	1.85
2.5-in. wood	B8	0.2083	0.07	37.0	0.6	2.98	7.71	4.63
4-in. wood	B9	0.333	0.07	37.0	0.6	4.76	12.3	7.38
2-in. wood	B10	0.167	0.07	37.0	0.6	2.39	6.18	3.71
3-in. wood	B11	0.25	0.07	37.0	0.6	3.58	9.25	5.55
3-in. insulation	B12	0.25	0.025	5.7	0.2	10.0	1.42	0.28
4-in. clay tile	C1	0.333	0.33	70.0	0.2	1.01	23.3	4.66
4-in. l.w. concrete block	C2	0.333	0.22	38.0	0.2	1.51	12.7	2.54
4-in. h.w. concrete block	C3	0.333	0.47	61.0	0.2	0.71	20.3	4.06
4-in. common brick	C4	0.333	0.42	120	0.2	0.79	40.0	8.00
4-in. h.w. concrete	C5	0.333	1.0	140	0.2	0.333	46.6	9.32
8-in. clay tile	C6	0.667	0.33	70	0.2	2.02	46.7	9.34
8-in. l.w. concrete block	C7	0.667	0.33	38.0	0.2	2.02	25.4	5.08
8-in. h.w. concrete block	C8	0.667	0.6	61.0	0.2	1.11	40.7	8.14
8-in. common brick	C9	0.667	0.42	120	0.2	1.59	80.0	16.00
8-in. h.w. concrete	C10	0.667	1.0	140	0.2	0.667	93.4	18.68
12-in. h.w. concrete	C11	1.0	1.0	140	0.2	1.00	140.0	28.00
2-in. h.w. concrete	C12	0.167	1.0	140	0.2	0.167	23.4	4.68
6-in. h.w. concrete	C13	0.5	1.0	140	0.2	0.50	70.0	14.00
4-in. l.w. concrete	C14	0.333	0.1	40	0.2	3.33	13.3	2.66
6-in. l.w. concrete	C15	0.5	0.1	40	0.2	5.0	20.0	4.00
8-in. l.w. concrete	C16	0.667	0.1	40	0.2	6.67	26.7	5.34
Inside surface resistance	E0					0.685		
0.75-in. plaster; 0.75-in. gypsum or other similar finishing layer	E1	0.0625	0.42	100	0.2	0.149	6.25	1.25
0.5-in. slag or stone	E2	0.0417	0.83	55	0.40	0.050	2.29	0.92
0.375-in. felt membrane	E3	0.0313	0.11	70	0.40	0.285	2.19	0.88
Ceiling air space	E4					1.0		
Acoustic tile	E5	0.0625	0.035	30	0.20	1.786	1.88	0.38

[a] Units: L = ft.; SH = Btu/(lb · deg F); K = Btu/(hr · ft · deg F); R = (hr · ft^2 · deg F)/Btu; D = lb/ft^3; WT = lb/ft^2; WT SH = Btu/(ft^2 · F)

Table 3.12 CLTD Correction For Latitude and Month Applied to Walls and Roofs, North Latitudes

Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	HOR
0	Dec	−3	−5	−5	−5	−2	0	3	6	9	−1
	Jan/Nov	−3	−5	−4	−4	−1	0	2	4	7	−1
	Feb/Oct	−3	−2	−2	−2	−1	−1	0	−1	0	0
	Mar/Sept	−3	0	1	−1	−1	−3	−3	−5	−8	0
	Apr/Aug	5	4	3	0	−2	−5	−6	−8	−8	−2
	May/Jul	10	7	5	0	−3	−7	−8	−9	−8	−4
	Jun	12	9	5	0	−3	−7	−9	−10	−8	−5
8	Dec	−4	−6	−6	−6	−3	0	4	8	12	−5
	Jan/Nov	−3	−5	−6	−5	−2	0	3	6	10	−4
	Feb/Oct	−3	−4	−3	−3	−1	−1	1	2	4	−1
	Mar/Sept	−3	−2	−1	−1	−1	−2	−2	−3	−4	0
	Apr/Aug	2	2	2	0	−1	−4	−5	−7	−7	−1
	May/Jul	7	5	4	0	−2	−5	−7	−9	−7	−2
	Jun	9	6	4	0	−2	−6	−8	−9	−7	−2
16	Dec	−4	−6	−8	−8	−4	−1	4	9	13	−9
	Jan/Nov	−4	−6	−7	−7	−4	−1	4	8	12	−7
	Feb/Oct	−3	−5	−5	−4	−2	0	2	5	7	−4
	Mar/Sept	−3	−3	−2	−2	−1	−1	0	0	0	−1
	Apr/Aug	−1	0	−1	−1	−1	−3	−3	−5	−6	0
	May/Jul	4	3	3	0	−1	−4	−5	−7	−7	0
	Jun	6	4	4	1	−1	−4	−6	−8	−7	0
24	Dec	−5	−7	−9	−10	−7	−3	3	9	13	−13
	Jan/Nov	−4	−6	−8	−9	−6	−3	3	9	13	−11
	Feb/Oct	−4	−5	−6	−6	−3	−1	3	7	10	−7
	Mar/Sept	−3	−4	−3	−3	−1	−1	1	2	4	−3
	Apr/Aug	−2	−1	0	−1	−1	−2	−1	−2	−3	0
	May/Jul	1	2	2	0	0	−3	−3	−5	−6	1
	Jun	3	3	3	1	0	−3	−4	−6	−6	1
32	Dec	−5	−7	−10	−11	−8	−5	2	9	12	−17
	Jan/Nov	−5	−7	−9	−11	−8	−4	2	9	12	−15
	Feb/Oct	−4	−6	−7	−8	−4	−2	4	8	11	−10
	Mar/Sep	−3	−4	−4	−4	−2	−1	3	5	7	−5
	Apr/Aug	−2	−2	−1	−2	0	−1	0	1	1	−1
	May/Jul	1	1	1	0	0	−1	−1	−3	−3	1
	Jun	1	2	2	1	0	−2	−2	−4	−4	2
40	Dec	−6	−8	−10	−13	−10	−7	0	7	10	−21
	Jan/Nov	−5	−7	−10	−12	−9	−6	1	8	11	−19
	Feb/Oct	−5	−7	−8	−9	−6	−3	3	8	12	−14
	Mar/Sep	−4	−5	−5	−6	−3	−1	4	7	10	−8
	Apr/Aug	−2	−3	−2	−2	0	0	2	3	4	−3
	May/Jul	0	0	0	0	0	0	0	0	1	1
	Jun	1	1	1	0	1	0	0	−1	−1	2
48	Dec	−6	−8	−11	−14	−13	−10	−3	2	6	−25
	Jan/Nov	−6	−8	−11	−13	−11	−8	−1	5	8	−24
	Feb/Oct	−5	−7	−10	−11	−8	−5	1	8	11	−18
	Mar/Sep	−4	−6	−6	−7	−4	−1	4	8	11	−11
	Apr/Aug	−3	−3	−3	−3	−1	0	4	6	7	−5
	May/Jul	0	−1	0	0	1	1	3	3	4	0
	Jun	1	1	2	1	2	1	2	2	3	2
56	Dec	−7	−9	−12	−16	−16	−14	−9	−5	−3	−28
	Jan/Nov	−6	−8	−11	−15	−14	−12	−6	−1	2	−27
	Feb/Oct	−6	−8	−10	−12	−10	−7	0	6	9	−22
	Mar/Sep	−5	−6	−7	−8	−5	−2	4	8	12	−15
	Apr/Aug	−3	−4	−4	−4	−1	1	5	7	9	−8
	May/Jul	0	0	0	0	2	2	5	6	7	−2
	Jun	2	1	2	1	3	3	4	5	6	1
64	Dec	−7	−9	−12	−16	−17	−18	−16	−14	−12	−30
	Jan/Nov	−7	−9	−12	−16	−16	−16	−13	−10	−8	−29
	Feb/Oct	−6	−8	−11	−14	−13	−10	−4	1	4	−26
	Mar/Sep	−5	−7	−9	−10	−7	−4	2	7	11	−20
	Apr/Aug	−3	−4	−4	−4	−1	1	5	9	11	−11
	May/Jul	1	0	1	0	3	4	6	8	10	−3
	Jun	2	2	2	2	4	4	6	7	9	0

(1) Corrections in this table are in degrees F. The correction is applied directly to the CLTD for a wall or roof as given in Tables 3.10 and 3.8.
(2) The CLTD correction given in this table is *not* applicable to Table 3.23, Cooling Load Temperature Differences for Conduction through Glass.
(3) For South latitudes, replace Jan. through Dec. by July through June.

Table 3.13 CLTD Corrections for Inside and Outside Design Conditions, F

a) Correction for inside design temperature, F (See Note 1)

Inside db, F	72	73	74	75	76	77	78	79	80
Correction, F	6	5	4	3	2	1	0	−1	−2

b) Correction for outside design conditions, F (See Note 2)

Design Outside db, F	Daily Range, F 10	12	14	16	18	20	22	24	26	28	30	32	34	36
88	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15
90	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13
92	2	1	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11
94	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7	−8	−9
96	6	5	4	3	2	1	0	−1	−2	−3	−4	−5	−6	−7
98	8	7	6	5	4	3	2	1	0	−1	−2	−3	−4	−5
100	10	9	8	7	6	5	4	3	2	1	0	−1	−2	−3
102	12	11	10	9	8	7	6	5	4	3	2	1	0	−1
104	14	13	12	11	10	9	8	7	6	5	4	3	2	1
106	16	15	14	13	12	11	10	9	8	7	6	5	4	3

(1) Correction for inside design = $(78 - T_R)$, where T_R is inside design db temperature, F
(2) Correction for outside design conditions = $(T_o - 85)$, where T_o is outside mean temperature given by

$$T_o = \text{Design outside db} - 1/2 \times \text{Daily Range}$$

Normally, the design outside db is taken from Column 6, 2 1/2%, Table 2.1 and the daily range is taken from Column 7, Table 2.1.

Table 3.14A Overall Coefficients of Heat Transmission (*U*-Factor) of Windows and Skylights, Btu/(hr·ft²·F)

Description	Exterior Vertical Panels: Summer**, No Indoor Shade	Summer**, Indoor Shade***	Winter*, No Indoor Shade	Winter*, Indoor Shade***	Exterior Horizontal Panels (Skylights): Summer [j]	Winter [i]
Flat Glass [b]						
Single Glass	1.04	0.81	1.10	0.83	0.83	1.23
Insulating Glass, Double [c]						
3/16 in. air space [d]	0.65	0.58	0.62	0.52	0.57	0.70
1/4 in. air space [d]	0.61	0.55	0.58	0.48	0.54	0.65
1/2 in. air space [e]	0.56	0.52	0.49	0.42	0.49	0.59
1/2 in. air space, low emittance coating [f]						
$e = 0.20$	0.38	0.37	0.32	0.30	0.36	0.48
$e = 0.40$	0.45	0.44	0.38	0.35	0.42	0.52
$e = 0.60$	0.51	0.48	0.43	0.38	0.46	0.56
Insulating Glass, Triple [c]						
1/4 in. air space [d]	0.44	0.40	0.39	0.31		
1/2 in. air space [g]	0.39	0.36	0.31	0.26		
Storm Windows						
1 in. to 4 in. air spaces [d]	0.50	0.48	0.50	0.42		
Plastic Bubbles [k]						
Single					0.80	1.15
Double					0.46	0.70

Table 3.14B Adjustment Factors for Various Window and Siding Patio Door Types (Multiply *U*-Values in Part A by These Factors)

Description	Single Glass	Double or Triple Glass	Storm Windows
Windows			
All Glass [h]	1.00	1.00	1.00
Wood Sash; 80% Glass	0.90	0.95	0.90
Wood Sash; 60% Glass	0.80	0.85	0.80
Metal Sash; 80% Glass	1.00	1.20 [m]	1.20 [m]
Sliding Patio Doors			
Wood Frame	0.95	1.00	—
Metal Frame	1.00	1.10 [m]	—

[a] See Table 3.14B for adjustments for various windows and sliding patio doors.
[b] Emittance of uncoated glass surface = 0.84.
[c] Double and triple refer to number of lights of glass.
[d] 0.125-in. glass.
[e] 0.25-in. glass
[f] Coating on either glass surface facing air space; all other glass surfaces uncoated.
[g] Window design: 0.25-in. glass, 0.125-in. glass, 0.25-in. glass.
[h] Refers to windows with negligible opaque areas.
[i] For heat flow up.
[j] For heat flow down.
[k] Based on area of opening, not total surface area.

[m] Values will be less than these when metal sash and frame incorporate thermal breaks. In some thermal break designs *U* values will be equal to or less than those for the glass. Window manufacturers should be consulted for specific data.

*15 mph outdoor air velocity; 0 F outdoor air; 70 F inside air temp natural convection.

**7.5 mph outdoor air velocity; 89 F outdoor air; 75 F inside air natural convection; solar radiation 248.3 Btu/(hr·ft²)

***Values apply to tightly closed venetian and vertical blinds, draperies, and roller shades.

The reciprocal of the above *U*-factors is the thermal resistance, *R*, for each type of glazing. If tightly drawn drapes (heavy close weave), closed Venetian blinds, or closely fitted roller shades are used internally, the additional *R* is approximately 0.29 (hr·ft²·F)/Btu. If miniature louvered solar screens are used in close proximity to the outer fenestration surface, the additional *R* is approximately 0.24 (hr·ft²·F)/Btu.

Table 3.15 U-Factors for Summer Conditions Btu/(hr·ft²·F)

Type*	Velocity of Air Sweeping Window, fpm: Still Air	185	275	365
CL & CL	0.56	0.64	0.66	0.67
HA & CL	0.56	0.64	0.66	0.67
Refl & CL	0.34	0.37	0.37	0.38

*CL = Clear 0.25-in. float; HA = Heat Absorbing 0.25-in. float; Refl. = 0.25-in. reflective float.

Table 3.16 Overall Coefficient of Heat Transmission (U-Factor; Btu/(hr·ft²·F) for Transparent Acrylic and Polycarbonate Sheeting of Vertical Windows

Thickness, in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
U-Factor for Winter Heat Loss[1]					
Single-Glazed	1.06	1.01	0.96	0.88	0.81
Reflective*	—	—	0.88	—	—
Double-Glazed; ¼-in. air space	0.55	0.52	0.49	—	—
Double-Glazed; ½-in. air space	0.47	0.45	0.43	—	—
U-Factor for Summer Heat Gain[2]					
Single-Glazed	0.98	0.93	0.89	0.82	0.76
Reflective*	—	—	0.83	—	—
Double Glazed; ¼-in. air space	0.56	0.53	0.50	—	—
Double-Glazed; ½-in. air space	0.50	0.48	0.45	—	—

[1]15 mph wind velocity.
[2]7.5 mph wind velocity.
*Aluminum metalized polyester film on plastic.

3.3 GLASS SOLAR LOAD

The CLTD concept, as applied to glass, handles only the conduction part of the cooling load. The Solar Heat Gain (SHG), Btu/(hr·ft²), through fenestration is obtained as the product of the Shading Coefficient (SC) of the particular glazing and the Solar Heat Gain Factor (SHGF), Btu/(hr·ft²), of the reference glazing material which is double strength 1/8 in. sheet glass.

$$SHG = SC \times (SHGF) \qquad (3.3)$$

The solar cooling load, q, which lags the solar heat gain, is obtained by the use of the maximum SHGF, $SHGF_{max}$, for the month, latitude and orientation and a conversion factor, the Cooling Load Factor, CLF, thus:

$$q = A \times (SC) \times (SHGF_{max}) \times (CLF) \qquad (3.4)$$

where

q = cooling load due to solar radiation through glass, Btu/hr
A = net glass area of the fenestration, ft²
SC = Shading Coefficient
$(SHGF)_{max}$ = maximum SHGF for the month, latitude and orientation, Btu/(hr·ft²)
CLF = Cooling Load Factor

Table 3.17 Solar Optical Properties and Shading Coefficients of Transparent Plastic Sheeting

Type of Plastic	Transmittance: Visible	Solar	SC
Acrylic			
Clear	0.92	0.85	0.98
Gray Tint	0.16	0.27	0.52
"	0.33	0.41	0.63
"	0.45	0.55	0.74
"	0.59	0.62	0.80
"	0.76	0.74	0.89
Bronze Tint	0.10	0.20	0.46
"	0.27	0.35	0.58
"	0.61	0.62	0.80
"	0.75	0.75	0.90
Reflective*	0.14	0.12	0.21
Polycarbonate			
Clear (0.125-in.)	0.88	0.82	0.98
Gray (0.125-in.)	0.50	0.57	0.74
Bronz (0.125-in.)	0.50	0.57	0.74

*Aluminum metallized polyester film on plastic.

Shading Coefficients for Typical Fenestrations

Table 3.18 gives Shading Coefficients for commonly used types of flat glass. The values are applicable to both sunlit and shaded glass, are based on still air (natural convection) at the inner surface, and are given for either h_o of 0.40 or 3.0 Btu/(hr·ft²·F). The values based on h_o of 4.0 are for 7.5 mph wind at the outer surface; those based on h_o of 3.0 are given for comparison to aid the designer to adjust the SC for outside wind conditions lower than 7.5 mph.

If solar-reflective films or coatings are used, the shading coefficient will be reduced. When heat-absorbing glass is used in double glazing, it should be installed in the outer light, so that the absorbed heat can be more readily dissipated back to the outside air.

Load Source	Equation	Reference, Table, Description
Solar	$q = A \times SC \times SHGF \times CLF$	→ Area Net Glass Area Calculated from Plans → Shading Coefficients for Combination of Type of Glass and Type of Shading Tables 3.17-3.22 → Maximum Solar Heat Gain Factor for Specific Orientation of Surface, Latitude and Month Table 3.25 for no external shading Externally shaded Location less than 24 deg N Lat. Table 3.26 Location at or more than 24 deg N Lat. Table 3.25, N orientation → Cooling Load Factor with No Interior Shading Table 3.27 Cooling Load Factor if Interior Shading is Used Table 3.28 For glass areas shaded externally use north orientation with either Table 3.27 or 3.28

Table 3.17 gives shading coefficients and solar transmittance of transparent acrylic and polycarbonate plastic sheeting which can be used for fenestration.

Shading Coefficients for Fenestration with Internal Shading - Draperies, Venetian Blinds and Roller Shades

The Shading Coefficients applicable to some of the more widely used types of internal shading are given in Table. 3.18.

Table 3.18 gives Shading Coefficients for commonly used types of flat glass. The values are applicable to both sunlit and shaded glass, are based on still air (natural convection) at the inner surface, and are given for either h_o of 4.0 or 3.0 Btu/-(hr · ft^2 · F). The values based on h_o of 4.0 are for 7.5 mph wind at the outer surface; those based on h_o of 3.0 are given for comparison to aid the designer to adjust the SC for outside wind conditions lower than 7.5 mph.

It also shows the Shading Coefficients for Venetian blinds and roller shades when used with insulating glass. The first line applies for windows in which both lights are high transmittance glass, while the second line applies when the outer light is heat-absorbing and the inner light is clear glass.

The Shading Coefficient with no interior shading is included for each classification of single and insulating glasses in Table 3.18 in order to give the designer a reference point.

Table 3.19 gives shading coefficients for double glazing with between-glass shading.

For single-glazed fenestration which is shaded on the inside by fabric drapes, the Shading Coefficient can be found by use of Table 3.20 and its accompanying figure, Fig. 3.1. Although flat-fabric properties of reflectance and transmittance are used to enter the figure, the resulting Shading Coefficient as read from Table 3.20 is for the selected glass type in combination with a loose-hanging drape with 100% fullness, i.e., fabric width is twice the width of the window opening. The notes accompanying Table 3.20 describe the use and limitations of the table.

Shading Coefficients for External Louvered Sun Screens

Table 3.21 gives Shading Coefficients for several types of horizontal-louvered sun screens. The definitions of the six groups (Group 1 through Group 6) are given with the table. Note that the Shading Coefficient decreases as the ratio S_H/P increases. (See sketch with Table 3.21.) Actual values of S_H/P, the shadow length per foot of horizontal projection, are given in the left side of Table 3.29. Commercially available sun screens will completely exclude direct solar radiation, but not reflected radiation when the ratio S_H/P exceeds approximattely 0.488 for Groups 1, 2, and 5 or when it exceeds approximately 0.839 for Groups 3, 4 and 6.

Maximum Solar Heat Gain Factor $(SHGF)_{max}$ and CLF

Maximum Solar Heat Gain Factor $(SHGF)_{max}$ is obtained from Table 3.25 for each latitude, month, and surface orientation.

Table 3.27 gives the CLF values for glass without interior shading. Table 3.28 gives the CLF values for glass with interior shading.

Glass Solar Load with Roof Overhangs and/or Side Fins

When exterior shading is uniform over the entire fenestration, as with horizontal-louvered sun screens, Eq. (3.4) may be used directly with the SC obtained from the tables. Non-uniform exterior shading, such as from roof overhangs and/or side fins does not have a special shading coefficient. Instead Eq. (3.4) is used to calculate the solar load separately for the shaded and for the unshaded areas. The $SHGF_{max}$ for the north orientation is to be used for the shaded glass area at latitudes greater than 24 deg. For latitudes 24 deg and lower the $SHGF_{max}$ is obtained from Table 3.26.

It is not possible to use the north orientation as a shaded surface below 24 deg N lat.; during a part of the year the northern surface in those locations receives direct solar radiation. For shaded skylights use the values for horizontal glass from Table 3.26 for all latitudes. *When the SHGF for externally shaded areas is used, the CLF for the north orientation should be used regardless of the actual orientation*.

The areas, shaded and unshaded, depend upon the location of the shadow line on a surface in the plane of the glass. Thus, they depend on the shadow length per foot of horizontal projection, SH/P, and on the shadow width per foot of vertical side projection SW/P_V. SH/P is given on the left side and SW/P_V on the right side of Table 3.29. Fig. 3.5 gives the physical description for external shading.

Calculation of Glass Solar Loads and Use of Related Tables

If there is any doubt regarding the exterior shading or if the glass area is covered by exterior shade for only short durations during the day, the $SHGF_{max}$ for sunlit-glass should be used. The $SHGF_{max}$ for shaded glass should only be used for that glass which is shaded due to overhangs or fins. For all other glass areas the Cooling Load Factor (CLF) accounts for the shading due to the relative rotation of the earth and sun.

Examples 3.9 - 3.11 show calculations of glass solar loads, using tables for various factors in Eqs. (3.4) or (3.5). Each example states the type, if any, of interior and/or exterior shading, type of glazing, and month, latitude and orientation. Example 3.9 emphasizes interior shading and Example 3.10 emphasizes exterior shading.

EXAMPLE 3.9 — Glass Solar Cooling Load, Facing South, Interior shading, July 21, 40 Deg North Latitude

Determine the maximum solar cooling load, $(q/A)_{max}$, Btu/(hr·ft²), for the following conditions:

Glass facing south
July 21 at 40 deg N lat
Concrete and grass surrounds building
Interior room construction and furnishings are lightweight

a. Sunlit double strength single clear glass (1/8 in. thick) with medium Venetian blinds, interior shading

b. Sunlit double insulating glass window
Heat absorbing gray-tinted outer glass (1/4 in.)
3/16 in. air space
Clear inner glass (1/4 in)
Outside film coefficient for summer low wind velocity
Unshaded outside and inside

c. Sunlit single glass, tinted for heat absorption, 1/4 in. thickness
Drapes of 100% fullness

EXAMPLE 3.9a

Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$	Table 1.2	Glass Solar Cooling Load Equation
$SHGF_{max}$	Table 3.25	At 40 deg lat for south-facing glass in July, the $SHGF_{max}$ = 109 Btu/(hr · ft^2)
SC	Table 3.18	**Type Glass** / **Nom. Thickness** / **Venetian Blinds Medium** Clear / 3/32 to 1/4 / 0.64 SC = 0.64

Item	Table	Explanation and Notes
CLF	Table 3.28	CLF_{max} is needed since $(q/A)_{max}$ is desired **Facing** **Solar Time, h** S . . . 11 12 13 . . . 0.75 0.83 0.80 $CLF_{max} = 0.83$
$(q/A)_{max}$		$(q/A)_{max} = SC \times (SHGF)_{max} \times (CLF)_{max}$ $= 0.64\ (109)\ (0.83)$ $= 57.9\ Btu/(hr \cdot ft^2)$

EXAMPLE 3.9b

Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$	Table 1.2	Glass Solar Cooling Load Equation
$SHGF_{max}$	Table 3.25	$SHGF_{max} = 109\ Btu/(hr \cdot ft^2)$, as in Part a above
SC	Table 3.18	For low wind velocity in summer, use $h_o = 3.0$. For insulating glass with a heat absorbing glass outer light and a clear inner light each - 1/4 in. with a 3/16 in. air space (Note d), the SC = 0.58
CLF	Table 3.27	Without interior shading CLF_{max} is needed since $(q/A)_{max}$ is desired **Facing** **Room Const.** **Solar Time, *h*** S L . . . 12 13 14 15 . . . 0.59 0.65 0.65 0.59 $CLF_{max} = 0.65$
$(q/A)_{max}$		$(q/A)_{max} = SC \times (SHGF_{max}) \times (CLF)_{max}$ $= 0.58\ (109)\ (0.65)$ $= 41.1\ Btu/(hr \cdot ft^2)$

EXAMPLE 3.9c

Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$	Table 1.2	Glass Solar Cooling Load Equation
$SHGF_{max}$	Table 3.25	$SHGF_{max} = 109\ Btu/(hr \cdot ft^2)$, as in Part a
SC	Table 3.20	Note 1 Satisfied, 100% fullness Note 3 To be followed If the fabric transmittance and fabric reflectance are not generally known or not conveniently available, use some average value. In this case assume index letter, *E*. **Glazing** / **SC for Index Letter** Single Glass 1/4 in. heat absorbing: *E* 0.46 SC = 0.46
CLF	Table 3.28	$CLF_{max} = 0.83$, as in Part a
$(q/A)_{max}$		$(q/A)_{max} = SC \times (SHGF)_{max} \times (CLF)_{max}$ $= 0.46\ (109)\ (0.83)$ $= 41.6\ Btu/(hr \cdot ft^2)$

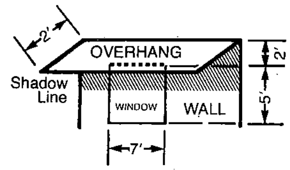
EXAMPLE 3.10 — Glass Solar Cooling Load, Facing South, External Shading, July 21, 40 Deg North Latitude

Determine the maximum solar cooling load, q_{max}, Btu/hr, given the following conditions:

Glass facing south
July 21 at 40 deg N lat.
Concrete and grass around the building
Room construction — light

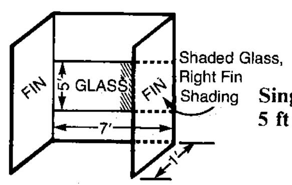
a. Single clear glass (1/8 in.)
Unshaded inside, 5 ft high × 7 ft wide glass area
Louvered sun screens on the outside; dark color and 17 louvers per in.

b. Clear sheet glass, unshaded inside with exterior shading
Roof overhang, 2 ft horizontal projection



Single light of glass
5 ft high × 7 ft wide, flush with outer wall
Top of window 2 ft below overhang

c. Single 1/4 in. tinted glass, unshaded inside
Side fin, each side 1 ft projection, in line with glass edge



Single-sheet of glass
5 ft high × 7 ft wide, flush with outer wall

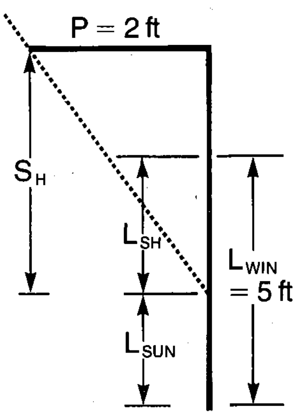
EXAMPLE 3.10a

Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$	Table 1.2	Glass Solar Cooling Load Equation
SC	Table 3.21 Table 3.29	Single clear glass with louvered sun screens of dark color and 17 louvers per in. are Group 3 according to the footnote. Therefore, for $S_H/P = 0.176$ SC = 0.51 0.314 0.42 0.577 0.31 0.839 0.18 and above 0.18 The shadow length in July for 40 deg N lat reaches a minimum value of 2.7 at noon. Since this is greater than 0.839, the SC is 0.18 for the total day.
$SHGF_{max}$	Table 3.25	At 40 deg N lat. and for a south facing orientation, the $SHGF_{max} = 109\ Btu/(hr \cdot ft^2)$
CLF	Table 3.27	Since the area, Shading Coefficient and Maximum Solar Heat Gain Factors are all constant, the solar cooling load through the glass varies only with the CLF. For glass without interior shading and facing south, and for a light room construction Solar time, hr = 12 13 14 15 CLF = . . . 0.59 0.65 0.65 0.59
q_{max}		$q_{max} = (5 \times 7)\ (0.18)\ (109)\ (0.65)$ $= 446.4\ Btu/hr$

EXAMPLE 3.10b

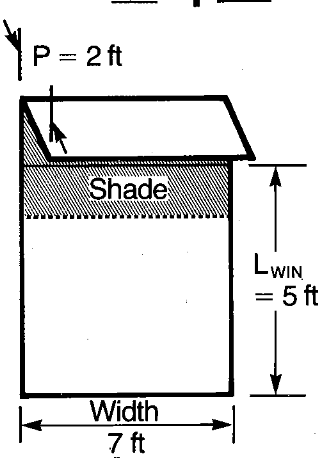
Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$		Solar Cooling Load Through Glass calculated separately for unshaded and shaded glass
Shadow limits of SH/*P*		Shadow length necessary for top of glass S_H/P = 2 ft down/2 ft projection = 1 To completely shadow the glass: S_H/P = 7 ft down/2 ft projection = 3.5
Actual Shading Length of Window in Sun L_{SUN} Length of Window in Shade L_{SH}	Table 3.29	The shadow length, S_H/P, for a south facing projection at 40 deg N lat in July is

Time, AM	S_H/P	Time, PM
8	14.3	4
9	4.3	3
10	3.3	2
11	2.9	1
12	2.7	12



Since the lowest value of 2.7 is greater than 1, a portion of the glass is always shaded. The total window is shaded until almost 10:00 AM when S_H/P drops back to 3.3 compared to 3.5. Since the south orientation is symmetric, the window is again completely shaded shortly after 2:00 PM solar time. Between 10:00 AM and 2:00 PM, it is partially shaded.

At 12 noon
Actual S_H = 2.7 × 2 ft projection = 5.4 ft down



Glass unshaded = 7 ft − 5.4 ft = 1.6

Glass area unshaded = 1.6 × 7 = 11.2 ft²

Glass area shaded = (5 × 7) − 11.2 = 23.8 ft²

Time,	10	11	12	13	14
S_H/P	3.3	2.9	2.7	2.9	3.3
L_{sun}	0.4	1.2	1.6	1.2	0.4
L_{sh}	4.6	3.8	3.4	3.8	4.6
A_{sun}	2.8	8.4	11.2	8.4	2.8
A_{sh}	32.2	26.6	23.8	26.6	32.2

Item	Table	Explanation and Notes
A_{sunlit} A_{shaded}		
SC	Table 3.18	For single, clear glass (assuming standard double strength (DS) glass) SC = 1.0
CLF	Table 3.27	
	Unshaded	10 11 12 13 14 (s) CLF 0.34 0.48 0.59 0.65 0.65
	Shaded	(N) CLF 0.63 0.71 0.76 0.80 0.82

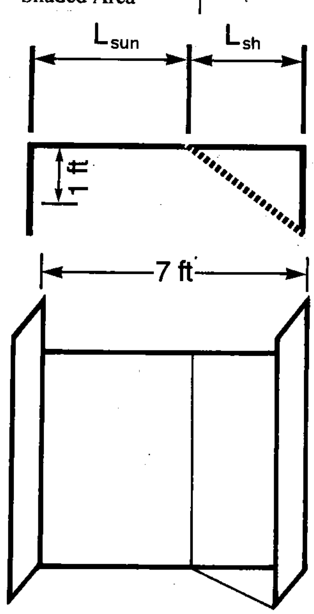
Item	Table	Explanation and Notes
$SHGF_{max}$ Sunlit		From Part a $SHGF_{max}$ = 109 Btu/(hr·ft²)
$SHGF_{max}$ Shaded	Table 3.25	For latitudes greater than 24 deg use north facing for shaded glass $SHGF_{max}$ = 38 Btu/(hr·ft²)
Cooling Load		**Unshaded** $q = A \times SC \times SGHF \times CLF$ $= A\ (1.0)\ (109) \times CLF$ $= 109 \times A \times CLF$ **Shaded** $q = A\ (1.0)\ (38) \times CLF$ $= 38 \times A \times CLF$ Since shaded areas are symmetric about noon but the CLF is greater in the afternoon, the load calculation will be made for the afternoon hours.

		12	13	14	Cooling Load Btu/hr 12	13	14
Unshaded	A	11.2	8.4	2.8			
	CLF	0.59	0.65	0.65	720	595	198
Shaded	A	23.8	26.6	32.2			
	CLF	0.76	0.80	0.82	687	809	1003
Total Btu/hr					1407	1404	1201

q_{max} = 1407 Btu/hr at 12 hr

EXAMPLE 3.10c

Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$		Solar Cooling Load Through Glass calculated separately for unshaded and shaded glass
SC	Table 3.1_	Since the fins surround the window, assume a low summer wind velocity across the window and h_o = 3.0. The SC for 1/4 in. tinted windows is then 0.73 with no interior shading
Sunlit and Shaded Area		Since the fins on each side are located at the edge of the window the shaded width produced by the fin is also the shaded part of the window



$L_{sh} = S_W$

Since P_v = 1 ft

$L_{sh} = (S_W/P_V) \times 1$ ft

L_{sun} = 7 ft. − L_{sh}

The shaded areas are tabulated below:

Left fin	16 hr	15	14	13	12
Right fin	8 hr	9	10	11	12
S_W/P_v	20.3	4.0	1.8	0.8	0
L_{sh}	0	4.0	1.8	0.8	0
L_{sun}	7	3.0	5.2	6.2	7
A_{sh}	35	20.0	9.0	4.0	0
A_{sun}	0	15.0	26.0	31.0	35

Item	Table	Explanation and Notes
$SHGF_{max}$ Unshaded	Table 3.25	$SHGF_{max} = 109$ Btu/(hr·ft^2) as in Part b
$SHGF_{max}$ Shaded	Table 3.25	$SHGF_{max} = 38$ Btu/(hr·ft^2) as in Part b
q sunlit		$q = A \times SC \times SHGF \times CLF$ $= (A)(0.73)(109)(CLF)$ $= 80 \times A \times CLF$
q shaded		$q = (A)(0.73)(38)(CLF)$ $= 28 \times A \times CLF$
CLF	Table 3.27	Time 10 11 12 13 14 15 Un- shaded CLF 0.34 0.48 0.59 0.65 0.65 0.59 Shaded CLF 0.63 0.71 0.76 0.80 0.82 0.82
		Since the CLF is greater in the afternoon, once again make the calculation for 12, 13 and 14 hr. The left fin will be creating the shadow in the afternoon.

Item	Time	12	13	14	Cooling Load (Btu/hr) 12	13	14
Total Cooling Load, q, for solar load through glass	Unshaded						
	A	35.0	31.0	26.0			
	CLF	0.59	0.65	0.65	1652	1612	1352
	Shaded						
	A	0.0	4.0	9.0			
	CLF	0.76	0.80	0.82	0	90	207
	Total				1652	1702	1559

The combined effect of the peak CLF at 13 hr and the smaller shaded glass near noon creates the peak solar cooling load at 13 rather than noon or 14 hr in this case.

If there were only the left fin present, the glass would have received direct sunlight up until 13 hr. Part of the load which keeps the CLF at 0.65 is due to solar heat gain from earlier hours. A more conservative calculation would be to use the full glass area as sunlit. Then the cooling load at 13 and 14 hr would be:

$$q_{13} = 80 \times 35 \times 0.65 = 1820 \text{ Btu/hr}$$
$$q_{14} = 80 \times 35 \times 0.65 = 1820 \text{ Btu/hr}$$

In this case the peak glass solar load would be approximately 10% higher at 13 and about 16% higher at 14 hr.

Example 3.11 — Calculation of Glass Solar Cooling Load Through Draped, Insulating Glass, Patio Doors Opening to Shaded Balcony of an Apartment House

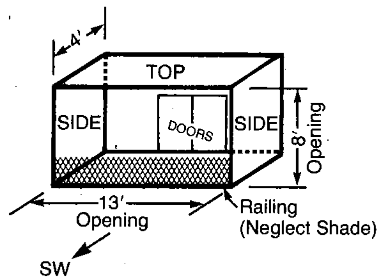
Calculate the glass solar cooling load through patio doors under the following conditions:

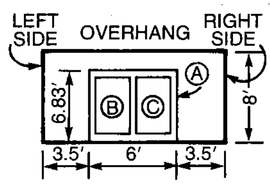
Externally shaded apartment house balcony
Insulating glass patio doors, wood frame, facing southwest
Drapes, 100% fullness, and assume fabric reflectance of 0.50, fabric transmittance of 0.15
Location: Chicago, IL
Month and Time: July 21, 6 PM, DST
Medium room construction

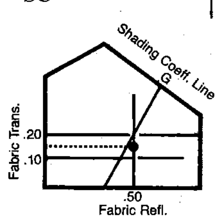
Door unit size centered on balcony width

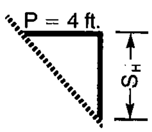
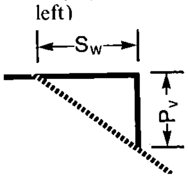
Overall unit size: 6 ft wide by 6.83 ft high.

A. Wood frame, overlap at centers
B. Glass 32 in. × 74 in. clear opening
C. Glass 32 in. × 74 in. clear opening
Each panel is 1/4 in. bronze-tinted outer, 1/4 in. air space, 1/4 in. clear inner





Item	Table	Explanation and Notes
$q = A \times SC \times SHGF \times CLF$	Table 1.2	Glass Solar Cooling Load is applied separately to shaded and unshaded glass $q = q_{unshaded} + q_{shaded}$
Latitude	Table 2.1	For Chicago, IL, Column 1 lists a latitude of 42 deg at the O'Hare Airport weather station
Glass Areas		Each pane A = (32 in.) (74 in.) $\times$ 1 ft^2/144 in.^{2} = 16.45 ft^2 Total glass $A = 2 \times 16.45 = 32.9$ ft^2 Gross Window Unit = 6 ft $\times$ 6.83 ft = 41.0 ft^2 % Glass = 32.9/41.0 $\times$ 100% = 80.2%
SC 	Table 3.20 Fig. 3.1	Glazing — SC for index letters . . . G Heat absorbing outer and regular in → 0.37 SC = 0.37

Item	Table	Explanation and Notes
Unshaded SHGF	Table 3.25	Since the tables are published for 40 and 44 deg latitudes, check to see if the difference is significant. For southwest in July: SHGF = 170 at 40 deg N lat and SHGF = 179 at 44 deg N lat Interpolate that SHGF = 175 Btu/(hr·ft²) for 42 deg N lat
Shaded SHGF	Table 3.25	Use the north orientation for shaded glass at latitudes greater than 24 deg SHGF = 38 Btu/(hr·ft²) This does not change very much with latitude
CLF	Table 3.28	With interior shading for southwest glass the CLF at 17 hr (5:00 PM) solar time is 0.69 Shaded glass (N) CLF = 0.78
S_H/p (Shade from top of balcony) 	Fig. 3.5, Top Table 3.29 Left Side	Shadow Length, ft per ft projection (S_H/p); Shadow width, ft per ft projection (S_W/P_v) Table 3.29, 40 deg N lat Time (5 PM) 0.7 — 1.3 ← 5 PM Time May and July: 0.9, 0.6, 0.3, 0.1 SW↑ SW↑
S_W/P_v (Shade from side of balcony. Shown right but may be left) 	Fig. 3.5 Lower Tables 3.29 Right Side	Table 3.29, 48 deg N lat Time (5 PM) 0.7 — 1.1 ← 5 PM Time May and July: 0.7, 0.4, 0.1, 0.3 SW↑ SW↑
		The shadow width at 5 PM is produced by the left side of balcony — above the line, in the afternoon. By interpolation, using 42 deg N latitude as one-fourth of way between 40 and 48 deg N lat. $S_H/p = 0.7$ (no interpolation needed) $S_W/P_v = 1.3 - 0.25\,(1.3 - 1.1) = 1.25$ It may be more convenient to use 1.3 without interpolation
S_H and S_W		$S_H = 0.7(4) = 2.80$ ft; $S_W = 1.25(4) = 5.00$ ft

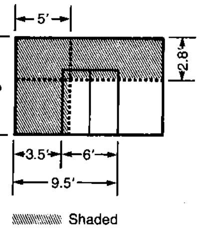
Item	Table	Explanation and Notes
$A_{unshaded}$ and A_{shaded} 		Assume unshaded part of patio door unit has the same percent glass to total glass plus frame as for total door unit. $A_{unshaded} = (8 - 2.8)\,(9.5 - 5)\,(0.8)$ $A_{unsh} = 5.2\,(4.5)\,(0.8) = 18.72\ ft^2$ $A_{shaded} = A_{glass} - A_{unsh} = 32.90 - 18.72$ $A_{sh} = 14.18\ ft^2$
$q_{unshaded}$		$q_{unsh} = [A(SC)\,(SHGF_{max})\,(CLF)]_{unsh}$ $= 18.72(0.37)\,(175)\,(0.69)$ $= 836$ Btu/hr
q_{shaded}		$q_{sh} = [A(SC)\,(SHGF_{max})\,(CLF)]_{sh\ (North)}$ $= 14.18(0.37)\,(38)\,(0.78)$ $= 156$ Btu/hr
Cooling Load due to Solar Load Thru Glass		$q = q_{unsh} + q_{sh} = 836 + 156$ $= 992$ Btu/hr

Table 3.18 Shading Coefficients for Glass Without or With Interior Shading by Venetian Blinds or Roller Shades

	Type of Glass	Nominal Thickness Each Light[a]	Solar Trans.[b]	No Interior Shading		Type of Interior Shading				
						Venetian Blinds		Roller Shades		
								Opaque		Translucent
				$h_o = 4.0$	$h_o = 3.0$	Medium	Light	Dark	Light	Light
SINGLE GLASS	Single									
	Clear	3/32 to 1/4	0.87-0.80	1.00	1.00					
	Clear	1/4 to 1/2	0.80-0.71	0.94	0.95					
	Clear	3/8	0.72	0.90	0.92	0.64	0.55	0.59	0.25	0.39
	Clear	1/2	0.67	0.87	0.88					
	Clear Pattern	1/8 to 9/32	0.87-0.79	0.83	0.85					
	Heat Absorbing Pattern	1/8		0.83	0.85					
	Heat Absorbing[c]	3/16 to 1/4	0.46	0.69	0.73					
	Heat Absorbing Pattern	3/16 to 1/4		0.69	0.73	0.57	0.53	0.45	0.30	0.36
	Tinted	1/8 to 7/32	0.59-0.45	0.69	0.73					
	Heat Absorbing or Pattern		0.44-0.30	0.60	0.64	0.54	0.52	0.40	0.28	0.32
	Heat Absorbing[c]	3/8	0.34	0.60	0.64					
	Heat Absorbing		0.44-0.30							
	or Pattern	1/2	0.24	0.53	0.58	0.42	0.40	0.36	0.28	0.31
	Reflective Coated Glass			0.30		0.25	0.23			
				0.40		0.33	0.29			
				0.50		0.42	0.38			
				0.60		0.50	0.44			
INSULATING GLASS	Double[d]									
	Clear Out	3/32, 1/8	0.71[a]	0.88	0.88	0.57	0.51	0.60	0.25	0.37
	Clear In									
	Clear Out	1/4	0.61[a]	0.81	0.82					
	Clear In									
	Heat Absorbing Out	1/4	0.36[a]	0.55	0.58					
	Clear In					0.39	0.36	0.40	0.22	0.30
	Reflective Coated Glass			0.20		0.19	0.18			
				0.30		0.27	0.26			
				0.40		0.34	0.33			
	Triple									
	Clear	1/4		0.71						
	Clear	1/8		0.80						

[a] Refer to manufacturer's literature for values.
[b] For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.
[c] Refers to grey, bronze and green tinted heat-absorbing glass.
[d] Refers to factory-fabricated units with 3/16, 1/4 or 1/2 in. air space or to prime windows plus storm windows.

Table 3.19 Shading Coefficients for Double Glazing with Between-Glass Shading

Type of Glass	Nominal Each Pane, in.	Solar Trans.[a]		Description of Air Space	Type of Shading		
					Venetian Blinds		Louvered Sun Screen
		Outer Pane	Inner Pane		Light	Medium	
Clear Out Clear In	3/32, 1/8	0.87	0.87	Shade in contact with glass or shade separated from glass by air space.	0.33	0.36	0.43
Clear Out Clear In	1/4	0.80	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.49
Heat-Abs.[b] Out				Shade in contact with glass or shade separated from glass by air space.	0.28	0.30	0.37
Clear In	1/4	0.46	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.41

[a] Refer to manufacturer's literature for exact values.
[b] Refers to grey, bronze, and green tinted heat-absorbing glass.

Table 3.20 Shading Coefficients for Single and Insulating Glass with Draperies

Glazing	Glass Trans.	Glass SC*	SC for Index Letters in Fig. 3.1** A	B	C	D	E	F	G	H	I	J
Single Glass												
1/4 in. Clear	0.80	0.95	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35
1/2 in. Clear	0.71	0.88	0.74	0.70	0.66	0.61	0.56	0.52	0.48	0.43	0.39	0.35
1/4 in. Heat Abs.	0.46	0.67	0.57	0.54	0.52	0.49	0.46	0.44	0.41	0.38	0.36	0.33
1/2 in. Heat Abs.	0.24	0.50	0.43	0.42	0.40	0.39	0.38	0.36	0.34	0.33	0.32	0.30
Reflective Coated	—	0.60	0.57	0.54	0.51	0.49	0.46	0.43	0.41	0.38	0.36	0.33
(See Manufacturers' literature	—	0.50	0.46	0.44	0.42	0.41	0.39	0.38	0.36	0.34	0.33	0.31
for exact values)	—	0.40	0.36	0.35	0.34	0.33	0.32	0.30	0.29	0.28	0.27	0.26
	—	0.30	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.21	0.21	0.20
Insulating Glass (1/2 in. Air Space)												
Clear Out and Clear In	0.64	0.83	0.66	0.62	0.58	0.56	0.52	0.48	0.45	0.42	0.37	0.35
Heat Abs. Out and Clear In	0.37	0.56	0.49	0.47	0.45	0.43	0.41	0.39	0.37	0.35	0.33	0.32
Reflective Coated	—	0.40	0.38	0.37	0.37	0.36	0.34	0.32	0.31	0.29	0.28	0.28
(see Manufacturers' literature	—	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24
for exact values)	—	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15

*For glass alone, with no drapery.
**Shading Coefficient values for the SC lines in Fig. 3.1 for representative glazings. Substitute for SC index letters in Fig. 3.1 values on the line of the glazing selected.

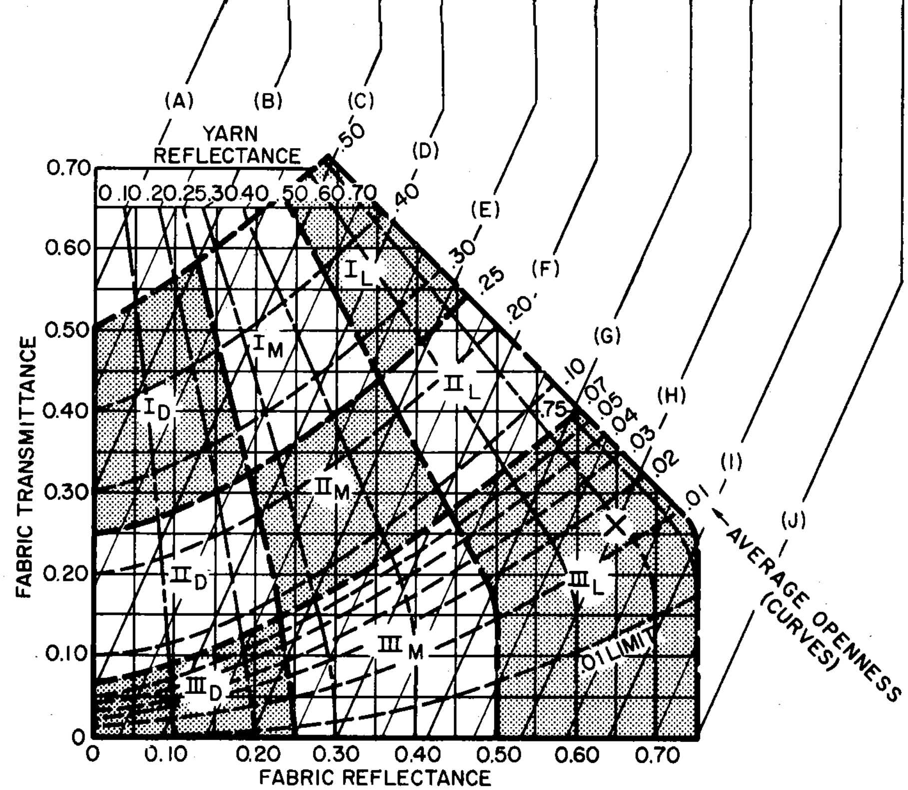
SHADING COEFFICIENT INDEX LETTER
GLAZING INDICATED IN TABLE 3.20
DRAPERIES ADD 100% FULLNESS
(Fabric width two times draped width)

Notes:

1. Shading Coefficients are for draped fabrics.
2. Other properties are for fabrics in flat orientation.
3. Use Fabric Reflectance and Transmittance to obtain accurate Shading Coefficients.
4. Use Openness and Yarn Reflectance or Openness and Fabric Reflectance to obtain the Various Environmental Characteristics, or to obtain Approximate Shading Coefficients.

CLASSIFICATION OF FABRICS
I = Open Weave
II = Semi-open Weave
III = Closed Weave

D = Dark "Color"
M = Medium "Color"
L = Lithy "Color"



To Obtain Fabric Designator (III_L, I_M, etc.): Using coordinates (1) Fabric Transmittance and Fabric Reflectance, or (2) Openness and Yarn Reflectance, find point on chart and note designator for that area. If properties are not known, classification may be approximated by eye using Fig. 3.2, Note 2.

To Obtain Shading Coefficient (SC): (1) Locate drapery fabric as a point using its known properties, or approximate using its fabric classification designator. For greatest accuracy use Fabric Transmittance and Fabric Reflectance. (2) Follow diagonal SC lines to lettered columns in Table 3.20. (3) Find SC on line with the glazing used. *Example:* SC of point "X" is 0.45 with 0.25 in. Clear Single Glass (Column H).
Note: SC are for 45 deg incident angle. For 30 deg or less, add 5% to number found in Table 3.20.

Fig. 3.1 Indoor Shading Properties of Drapery Fabrics

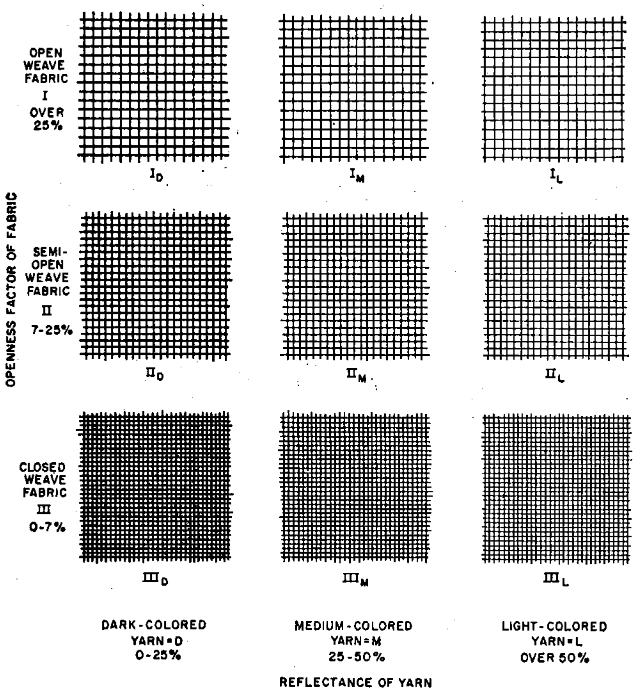


Fig. 3.2 Classification of Drapery Fabrics

Note 1. Designators I_M, III_L indicate *open weave, medium colored yarn,* and *closed weave light colored yarn,* etc.

Note 2. Classes may be approximated by eye. With *closed fabrics*, no objects are visible through the material, and large light or dark areas may show. *Semi-open fabrics* do not permit details to be seen and large objects are clearly defined. *Open fabrics* allow details to be seen and the general view is relatively clear with no confusion of vision. Light, medium, and dark fabrics may be identified by eye normally; keep in mind it is the yarn *color* or shade of light or dark which is being observed.

Example A: A drape with 100% fullness, having a fabric transmittance of 0.20 and a fabric reflectance of 0.40, is used with 0.25-in. glass. What SC should be used?

Solution: From Fig. 3.1, the 0.20 and 0.40 intersection is nearest line F. Table 3.20 assigns SC 0.55 to column F for 0.25-in. clear single glass. Interpolate if necessary; see notes for other uses.

Example B: For the same drapery as in *Example A* the incident angle for which the SC is desired is 30 deg. What SC should be used?

Solution: Add 5% to the value found in *Example A:*

$$SC = (1 + 0.05) \times 0.55 = 0.58$$

Example C: Determine the Fabric Designator for fabric having an openness factor of 0.10 and a yarn reflectance of 0.60.

Solution: On Fig. 3.1, these lines intersect in the area of Designator II_L. Refer also to Fig. 3.2. Fabric is semi-open and light color. Additional information available: probable fabric reflectance is 0.50; and fabric transmittance is 0.35. See text referring to Fig. 3.2.

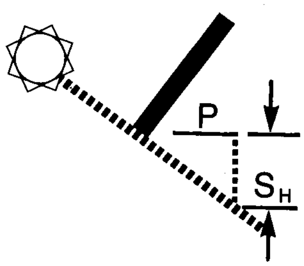


Table 3.21 Shading Coefficients for Louvered Sun Screens

Profile Angle, Deg	S_H/P*	Group 1 Transmittance	Group 1 SC	Group 2 Transmittance	Group 2 SC
10	0.176	0.23	0.35	0.25	0.33
20	0.314	0.06	0.17	0.14	0.23
30	0.577	0.04	0.15	0.12	0.21
40	0.839	0.04	0.15	0.11	0.20
& above	& above				

Profile Angle, Deg	S_H/P*	Group 3 Transmittance	Group 3 SC	Group 4 Transmittance	Group 4 SC
10	0.176	0.40	0.51	0.48	0.59
20	0.314	0.32	0.42	0.39	0.50
30	0.577	0.21	0.31	0.28	0.38
40	0.839	0.07	0.18	0.20	0.30
& above	& above				

Profile Angle, Deg	S_H/P*	Group 5 Transmittance	Group 5 SC	Group 6 Transmittance	Group 6 SC
10	0.176	0.15	0.27	0.26	0.45
20	0.314	0.04	0.11	0.20	0.35
30	0.577	0.03	0.10	0.13	0.26
40	0.839	0.03	0.10	0.04	0.13
& above	& above				

*S_H/P values as given in the left side of Table 3.29.
S_H/P = shadow height (S_H) per foot of projection (P)

Group 1. Black, 23 louvers per inch, width over spacing ratio 1.15.
Group 2. Light color, high reflectance, otherwise same as Group 1.
Group 3. Black or dark color, 17 louvers per inch, w/s ratio 0.85.
Group 4. Light color or unpainted aluminum, high reflectance, otherwise the same as Group 3.
Group 5. Same as Group 1 except two lights 1/4 in. clear glass with 1/2 in. air space.
Group 6. Same as Group 3 except two lights 1/4 in. clear glass with 1/2 in. air space.
U-value = 0.85 Btu/(hr · ft^2 · F) for Groups 1 through 4, when used with single glazing.

Table 3.22 Shading Coefficients for Domed Skylights

Dome	Light Diffuser (Translucent)	Curb (See Fig. 21) Height, in.	Curb (See Fig. 21) Width to Height Ratio	Shading Coefficient	*U*-Factor
Clear $\tau = 0.86$	yes $\tau = 0.58$	0	∞	0.61	0.46
		9	5	0.58	0.43
		18	2.5	0.50	0.40
Clear $\tau = 0.86$	None	0	∞	0.99	0.80
		9	5	0.88	0.75
		18	2.5	0.80	0.70
Translucent $\tau = 0.52$	None	0	∞	0.57	0.80
		18	2.5	0.46	0.70
Translucent $\tau = 0.27$	None	0	∞	0.34	0.80
		9	5	0.30	0.75
		18	2.5	0.28	0.70

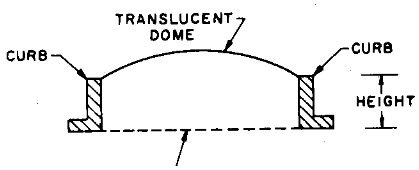


Fig. 3.3 Terminology for Domed Skylights

Table 3.23 Cooling Load Temperature Difference for Conduction Through Glass and Conduction Through Doors

Solar Time, hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CLTD, F	1	0	-1	-2	-2	-2	-2	0	2	4	7	9	12	13	14	14	13	12	10	8	6	4	3	2

Corrections: The values in the table were calculated for an inside temperature of 78 F and an outdoor maximum temperature of 95 F with an outdoor daily range of 21 deg F. The table remains approximately correct for other outdoor maximums (93 - 102 F) and other outdoor daily ranges (16 - 34 deg F), provided the outdoor daily average temperature remains approximately 85 F. If the room air temperature is different from 78 F, and/or the outdoor daily average temperature is different from 85 F, the following rules apply;

(A) For room temperature other than 78 F, see Table 3.13.
(B) For outdoor conditions other than those listed above, see Table 3.13.

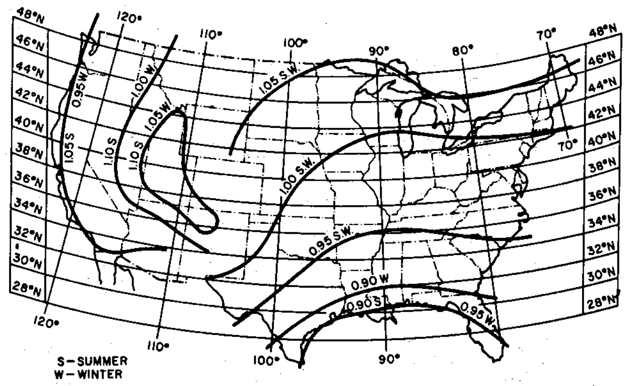


Fig. 3.4 Estimated Atmospheric Clearness Numbers in the U.S. for Nonindustrial Localities

Table 3.24 Solar Reflectances of Various Foreground Surfaces*

Foreground Surface	Incident Angle, deg 20	30	40	50	60	70
New Concrete	0.31	0.31	0.32	0.32	0.33	0.34
Old Concrete	0.22	0.22	0.22	0.23	0.23	0.25
Bright Green Grass	0.21	0.22	0.23	0.25	0.28	0.31
Crushed Rock	0.20	0.20	0.20	0.20	0.20	0.20
Bitumen and Gravel Roof	0.14	0.14	0.14	0.14	0.14	0.14
Bituminous Parking Lot	0.09	0.09	0.10	0.10	0.11	0.12

Table 3.25 Maximum Solar Heat Gain Factor, Btu/(hr · ft²) for Sunlit Glass, North Latitudes

0 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	34	34	88	177	234	254	235	182	118	296
Feb.	36	39	132	205	245	247	210	141	67	306
Mar.	38	87	170	223	242	223	170	87	38	303
Apr.	71	134	193	224	221	184	118	38	37	284
May	113	164	203	218	201	154	80	37	37	265
June	129	173	206	212	191	140	66	37	37	255
July	115	164	201	213	195	149	77	38	38	260
Aug.	75	134	187	216	212	175	112	39	38	276
Sep.	40	84	163	213	231	213	163	84	40	293
Oct.	37	40	129	199	236	238	202	135	66	299
Nov.	35	35	88	175	230	250	230	179	117	293
Dec.	34	34	71	164	226	253	240	196	138	288

4 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	33	33	79	170	229	252	237	193	141	286
Feb.	35	35	123	199	242	248	215	152	88	301
Mar.	38	77	163	219	242	227	177	96	43	302
Apr.	55	125	189	223	223	190	126	43	38	287
May	93	154	200	220	206	161	89	38	38	272
June	110	164	202	215	196	147	73	38	38	263
July	96	154	197	215	200	156	85	39	38	267
Aug.	59	124	184	215	214	181	120	42	40	279
Sep.	39	75	156	209	231	216	170	93	44	293
Oct.	36	36	120	193	234	239	207	148	86	294
Nov.	34	34	79	168	226	248	232	190	139	284
Dec.	33	33	62	157	221	250	242	206	160	277

8 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	32	32	71	163	224	250	242	203	162	275
Feb.	34	34	114	193	239	248	219	165	110	294
Mar.	37	67	156	215	241	230	184	110	55	300
Apr.	44	117	184	221	225	195	134	53	39	289
May	74	146	198	220	209	167	97	39	38	277
June	90	155	200	217	200	141	82	39	39	269
July	77	145	195	215	204	162	93	40	39	272
Aug.	47	117	179	214	216	186	128	51	41	282
Sep.	38	66	149	205	230	219	176	107	56	290
Oct.	35	35	112	187	231	239	211	160	108	288
Nov.	33	33	71	161	220	245	233	200	160	273
Dec.	31	31	55	149	215	246	247	215	179	265

12 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	31	31	63	155	217	246	247	212	182	262
Feb.	34	34	105	186	235	248	226	177	133	286
Mar.	36	58	148	210	240	233	190	124	73	297
Apr.	40	108	178	219	227	200	142	64	40	290
May	60	139	194	220	212	173	106	40	40	280
June	75	149	198	217	204	161	90	40	40	274
July	63	139	191	215	207	168	102	41	41	275
Aug.	42	109	174	212	218	191	135	62	142	282
Sep.	37	57	142	201	229	222	182	121	73	287
Oct.	34	34	103	180	227	238	219	172	130	280
Nov.	32	32	63	153	214	241	243	209	179	260
Dec.	30	30	47	141	207	242	251	223	197	250

16 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	30	30	55	147	210	244	251	223	199	248
Feb.	33	33	96	180	231	247	233	188	154	275
Mar.	35	53	140	205	239	235	197	138	93	291
Apr.	39	99	172	216	227	204	150	77	45	289
May	52	132	189	218	215	179	115	45	41	282
June	66	142	194	217	207	167	99	41	41	277
July	55	132	187	214	210	174	111	44	42	277
Aug.	41	100	168	209	219	196	143	74	46	282
Sep.	36	50	134	196	227	224	191	134	93	282
Oct.	33	33	95	174	223	237	225	183	150	270
Nov.	30	30	55	145	206	241	247	220	196	246
Dec.	29	29	41	132	198	241	254	233	212	234

20 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	29	29	48	138	201	243	253	233	214	232
Feb.	31	31	88	173	226	244	238	201	174	263
Mar.	34	49	132	200	237	236	206	152	115	284
Apr.	38	92	166	213	228	208	158	91	58	287
May	47	123	184	217	217	184	124	54	42	283
June	59	135	189	216	210	173	108	45	42	279
July	48	124	182	213	212	179	119	53	43	278
Aug.	40	91	162	206	220	200	152	88	57	280
Sep.	36	46	127	191	225	225	199	148	114	275
Oct.	32	32	87	167	217	236	231	196	170	258
Nov.	29	29	48	136	197	239	249	229	211	230
Dec.	27	27	35	122	187	238	254	241	226	217

24 Deg										
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	27	27	41	128	190	240	253	241	227	214
Feb.	30	30	80	165	220	244	243	213	192	249
Mar.	34	45	124	195	234	237	214	168	137	275
Apr.	37	88	159	209	228	212	169	107	75	283
May	43	117	178	214	218	190	132	67	46	282
June	55	127	184	214	212	179	117	55	43	279
July	45	116	176	210	213	185	129	65	46	278
Aug.	38	87	156	203	220	204	162	103	72	277
Sep.	35	42	119	185	222	225	206	163	134	266
Oct.	31	31	79	159	211	237	235	207	187	244
Nov.	27	27	42	126	187	236	249	237	224	213
Dec.	26	26	29	112	180	234	247	247	237	199

28 Deg										
	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	25	25	35	117	183	235	251	247	238	196
Feb.	29	29	72	157	213	244	246	224	207	234
Mar.	33	41	116	189	231	237	221	182	157	265
Apr.	36	84	151	205	228	216	178	124	94	278
May	40	115	172	211	219	195	144	83	58	280
June	51	125	178	211	213	184	128	68	49	278
July	41	114	170	208	215	190	140	80	57	276
Aug.	38	83	149	199	220	207	172	120	91	272
Sep.	34	38	111	179	219	226	213	177	154	256
Oct.	30	30	71	151	204	236	238	217	202	229
Nov.	26	26	35	115	181	232	247	243	235	195
Dec.	24	24	24	99	172	227	248	251	246	179

Table 3.25 Maximum Solar Heat Gain Factor, Btu/(hr · ft²) for Sunlit Glass, North Latitudes (continued)

32 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	24	24	29	105	175	229	249	250	246	176
Feb.	27	27	65	149	205	242	248	232	221	217
Mar.	32	37	107	183	227	237	227	195	176	252
Apr.	36	80	146	200	227	219	187	141	115	271
May	38	111	170	208	220	199	155	99	74	277
June	44	122	176	208	214	189	139	83	60	276
July	40	111	167	204	215	194	150	96	72	273
Aug.	37	79	141	195	219	210	181	136	111	265
Sep.	33	35	103	173	215	227	218	189	171	244
Oct.	28	28	63	143	195	234	239	225	215	213
Nov.	24	24	29	103	173	225	245	246	243	175
Dec.	22	22	22	84	162	218	246	252	252	158

36 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	22	22	24	90	166	219	247	252	252	155
Feb.	26	26	57	139	195	239	248	239	232	199
Mar.	30	33	99	176	223	238	232	206	192	238
Apr.	35	76	144	196	225	221	196	156	135	262
May	38	107	168	204	220	204	165	116	93	272
June	47	118	175	205	215	194	150	99	77	273
July	39	107	165	201	216	199	161	113	90	268
Aug.	36	75	138	190	218	212	189	151	131	257
Sep.	31	31	95	167	210	228	223	200	187	230
Oct.	27	27	56	133	187	230	239	231	225	195
Nov.	22	22	24	87	163	215	243	248	248	154
Dec.	20	20	20	69	151	204	241	253	254	136

40 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	20	20	20	74	154	205	241	252	254	133
Feb.	24	24	50	129	186	234	246	244	241	180
Mar.	29	29	93	169	218	238	236	216	206	223
Apr.	34	71	140	190	224	223	203	170	154	252
May	37	102	165	202	220	208	175	133	113	265
June	48	113	172	205	216	199	161	116	95	267
July	38	102	163	198	216	203	170	129	109	262
Aug.	35	71	135	185	216	214	196	165	149	247
Sep.	30	30	87	160	203	227	226	209	200	215
Oct.	25	25	49	123	180	225	238	236	234	177
Nov.	20	20	20	73	151	201	237	248	250	132
Dec.	18	18	18	60	135	188	232	249	253	113

44 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	17	17	17	64	138	189	232	248	252	109
Feb.	22	22	43	117	178	227	246	248	247	160
Mar.	27	27	87	162	211	236	238	224	218	206
Apr.	33	66	136	185	221	224	210	183	171	240
May	36	96	162	201	219	211	183	148	132	257
June	47	108	169	205	215	203	171	132	115	261
July	37	96	159	198	215	206	179	144	128	254
Aug.	34	66	132	180	214	215	202	177	165	236
Sep.	28	28	80	152	198	226	227	216	211	199
Oct.	23	23	42	111	171	217	237	240	239	157
Nov.	18	18	18	64	135	186	227	244	248	109
Dec.	15	15	15	49	115	175	217	240	246	89

48 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	15	15	15	53	118	175	216	239	245	85
Feb.	20	20	36	103	168	216	242	249	250	138
Mar.	26	26	80	154	204	234	239	232	228	188
Apr.	31	61	132	180	219	225	215	194	186	226
May	35	97	158	200	218	214	192	163	150	247
June	46	110	165	204	215	206	180	148	134	252
July	37	96	156	196	214	209	187	158	146	244
Aug.	33	61	128	174	211	216	208	188	180	223
Sep.	27	27	72	144	191	223	228	223	220	182
Oct.	21	21	35	96	161	207	233	241	242	136
Nov.	15	15	15	52	115	172	212	234	240	85
Dec.	13	13	13	36	91	156	195	225	233	65

52 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	13	13	13	39	92	155	193	222	230	62
Feb.	18	18	29	85	156	202	235	247	250	115
Mar.	24	24	73	145	196	230	239	238	236	169
Apr.	30	56	128	177	215	224	220	204	199	211
May	34	98	154	198	217	217	199	175	167	235
June	45	111	161	202	214	210	188	162	152	242
July	36	97	152	194	213	212	195	171	163	233
Aug.	32	56	124	169	208	216	212	197	193	208
Sep.	25	25	65	136	182	218	228	228	227	163
Oct.	19	19	28	80	148	192	225	238	240	114
Nov.	13	13	13	39	90	152	189	217	225	62
Dec.	10	10	10	19	73	127	172	199	209	42

56 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	10	10	10	21	74	126	169	194	205	40
Feb.	16	16	21	71	139	184	223	239	244	91
Mar.	22	22	65	136	185	224	238	241	241	149
Apr.	28	58	123	173	211	223	223	213	210	195
May	36	99	149	195	215	218	206	187	181	222
June	53	111	160	199	213	213	196	174	168	231
July	37	98	147	192	211	214	201	183	177	221
Aug.	30	56	119	165	203	216	215	206	203	193
Sep.	23	23	58	126	171	211	227	230	231	144
Oct.	16	16	20	68	132	176	213	229	234	91
Nov.	10	10	10	21	72	122	165	190	200	40
Dec.	7	7	7	7	47	92	135	159	171	23

60 Deg

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	7	7	7	7	46	88	130	152	164	21
Feb.	13	13	13	58	118	168	204	225	231	68
Mar.	20	20	56	125	173	215	234	241	242	128
Apr.	27	59	118	168	206	222	225	220	218	178
May	43	98	149	192	212	220	211	198	194	208
June	58	110	162	197	213	215	202	186	181	217
July	44	97	147	189	208	215	206	193	190	207
Aug.	28	57	114	161	199	214	217	213	211	176
Sep.	21	21	50	115	160	202	222	229	231	123
Oct.	14	14	14	56	111	159	193	215	221	67
Nov.	7	7	7	7	45	86	127	148	160	22
Dec.	4	4	4	4	16	51	76	100	107	9

Table 3.25 Maximum Solar Heat Gain Factor, Btu/(hr ft²) for Sunlit Glass, North Latitudes (continued)

64 Deg										
	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	3	3	3	3	15	45	67	89	96	8
Feb.	11	11	11	43	89	144	177	202	210	45
Mar.	18	18	47	113	159	203	226	236	239	105
Apr.	25	59	113	163	201	219	225	225	224	160
May	48	97	150	189	211	220	215	207	204	192
June	62	114	162	193	213	216	208	196	193	203
July	49	96	148	186	207	215	211	202	200	192
Aug.	27	58	109	157	193	211	217	217	217	159
Sep.	19	19	43	103	148	189	213	224	227	101
Oct.	11	11	11	40	83	135	167	191	199	46
Nov.	4	4	4	4	15	44	66	87	93	8
Dec.	0	0	0	0	1	5	11	14	15	1

Table 3.26 Maximum Solar Heat Gain Factor For Externally Shaded Glass, Btu/(hr·ft²) (Based on Ground Reflectance of 0.2)

Use for latitudes 0 - 24 deg.
For latitudes greater than 24, use north orientation, Table 3.25
For horizontal glass in shade, use the tabulated values for all latitudes

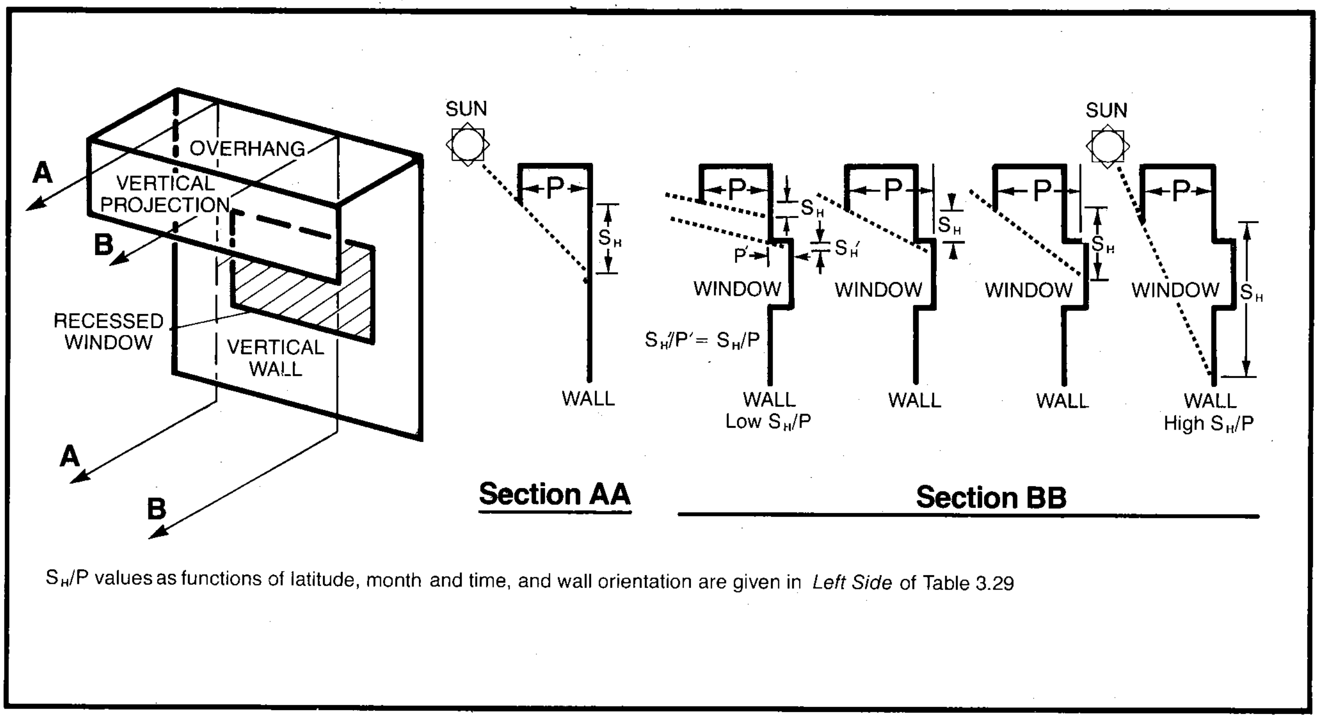
	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	(ALL LATIT.) HOR
Jan.	31	31	31	32	34	36	37	37	38	16
Feb.	34	34	34	35	36	37	38	38	39	16
Mar.	36	36	37	38	39	40	40	39	39	19
Apr.	40	40	41	42	42	42	41	40	40	24
May	43	44	45	46	45	43	41	40	40	28
June	45	46	47	47	46	44	41	40	40	31
July	45	45	46	47	47	45	42	41	41	31
Aug.	42	42	43	45	46	45	43	42	42	28
Sept.	37	37	38	40	41	42	42	41	41	23
Oct.	34	34	34	36	38	39	40	40	40	19
Nov.	32	32	32	32	34	36	38	38	39	17
Dec.	30	30	30	31	32	34	36	37	37	15

Table 3.27 Cooling Load Factors for Glass without Interior Shading, North Latitudes

Fenestration Facing	Room Construction	Solar Time, hr. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	L	0.17	0.14	0.11	0.09	0.08	0.33	0.42	0.48	0.56	0.63	0.71	0.76	0.80	0.82	0.82	0.79	0.79	0.84	0.61	0.48	0.38	0.31	0.25	0.20
N	M	0.23	0.20	0.18	0.16	0.14	0.34	0.41	0.46	0.53	0.59	0.65	0.70	0.74	0.75	0.76	0.74	0.75	0.79	0.61	0.50	0.42	0.36	0.31	0.27
(Shaded)	H	0.25	0.23	0.21	0.20	0.19	0.38	0.45	0.49	0.55	0.60	0.65	0.69	0.72	0.72	0.72	0.70	0.70	0.75	0.57	0.46	0.39	0.34	0.31	0.28
	L	0.06	0.05	0.04	0.03	0.03	0.26	0.43	0.47	0.44	0.41	0.40	0.39	0.39	0.38	0.36	0.33	0.30	0.26	0.20	0.16	0.13	0.10	0.08	0.07
NNE	M	0.09	0.08	0.07	0.06	0.06	0.24	0.38	0.42	0.39	0.37	0.37	0.36	0.36	0.36	0.34	0.33	0.30	0.27	0.22	0.18	0.16	0.14	0.12	0.10
	H	0.11	0.10	0.09	0.09	0.08	0.26	0.39	0.42	0.39	0.36	0.35	0.34	0.34	0.33	0.32	0.31	0.28	0.25	0.21	0.18	0.16	0.14	0.13	0.12
	L	0.04	0.04	0.03	0.02	0.02	0.23	0.41	0.51	0.51	0.45	0.39	0.36	0.33	0.31	0.28	0.26	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05
NE	M	0.07	0.06	0.06	0.05	0.04	0.21	0.36	0.44	0.45	0.40	0.36	0.33	0.31	0.30	0.28	0.26	0.24	0.21	0.17	0.15	0.13	0.11	0.09	0.08
	H	0.09	0.08	0.08	0.07	0.07	0.23	0.37	0.44	0.44	0.39	0.34	0.31	0.29	0.27	0.26	0.24	0.22	0.20	0.17	0.14	0.13	0.12	0.11	0.10
	L	0.04	0.03	0.03	0.02	0.02	0.21	0.40	0.52	0.57	0.53	0.45	0.39	0.34	0.31	0.28	0.25	0.22	0.18	0.14	0.12	0.09	0.08	0.06	0.05
ENE	M	0.07	0.06	0.05	0.05	0.04	0.20	0.35	0.45	0.49	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.23	0.20	0.17	0.14	0.12	0.11	0.09	0.08
	H	0.09	0.09	0.08	0.07	0.07	0.22	0.36	0.46	0.49	0.45	0.38	0.33	0.30	0.27	0.25	0.23	0.21	0.19	0.16	0.14	0.13	0.12	0.11	0.10
	L	0.04	0.03	0.03	0.02	0.02	0.19	0.37	0.51	0.57	0.57	0.50	0.42	0.37	0.32	0.29	0.25	0.22	0.19	0.15	0.12	0.10	0.08	0.06	0.05
E	M	0.07	0.06	0.06	0.05	0.05	0.18	0.33	0.44	0.50	0.51	0.46	0.39	0.35	0.31	0.29	0.26	0.23	0.21	0.17	0.15	0.13	0.11	0.10	0.08
	H	0.09	0.09	0.08	0.08	0.07	0.20	0.34	0.45	0.49	0.49	0.43	0.36	0.32	0.29	0.26	0.24	0.22	0.19	0.17	0.15	0.13	0.12	0.11	0.10
	L	0.05	0.04	0.03	0.03	0.02	0.17	0.34	0.49	0.58	0.61	0.57	0.48	0.41	0.36	0.32	0.28	0.24	0.20	0.16	0.13	0.10	0.09	0.07	0.06
ESE	M	0.08	0.07	0.06	0.05	0.05	0.16	0.31	0.43	0.51	0.54	0.51	0.44	0.39	0.35	0.32	0.29	0.26	0.22	0.19	0.16	0.14	0.12	0.11	0.09
	H	0.10	0.09	0.09	0.08	0.08	0.19	0.32	0.43	0.50	0.52	0.49	0.41	0.36	0.32	0.29	0.26	0.24	0.21	0.18	0.16	0.14	0.13	0.12	0.11
	L	0.05	0.04	0.04	0.03	0.03	0.13	0.28	0.43	0.55	0.62	0.63	0.57	0.48	0.42	0.37	0.33	0.28	0.24	0.19	0.15	0.12	0.10	0.08	0.07
SE	M	0.09	0.08	0.07	0.06	0.05	0.14	0.26	0.38	0.48	0.54	0.56	0.51	0.45	0.40	0.36	0.33	0.29	0.25	0.21	0.18	0.16	0.14	0.12	0.10
	H	0.11	0.10	0.10	0.09	0.08	0.17	0.28	0.40	0.49	0.53	0.53	0.48	0.41	0.36	0.33	0.30	0.27	0.24	0.20	0.18	0.16	0.14	0.13	0.12
	L	0.07	0.05	0.04	0.04	0.03	0.06	0.15	0.29	0.43	0.55	0.63	0.64	0.60	0.52	0.45	0.40	0.35	0.29	0.23	0.18	0.15	0.12	0.10	0.08
SSE	M	0.11	0.09	0.08	0.07	0.06	0.08	0.16	0.26	0.38	0.48	0.55	0.57	0.54	0.48	0.43	0.39	0.35	0.30	0.25	0.21	0.18	0.16	0.14	0.12
	H	0.12	0.11	0.11	0.10	0.09	0.12	0.19	0.29	0.40	0.49	0.54	0.55	0.51	0.44	0.39	0.35	0.31	0.27	0.23	0.20	0.18	0.16	0.15	0.13
	L	0.08	0.07	0.05	0.04	0.04	0.06	0.09	0.14	0.22	0.34	0.48	0.59	0.65	0.65	0.59	0.50	0.43	0.36	0.28	0.22	0.18	0.15	0.12	0.10
S	M	0.12	0.11	0.09	0.08	0.07	0.08	0.11	0.14	0.21	0.31	0.42	0.52	0.57	0.58	0.53	0.47	0.41	0.35	0.29	0.25	0.21	0.18	0.16	0.14
	H	0.13	0.12	0.12	0.11	0.10	0.11	0.14	0.17	0.24	0.33	0.43	0.51	0.56	0.55	0.50	0.43	0.37	0.32	0.26	0.22	0.20	0.18	0.16	0.15
	L	0.10	0.08	0.07	0.06	0.05	0.06	0.09	0.11	0.15	0.19	0.27	0.39	0.52	0.62	0.67	0.65	0.58	0.46	0.36	0.28	0.23	0.19	0.15	0.12
SSW	M	0.14	0.12	0.11	0.09	0.08	0.09	0.11	0.13	0.15	0.18	0.25	0.35	0.46	0.55	0.59	0.59	0.53	0.44	0.35	0.30	0.25	0.22	0.19	0.16
	H	0.15	0.14	0.13	0.12	0.11	0.12	0.14	0.16	0.18	0.21	0.27	0.37	0.46	0.53	0.57	0.55	0.49	0.40	0.32	0.26	0.23	0.20	0.18	0.16
	L	0.12	0.10	0.08	0.06	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.24	0.36	0.49	0.60	0.66	0.66	0.58	0.43	0.33	0.27	0.22	0.18	0.14
SW	M	0.15	0.14	0.12	0.10	0.09	0.09	0.10	0.12	0.13	0.15	0.17	0.23	0.33	0.44	0.53	0.58	0.59	0.53	0.41	0.33	0.28	0.24	0.21	0.18
	H	0.15	0.14	0.13	0.12	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.25	0.34	0.44	0.52	0.56	0.56	0.49	0.37	0.30	0.25	0.21	0.19	0.17
	L	0.12	0.10	0.08	0.07	0.05	0.06	0.07	0.09	0.10	0.12	0.13	0.17	0.26	0.40	0.52	0.62	0.66	0.61	0.44	0.34	0.27	0.22	0.18	0.15
WSW	M	0.15	0.13	0.12	0.10	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.17	0.24	0.35	0.46	0.54	0.58	0.55	0.42	0.34	0.28	0.24	0.21	0.18
	H	0.15	0.14	0.13	0.12	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.19	0.26	0.36	0.46	0.53	0.56	0.51	0.38	0.30	0.25	0.21	0.19	0.17
	L	0.12	0.10	0.08	0.06	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.14	0.20	0.32	0.45	0.57	0.64	0.61	0.44	0.34	0.27	0.22	0.18	0.14
W	M	0.15	0.13	0.11	0.10	0.09	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.19	0.29	0.40	0.50	0.56	0.55	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.21	0.30	0.40	0.49	0.54	0.52	0.38	0.30	0.24	0.21	0.18	0.16
	L	0.12	0.10	0.08	0.06	0.05	0.06	0.07	0.09	0.10	0.12	0.13	0.15	0.17	0.26	0.40	0.53	0.63	0.62	0.44	0.34	0.27	0.22	0.18	0.14
WNW	M	0.15	0.13	0.11	0.10	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.17	0.24	0.35	0.47	0.55	0.55	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.25	0.36	0.46	0.53	0.52	0.38	0.30	0.24	0.20	0.18	0.16
	L	0.11	0.09	0.08	0.06	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.17	0.19	0.23	0.33	0.47	0.59	0.60	0.42	0.33	0.26	0.21	0.17	0.14
NW	M	0.14	0.12	0.11	0.09	0.08	0.09	0.10	0.11	0.13	0.15	0.16	0.17	0.18	0.21	0.30	0.42	0.51	0.54	0.39	0.32	0.26	0.22	0.19	0.16
	H	0.14	0.12	0.11	0.10	0.10	0.10	0.12	0.13	0.15	0.16	0.18	0.18	0.19	0.22	0.30	0.41	0.50	0.51	0.36	0.29	0.23	0.20	0.17	0.15
	L	0.12	0.09	0.08	0.06	0.05	0.07	0.11	0.14	0.18	0.22	0.25	0.27	0.29	0.30	0.33	0.44	0.57	0.62	0.44	0.33	0.26	0.21	0.17	0.14
NNW	M	0.15	0.13	0.11	0.10	0.09	0.10	0.12	0.15	0.18	0.21	0.23	0.26	0.27	0.28	0.31	0.39	0.51	0.56	0.41	0.33	0.27	0.23	0.20	0.17
	H	0.14	0.13	0.12	0.11	0.10	0.12	0.15	0.17	0.20	0.23	0.25	0.26	0.28	0.28	0.31	0.38	0.49	0.53	0.38	0.30	0.25	0.21	0.18	0.16
	L	0.11	0.09	0.07	0.06	0.05	0.07	0.14	0.24	0.36	0.48	0.58	0.66	0.72	0.74	0.73	0.67	0.59	0.47	0.37	0.29	0.24	0.19	0.16	0.13
HOR.	M	0.16	0.14	0.12	0.11	0.09	0.11	0.16	0.24	0.33	0.43	0.52	0.59	0.64	0.67	0.66	0.62	0.56	0.47	0.38	0.32	0.28	0.24	0.21	0.18
	H	0.17	0.16	0.15	0.14	0.13	0.15	0.20	0.28	0.36	0.45	0.52	0.59	0.62	0.64	0.62	0.58	0.51	0.42	0.35	0.29	0.26	0.23	0.21	0.19

Table 3.28 Cooling Load Factors for Glass with Interior Shading, North Latitudes (All Room Constructions)

Fenestration Facing	Solar Time, hr 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	0.08	0.07	0.06	0.06	0.07	0.73	0.66	0.65	0.73	0.80	0.86	0.89	0.89	0.86	0.82	0.75	0.78	0.91	0.24	0.18	0.15	0.13	0.11	0.10
NNE	0.03	0.03	0.02	0.02	0.03	0.64	0.77	0.62	0.42	0.37	0.37	0.37	0.36	0.35	0.32	0.28	0.23	0.17	0.08	0.07	0.06	0.05	0.04	0.04
NE	0.03	0.02	0.02	0.02	0.02	0.56	0.76	0.74	0.58	0.37	0.29	0.27	0.26	0.24	0.22	0.20	0.16	0.12	0.06	0.05	0.04	0.04	0.03	0.03
ENE	0.03	0.02	0.02	0.02	0.02	0.52	0.76	0.80	0.71	0.52	0.31	0.26	0.24	0.22	0.20	0.18	0.15	0.11	0.06	0.05	0.04	0.04	0.03	0.03
E	0.03	0.02	0.02	0.02	0.02	0.47	0.72	0.80	0.76	0.62	0.41	0.27	0.24	0.22	0.20	0.17	0.14	0.11	0.06	0.05	0.05	0.04	0.03	0.03
ESE	0.03	0.03	0.02	0.02	0.02	0.41	0.67	0.79	0.80	0.72	0.54	0.34	0.27	0.24	0.21	0.19	0.15	0.12	0.07	0.06	0.05	0.04	0.04	0.03
SE	0.03	0.03	0.02	0.02	0.02	0.30	0.57	0.74	0.81	0.79	0.68	0.49	0.33	0.28	0.25	0.22	0.18	0.13	0.08	0.07	0.06	0.05	0.04	0.04
SSE	0.04	0.03	0.03	0.03	0.02	0.12	0.31	0.54	0.72	0.81	0.81	0.71	0.54	0.38	0.32	0.27	0.22	0.16	0.09	0.08	0.07	0.06	0.05	0.04
S	0.04	0.04	0.03	0.03	0.03	0.09	0.16	0.23	0.38	0.58	0.75	0.83	0.80	0.68	0.50	0.35	0.27	0.19	0.11	0.09	0.08	0.07	0.06	0.05
SSW	0.05	0.04	0.04	0.03	0.03	0.09	0.14	0.18	0.22	0.27	0.43	0.63	0.78	0.84	0.80	0.66	0.46	0.25	0.13	0.11	0.09	0.08	0.07	0.06
SW	0.05	0.05	0.04	0.04	0.03	0.07	0.11	0.14	0.16	0.19	0.22	0.38	0.59	0.75	0.83	0.81	0.69	0.45	0.16	0.12	0.10	0.09	0.07	0.06
WSW	0.05	0.05	0.04	0.04	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.23	0.44	0.64	0.78	0.84	0.78	0.55	0.16	0.12	0.10	0.09	0.07	0.06
W	0.05	0.05	0.04	0.04	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.31	0.53	0.72	0.82	0.81	0.61	0.16	0.12	0.10	0.08	0.07	0.06
WNW	0.05	0.05	0.04	0.03	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.18	0.22	0.43	0.65	0.80	0.84	0.66	0.16	0.12	0.10	0.08	0.07	0.06
NW	0.05	0.04	0.04	0.03	0.03	0.07	0.11	0.14	0.17	0.19	0.20	0.21	0.22	0.30	0.52	0.73	0.82	0.69	0.16	0.12	0.10	0.08	0.07	0.06
NNW	0.05	0.05	0.04	0.03	0.03	0.11	0.17	0.22	0.26	0.30	0.32	0.33	0.34	0.34	0.39	0.61	0.82	0.76	0.17	0.12	0.10	0.08	0.07	0.06
HOR.	0.06	0.05	0.04	0.04	0.03	0.12	0.27	0.44	0.59	0.72	0.81	0.85	0.85	0.81	0.71	0.58	0.42	0.25	0.14	0.12	0.10	0.08	0.07	0.06



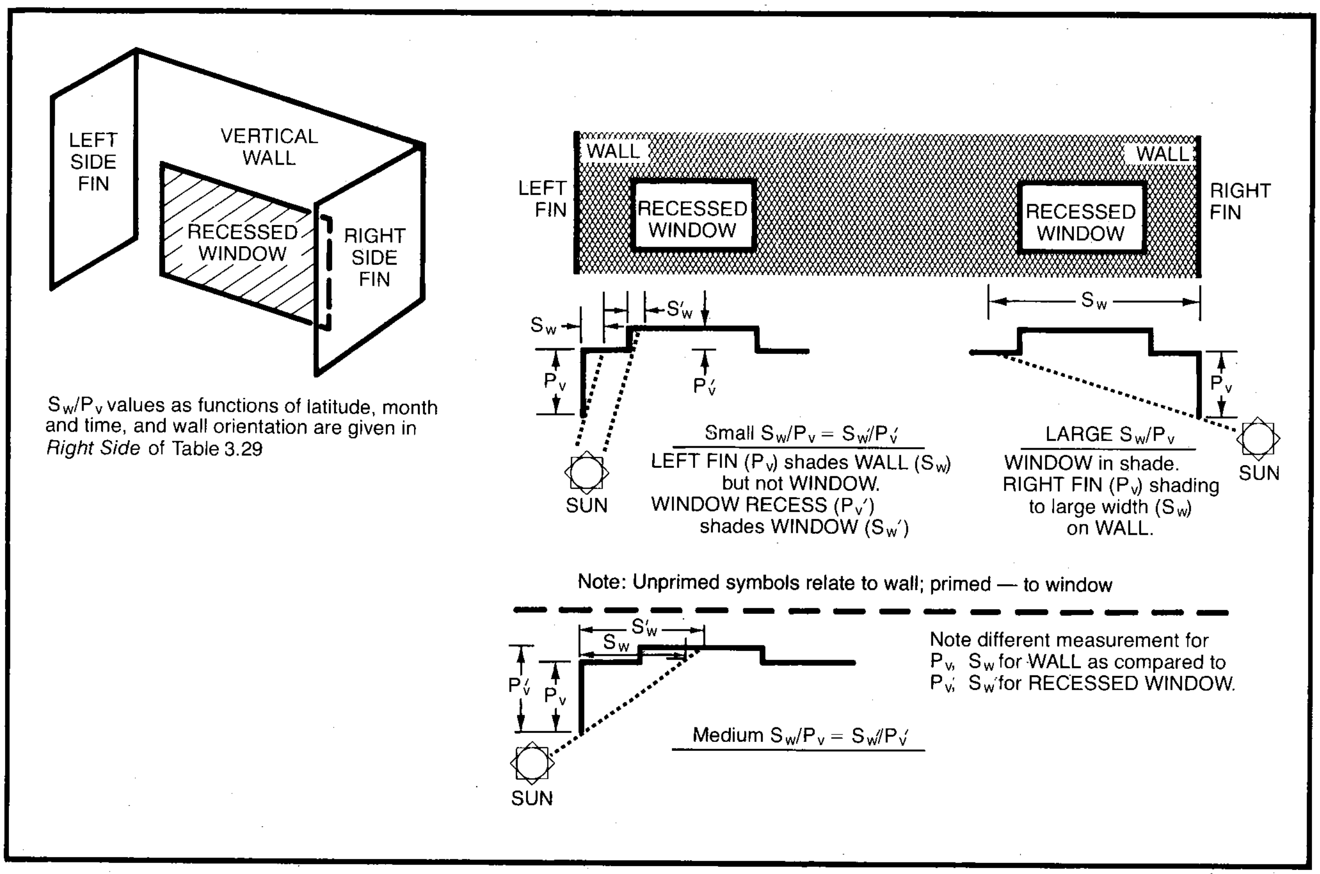


Fig. 3.5 Exterior Shading

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections

DATE	SOLAR TIME AM	HORIZONTAL PROJECTION 0.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 0.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME PM
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	
DEC	7			0.7	0.4	0.3	0.2	0.3	0.3	0.6	8.1					2.6	1.1	0.4	0.0	0.4	0.9	2.2	34.0			5
	8			1.7	0.8	0.6	0.5	0.6	0.7	1.2	7.1					3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.9			4
	9			3.7	1.4	1.0	0.9	0.9	1.0	1.6	5.7					4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.3			3
	10			19.1	2.9	1.7	1.4	1.3	1.5	2.0	4.0					14.1	2.0	0.9	0.3	0.1	0.5	1.2	3.0			2
	11				14.3	3.7	2.4	2.0	2.0	2.2	3.3	8.1					6.8	1.7	0.7	0.3	0.1	0.6	1.3	4.0		1
	12						6.3	3.3	2.5	2.4	2.5	3.3	6.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	7		8.1	0.6	0.3	0.3	0.2	0.3	0.4	0.7					30.9	2.2	0.9	0.4	0.0	0.5	1.1	2.7				5
	8			1.4	0.8	0.6	0.5	0.6	0.8	1.4	57.3					2.4	1.0	0.4	0.0	0.4	1.0	2.4				4
	9			2.9	1.4	1.0	0.9	0.9	1.2	2.0	11.4					3.1	1.2	0.5	0.1	0.3	0.8	1.9	12.1			3
	10			9.5	2.7	1.7	1.4	1.4	1.7	2.4	6.3					6.4	1.6	0.7	0.2	0.2	0.6	1.4	4.1			2
	11				9.5	3.7	2.6	2.1	2.2	2.6	4.0	14.3					4.4	1.4	0.6	0.2	0.2	0.7	1.6	5.9		1
	12						7.1	4.0	2.9	2.7	2.9	4.0	7.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	7		1.3	0.5	0.3	0.3	0.3	0.3	0.5	1.4					5.0	1.5	0.7	0.2	0.2	0.7	1.5	5.1				5
	8		3.3	1.0	0.7	0.6	0.6	0.7	1.0	2.6					5.6	1.6	0.7	0.2	0.2	0.6	1.4	4.5				4
	9		7.1	2.0	1.2	1.0	1.0	1.1	1.6	3.7					7.7	1.7	0.8	0.3	0.1	0.6	1.3	3.7				3
	10		57.3	4.0	2.2	1.7	1.6	1.8	2.4	4.7					35.4	2.2	0.9	0.4	0.0	0.4	1.1	2.6				2
	11			19.1	5.7	3.7	3.1	3.1	3.5	5.1	11.4					6.6	1.7	0.7	0.2	0.2	0.6	1.4	4.0			1
	12						14.3	7.1	5.7	5.1	5.7	7.1	14.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.7	0.4	0.3	0.3	0.3	0.4	0.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4					5
	8		1.5	0.8	0.6	0.6	0.6	0.8	1.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4					4
	9		2.6	1.4	1.1	1.0	1.1	1.4	2.6						2.4	1.0	0.4	0.0	0.4	1.0	2.4					3
	10		4.7	2.5	1.9	1.7	1.9	2.5	4.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4					2
	11		9.5	5.1	4.0	3.7	4.0	5.1	9.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4					1
	12														2.4	1.0	0.4	0.0	0.4	1.0	2.4					12
APR/AUG	7	1.3	0.5	0.3	0.3	0.3	0.3	0.5	1.4					4.7	1.5	0.6	0.2	0.2	0.7	1.5	5.4					5
	8	2.5	1.0	0.6	0.6	0.6	0.7	1.1	3.5					4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.2					4
	9	3.5	1.5	1.1	1.0	1.0	1.2	2.0	8.1					3.4	1.2	0.6	0.1	0.3	0.8	1.8	9.0					3
	10	4.3	2.2	1.7	1.6	1.7	2.2	4.0						2.4	1.0	0.4	0.0	0.4	1.0	2.4						2
	11	4.7	3.3	2.9	3.1	3.7	6.3	28.6						1.3	0.6	0.1	0.3	0.8	1.8	8.7						1
	12	4.7	5.1	7.1	14.3									0.0	0.4	1.0	2.4									12
MAY/JUL	7	0.7	0.4	0.3	0.2	0.3	0.3	0.6	8.1					2.7	1.1	0.5	0.0	0.4	0.9	2.2	30.9					5
	8	1.4	0.8	0.6	0.5	0.6	0.8	1.4						2.4	1.0	0.4	0.0	0.4	1.0	2.4						4
	9	2.0	1.2	0.9	0.9	1.0	1.4	2.9						1.9	0.8	0.3	0.1	0.5	1.2	3.1						3
	10	2.4	1.7	1.4	1.4	1.7	2.7	9.5						1.4	0.6	0.2	0.2	0.7	1.6	6.4						2
	11	2.6	2.2	2.1	2.6	3.7	9.5							0.7	0.2	0.2	0.6	1.4	4.4							1
	12	2.7	2.9	4.0	7.1									0.0	0.4	1.0	2.4									12
JUN	7	0.6	0.3	0.3	0.2	0.3	0.4	0.7						2.2	0.9	0.4	0.0	0.4	1.1	2.6						5
	8	1.2	0.7	0.6	0.5	0.6	0.8	1.7						2.0	0.9	0.3	0.1	0.5	1.2	3.0						4
	9	1.6	1.0	0.9	0.9	1.0	1.4	3.7						1.6	0.7	0.2	0.2	0.6	1.4	4.2						3
	10	2.0	1.5	1.3	1.4	1.7	2.9	19.1						1.2	0.5	0.1	0.3	0.9	2.0	14.1						2
	11	2.2	2.0	2.0	2.4	3.7	14.3							0.6	0.1	0.3	0.7	1.7	6.8							1
	12	2.4	2.5	3.3	6.3									0.0	0.4	1.0	2.4									12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

DATE	SOLAR TIME AM	HORIZONTAL PROJECTION 8.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 8.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME PM
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	
DEC	7			0.6	0.3	0.2	0.2	0.2	0.2	0.4	3.3					2.9	1.1	0.5	0.1	0.3	0.9	2.1	17.7			5
	8			1.7	0.7	0.5	0.4	0.4	0.6	0.9	3.3					3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.6			4
	9			5.1	1.4	0.9	0.8	0.7	0.8	1.2	2.9					6.9	1.7	0.7	0.3	0.1	0.6	1.3	3.9			3
	10				3.1	1.6	1.2	1.1	1.2	1.4	2.5	19.1					2.8	1.1	0.5	0.0	0.4	0.9	2.1	21.0		2
	11				57.3	3.5	2.0	1.5	1.4	1.6	2.1	4.0					26.6	2.2	0.9	0.4	0.0	0.5	1.1	2.7		1
	12						4.3	2.4	1.8	1.7	1.8	2.4	4.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	7		57.3	0.5	0.3	0.2	0.2	0.2	0.3	0.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4				5
	8			1.4	0.7	0.5	0.5	0.5	0.6	1.0	7.1					3.0	1.1	0.5	0.1	0.3	0.9	2.0	14.6			4
	9			3.7	1.4	0.9	0.8	0.8	0.9	1.4	4.3					4.7	1.5	0.6	0.2	0.2	0.7	1.5	5.4			3
	10			57.3	2.9	1.6	1.2	1.2	1.3	1.7	3.3					51.5	2.3	1.0	0.4	0.0	0.4	1.0	2.6			2
	11				19.1	3.5	2.1	1.7	1.6	1.8	2.5	5.7					11.2	1.9	0.8	0.3	0.1	0.5	1.2	3.2		1
	12						4.7	2.6	2.1	1.9	2.1	2.6	4.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	7		1.4	0.4	0.3	0.2	0.2	0.3	0.4	1.0					6.0	1.6	0.7	0.2	0.2	0.6	1.4	4.3				5
	8		5.1	1.1	0.7	0.5	0.5	0.6	0.8	1.8					9.7	1.9	0.8	0.3	0.1	0.5	1.2	3.4				4
	9			2.2	1.2	1.0	0.9	1.0	1.2	2.4						2.4	1.0	0.4	0.0	0.4	1.0	2.5				3
	10			6.3	2.5	1.7	1.4	1.4	1.7	2.7	9.5					4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.1			2
	11				8.1	3.5	2.6	2.2	2.4	2.9	4.7	19.1					3.4	1.2	0.6	0.1	0.3	0.8	1.8	9.0		1
	12						8.1	4.0	3.3	2.9	3.3	4.0	8.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.8	0.4	0.3	0.3	0.3	0.4	0.6	7.1					2.7	1.1	0.5	0.0	0.4	0.9	2.2	26.8				5
	8		1.9	0.9	0.6	0.6	0.6	0.8	1.2	7.1					3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.4				4
	9		4.0	1.6	1.2	1.0	1.0	1.2	2.0	7.1					3.8	1.3	0.6	0.1	0.3	0.8	1.7	7.2				3
	10		11.4	3.3	2.1	1.7	1.7	2.0	2.9	7.1					6.4	1.6	0.7	0.2	0.2	0.6	1.4	4.1				2
	11			11.4	5.1	3.7	3.3	3.5	4.3	7.1	28.6					3.2	1.2	0.5	0.1	0.3	0.8	1.9	11.6			1
	12						19.1	9.5	8.1	7.1	8.1	9.5	19.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	6	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1					4.9	1.5	0.7	0.2	0.2	0.7	1.5	5.1					6
	7	1.7	0.6	0.4	0.3	0.3	0.3	0.5	1.3					5.8	1.6	0.7	0.2	0.2	0.6	1.4	4.4					5
	8	4.0	1.2	0.8	0.6	0.6	0.7	1.0	2.5					6.5	1.6	0.7	0.2	0.2	0.6	1.4	4.1					4
	9	7.1	2.0	1.3	1.0	1.0	1.2	1.7	4.3					6.7	1.7	0.7	0.3	0.1	0.6	1.3	4.0					3
	10	11.4	3.3	2.1	1.8	1.8	2.1	3.1	8.1					6.0	1.6	0.7	0.2	0.2	0.6	1.4	4.3					2
	11	14.3	6.3	4.3	3.7	3.7	4.7	7.1	28.6					3.8	1.3	0.6	0.1	0.3	0.8	1.7	7.5					1
	12	14.3	19.1	19.1	57.3									0.0	0.4	1.0	2.4									12
MAY/JUL	6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0					2.8	1.1	0.5	0.0	0.4	0.9	2.1	21.4					6
	7	0.9	0.5	0.3	0.3	0.3	0.4	0.7	4.3					3.0	1.1	0.5	0.1	0.3	0.9	2.0	14.5					5
	8	1.9	0.9	0.7	0.6	0.6	0.8	1.3	8.1					3.0	1.1	0.5	0.1	0.3	0.9	2.0	14.5					4
	9	2.9	1.5	1.1	1.0	1.1	1.4	2.4	28.6					2.7	1.1	0.5	0.0	0.4	0.9	2.2	26.4					3
	10	3.7	2.2	1.7	1.7	1.8	2.5	5.1						2.1	0.9	0.4	0.1	0.5	1.1	2.8						2
	11	4.3	3.3	2.9	3.1	4.0	6.3	57.3						1.1	0.5	0.1	0.3	0.9	2.0	14.8						1
	12	4.7	5.1	6.3	11.4									0.0	0.4	1.0	2.4									12
JUN	6	0.1	0.1	0.1	0.1	0.1	0.1	0.2						2.3	1.0	0.4	0.0	0.4	1.0	2.5						6
	7	0.8	0.4	0.3	0.3	0.3	0.4	0.8	57.3					2.5	1.0	0.4	0.0	0.4	1.0	2.4						5
	8	1.5	0.8	0.6	0.6	0.6	0.8	1.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4						4
	9	2.2	1.3	1.0	1.0	1.1	1.4	2.9						2.1	0.9	0.4	0.0	0.5	1.1	2.8						3
	10	2.9	2.0	1.6	1.6	1.8	2.6	7.1						1.6	0.7	0.2	0.2	0.6	1.4	4.2						2
	11	3.5	2.7	2.6	2.9	4.0	8.1							0.9	0.3	0.1	0.5	1.1	2.9							1
	12	3.7	4.0	5.1	9.5									0.0	0.4	1.0	2.4									12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

HORIZONTAL PROJECTION 16.0 DEG NORTH LATITUDE — SHADOW LENGTH, FOOT PER FOOT PROJECTION

DATE	SOLAR TIME AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
DEC	7			0.4	0.2	0.1	0.1	0.1	0.2	0.3	1.6		
	8			1.7	0.6	0.4	0.4	0.4	0.4	0.6	2.0		
	9			8.1	1.3	0.8	0.6	0.6	0.7	0.9	1.9		
	10				3.5	1.4	1.0	0.9	0.9	1.1	1.7	6.3	
	11					3.1	1.6	1.2	1.1	1.2	1.5	2.7	28.6
	12						3.3	1.7	1.3	1.2	1.3	1.7	3.3
JAN/NOV	7			0.4	0.2	0.2	0.1	0.2	0.2	0.3	8.1		
	8			1.4	0.6	0.4	0.4	0.4	0.5	0.8	3.3		
	9			5.1	1.3	0.8	0.7	0.6	0.8	1.1	2.5		
	10				3.1	1.5	1.1	1.0	1.0	1.2	2.1	11.4	
	11					3.3	1.7	1.3	1.2	1.3	1.7	3.3	
	12						3.5	2.0	1.5	1.4	1.5	2.0	3.5
FEB/OCT	7		1.5	0.4	0.2	0.2	0.2	0.2	0.3	0.8			
	8		11.4	1.1	0.6	0.5	0.5	0.5	0.7	1.3			
	9			2.7	1.2	0.9	0.8	0.8	1.0	1.7	8.1		
	10			14.3	2.6	1.5	1.2	1.2	1.3	1.9	4.0		
	11				14.3	3.5	2.1	1.7	1.7	2.0	2.7	6.3	
	12						5.1	2.7	2.1	2.0	2.1	2.7	5.1
MAR/SEP	7		0.8	0.4	0.3	0.2	0.3	0.3	0.6	3.5			
	8		2.4	0.9	0.6	0.6	0.6	0.7	1.0	3.5			
	9		7.1	1.9	1.2	1.0	0.9	1.1	1.5	3.5			
	10			4.3	2.2	1.7	1.5	1.6	2.1	3.5	28.6		
	11				7.1	3.5	2.7	2.5	2.7	3.5	6.3		
	12						9.5	5.1	3.7	3.5	3.7	5.1	9.5
APR/AUG	6	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.3				
	7	2.5	0.6	0.4	0.3	0.3	0.4	0.5	1.2				
	8	9.5	1.4	0.8	0.6	0.6	0.7	0.9	2.0				
	9		2.7	1.5	1.1	1.0	1.1	1.5	2.7				
	10		5.7	2.7	2.0	1.8	1.9	2.4	4.0	19.1			
	11		28.6	7.1	4.7	3.7	3.7	4.3	6.3	14.3			
	12						28.6	19.1	14.3	14.3	14.3	19.1	28.6
MAY/JUL	6	0.3	0.1	0.1	0.1	0.1	0.1	0.2	1.7				
	7	1.2	0.6	0.4	0.3	0.4	0.4	0.7	3.1				
	8	2.7	1.1	0.8	0.6	0.7	0.8	1.2	4.3				
	9	5.1	1.9	1.3	1.1	1.1	1.3	2.0	6.3				
	10	8.1	3.3	2.1	1.9	1.9	2.2	3.5	11.4				
	11	11.4	5.7	4.3	3.7	4.0	5.1	8.1	57.3				
	12	14.3	14.3	19.1	28.6								
JUN	6	0.3	0.2	0.1	0.1	0.1	0.2	0.3					
	7	1.1	0.5	0.4	0.4	0.4	0.5	0.8	7.1				
	8	2.1	1.0	0.8	0.6	0.7	0.9	1.4	8.1				
	9	3.5	1.7	1.2	1.1	1.2	1.4	2.4	11.4				
	10	5.1	2.6	2.0	1.8	1.9	2.5	4.3	28.6				
	11	7.1	4.3	3.7	3.5	4.0	5.7	14.3					
	12	8.1	8.1	11.4	19.1								
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE

SIDE PROJECTION 16.0 DEG NORTH LATITUDE — SHADOW WIDTH, FOOT PER FOOT PROJECTION

DATE	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	TIME PM
DEC			3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.2			5
			4.6	1.4	0.6	0.2	0.2	0.7	1.6	5.6			4
			13.9	2.0	0.9	0.3	0.1	0.5	1.2	3.0			3
				3.8	1.3	0.6	0.1	0.3	0.8	1.7	7.4		2
					2.6	1.1	0.5	0.0	0.4	0.9	2.2	32.7	1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV			2.5	1.0	0.4	0.0	0.4	1.0	2.3	54.0			5
			3.6	1.3	0.6	0.1	0.3	0.8	1.8	8.3			4
			7.7	1.7	0.8	0.3	0.1	0.6	1.3	3.7			3
				3.1	1.2	0.5	0.1	0.3	0.8	1.9	12.3		2
					2.4	1.0	0.4	0.0	0.4	1.0	2.4		1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT		7.4	1.7	0.8	0.3	0.1	0.6	1.3	3.8				5
		26.6	2.2	0.9	0.4	0.0	0.5	1.1	2.7				4
			3.3	1.2	0.5	0.1	0.3	0.8	1.9	10.1			3
			11.8	1.9	0.8	0.3	0.1	0.5	1.2	3.1			2
				7.7	1.7	0.8	0.3	0.1	0.6	1.3	3.7		1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP		3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.5				5
		4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.3				4
		8.0	1.8	0.8	0.3	0.1	0.6	1.3	3.6				3
			2.8	1.1	0.5	0.1	0.4	0.9	2.1	19.0			2
				2.5	1.0	0.4	0.0	0.4	1.0	2.3	70.7		1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	5.1	1.5	0.7	0.2	0.2	0.7	1.5	5.0					6
	7.7	1.7	0.8	0.3	0.1	0.6	1.3	3.7					5
	14.6	2.0	0.9	0.3	0.1	0.5	1.1	3.0					4
		2.4	1.0	0.4	0.0	0.4	1.0	2.4					3
		3.1	1.2	0.5	0.1	0.3	0.8	1.9	12.1				2
		7.5	1.7	0.8	0.3	0.1	0.6	1.3	3.8				1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	2.9	1.1	0.5	0.1	0.3	0.9	2.1	17.8					6
	3.5	1.3	0.6	0.1	0.3	0.8	1.8	8.9					5
	4.1	1.4	0.6	0.2	0.2	0.7	1.6	6.5					4
	4.6	1.4	0.6	0.2	0.2	0.7	1.6	5.6					3
	4.5	1.4	0.6	0.2	0.2	0.7	1.6	5.7					2
	3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.4					1
	0.0	0.4	1.0	2.4									12
JUN	2.4	1.0	0.4	0.0	0.4	1.0	2.4						6
	2.8	1.1	0.5	0.0	0.4	0.9	2.1	20.4					5
	3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.3					4
	3.2	1.2	0.5	0.1	0.3	0.8	1.9	11.3					3
	2.8	1.1	0.5	0.1	0.4	0.9	2.1	19.9					2
	1.7	0.8	0.3	0.1	0.6	1.3	3.8						1
	0.0	0.4	1.0	2.4									12
	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

HORIZONTAL PROJECTION 24.0 DEG NORTH LATITUDE — SHADOW LENGTH, FOOT PER FOOT PROJECTION

DATE	SOLAR TIME AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
DEC	7			0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.6		
	8			1.5	0.5	0.3	0.3	0.3	0.3	0.5	1.3		
	9			28.6	1.2	0.7	0.5	0.5	0.5	0.7	1.3		
	10				3.5	1.2	0.8	0.7	0.7	0.8	1.2	3.5	
	11					2.7	1.3	1.0	0.8	0.9	1.1	1.9	11.4
	12						2.4	1.3	1.0	0.9	1.0	1.3	2.4
JAN/NOV	7			0.2	0.1	0.1	0.1	0.1	0.1	0.2	2.6		
	8			1.3	0.5	0.4	0.3	0.3	0.4	0.6	1.9		
	9			8.1	1.2	0.7	0.6	0.5	0.6	0.8	1.7		
	10				3.3	1.3	0.9	0.8	0.8	0.9	1.5	5.1	
	11					2.9	1.4	1.4	1.0	1.0	1.3	2.2	19.1
	12						2.7	1.5	1.1	1.0	1.1	1.5	2.7
FEB/OCT	7		1.4	0.3	0.2	0.2	0.2	0.2	0.2	0.6			
	8			1.1	0.6	0.4	0.4	0.4	0.6	1.0	19.1		
	9			3.3	1.2	0.8	0.7	0.7	0.8	1.2	3.7		
	10				2.7	1.4	1.1	1.0	1.0	1.4	2.5	28.6	
	11				28.6	3.1	1.7	1.4	1.3	1.4	1.9	3.7	
	12						3.7	2.1	1.5	1.4	1.5	2.1	3.7
MAR/SEP	7		0.9	0.4	0.3	0.2	0.2	0.3	0.5	2.2			
	8		3.3	1.0	0.6	0.5	0.5	0.6	0.9	2.2			
	9			2.1	1.2	0.9	0.8	0.9	1.2	2.2			
	10			7.1	2.5	1.6	1.3	1.3	1.5	2.2	5.7		
	11				9.5	3.5	2.2	1.9	1.9	2.2	3.3	9.5	
	12						5.7	3.3	2.5	2.2	2.5	3.3	5.7
APR/AUG	6	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.4				
	7	4.0	0.7	0.4	0.3	0.3	0.4	0.5	1.1				
	8		1.7	0.9	0.7	0.6	0.7	0.9	1.5	28.6			
	9		4.0	1.7	1.2	1.0	1.1	1.3	2.1	7.1			
	10		19.1	3.7	2.1	1.7	1.7	1.9	2.6	5.1			
	11			28.6	6.3	3.7	3.1	2.9	3.3	4.7	11.4		
	12						11.4	6.3	5.1	4.7	5.1	6.3	11.4
MAY/JUL	6	0.4	0.2	0.2	0.1	0.1	0.2	0.3	2.0				
	7	1.7	0.7	0.4	0.4	0.4	0.5	0.7	2.4				
	8	4.7	1.3	0.9	0.7	0.7	0.8	1.2	2.9				
	9	19.1	2.6	1.5	1.2	1.1	1.2	1.7	3.5				
	10		5.7	2.7	2.1	1.9	2.0	2.6	4.3	57.3			
	11		28.6	7.1	4.7	4.0	4.0	4.7	6.3	19.1			
	12						28.6	19.1	14.3	14.3	14.3	19.1	28.6
JUN	6	0.4	0.2	0.2	0.2	0.2	0.2	0.4	11.4				
	7	1.4	0.6	0.5	0.4	0.4	0.5	0.9	4.0				
	8	3.3	1.2	0.8	0.7	0.7	0.9	1.3	4.0				
	9	7.1	2.2	1.4	1.2	1.2	1.3	2.0	4.7				
	10	19.1	4.3	2.5	2.1	2.0	2.1	3.1	6.3				
	11		9.5	5.7	4.3	4.0	4.3	5.7	11.4				
	12								57.3	57.3	57.3		
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE

SIDE PROJECTION 24.0 DEG NORTH LATITUDE — SHADOW WIDTH, FOOT PER FOOT PROJECTION

DATE	SOLAR TIME AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	TIME PM
DEC	7			3.2	1.2	0.5	0.1	0.3	0.8	1.9	11.6			5
	8			5.5	1.6	0.7	0.2	0.2	0.6	1.4	4.6			4
	9			59.9	2.3	1.0	0.4	0.0	0.4	1.0	2.5			3
	10				5.0	1.5	0.7	0.2	0.2	0.7	1.5	5.0		2
	11					3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.2	1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	7			2.7	1.1	0.5	0.0	0.4	0.9	2.2	30.5			5
	8			4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.1			4
	9			15.3	2.0	0.9	0.3	0.1	0.5	1.1	2.9			3
	10				4.1	1.4	0.6	0.2	0.2	0.7	1.6	6.4		2
	11					2.8	1.1	0.5	0.1	0.4	0.9	2.1	20.0	1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	7		9.0	1.8	0.8	0.3	0.1	0.6	1.3	3.5				5
	8			2.5	1.0	0.4	0.0	0.4	1.0	2.3	54.0			4
	9			4.8	1.5	0.7	0.2	0.2	0.7	1.5	5.3			3
	10				2.6	1.1	0.4	0.0	0.4	0.9	2.2	38.7		2
	11				28.2	2.2	0.9	0.4	0.0	0.5	1.1	2.7		1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.2				5
	8		6.1	1.6	0.7	0.2	0.2	0.6	1.4	4.3				4
	9			2.4	1.0	0.4	0.0	0.4	1.0	2.5				3
	10			5.8	1.6	0.7	0.2	0.2	0.6	1.4	4.5			2
	11				5.2	1.5	0.7	0.2	0.2	0.7	1.5	4.9		1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	6	5.3	1.5	0.7	0.2	0.2	0.7	1.5	4.8					6
	7	11.7	1.9	0.8	0.3	0.1	0.5	1.2	3.1					5
	8		2.5	1.0	0.4	0.0	0.4	1.0	2.3	54.7				4
	9		3.9	1.3	0.6	0.1	0.3	0.8	1.7	7.1				3
	10		13.4	2.0	0.9	0.3	0.1	0.5	1.2	3.0				2
	11			8.7	1.8	0.8	0.3	0.1	0.6	1.3	3.5			1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	6	3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.9					6
	7	4.3	1.4	0.6	0.2	0.2	0.7	1.6	6.1					5
	8	6.7	1.7	0.7	0.2	0.1	0.6	1.4	4.0					4
	9	15.7	2.0	0.9	0.3	0.1	0.5	1.1	2.9					3
	10		2.7	1.1	0.5	0.0	0.4	0.9	2.2	25.3				2
	11		6.1	1.6	0.7	0.2	0.2	0.6	1.4	4.3				1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	6	2.5	1.0	0.4	0.0	0.4	1.0	2.3	64.9					6
	7	3.3	1.2	0.5	0.1	0.3	0.8	1.9	10.0					5
	8	4.5	1.4	0.6	0.2	0.2	0.7	1.6	5.7					4
	9	6.5	1.6	0.7	0.2	0.2	0.6	1.4	4.1					3
	10	11.4	1.9	0.8	0.3	0.1	0.5	1.2	3.2					2
	11	76.2	2.3	1.0	0.4	0.0	0.4	1.0	2.5					1
	12						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

HORIZONTAL PROJECTION — 32.0 DEG NORTH LATITUDE — SHADOW LENGTH, FOOT PER FOOT PROJECTION

DATE	SOLAR TIME AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
DEC	8			1.2	0.3	0.2	0.2	0.2	0.2	0.3	0.8		
	9				1.0	0.5	0.4	0.4	0.4	0.5	0.9	14.3	
	10				3.5	1.0	0.6	0.5	0.5	0.6	0.9	2.1	
	11					2.2	1.0	0.7	0.6	0.7	0.8	1.3	6.3
	12						1.8	1.0	0.8	0.7	0.8	1.0	1.8
JAN/NOV	7			0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.6		
	8			1.1	0.4	0.3	0.2	0.2	0.3	0.4	1.2		
	9			28.6	1.0	0.6	0.4	0.4	0.4	0.6	1.1		
	10				3.3	1.1	0.7	0.6	0.6	0.7	1.0	2.9	
	11					2.5	1.2	0.8	0.7	0.8	1.0	1.6	8.1
	12						2.1	1.1	0.8	0.8	0.8	1.1	2.1
FEB/OCT	7		1.3	0.2	0.2	0.1	0.1	0.1	0.2	0.4			
	8			1.0	0.5	0.4	0.3	0.3	0.4	0.8	5.1		
	9			4.0	1.1	0.7	0.6	0.6	0.6	0.9	2.2		
	10				2.7	1.3	0.9	0.8	0.8	1.0	1.7	7.1	
	11					2.7	1.4	1.1	1.0	1.1	1.4	2.5	57.3
	12						2.7	1.5	1.2	1.1	1.2	1.5	2.7
MAR/SEP	7		0.9	0.4	0.3	0.2	0.2	0.3	0.4	1.6			
	8		4.7	1.0	0.6	0.5	0.5	0.5	0.7	1.6			
	9			2.6	1.2	0.8	0.8	0.8	1.0	1.6	8.1		
	10			28.6	2.6	1.5	1.2	1.1	1.2	1.6	3.1		
	11				19.1	3.1	1.9	1.5	1.4	1.6	2.1	4.7	
	12						4.3	2.2	1.7	1.6	1.7	2.2	4.3
APR/AUG	6	0.6	0.2	0.1	0.1	0.1	0.1	0.2	0.5				
	7	9.5	0.8	0.5	0.4	0.3	0.4	0.5	1.0				
	8		2.1	1.0	0.7	0.6	0.6	0.8	1.3	5.7			
	9		8.1	2.0	1.2	1.0	1.0	1.1	1.5	3.5			
	10			5.7	2.4	1.7	1.5	1.5	1.9	2.9	11.4		
	11				8.1	3.5	2.5	2.2	2.2	2.7	4.3	19.1	
	12						7.1	3.7	2.9	2.7	2.9	3.7	7.1
MAY/JUL	6	0.6	0.3	0.2	0.2	0.2	0.2	0.4	2.0				
	7	2.4	0.8	0.5	0.4	0.4	0.5	0.7	2.0				
	8	14.3	1.7	1.0	0.8	0.7	0.8	1.1	2.1				
	9		3.7	1.7	1.3	1.1	1.2	1.4	2.4	11.4			
	10		19.1	3.7	2.2	1.9	1.8	2.1	2.7	6.3			
	11			28.6	6.3	4.0	3.3	3.1	3.5	5.1	11.4		
	12						11.4	6.3	5.1	4.7	5.1	6.3	11.4
JUN	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
	6	0.6	0.3	0.2	0.2	0.2	0.3	0.5	5.1				
	7	2.0	0.8	0.5	0.5	0.5	0.6	0.9	2.9				
	8	6.3	1.5	1.0	0.8	0.8	0.9	1.2	2.7				
	9		3.1	1.7	1.3	1.2	1.3	1.7	3.1				
	10		9.5	3.3	2.2	2.0	2.0	2.4	3.5	11.4			
	11			14.3	5.7	4.0	3.5	3.7	4.7	7.1	28.6		
	12						19.1	9.5	7.1	6.3	7.1	9.5	19.1
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE

SIDE PROJECTION — 32.0 DEG NORTH LATITUDE — SHADOW WIDTH, FOOT PER FOOT PROJECTION

DATE	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	TIME PM
DEC			6.4	1.6	0.7	0.2	0.2	0.6	1.4	4.1			4
				2.6	1.1	0.4	0.0	0.4	1.0	2.3	40.9		3
				6.6	1.7	0.7	0.2	0.2	0.6	1.4	4.1		2
					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.3	1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV			2.7	1.1	0.5	0.0	0.4	0.9	2.2	25.2			5
			4.9	1.5	0.7	0.2	0.2	0.7	1.5	5.1			4
			58.6	2.3	1.0	0.4	0.0	0.4	1.0	2.5			3
				5.4	1.5	0.7	0.2	0.2	0.7	1.5	4.7		2
					3.2	1.2	0.5	0.1	0.3	0.8	1.9	11.4	1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT		10.8	1.9	0.8	0.3	0.1	0.5	1.2	3.2				5
			2.9	1.1	0.5	0.1	0.3	0.9	2.0	15.3			4
			7.3	1.7	0.8	0.3	0.1	0.6	1.3	3.8			3
				3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.3		2
					2.6	1.1	0.4	0.0	0.4	0.9	2.2	38.6	1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP		3.9	1.3	0.6	0.1	0.3	0.8	1.7	7.0				5
		10.4	1.9	0.8	0.3	0.1	0.5	1.2	3.3				4
			3.3	1.2	0.5	0.1	0.3	0.8	1.9	10.5			3
			23.3	2.1	0.9	0.4	0.0	0.5	1.1	2.7			2
				13.2	2.0	0.9	0.3	0.1	0.5	1.2	3.0		1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	5.7	1.6	0.7	0.2	0.2	0.6	1.4	4.5					6
	26.2	2.2	0.9	0.4	0.0	0.5	1.1	2.7					5
		3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.5				4
		8.6	1.8	0.8	0.3	0.1	0.6	1.3	3.5				3
			3.6	1.3	0.6	0.1	0.3	0.8	1.8	7.9			2
				3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.6		1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	3.2	1.2	0.5	0.1	0.3	0.8	1.9	10.7					6
	5.6	1.6	0.7	0.2	0.2	0.6	1.4	4.5					5
	19.8	2.1	0.9	0.4	0.1	0.5	1.1	2.8					4
		3.2	1.2	0.5	0.1	0.3	0.8	1.9	10.7				3
		9.9	1.9	0.8	0.3	0.1	0.5	1.2	3.3				2
			8.3	1.8	0.8	0.3	0.1	0.6	1.3	3.6			1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	1.9	0.8	0.3	0.1	0.5	1.2	3.2						7
	2.7	1.1	0.5	0.0	0.4	0.9	2.2	24.9					6
	4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.3					5
	8.4	1.8	0.8	0.3	0.1	0.6	1.3	3.6					4
		2.5	1.0	0.4	0.0	0.4	1.0	2.3					3
		4.6	1.4	0.6	0.2	0.2	0.7	1.6	5.5				2
			3.5	1.3	0.6	0.1	0.3	0.8	1.8	8.7			1
						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

DATE	SOLAR TIME	HORIZONTAL PROJECTION 40.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 40.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME
	AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	PM
DEC	8			0.7	0.2	0.1	0.1	0.1	0.1	0.2	0.4					7.2	1.7	0.8	0.3	0.1	0.6	1.3	3.9			4
	9				0.8	0.4	0.3	0.2	0.3	0.3	0.6	4.7					2.8	1.1	0.5	0.1	0.4	0.9	2.1	18.7		3
	10				3.1	0.8	0.5	0.4	0.4	0.4	0.6	1.4					8.3	1.8	0.8	0.3	0.1	0.6	1.3	3.6		2
	11					1.8	0.8	0.5	0.5	0.5	0.6	0.9	3.7					3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.8	1
	12						1.3	0.7	0.5	0.5	0.5	0.7	1.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	8			0.8	0.3	0.2	0.1	0.1	0.2	0.2	0.7					5.5	1.6	0.7	0.2	0.2	0.6	1.4	4.6			4
	9				0.8	0.4	0.3	0.3	0.3	0.4	0.8	19.1					2.5	1.0	0.4	0.0	0.4	1.0	2.3	54.9		3
	10				3.1	0.9	0.6	0.4	0.4	0.5	0.7	1.8					6.8	1.7	0.7	0.3	0.1	0.6	1.3	4.0		2
	11					2.0	0.9	0.6	0.6	0.6	0.7	1.1	4.7					3.5	1.3	0.6	0.1	0.3	0.8	1.8	8.8	1
	12						1.5	0.8	0.6	0.6	0.6	0.8	1.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	7		0.9	0.2	0.1	0.1	0.1	0.1	0.1	0.2					12.5	2.0	0.9	0.3	0.1	0.5	1.2	3.1				5
	8			0.9	0.4	0.3	0.3	0.3	0.3	0.6	2.6					3.3	1.2	0.5	0.1	0.3	0.8	1.9	9.7			4
	9			5.7	1.0	0.6	0.5	0.4	0.5	0.7	1.5					12.3	1.9	0.8	0.3	0.1	0.5	1.2	3.1			3
	10				2.7	1.1	0.7	0.6	0.6	0.8	1.2	3.7					4.4	1.4	0.6	0.2	0.2	0.7	1.6	5.9		2
	11					2.4	1.2	0.8	0.8	0.8	1.0	1.7	11.4					3.0	1.1	0.5	0.1	0.3	0.9	2.0	14.8	1
	12						2.1	1.2	0.9	0.8	0.9	1.2	2.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.9	0.3	0.2	0.2	0.2	0.2	0.4	1.2					4.4	1.4	0.6	0.2	0.2	0.7	1.6	5.8				5
	8		11.4	1.0	0.6	0.4	0.4	0.5	0.6	1.2					26.8	2.2	0.9	0.4	0.0	0.5	1.1	2.7				4
	9			3.1	1.1	0.8	0.6	0.6	0.8	1.2	3.7					4.6	1.4	0.6	0.2	0.2	0.7	1.6	5.5			3
	10				2.6	1.3	1.0	0.9	0.9	1.2	2.1	19.1					2.8	1.1	0.5	0.1	0.4	0.9	2.1	18.6		2
	11					2.9	1.5	1.2	1.1	1.2	1.5	2.9						2.4	1.0	0.4	0.0	0.4	1.0	2.4		1
	12						3.1	1.7	1.3	1.2	1.3	1.7	3.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	6	0.8	0.2	0.2	0.1	0.1	0.2	0.2	0.6					6.4	1.6	0.7	0.2	0.2	0.6	1.4	4.1					6
	7		0.9	0.5	0.4	0.3	0.4	0.5	0.9	28.6					2.5	1.0	0.4	0.0	0.4	1.0	2.4					5
	8		2.9	1.0	0.7	0.6	0.6	0.7	1.1	3.1					4.8	1.5	0.7	0.2	0.2	0.7	1.5	5.3				4
	9			2.4	1.2	1.0	0.9	0.9	1.2	2.2						2.5	1.0	0.4	0.0	0.4	1.0	2.4				3
	10			11.4	2.6	1.6	1.3	1.2	1.4	2.0	4.3					8.9	1.8	0.8	0.3	0.1	0.6	1.3	3.5			2
	11				14.3	3.3	2.1	1.7	1.7	1.9	2.6	6.3					8.5	1.8	0.8	0.3	0.1	0.6	1.3	3.5		1
	12						4.7	2.6	2.0	1.9	2.0	2.6	4.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	5	0.1	0.1	0.0	0.0	0.0	0.1	0.1						2.2	0.9	0.4	0.0	0.5	1.1	2.7						7
	6	0.8	0.4	0.3	0.2	0.2	0.3	0.5	1.9					3.6	1.3	0.6	0.1	0.3	0.8	1.8	8.2					6
	7	3.7	0.9	0.6	0.5	0.4	0.5	0.7	1.6					8.6	1.8	0.8	0.3	0.1	0.6	1.3	3.5					5
	8		2.1	1.1	0.8	0.7	0.8	1.0	1.7	14.3					2.8	1.1	0.5	0.0	0.4	0.9	2.1	20.3				4
	9		7.1	2.1	1.3	1.1	1.1	1.2	1.8	4.3					6.7	1.7	0.7	0.2	0.2	0.6	1.4	4.0				3
	10			5.7	2.5	1.8	1.6	1.6	2.0	3.3	14.3					3.5	1.3	0.6	0.1	0.3	0.8	1.8	8.7			2
	11				9.5	3.7	2.6	2.2	2.4	2.9	4.3	19.1					3.8	1.3	0.6	0.1	0.3	0.8	1.7	7.2		1
	12						7.1	4.0	2.9	2.7	2.9	4.0	7.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	5	0.2	0.1	0.1	0.1	0.1	0.1	0.2						1.9	0.8	0.3	0.1	0.5	1.2	3.1						7
	6	0.8	0.4	0.3	0.3	0.3	0.3	0.6	3.7					3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.9					6
	7	2.9	0.9	0.6	0.5	0.5	0.6	0.8	2.2					5.8	1.6	0.7	0.2	0.2	0.6	1.4	4.4					5
	8	57.3	2.0	1.1	0.8	0.8	0.8	1.1	2.1					79.5	2.3	1.0	0.4	0.0	0.4	1.0	2.5					4
	9		5.1	2.0	1.4	1.2	1.2	1.4	2.1	7.1					4.4	1.4	0.6	0.2	0.2	0.7	1.6	5.8				3
	10			4.7	2.5	1.9	1.7	1.8	2.4	4.3	57.3					2.6	1.1	0.4	0.0	0.4	0.9	2.2	34.3			2
	11				8.1	4.0	2.9	2.6	2.7	3.5	6.3	57.3					2.8	1.1	0.5	0.1	0.4	0.9	2.1	18.4		1
	12						9.5	4.7	3.7	3.3	3.7	4.7	9.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

DATE	SOLAR TIME AM	HORIZONTAL PROJECTION 48.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 48.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME PM
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	
DEC	8			0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					7.5	1.7	0.8	0.3	0.1	0.6	1.3	3.8			4
	9				0.4	0.2	0.2	0.1	0.1	0.2	0.3	2.0					3.0	1.2	0.5	0.1	0.3	0.9	2.0	14.0		3
	10				2.5	0.5	0.3	0.2	0.2	0.3	0.4	0.8					10.1	1.9	0.8	0.3	0.1	0.5	1.2	3.3		2
	11					1.2	0.5	0.4	0.3	0.3	0.4	0.6	2.2					3.9	1.3	0.6	0.1	0.3	0.8	1.7	7.0	1
	12						0.9	0.5	0.4	0.3	0.4	0.5	0.9						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	8			0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.3					5.9	1.6	0.7	0.2	0.2	0.6	1.4	4.4			4
	9				0.6	0.3	0.2	0.2	0.2	0.3	0.5	4.7					2.7	1.1	0.5	0.0	0.4	0.9	2.2	23.8		3
	10				2.5	0.6	0.4	0.3	0.3	0.3	0.5	1.1					8.3	1.8	0.8	0.3	0.1	0.6	1.3	3.6		2
	11					1.4	0.6	0.4	0.4	0.4	0.5	0.8	2.9					3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.7	1
	12						1.1	0.6	0.4	0.4	0.4	0.6	1.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	7		0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.1					13.7	2.0	0.9	0.3	0.1	0.5	1.2	3.0				5
	8			0.8	0.3	0.2	0.2	0.2	0.2	0.4	1.5					3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.6			4
	9			8.1	0.8	0.5	0.4	0.3	0.4	0.5	1.0					25.2	2.2	0.9	0.4	0.0	0.5	1.1	2.7			3
	10				2.6	0.9	0.6	0.5	0.5	0.6	0.8	2.2					5.4	1.5	0.7	0.2	0.2	0.6	1.5	4.7		2
	11					2.0	0.9	0.6	0.6	0.6	0.7	1.2	6.3					3.3	1.2	0.5	0.1	0.3	0.8	1.9	10.4	1
	12						1.6	0.9	0.6	0.6	0.6	0.9	1.6						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.9	0.3	0.2	0.2	0.2	0.2	0.3	0.9					5.0	1.5	0.7	0.2	0.2	0.7	1.5	5.0				5
	8			1.0	0.5	0.4	0.4	0.4	0.5	0.9	28.6					2.5	1.0	0.4	0.0	0.4	1.0	2.3	79.4			4
	9			3.7	1.0	0.7	0.6	0.5	0.6	0.9	2.2					6.8	1.7	0.7	0.3	0.1	0.6	1.3	4.0			3
	10				2.7	1.2	0.8	0.7	0.7	0.9	1.4	5.7					3.6	1.3	0.6	0.1	0.3	0.8	1.8	8.0		2
	11					2.5	1.3	0.9	0.8	0.9	1.2	2.0	19.1					2.8	1.1	0.5	0.0	0.4	0.9	2.1	21.4	1
	12						2.4	1.3	1.0	0.9	1.0	1.3	2.4						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	6	1.1	0.3	0.2	0.2	0.2	0.2	0.2	0.6					7.3	1.7	0.8	0.3	0.1	0.6	1.3	3.8					6
	7		1.0	0.5	0.4	0.3	0.4	0.4	0.8	5.7					2.9	1.1	0.5	0.1	0.3	0.9	2.1	17.6				5
	8		4.3	1.1	0.7	0.6	0.6	0.6	0.9	2.1					7.7	1.7	0.8	0.3	0.1	0.6	1.3	3.7				4
	9			2.7	1.2	0.9	0.8	0.8	1.0	1.6	7.1					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.1			3
	10				2.7	1.5	1.1	1.0	1.1	1.4	2.6						2.5	1.0	0.4	0.0	0.4	1.0	2.4			2
	11				57.3	3.1	1.7	1.3	1.3	1.4	1.8	3.5					37.4	2.2	0.9	0.4	0.0	0.4	1.1	2.6		1
	12						3.5	1.9	1.5	1.4	1.5	1.9	3.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	5	0.2	0.1	0.1	0.1	0.1	0.1	0.3						2.2	0.9	0.4	0.0	0.5	1.1	2.6						7
	6	1.1	0.4	0.3	0.3	0.3	0.3	0.5	1.7					4.1	1.4	0.6	0.2	0.2	0.7	1.6	6.5					6
	7	8.1	1.1	0.6	0.5	0.5	0.5	0.7	1.4					18.9	2.1	0.9	0.4	0.1	0.5	1.1	2.8					5
	8		2.9	1.2	0.8	0.7	0.7	0.9	1.3	4.7					4.0	1.3	0.6	0.1	0.3	0.7	1.7	6.8				4
	9		57.3	2.5	1.4	1.0	1.0	1.1	1.4	2.6					75.2	2.3	1.0	0.4	0.0	0.4	1.0	2.5				3
	10			11.4	2.7	1.7	1.4	1.3	1.5	2.1	4.7					9.0	1.8	0.8	0.3	0.1	0.6	1.2	3.5			2
	11				14.3	3.5	2.1	1.8	1.7	2.0	2.7	6.3					9.3	1.8	0.8	0.3	0.1	0.5	1.2	3.4		1
	12						4.7	2.6	2.1	1.9	2.1	2.6	4.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	5	0.3	0.2	0.1	0.1	0.2	0.2	0.4						2.0	0.9	0.3	0.1	0.5	1.2	3.0						7
	6	1.1	0.5	0.3	0.3	0.3	0.4	0.6	2.7					3.4	1.2	0.6	0.1	0.3	0.8	1.8	9.0					8
	7	5.1	1.1	0.6	0.5	0.5	0.6	0.8	1.8					9.9	1.9	0.8	0.3	0.1	0.5	1.2	3.3					5
	8		2.6	1.2	0.9	0.8	0.8	1.0	1.6	8.1					3.2	1.2	0.5	0.1	0.3	0.8	1.9	10.6				4
	9		14.3	2.4	1.4	1.1	1.1	1.2	1.6	3.5					14.0	2.0	0.9	0.3	0.1	0.5	1.2	3.0				3
	10			8.1	2.7	1.8	1.5	1.5	1.7	2.6	6.3					5.8	1.6	0.7	0.2	0.2	0.6	1.4	4.4			2
	11				14.3	3.7	2.4	2.0	2.0	2.2	3.3	8.1					6.5	1.7	0.7	0.2	0.2	0.6	1.4	4.1		1
	12						5.7	3.1	2.4	2.1	2.4	3.1	5.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (continued)

DATE	SOLAR TIME AM	HORIZONTAL PROJECTION 56.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 56.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME PM
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	
DEC	9				0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.4					3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.6		3
	10				1.3	0.2	0.2	0.1	0.1	0.1	0.2	0.4					11.4	1.9	0.8	0.3	0.1	0.5	1.2	3.2		2
	11					0.7	0.3	0.2	0.2	0.2	0.2	0.3	1.1					4.0	1.4	0.6	0.2	0.2	0.7	1.7	6.6	1
	12						0.5	0.3	0.2	0.2	0.2	0.3	0.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	9				0.3	0.1	0.1	0.1	0.1	0.1	0.2	1.6					2.8	1.1	0.5	0.1	0.4	0.9	2.1	18.1		3
	10				1.7	0.4	0.2	0.2	0.2	0.2	0.3	0.6					9.5	1.8	0.8	0.3	0.1	0.5	1.2	3.4		2
	11					0.9	0.4	0.3	0.2	0.2	0.3	0.4	1.7					3.9	1.3	0.6	0.1	0.3	0.8	1.7	7.1	1
	12						0.6	0.3	0.3	0.2	0.3	0.3	0.6						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	8			0.5	0.2	0.1	0.1	0.1	0.1	0.2	0.8					4.0	1.4	0.6	0.2	0.2	0.7	1.7	6.7			4
	9			28.6	0.6	0.3	0.2	0.2	0.3	0.3	0.6					98.5	2.3	1.0	0.4	0.0	0.4	1.0	2.5			3
	10				2.2	0.6	0.4	0.3	0.3	0.4	0.6	1.4					6.5	1.6	0.7	0.2	0.2	0.6	1.4	4.1		2
	11					1.5	0.6	0.5	0.4	0.4	0.5	0.8	3.5					3.5	1.3	0.6	0.1	0.3	0.8	1.8	8.7	1
	12						1.1	0.6	0.5	0.4	0.5	0.6	1.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.8	0.3	0.2	0.2	0.1	0.2	0.2	0.7					5.7	1.6	0.7	0.2	0.2	0.6	1.4	4.5				5
	8			0.9	0.4	0.3	0.3	0.3	0.4	0.7	5.7					2.8	1.1	0.5	0.1	0.4	0.9	2.1	18.6			4
	9			4.7	0.9	0.6	0.4	0.4	0.5	0.7	1.5					10.7	1.9	0.8	0.3	0.1	0.5	1.2	3.2			3
	10				2.6	1.0	0.6	0.6	0.6	0.7	1.0	3.1					4.6	1.4	0.6	0.2	0.2	0.7	1.6	5.6		2
	11					2.1	1.0	0.7	0.6	0.7	0.8	1.4	8.1					3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.5	1
	12						1.7	1.0	0.7	0.7	0.7	1.0	1.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	5	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.4					2.9	1.1	0.5	0.1	0.3	0.9	2.0	15.6					7
	6	1.5	0.3	0.2	0.2	0.2	0.2	0.3	0.6					8.7	1.8	0.8	0.3	0.1	0.6	1.3	3.5					6
	7		1.2	0.5	0.4	0.3	0.3	0.4	0.7	3.1					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.7				5
	8		8.1	1.1	0.6	0.5	0.5	0.6	0.7	1.5					16.8	2.1	0.9	0.3	0.1	0.5	1.1	2.9				4
	9			3.5	1.2	0.8	0.7	0.7	0.8	1.2	3.5					5.0	1.5	0.7	0.2	0.2	0.7	1.5	5.1			3
	10				2.9	1.3	0.9	0.8	0.9	1.1	1.8	9.5					3.2	1.2	0.5	0.1	0.3	0.8	1.9	10.7		2
	11					2.7	1.4	1.1	1.0	1.0	1.3	2.4	28.6					2.7	1.1	0.5	0.0	0.4	0.9	2.2	31.3	1
	12						2.6	1.4	1.1	1.0	1.1	1.4	2.6						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	4	0.0	0.0	0.0	0.0	0.0	0.0	0.1						1.4	0.6	0.2	0.2	0.7	1.6	6.0						8
	5	0.4	0.2	0.2	0.1	0.2	0.2	0.4						2.3	1.0	0.4	0.0	0.4	1.0	2.5						7
	6	1.5	0.5	0.4	0.3	0.3	0.4	0.5	1.5					4.9	1.5	0.7	0.2	0.2	0.7	1.5	5.1					6
	7		1.2	0.6	0.5	0.5	0.5	0.6	1.2	57.3					2.5	1.0	0.4	0.0	0.4	1.0	2.3	87.5				5
	8		4.3	1.2	0.8	0.7	0.6	0.8	1.1	2.7					6.5	1.6	0.7	0.2	0.2	0.6	1.4	4.1				4
	9			3.1	1.4	1.0	0.9	0.9	1.1	1.8	8.1					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.6			3
	10				2.9	1.6	1.2	1.1	1.2	1.5	2.7	57.3					2.5	1.0	0.4	0.0	0.4	1.0	2.3	70.3		2
	11				57.3	3.3	1.8	1.4	1.3	1.4	1.9	3.5					61.7	2.3	1.0	0.4	0.0	0.4	1.0	2.5		1
	12						3.5	2.0	1.5	1.4	1.5	2.0	3.5						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	4	0.1	0.1	0.1	0.1	0.1	0.1	0.5						1.3	0.6	0.1	0.3	0.8	1.7	7.3						8
	5	0.5	0.3	0.2	0.2	0.2	0.3	0.6						2.1	0.9	0.4	0.0	0.5	1.1	2.8						7
	6	1.5	0.6	0.4	0.3	0.4	0.4	0.7	2.2					4.1	1.4	0.6	0.2	0.2	0.7	1.6	6.4					6
	7	19.1	1.3	0.7	0.6	0.5	0.6	0.8	1.5					34.5	2.2	0.9	0.4	0.0	0.4	1.1	2.6					5
	8		3.7	1.3	0.9	0.7	0.7	0.9	1.3	3.7					5.0	1.5	0.7	0.2	0.2	0.7	1.5	5.0				4
	9			2.9	1.4	1.1	1.0	1.0	1.3	2.2	14.3					2.9	1.1	0.5	0.1	0.3	0.9	2.1	16.7			3
	10			57.3	3.1	1.7	1.3	1.2	1.3	1.8	3.5					39.7	2.3	1.0	0.4	0.0	0.4	1.1	2.6			2
	11				28.6	3.5	2.0	1.5	1.5	1.6	2.1	4.3					24.1	2.2	0.9	0.4	0.0	0.5	1.1	2.7		1
	12						4.0	2.2	1.7	1.5	1.7	2.2	4.0						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

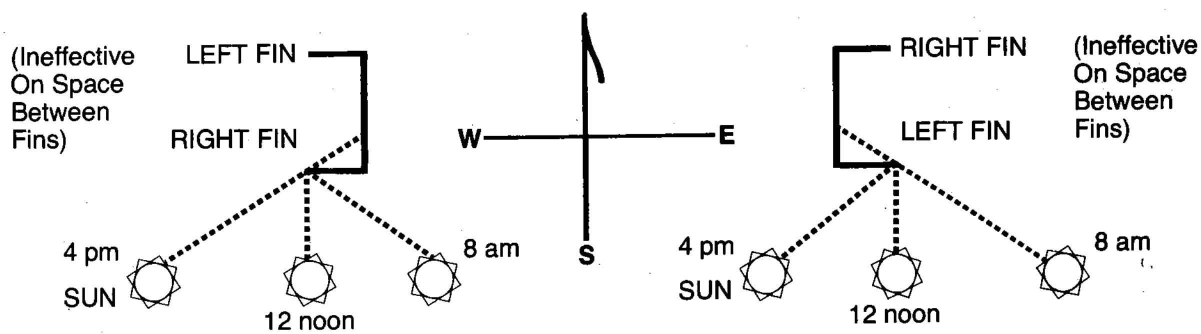
Table 3.29 Shadow Lengths and Shadow Widths for Building Exterior Projections (concluded)

DATE	SOLAR TIME	HORIZONTAL PROJECTION 64.0 DEG NORTH LATITUDE SHADOW LENGTH, FOOT PER FOOT PROJECTION												SIDE PROJECTION 64.0 DEG NORTH LATITUDE SHADOW WIDTH, FOOT PER FOOT PROJECTION												TIME
	AM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	PM
DEC	11					0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2					4.1	1.4	0.6	0.2	0.2	0.7	1.6	6.5	1
	12						0.1	0.1	0.1	0.1	0.1	0.1	0.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JAN/NOV	10				0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.2					10.3	1.9	0.8	0.3	0.1	0.5	1.2	3.3		2
	11					0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.6					4.0	1.3	0.6	0.1	0.3	0.7	1.7	6.8	1
	12						0.3	0.1	0.1	0.1	0.1	0.1	0.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
FEB/OCT	8			0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.3					4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.2			4
	9				0.4	0.2	0.1	0.1	0.1	0.2	0.3	14.3					2.5	1.0	0.4	0.0	0.4	1.0	2.4			3
	10				1.6	0.4	0.3	0.2	0.2	0.2	0.3	0.8					7.5	1.7	0.8	0.3	0.1	0.6	1.3	3.8		2
	11					1.0	0.4	0.3	0.2	0.3	0.3	0.5	2.1					3.7	1.3	0.6	0.1	0.3	0.8	1.7	7.8	1
	12						0.7	0.4	0.3	0.3	0.3	0.4	0.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAR/SEP	7		0.7	0.2	0.1	0.1	0.1	0.1	0.2	0.5					6.3	1.6	0.7	0.2	0.2	0.6	1.4	4.2				5
	8			0.8	0.3	0.2	0.2	0.2	0.3	0.5	2.6					3.2	1.2	0.5	0.1	0.3	0.8	1.9	11.6			4
	9			6.3	0.8	0.4	0.3	0.3	0.4	0.5	1.0					18.8	2.1	0.9	0.4	0.1	0.5	1.1	2.8			3
	10				2.4	0.8	0.5	0.4	0.4	0.5	0.7	2.0					5.5	1.6	0.7	0.2	0.2	0.6	1.4	4.6		2
	11					1.7	0.8	0.5	0.5	0.5	0.6	1.0	4.7					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.7	1
	12						1.3	0.7	0.5	0.5	0.5	0.7	1.3						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
APR/AUG	5	0.2	0.1	0.1	0.1	0.1	0.1	0.2	1.0					3.0	1.2	0.5	0.1	0.3	0.9	2.0	14.2					7
	6	2.1	0.4	0.2	0.2	0.2	0.2	0.3	0.6					11.1	1.9	0.8	0.3	0.1	0.5	1.2	3.2					6
	7		1.2	0.5	0.4	0.3	0.3	0.4	0.6	2.1					4.0	1.3	0.6	0.1	0.3	0.7	1.7	6.8				5
	8			1.1	0.6	0.5	0.4	0.5	0.6	1.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4				4
	9			4.3	1.1	0.7	0.6	0.6	0.6	0.9	2.1					7.8	1.7	0.8	0.3	0.1	0.6	1.3	3.7			3
	10				2.9	1.1	0.8	0.7	0.7	0.8	1.3	4.3					4.2	1.4	0.6	0.2	0.2	0.7	1.6	6.3		2
	11					2.4	1.2	0.8	0.8	0.8	1.0	1.7	9.5					3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.9	1
	12						2.1	1.1	0.8	0.8	0.8	1.1	2.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
MAY/JUL	4	0.2	0.1	0.1	0.1	0.1	0.2	0.6						1.4	0.6	0.2	0.2	0.7	1.6	5.7						8
	5	0.6	0.3	0.2	0.2	0.2	0.3	0.5	28.6					2.5	1.0	0.4	0.0	0.4	1.0	2.4						7
	6	2.1	0.6	0.4	0.3	0.3	0.4	0.6	1.4					6.3	1.6	0.7	0.2	0.2	0.6	1.4	4.2					6
	7		1.5	0.7	0.5	0.5	0.5	0.6	1.0	6.3					3.0	1.2	0.5	0.1	0.3	0.9	2.0	13.2				5
	8		8.1	1.3	0.8	0.6	0.6	0.7	0.9	1.9					14.3	2.0	0.9	0.3	0.1	0.5	1.2	3.0				4
	9			4.0	1.4	0.9	0.8	0.8	0.9	1.3	3.7					5.1	1.5	0.7	0.2	0.2	0.7	1.5	4.9			3
	10				3.1	1.4	1.0	0.9	0.9	1.2	1.9	8.1					3.4	1.2	0.5	0.1	0.3	0.8	1.8	9.4		2
	11					2.9	1.5	1.1	1.0	1.1	1.3	2.4	28.6					2.7	1.1	0.5	0.0	0.4	0.9	2.2	23.5	1
	12						2.7	1.5	1.1	1.0	1.1	1.5	2.7						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
JUN	4	0.3	0.2	0.2	0.2	0.2	0.3	1.1						1.4	0.6	0.2	0.2	0.7	1.7	6.6						8
	5	0.6	0.4	0.3	0.3	0.3	0.4	0.7						2.3	1.0	0.4	0.0	0.4	1.0	2.6						7
	6	2.1	0.7	0.5	0.4	0.4	0.5	0.7	1.9					5.3	1.5	0.7	0.2	0.2	0.7	1.5	4.8					6
	7		1.5	0.8	0.6	0.5	0.6	0.7	1.2	11.4					2.8	1.1	0.5	0.0	0.4	0.9	2.1	22.7				5
	8		6.3	1.4	0.9	0.7	0.7	0.8	1.1	2.4					9.8	1.9	0.8	0.3	0.1	0.5	1.2	3.3				4
	9			3.7	1.4	1.0	0.8	0.9	1.0	1.6	5.1					4.4	1.4	0.6	0.2	0.2	0.7	1.6	5.8			3
	10				3.3	1.5	1.1	1.0	1.0	1.3	2.1	11.4					3.1	1.2	0.5	0.1	0.3	0.9	2.0	12.3		2
	11					3.1	1.6	1.2	1.1	1.2	1.5	2.7	57.3					2.6	1.1	0.4	0.0	0.4	0.9	2.2	35.7	1
	12						3.1	1.7	1.3	1.2	1.3	1.7	3.1						2.4	1.0	0.4	0.0	0.4	1.0	2.4	12
		N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	PM

Use of Shadow Width Tables

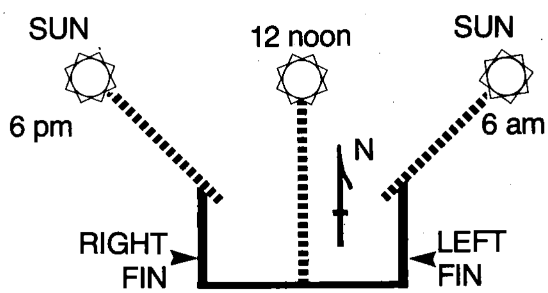
1. Blank spaces denote complete shading; zero values denote full sunlit surface.
2. Right or left side fins, or both, may exist, but only one at a time can produce shading on a given surface between the fins.
3. Significance of lines across a column.
   (a) *Each* time a line is crossed when moving down (or up) a column, one fin becomes ineffective and the opposite fin (if one physically exists) becomes effective.
   (b) Values *above the first line* in a column are for shading from a right fin in the morning based on top orientation headings (or from a left fin in the afternoon based on bottom orientation listing).
4. Example, Table 3.29 40 deg N

Date	Time AM	E (AM) ___Line		W (AM) (Not Shown)	Time PM
Dec.	8	0.8	↑	↓ (AM)	4
	9	1.1			3
	10	1.8			2
	11 ↓	3.7	Right fin on West Surface		1
	12	Full Shade			12
	→		Left fin on East Surface	(PM) ↑	
		W (PM)		E (PM) (Not Shown)	



5. Example, Table 3.29 16 deg N lat

Date	Time AM		Line crossed ↓ N (AM) ___Line		Time PM
May/July	6		2.9		6
	7		3.5		5
	8		4.1	↑	4
	9	Left fin	4.6	Right fin	3
	10	on North	4.5	on North	2
	11	Surface AM	3.1	Surface PM	1
	12		0.0		12
			___Line N (PM) Line crossed		



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INTERNAL LOADS

Internal loads involve components of the cooling loads which arise from sources internal to the conditioned space. The components are:

4.1 Lighting
4.2 People
4.3 Appliances and Laboratory Equipment
4.4 Power Equipment
4.5 Other Internal Loads

4.1 LIGHTING

Load Source	Equation	Description and Reference
Lights	$q_s = 3.41 \times q_i \times F_u \times F_s \times CLF$	q_s → Sensible cooling load in Btu/hr (vented lights require an adjustment for space cooling load — see Example 4.2) 3.41 → Conversion factor Btu/hr per watt q_i → Total lamp wattage F_u → Fraction of q_i in use F_s → Special ballast allowance factor for fluorescent fixtures — Table 4.1 CLF → Cooling load factor — Table 4.4 aided by Tables 4.2 and 4.3 CLF = 1.0 when cooling system is operated only when lights are on, or CLF = 1.0 when lights are on more than 16 hr per day

Table 4.1 Average Values of Ballast Factor, F_s, for Fluorescent Lights

Users should consult manufacturer's specifications when possible. Speciality equipment, energy savings ballasts and other lighting system conditions can produce significantly different results from these values.

Lamp Wattage	No. of Lamps Per Fixture	F_s
35	1	1.30
40		
35	2	1.20
40		
60	1	1.30
75		
60	2	1.20
75		
110	1	1.25
110	2	1.07
160	1	1.15
160	2	1.08
185	1	1.08
215		
185	2	1.06
215		

Table 4.2 "a" Classification for Lights

This table is based on rooms having an average amount of furnishings

"a"	Light Fixture and Ventilation Arrangements
0.45	Recessed lights which are not vented Low air supply rate — less than 0.5 cfm/ft² of floor area Supply and return diffusers below ceiling
0.55	Recessed lights which are not vented Medium to high air supply rate — more than 0.5 cfm/ft² of floor area Supply and return diffusers below ceiling or through ceiling space and grill
0.65	Vented light fixtures Medium to high air supply rate — more than 0.5 cfm/ft² of floor area Supply air through ceiling or wall but return air flows around light fixtures and through ceiling space
0.75	Vented or free hanging lights Supply air through ceiling or wall but return air flows around light fixtures and through a ducted return

EXAMPLE 4.1

Given the following design conditions, determine the cooling load at 1200, 1400, and 1600 hr due to lighting within the space:

Lighting
- **Unvented recessed fluorescent lights**
- **Lights on from 8:00 AM until 6:00 PM**
- **Two 40-W lamps per fixture, 12 fixtures with only 9 on at a time**

Room Usage and Construction
- **Space contains office furniture**
- **Floor construction: tile over 8 in. concrete floor**
- **Estimated supply air requirements: 0.7 cfm/ft² (based on experience with other applications in this area)**

Item	Table	Explanation and Notes
q_i — Input Power		$q_i \times 2$ lamps $\times$ 40 W $\times$ 12 fixtures = 960 W
F_u — Fraction in Use		$F_u = 9/12 = 0.75$
F_s — Ballast Allowance	Table 4.1	$F_s = 1.20$
CLF	Table 4.2	"a" for: Recessed and unvented fixtures. Air supply rate over 0.5 cfm ft² "a" = 0.55
	Table 4.3	"b" for: Tile over 8 in. concrete floor. Medium ventilation rate. Lights and ceiling not vented "b" = C **Remember:** For tile floor use letter designation in the next row down with the same floor weight. (See note, Table 4.3)
	Table 4.4B	CLF for: "a" = 0.55 "b" = C at 1200 hr Lights have been on for 4 hr CLF = 0.72

Item	Table	Explanation and Notes
q_s		$q_s = 3.41 \times q_i \times F_u \times F_s \times$ CLF $= 3.41 \times 960 \times 0.75 \times 1.20 \times 0.72 = 2120$ Btu/hr
Solution		The complete solution is **Time** / **CLF** / **q(Btu/hr)** 1200 / 0.72 / 2120 1400 / 0.75 / 2200 1600 / 0.78 / 2290 **NOTE:** If the cooling system had not been operated continuously, but shut down after 6:00 PM the cooling load would have been $q = 2940$ Btu/hr since CLF = 1.0 for that case.

EXAMPLE 4.2

Solve Example 4.1 for 1200 hr with the following changes:
Vented lights with ducted returns replace unvented recessed lights
Floor area is 257 ft²

Item	Table	Explanation and Notes
q_i, F_u, F_s		From previous solution (Example 4.1): $q_i = 960$ W $F_u = 0.75$ $F_s = 1.20$
CLF	Table 4.2	"a" for: Vented fixtures Ducted return air "a" = 0.75
	Table 4.3	"b" for: 8 in. concrete floor Vented ceiling space (closest description available) "b" = C
	Table 4.4B	for: "a" = 0.75 "b" = C At 4 hr CLF = 0.84
q_s		$q_s = 3.41 \times 960 \times 0.75 \times 1.20 \times 0.84$ $= 2480$ Btu/hr, total load from lights

This gives the cooling load at the cooling coil but the correct space cooling load is obtained by subtracting off the portion of heat that goes directly into the return duct.

The estimated supply rate for the space is 0.7 cfm/ft² × 257 ft² = 180 cfm.

The vented air rate for each light fixture is

$$\frac{180}{12} = 15 \text{ cfm/fixture}$$

From Fig. 4.1 and using the ducted return curve gives

$$f = 0.65$$

The heat removed by the vented air from each fixture to the return ducts is

$$f \times \frac{\text{Watts}}{\text{fixture}} \times F_s \times 3.41 = 0.65 \times 80 \times 1.20 \times 3.41 = 213 \text{ Btu/hr per fixture}$$

The heat removed from the nine fixtures that are turned on is

$$213 \times 9 = 1920 \text{ Btu/hr}$$

The space cooling load is thus

$$2480 - 1920 = 560 \text{ Btu/hr}$$

Consider that the other space sensible loads add to 3500 Btu/hr with the room temperature of 78° F and the supply air of 55° F.

The total space load is

$$560 + 3500 = 4060 \text{ Btu/hr}$$

Using Eq. (6.15) the required amount of supply air is

$$\text{cfm} = \frac{q}{1.10 \times \Delta t} = \frac{4060}{1.10 \times (78 - 55)} = 160 \text{ cfm}$$

The calculated supply rate of 160 cfm differs from the estimated value of 180 cfm. Because the heat removed per fixture used an initially estimated value of 180 cfm, the problem could be re-solved and a new space cooling load found. If the two values were almost equal, the extra step would not be required.

The new ventilation rate for each light fixture is

$$\frac{160}{12} = 13.3 \text{ cfm/fixture}$$

From Fig. 4.1 and using the ducted return curve gives

$$f = 0.61$$

The heat removed by the vented air from each fixture is

$$f \times \frac{\text{Watts}}{\text{fixture}} \times F_s \times 3.41 = 0.61 \times 80 \times 1.20 \times 3.41 = 200 \text{ Btu/hr per fixture}$$

The heat removed from the nine fixtures that are turned on is

$$200 \times 9 = 1800 \text{ Btu/hr}$$

The new space cooling load is thus

$$2480 - 1800 = 680 \text{ Btu/hr}$$

The new total space load is

$$680 + 3500 = 4180 \text{ Btu/hr}$$

The required amount of supply air is

$$\text{cfm} = \frac{q}{1.10 \times \Delta t} = \frac{4180}{1.10 \times 23} = 165 \text{ cfm}$$

This value of 165 cfm is close enough to the previous result of 160 cfm. Any resolving of the problem will not cause any further appreciable change.

Note that the required supply rate for the lights not vented (Example 4.1) is

$$\text{cfm} = \frac{q}{1.10 \times \Delta t} = \frac{2120 + 3500}{1.10 \times (78 - 55)} = 222 \text{ cfm}$$

The temperature rise for the ducted return air through the vented fixtures is

$$\Delta t = \frac{q}{1.10 \times \text{cfm}} = \frac{200 \text{ Btu/hr per fixture}}{1.10 \times 13.3 \text{ cfm per fixture}} = 13.7 \text{ deg F}$$

Table 4.3 "b" Classification for Lights

This table is based on floor covered with carpet and rubber pad. For floor covered with floor tile use letter designation in next row down with the same floor weight.

Room Air Circulation and Type of Supply and Return	Floor Construction and Floor Weight in Pounds Per Square Foot of Floor Area: 2 in. Wooden Floor 10 lb/ft²	3 in. Concrete Floor 40 lb/ft²	6 in. Concrete Floor 75 lb/ft²	8 in. Concrete Floor 120 lb/ft²	12 in. Concrete Floor 160 lb/ft²
Low ventilation rate — minimum required to handle cooling load. Supply through floor, wall or ceiling diffuser. Ceiling space not vented.	B	B	C	D	D
Medium ventilation rate. Supply through floor, wall or ceiling diffuser. Ceiling space not vented.	A	B	C	D	D
High room air circulation induced by primary air of induction unit or by fan coil unit. Return through ceiling space.	A	B	C	C	D
Very high room air circulation used to minimize room temperature gradients. Return through ceiling space.	A	A	B	C	D

Table 4.4A Cooling Load Factors When Lights Are on for 8 Hours

"a" Classification	"b" Classification	Number of hours after lights are turned on																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.45	A	0.02	0.46	0.57	0.65	0.72	0.77	0.82	0.85	0.88	0.46	0.37	0.30	0.24	0.19	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02
	B	0.07	0.51	0.56	0.61	0.65	0.68	0.71	0.74	0.77	0.34	0.31	0.28	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08
	C	0.11	0.55	0.58	0.60	0.63	0.65	0.67	0.69	0.71	0.28	0.26	0.25	0.23	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.12
	D	0.14	0.58	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.16	0.16	0.16	0.15	0.15
0.55	A	0.01	0.56	0.65	0.72	0.77	0.82	0.85	0.88	0.90	0.37	0.30	0.24	0.19	0.16	0.13	0.10	0.08	0.07	0.05	0.04	0.03	0.03	0.02	0.02
	B	0.06	0.60	0.64	0.68	0.71	0.74	0.76	0.79	0.81	0.28	0.25	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.06
	C	0.09	0.63	0.66	0.68	0.70	0.71	0.73	0.75	0.76	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10
	D	0.11	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.72	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12
0.65	A	0.01	0.66	0.73	0.78	0.82	0.86	0.88	0.91	0.93	0.29	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01
	B	0.04	0.69	0.72	0.75	0.77	0.80	0.82	0.84	0.85	0.22	0.19	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05
	C	0.07	0.72	0.73	0.75	0.76	0.78	0.79	0.80	0.82	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.09	0.08	0.08	0.07
	D	0.09	0.73	0.74	0.75	0.76	0.77	0.77	0.78	0.79	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09
0.75	A	0.01	0.76	0.80	0.84	0.87	0.90	0.92	0.93	0.95	0.21	0.17	0.13	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01
	B	0.03	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.15	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.04
	C	0.05	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.13	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05
	D	0.06	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.10	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07

Table 4.4B Cooling Load Factors when Lights Are on for 10 Hours

"a" Classification	"b" Classification	Number of hours after lights are turned on																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.45	A	0.03	0.47	0.58	0.66	0.73	0.78	0.82	0.86	0.88	0.91	0.93	0.49	0.39	0.32	0.26	0.21	0.17	0.13	0.11	0.09	0.07	0.06	0.05	0.04
	B	0.10	0.54	0.59	0.63	0.66	0.70	0.73	0.76	0.78	0.80	0.82	0.39	0.35	0.32	0.28	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.12	0.11
	C	0.15	0.59	0.61	0.64	0.66	0.68	0.70	0.72	0.73	0.75	0.76	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.16
	D	0.18	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.69	0.70	0.71	0.27	0.26	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.19	0.19
0.55	A	0.02	0.57	0.65	0.72	0.78	0.82	0.85	0.88	0.91	0.92	0.94	0.40	0.32	0.26	0.21	0.17	0.14	0.11	0.09	0.07	0.06	0.05	0.04	0.03
	B	0.08	0.62	0.66	0.69	0.73	0.75	0.78	0.80	0.82	0.84	0.85	0.32	0.29	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09
	C	0.12	0.66	0.68	0.70	0.72	0.74	0.75	0.77	0.78	0.79	0.81	0.27	0.25	0.24	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.14	0.13
	D	0.15	0.69	0.70	0.71	0.72	0.73	0.73	0.74	0.75	0.76	0.76	0.22	0.22	0.21	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15
0.65	A	0.02	0.66	0.73	0.78	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.31	0.25	0.20	0.16	0.13	0.11	0.08	0.07	0.05	0.04	0.04	0.03	0.02
	B	0.06	0.71	0.74	0.76	0.79	0.81	0.83	0.84	0.86	0.87	0.89	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07
	C	0.09	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.21	0.20	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.12	0.11	0.11	0.10
	D	0.11	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12
0.75	A	0.01	0.76	0.81	0.84	0.88	0.90	0.92	0.93	0.95	0.96	0.97	0.22	0.18	0.14	0.12	0.09	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02
	B	0.04	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05
	C	0.07	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.89	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.07
	D	0.08	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.12	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09

Table 4.4C Cooling Load Factors when Lights Are on for 12 Hours

"a" Classification	"b" Classification	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		Number of hours after lights are turned on																							
0.45	A	0.05	0.49	0.59	0.67	0.73	0.78	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.51	0.41	0.33	0.27	0.22	0.17	0.14	0.11	0.09	0.07	0.06
	B	0.13	0.57	0.61	0.65	0.69	0.72	0.75	0.77	0.79	0.82	0.83	0.85	0.87	0.43	0.39	0.35	0.31	0.28	0.25	0.23	0.21	0.18	0.17	0.15
	C	0.19	0.63	0.65	0.67	0.69	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20
	D	0.22	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.74	0.75	0.76	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.23
0.55	A	0.04	0.58	0.66	0.73	0.78	0.82	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.42	0.34	0.27	0.22	0.18	0.14	0.11	0.09	0.07	0.06	0.05
	B	0.11	0.65	0.68	0.72	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.35	0.32	0.28	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.12
	C	0.15	0.69	0.71	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.30	0.29	0.27	0.25	0.24	0.22	0.21	0.20	0.19	0.17	0.16
	D	0.18	0.72	0.73	0.74	0.75	0.76	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19
0.65	A	0.03	0.67	0.74	0.79	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.33	0.26	0.21	0.17	0.14	0.11	0.09	0.07	0.06	0.05	0.04
	B	0.09	0.73	0.75	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.27	0.25	0.22	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10
	C	0.12	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.24	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.14	0.13
	D	0.14	0.79	0.79	0.80	0.80	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15
0.75	A	0.02	0.77	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.23	0.19	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03
	B	0.06	0.81	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.19	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07
	C	0.09	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09
	D	0.10	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11

Table 4.4D Cooling Load Factors when Lights Are on for 14 Hours

"a" Classification	"b" Classification	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		Number of hours after lights are turned on																							
0.45	A	0.07	0.51	0.61	0.68	0.74	0.79	0.83	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.53	0.42	0.34	0.27	0.22	0.18	0.14	0.12	0.09
	B	0.18	0.61	0.65	0.68	0.72	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.46	0.41	0.37	0.34	0.30	0.27	0.24	0.22	0.20
	C	0.24	0.67	0.69	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.27	0.25
	D	0.26	0.71	0.72	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.80	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.28
0.55	A	0.06	0.69	0.68	0.74	0.79	0.83	0.86	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.98	0.43	0.35	0.28	0.22	0.18	0.15	0.12	0.09	0.08
	B	0.15	0.68	0.71	0.74	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.38	0.34	0.31	0.27	0.25	0.22	0.20	0.18	0.16
	C	0.19	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.21
	D	0.22	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.83	0.84	0.29	0.28	0.28	0.27	0.26	0.25	0.24	0.24	0.23
0.65	A	0.05	0.69	0.75	0.80	0.84	0.87	0.89	0.92	0.93	0.95	0.96	0.96	0.97	0.98	0.98	0.34	0.27	0.22	0.17	0.14	0.11	0.09	0.07	0.06
	B	0.11	0.75	0.78	0.80	0.82	0.64	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.29	0.26	0.24	0.21	0.19	0.17	0.16	0.14	0.13
	C	0.15	0.79	0.80	0.82	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.26	0.25	0.23	0.22	0.20	0.19	0.18	0.17	0.16
	D	0.17	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.87	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.18	0.18
0.75	A	0.03	0.78	0.82	0.86	0.88	0.91	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.24	0.19	0.16	0.12	0.10	0.08	0.07	0.05	0.04
	B	0.08	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.96	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09
	C	0.11	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93	0.93	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11
	D	0.12	0.87	0.87	0.87	0.88	0.88	0.89	0.89	0.89	0.90	0.90	0.90	0.90	0.91	0.91	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13

Table 4.4E Cooling Load Factors when Lights Are on for 16 Hours

"a" Classification	"b" Classification	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		Number of hours after lights are turned on																							
0.45	A	0.12	0.54	0.63	0.70	0.76	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.54	0.43	0.35	0.28	0.23	0.18	0.15
	B	0.23	0.66	0.69	0.72	0.75	0.78	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.49	0.44	0.39	0.35	0.32	0.29	0.26
	C	0.29	0.72	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.45	0.42	0.39	0.37	0.35	0.33	0.31
	D	0.31	0.75	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.40	0.39	0.37	0.36	0.35	0.34	0.33
0.55	A	0.10	0.63	0.70	0.76	0.81	0.84	0.87	0.90	0.92	0.93	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.44	0.35	0.28	0.23	0.18	0.15	0.12
	B	0.19	0.72	0.75	0.77	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.40	0.36	0.32	0.29	0.26	0.24	0.21
	C	0.24	0.77	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.91	0.37	0.34	0.32	0.30	0.29	0.27	0.25
	D	0.26	0.80	0.80	0.81	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.33	0.32	0.31	0.30	0.29	0.28	0.27
0.65	A	0.07	0.71	0.77	0.81	0.85	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.99	0.34	0.27	0.22	0.18	0.14	0.12	0.09
	B	0.15	0.78	0.81	0.82	0.84	0.86	0.87	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.96	0.31	0.28	0.25	0.23	0.20	0.18	0.16
	C	0.18	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.89	0.90	0.90	0.91	0.92	0.92	0.93	0.93	0.28	0.27	0.25	0.24	0.22	0.21	0.20
	D	0.20	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.89	0.90	0.90	0.25	0.25	0.24	0.23	0.22	0.22	0.21
0.75	A	0.05	0.79	0.83	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.24	0.20	0.16	0.13	0.10	0.08	0.07
	B	0.11	0.85	0.86	0.87	0.89	0.90	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.96	0.96	0.96	0.97	0.22	0.20	0.18	0.16	0.15	0.13	0.12
	C	0.13	0.87	0.88	0.89	0.89	0.90	0.91	0.91	0.92	0.92	0.93	0.93	0.94	0.94	0.94	0.95	0.95	0.20	0.19	0.18	0.17	0.16	0.15	0.14
	D	0.14	0.89	0.89	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.91	0.92	0.92	0.92	0.92	0.93	0.93	0.18	0.18	0.17	0.17	0.16	0.16	0.15

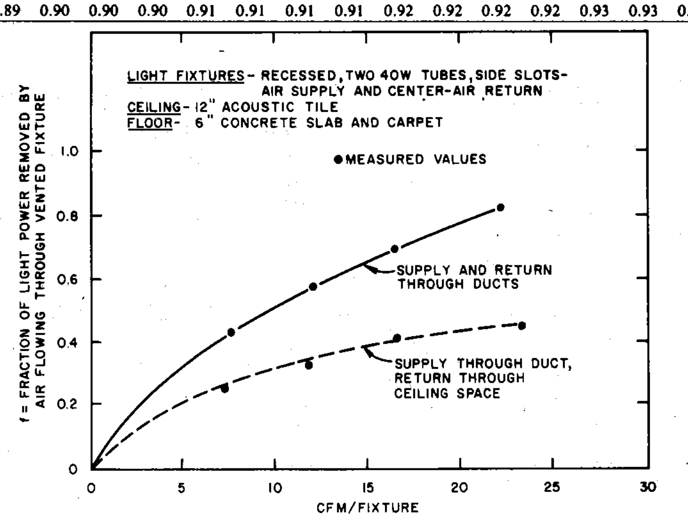

Fig. 1 Heat Removal for Vented Light Fixtures

4.2 PEOPLE

Load Source	Equation	Description and Reference
People	$q_s = \frac{q_s}{\text{person}} \times \text{No. of people} \times \text{CLF}$	→ q_s: Sensible cooling load in Btu/hr → q_s/person: Sensible heat gain per person — Table 4.5 → No. of people: Number of people — if not known use first column in Table 5.3 to calculate number → CLF: Cooling load factor — Table 4.6 Use CLF = 1.0 if cooling system does not run 24 hr a day. Use CLF = 1.0 for auditoriums, theaters or when people density is high, such as for more than 100 people/1000 ft².
	$q_l = \frac{q_l}{\text{person}} \times \text{No. of people}$	→ q_l: Latent cooling load in Btu/hr → q_l/person: Latent heat gain per person — Table 4.5 → No. of people: Number of people — if not known use first column in Table 5.3 to calculate the number

EXAMPLE 4.3

Determine the cooling load at 1400 and 2000 hr due to 6 people in an office from 9:00 AM to 5:00 PM. The office temperature is 78 F.

SOLUTION 4.3

Because Table 4.5 is based on 78 F the tabulated data can be used directly. For very light office work

$$q_{s/\text{person}} = 230 \text{ Btu/hr}$$
$$q_{l/\text{person}} = 190 \text{ Btu/hr}$$

People occupy the office for 8 hr and 1400 is 5 hr after entering the conditioned space, thus Table 4.5 gives

$$\text{CLF} = 0.76$$

Thus $q_s = 0.76 \times 230 \times 6 = 1050$ Btu/hr at 1400 hr
$q_l = 190 \times 6 = 1140$ Btu/hr at 1400 hr

2000 hr is 11 hr after entering the office thus Table 4.5 gives

$$\text{CLF} = 0.25$$

Thus $q_s = 0.25 \times 230 \times 6 = 345$ Btu/hr at 2000 hr
$q_l = 0$ (No latent load after people have left the space)

If the cooling system is shut down after 5:00 PM then a CLF of 1.0 should be used to find q_s.

Table 4.5 Rates of Heat Gain from Occupants of Conditioned Spaces [a]

Degree of Activity	Typical Application	ADULT MALE $q_{s/\text{person}} + q_{l/\text{person}}$ Watts	ADULT MALE $q_{s/\text{person}} + q_{l/\text{person}}$ Btu/h	ADJUSTED GROUP[b] $q_{s/\text{person}} + q_{l/\text{person}}$ Watts	ADJUSTED GROUP[b] $q_{s/\text{person}} + q_{l/\text{person}}$ Btu/h	ADJUSTED GROUP[b] $q_{s/\text{person}}$ Watts	ADJUSTED GROUP[b] $q_{s/\text{person}}$ Btu/h	ADJUSTED GROUP[b] $q_{l/\text{person}}$ Watts	ADJUSTED GROUP[b] $q_{l/\text{person}}$ Btu/h
Seated at rest	Theater, movie	115	400	100	350	60	210	40	140
Seated, very light work writing	Offices, hotels, apts	140	480	120	420	65	230	55	190
Seated, eating	Restaurant[c]	150	520	170	580[c]	75	255	95	325
Seated, light work, typing	Offices, hotels, apts	185	640	150	510	75	255	75	255
Standing, light work or walking slowly	Retail Store, bank	235	800	185	640	90	315	95	325
Light bench work	Factory	255	880	230	780	100	345	130	435
Walking, 3 mph, light machine work	Factory	305	1040	305	1040	100	345	205	695
Bowling[d]	Bowling alley	350	1200	280	960	100	345	180	615
Moderate dancing	Dance hall	400	1360	375	1280	120	405	255	875
Heavy work, heavy machine work, lifting	Factory	470	1600	470	1600	165	565	300	1035
Heavy work, athletics	Gymnasium	585	2000	525	1800	185	635	340	1165

[a]Note: Tabulated values are based on 78 F room dry-bulb temperature. For 80 F room dry-bulb, the total heat remains the same, but the sensible heat value should be decreased by approximately 8% and the latent heat values increased accordingly.

[b]Adjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[c]Adjusted total heat value for eating in a restaurant, includes 60 Btu/hr for food per individual (30 Btu sensible and 30 Btu latent).

[d]For bowling figure one person per alley actually bowling, and all others as sitting (400 Btu/hr) or standing and walking slowly (790 Btu/hr).

Also refer to Tables 4 and 5, Chapter 8, 1977 ASHRAE Handbook of Fundamentals.

Table 4.6 Sensible Heat Cooling Load Factors for People

Total Hours in Space	Hours after Each Entry Into Space																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	0.49	0.58	0.17	0.13	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.49	0.59	0.66	0.71	0.27	0.21	0.16	0.14	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01
6	0.50	0.60	0.67	0.72	0.76	0.79	0.34	0.26	0.21	0.18	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03
8	0.51	0.61	0.67	0.72	0.76	0.80	0.82	0.84	0.38	0.30	0.25	0.21	0.18	0.15	0.13	0.12	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04
10	0.53	0.62	0.69	0.74	0.77	0.80	0.83	0.85	0.87	0.89	0.42	0.34	0.28	0.23	0.20	0.17	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.06
12	0.55	0.64	0.70	0.75	0.79	0.81	0.84	0.86	0.88	0.89	0.91	0.92	0.45	0.36	0.30	0.25	0.21	0.19	0.16	0.14	0.12	0.11	0.09	0.08
14	0.58	0.66	0.72	0.77	0.80	0.83	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.47	0.38	0.31	0.26	0.23	0.20	0.17	0.15	0.13	0.11
16	0.62	0.70	0.75	0.79	0.82	0.85	0.87	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.49	0.39	0.33	0.28	0.24	0.20	0.18	0.16
18	0.66	0.74	0.79	0.82	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.50	0.40	0.33	0.28	0.24	0.21

4.3 APPLIANCES AND LABORATORY EQUIPMENT

Load	Equation	Description and Reference
Appliance and Laboratory Equipment	q_s = sensible × CLF	→ Sensible cooling load in Btu/hr → Sensible heat gain per appliance in Btu/hr use Tables 4.8 and 4.9. If details about appliances are not known use $q_s = C_s \times q_r \times$ CLF q_r → Manufacturer's input rating in Btu/hr C_s → Coefficient — Use Table 4.7 → Cooling load factor — Use Table 4.10 or 4.11. Use CLF = 1.0 if cooling system does not run 24 hr a day
	q_l = latent	→ Latent cooling load in Btu/hr → Latent cooling load per appliance in Btu/hr use Tables 4.8 and 4.9. If details about appliances are not known use $q_l = C_l \times q_r$ q_r → Manufacturer's input rating in Btu/hr C_l → Coefficient — Use Table 4.7

EXAMPLE 4.4

Determine the cooling load in a space at 1200 hr due to an electrical coffee brewer and one warmer. The brewer is turned on at 9:00 AM and turned off at 3:00 PM. The brewer does not have an exhaust hood and the cooling system runs 24 hr a day.

SOLUTION 4.4

From Table 4.8 a coffee brewer with one warmer without a hood has

$$\text{Sensible} = 770 + 230 = 1000 \text{ Btu/hr}$$
$$\text{Latent} = 230 + 70 = 300 \text{ Btu/hr}$$

The brewer is on for 6 hr and 1200 hr is 3 hr after is has been turned on. From Table 4.11 (unhooded) the cooling load factor is

$$\text{CLF} = 0.71$$

The cooling load at 1200 hr is thus

$$q_s = 0.71 \times 1000 = 710 \text{ Btu/hr}$$
$$q_l = 300 \text{ Btu/hr}$$

EXAMPLE 4.5

Repeat Example 4.4 but with the information that the unhooded electrical appliance has a manufacturer's input rating of 2675 Btu/hr.

SOLUTION 4.5

For unhooded, electrical appliance, Table 4.7 gives

$$C_s = 0.33 \text{ and } C_l = 0.17$$

The appliance is on for 6 hr and 1200 hr is 3 hr after it has been turned on. From Table 4.11 (unhooded) the cooling load factor is

$$\text{CLF} = 0.71$$

The cooling load at 1200 hr is thus

$$q_s = 0.33 \times 2675 \times 0.71 = 627 \text{ Btu/hr}$$
$$q_l = 0.17 \times 2675 = 455 \text{ Btu/hr}$$

Table 4.7 Coefficients for Appliances and Certain Laboratory Equipment

	C_s	C_l
Hooded-Electric or steam heated	0.16	0.0
Hooded-Gas heated	0.10	0.0
Unhooded-Electric or steam heated	0.33	0.17
Unhooded-Gas heated	0.33	0.17

Table 4.8 Recommended Rate of Heat Gain from Commercial Cooking Appliances Located in the Air-Conditioned Area[a]

				Manufacturer's Input Rating			Recommended Rate of Heat Gain, Btuh			
							Without Hood			With Hood[b]
Appliance	Capacity	Overall Dim., Inches Width × Depth × Height	Miscellaneous Data (Dimensions in Inches)	Boiler hp or Watts	Btuh	Probable Max. Hourly Input Btuh	Sensible	Latent	Total	All Sensible
Gas-Burning, Counter Type										
Broiler-griddle		31 × 20 × 18			36,000	18,000	11,700	6,300	18,000	3,600
Coffee brewer										
per burner			With *warm* position		5,500	2,500	1,750	750	2,500	500
Water heater burner			With storage tank		11,000	5,000	3,850	1,650	5,500	1,100
Coffee urn	3 gal	12-inch dia.			10,000	5,000	3,500	1,500	5,000	1,000
	5 gal.	14-inch dia.			15,000	7,500	5,250	2,250	7,500	1,500
	8 gal. twin	25-inch wide			20,000	10,000	7,000	3,000	10,000	2,000
Deep fat fryer	15 lb fat	14 × 21 × 15			30,000	15,000	7,500	7,500	15,000	3,000
Dry food warmer										
per sq ft of top					1,400	700	560	140	700	140
Griddle, frying										
per sq ft of top					15,000	7,500	4,900	2,600	7,500	1,500
Short order stove,										
per burner			Open grates		10,000	5,000	3,200	1,800	5,000	1,000
Steam table										
per sq ft of top					2,500	1,250	750	500	1,250	250
Toaster, continuous	360 slices/hr	19 × 16 × 30	2 slices wide		12,000	6,000	3,600	2,400	6,000	1,200
	720 slices/hr	24 × 16 × 30	4 slices wide		20,000	10,000	6,000	4,000	10,000	2,000
Gas-Burning, Floor Mounted Type										
Broiler, unit		24 × 26 grid	Same burner heats oven		70,000	35,000				7,000
Deep fat fryer	32 lb fat		14-in. kettle		65,000	32,500				6,500
	56 lb fat		18-in. kettle		100,000	50,000				10,000
Oven, deck, per sq ft			Same for 7 and 12							
of hearth area			high decks		4,000	2,000				400
Oven, roasting		32 × 32 × 60	Two ovens—24 × 28 × 15		80,000	40,000	Exhaust hood required	Exhaust hood required	Exhaust hood required	8,000
Range, heavy duty		32 × 42 × 33								
Top section			32 wide × 39 deep		64,000	32,000				6,400
Oven			25 × 28 × 15		40,000	20,000				4,000
Range, jr., heavy duty		31 × 35 × 33								
Top section			31 wide × 32 deep		45,000	22,500				4,500
Oven			24 × 28 × 15		35,000	17,500				3,500
Range, restaurant type										
Per 2 burner sect.			12 wide × 28 deep		24,000	12,000				2,400
Per oven			24 × 22 × 14		30,000	15,000				3,000
Per broiler-griddle			24 wide × 26 deep		35,000	17,500				3,500
Electric, Counter Type										
Coffee brewer										
per burner				625	2,130	1,000	770	230	1,000	340
per warmer				160	545	300	230	70	300	90
automatic	240 cups per hr	27 × 21 × 22	4-burner + water htr.	5,000	17,000	8,500	6,500	2,000	8,500	1,700
Coffee urn	3 gal.			2,000	6,800	3,400	2,550	850	3,400	1,000
	5 gal.			3,000	10,200	5,100	3,850	1,250	5,100	1,600
	8 gal. twin			4,000	13,600	6,800	5,200	1,600	6,800	2,100
Deep fat fryer	14 lb fat	13 × 22 × 10		5,500	18,750	9.400	2,800	6,600	9,400	3,000
	21 lb fat	16 × 22 × 10		8,000	27,300	13,700	4,100	9,600	13,700	4,300
Dry food warmer,				240	820	400	320	80	400	130
per sq ft of top										
Egg boiler	2 cups	10 × 13 × 25		1,100	3,750	1,900	1,140	760	1,900	600
Griddle, frying,				2,700	9,200	4,600	3,000	1,600	4,600	1,500
per sq ft of top										
Griddle-Grill		18 × 20 × 13	Grid, 200 sq in.	6,000	20,400	10,200	6,600	3,600	10,200	3,200
Hotplate		18 × 20 × 13	2 heating units	5,200	17,700	8,900	5,300	3,600	8,900	2,800
Roaster		18 × 20 × 13		1,650	5,620	2,800	1,700	1,100	2,800	900
Roll warmer		18 × 20 × 13		1,650	5,620	2,800	2,600	200	2,800	900
Toaster, continuous	360 slices/hr	15 × 15 × 28	2 slices wide	2,200	7,500	3,700	1.960	1,740	3,700	1,200
	720 slices/hr	20 × 15 × 28	4 slices wide	3,000	10,200	5,100	2,700	2,400	5,100	1,600
Toaster, pop-up	4 slice	12 × 11 × 9		2,540	8,350	4,200	2,230	1.970	4,200	1,300
Waffle iron		18 × 20 × 13	2 grids	1,650	5,620	2,800	1,680	1,120	2,800	900

Table 4.8 Recommended Rate of Heat Gain from Commercial Cooking Appliances Located in the Air-Conditioned Area[a] (Continued)

Appliance	Capacity	Overall Dim., Inches Width × Depth × Height	Miscellaneous Data (Dimensions in Inches)	Manufacturer's Input Rating: Boiler hp or Watts	Manufacturer's Input Rating: Btuh	Probable Max. Hourly Input Btuh	Recommended Rate of Heat Gain, Btuh: Without Hood: Sensible	Without Hood: Latent	Without Hood: Total	With Hood[b]: All Sensible
Electric, Floor Mounted Type										
Griddle[c]		36 × 32 × 37	36 × 25 cooking surface	16,800	57,300					2,060
Broiler, no oven			23 wide × 25 deep grid	12,000	40,900	20,500				6,500
with oven			23 × 27 × 12 oven	18,000	61,400	30,700				9,800
Broiler, single deck[c]		36 × 36 × 54		16,000	54,600					10,800
Deep fat fryer	28 lb fat	20 × 38 × 36	14 wide × 15 deep kettle	12,000	40,900	20,500				6,500
	60 lb fat	24 × 36 × 36	20 wide × 20 deep kettle	18,000	61,400	30,700				9,800
Fryer[c]		15 × 32 × 36	13 × 23 cooking surface	22,000	75,000					730
Oven, baking, per sq ft of hearth			Compartment 8-in. high	500	1,700	850	Exhaust hood required	Exhaust hood required	Exhaust hood required	270
Oven, roasting, per sq ft of hearth			Compartment 12-in. high	900	3,070	1,500				490
Range, heavy duty[c]										
Top section		38 × 36 × 37	36 × 24 cooking surface	15,000	51,200					19,100
Oven				6,700	22,900					1,700
Range, medium duty		30 × 32 × 36								
Top section				8,000	27,300	13,600				4,300
Oven				3,600	12,300	6,200				1,900
Range, light duty		30 × 29 × 36								
Top section				6,600	22,500	11,200				3,600
Oven				3,000	10,200	5,100				1,600
Convection Oven[c]		38 × 36 × 55		11,000	37,500					1,540
Charbroiler[c]		36 × 24 × 34	30 × 18 cooking surface	16,500	56,300					4,320
Steam cooker, two sections[c]		36 × 29 × 64		24,000	81,900					3,140
Steam Heated										
Coffee urn	3 gal.			0.2	6,600	3,300	2,180	1,120	3.300	1,000
	5 gal.			0.3	10,000	5,000	3,300	1,700	5,000	1,600
	8 gal. twin			0.4	13,200	6,600	4,350	2,250	6,600	2,100
Steam table per sq ft of top			With insets	0.05	1,650	825	500	325	825	260
Bain marie per sq ft of top			Open Tank	0.10	3,300	1,650	825	825	1,650	520
Oyster steamer				0.5	16,500	8,250	5,000	3,250	8,250	2,600
Steam kettles per gal. capacity			Jacketed type	0.06	2,000	1,000	600	400	1,000	320
Compartment steamer per compartment		24 × 25 × 12 compartment	Floor mounted	1.2	40,000	20,000	12,000	8,000	20,000	6,400
Compartment steamer	3 pans 12 × 20 × 2.5		Single counter unit	0.5	16,500	8,250	5,000	3,250	8,250	2,600
Plate warmer per cu ft				0.05	1,650	825	550	275	825	260

[a]The data in this table (except as noted in c below) was determined by assuming the hourly heat input was 0.50 times the manufacturer's energy input rating. This is felt to be conservative on the average but could result in heat gain estimates higher or lower than actual heat gains depending on the appliance. Consult the text for additional discussion.

[b]For poorly designed or undersized exhaust systems the heat gains in this column should be doubled and half the increase assumed as latent heat.

[c]Based on measured heat gain at typical idle conditions. For open island canopies multiply values by 1.32.

Table 4.10 Sensible Heat Cooling Load Factors for Hooded Appliances

Total Operational Hours	Hours after appliances are on																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	0.27	0.40	0.25	0.18	0.14	0.11	0.09	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
4	0.28	0.41	0.51	0.59	0.39	0.30	0.24	0.19	0.16	0.14	0.12	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02
6	0.29	0.42	0.52	0.59	0.65	0.70	0.48	0.37	0.30	0.25	0.21	0.18	0.16	0.14	0.12	0.11	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04
8	0.31	0.44	0.54	0.61	0.66	0.71	0.75	0.78	0.55	0.43	0.35	0.30	0.25	0.22	0.19	0.16	0.14	0.13	0.11	0.10	0.08	0.07	0.06	0.06
10	0.33	0.46	0.55	0.62	0.68	0.72	0.76	0.79	0.81	0.84	0.60	0.48	0.39	0.33	0.28	0.24	0.21	0.18	0.16	0.14	0.12	0.11	0.09	0.08
12	0.36	0.49	0.58	0.64	0.69	0.74	0.77	0.80	0.82	0.85	0.87	0.88	0.64	0.51	0.42	0.36	0.31	0.26	0.23	0.20	0.18	0.15	0.13	0.12
14	0.40	0.52	0.61	0.67	0.72	0.76	0.79	0.82	0.84	0.86	0.88	0.89	0.91	0.92	0.67	0.54	0.45	0.38	0.32	0.28	0.24	0.21	0.19	0.16
16	0.45	0.57	0.65	0.70	0.75	0.78	0.81	0.84	0.86	0.87	0.89	0.90	0.92	0.93	0.94	0.94	0.69	0.56	0.46	0.39	0.34	0.29	0.25	0.22
18	0.52	0.63	0.70	0.75	0.79	0.82	0.84	0.86	0.88	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.96	0.71	0.58	0.48	0.41	0.35	0.30

Table 4.11 Sensible Heat Cooling Load Factors for Unhooded Appliances, Motors, etc.

Total Operational Hours	Hours after appliances are on																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	0.56	0.64	0.15	0.11	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.57	0.65	0.71	0.75	0.23	0.18	0.14	0.12	0.10	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01
6	0.57	0.65	0.71	0.76	0.79	0.82	0.29	0.22	0.18	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02
8	0.58	0.66	0.72	0.76	0.80	0.82	0.85	0.87	0.33	0.26	0.21	0.18	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.04	0.03
10	0.60	0.68	0.73	0.77	0.81	0.83	0.85	0.87	0.89	0.90	0.36	0.29	0.24	0.20	0.17	0.15	0.13	0.11	0.10	0.08	0.07	0.07	0.06	0.05
12	0.62	0.69	0.75	0.79	0.82	0.84	0.86	0.88	0.89	0.91	0.92	0.93	0.38	0.31	0.25	0.21	0.18	0.16	0.14	0.12	0.11	0.09	0.08	0.07
14	0.64	0.71	0.76	0.80	0.83	0.85	0.87	0.89	0.90	0.92	0.93	0.93	0.94	0.95	0.40	0.32	0.27	0.23	0.19	0.17	0.15	0.13	0.11	0.10
16	0.67	0.74	0.79	0.82	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.96	0.97	0.42	0.34	0.28	0.24	0.20	0.18	0.15	0.13
18	0.71	0.78	0.82	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.43	0.35	0.29	0.24	0.21	0.18

Table 4.9 Rate of Heat Gain from Miscellaneous Appliances

Appliance	Miscellaneous Data	Manufacturer's Rating: Watts	Manufacturer's Rating: Btu/hr	Recommended Rate of Heat Gain: Sensible	Latent	Total
Electrical Appliances						
Hair dryer	Blower type	1580	5400	2300	400	2700
Hair Dryer	Helmet type	705	2400	1870	330	2200
Permanent wave machine	60 heaters @25 W 36 in normal use	1500	5000	850	150	1000
Neon sign, per linear ft of tube	0.5 in., dia			30		30
	0.375 in., dia			60		60
Sterilizer, instrument		1100	3750	650	1200	1850
Magnetic Card Type-Writer			690	350	0	350
Small Copier	Running		6000	6000	0	6000
	Standby		3000	3000	0	3000
Large Copier	Running		12,000	12,000	0	12,000
	Standby		6000	6000	0	6000
Gas-Burning Appliances						
Lab Burners						
Bunsen	0.4375 in. barrel		3000	1680	420	2100
Fishtail	1.5 in. wide		5000	2800	700	3500
Meeker	1 in. diameter		6000	3360	840	4200
Gas light, per burner	Mantle type		2000	1800	200	2000
Cigar lighter	Continuous flame		2500	900	100	1000

4.4 POWER EQUIPMENT

Load	Equation	Description and Reference
Electrical Motor and Driven Equipment	$q_s = \mathrm{B\ (A,\ C)} \times F_L \times \mathrm{CLF}$	q_s → Sensible cooling load in Btu/hr
	B (A, C)	→ Information in Column A, B or C in Btu/hr — Use Table 4.12
	F_L	→ Load Factor — F_L is power used divided by rated horsepower — Use Table 4.13 for overloads — If available use manufacturer's performance data
	CLF	→ Cooling Load Factor — Use Table 4.11. CLF = 1.0 if cooling system is not on 24 hr a day.

EXAMPLE 4.6

A 75-hp, 3-phase motor drives a piece of equipment and both motor and the power absorbing equipment are in the conditioned space. It takes only 65 hp to drive the equipment thus the full capability of the motor is not used. When the equipment is used continuously from 10:00 AM to 2:00 PM determine the cooling load at 1200 hr. The cooling system runs 24 hr a day.

SOLUTION 4.6

If the partial load curve is not known, for larger motors estimate the motor load factor as

$$F_L = 65/75 = 0.867$$

For smaller motors, especially fractional horsepower, use $F_L = 1.0$.

Using Table 4.12, 75 hp and the motor in-driven equipment in classification in Column A

$$A \rightarrow 212{,}000 \text{ Btu/hr}$$

The equipment is operating 4 hr and 1200 hr is 2 hr after the equipment is turned on, thus Table 4.11 gives

$$\text{CLF} = 0.65$$

The sensible cooling load is

$$q_s = 212{,}000 \times 0.867 \times 0.65 = 119{,}500 \text{ Btu/hr}$$

If the cooling system is shut down after 2:00 PM then CLF = 1.0 and the cooling load is q_s = 184,000 Btu/hr.

Table 4.12 Heat Gain From Typical Electric Motors

Motor Name-plate or Rated Horse-power	Motor Type	Nom-inal rpm	Full Load Motor Effici-ency In Percent	Location of Motor and Driven Equipment with Respect to Conditioned Space or Air Stream: A Motor in, Driven Equip-ment in Btu/hr	B Motor out, Driven Equip-ment in Btu/hr	C Motor in, Driven Equip-ment Out Btu/hr
0.05	Shaded Pole	1500	35	360	130	240
0.08	Shaded Pole	1500	35	580	200	380
0.125	Shaded Pole	1500	35	900	320	590
0.16	Shaded Pole	1500	35	1160	400	760
0.25	Split Phase	1750	54	1180	640	540
0.33	Split Phase	1750	56	1500	840	660
0.50	Split Phase	1750	60	2120	1270	850
0.75	3-Phase	1750	72	2650	1900	740
1	3-Phase	1750	75	3390	2550	850
1.5	3-Phase	1750	77	4960	3820	1140
2	3-Phase	1750	79	6440	5090	1350
3	3-Phase	1750	81	9430	7640	1790
5	3-Phase	1750	82	15500	12700	2790
7.5	3-Phase	1750	84	22700	19100	3640
10	3-Phase	1750	85	29900	24500	4490
15	3-Phase	1750	86	44400	38200	6210
20	3-Phase	1750	87	58500	50900	7610
25	3-Phase	1750	88	72300	63600	8680
30	3-Phase	1750	89	85700	76350	9440
40	3-Phase	1750	89	114000	102000	12600
50	3-Phase	1750	89	143000	127000	15700
60	3-Phase	1750	89	172000	153000	18900
75	3-Phase	1750	90	212000	191000	21200
100	3-Phase	1750	90	283000	255000	28300
125	3-Phase	1750	90	353000	318000	35300
150	3-Phase	1750	91	420000	382000	37800
200	3-Phase	1750	91	559000	509000	50300
250	3-Phase	1750	91	699000	636000	62900

Table 4.13 Typical Overload Limits, F_L, with Standard Motors*

Horsepower	0.05-0.25	0.16-0.33	0.67-0.75	1 and up
AC open	1.4	1.35	1.25	1.15
AC TEFC** and DC	—	1.0	1.0	1.0

*Some shaded pole, capacitor start, and special purpose motors have a service factor varying 1.0 up to 1.75.

**TEFC (totally enclosed fan-cooled) motors can be purchased with a service factor above 1.0.

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INFILTRATION AND VENTILATION

5.1 INTRODUCTION

Load	Equation	Description and References
Sensible Heating or Cooling Load due to Infiltration or ventilation	$q_s = 1.10 \times (\Delta t) \times \text{scfm}$	q_s → Sensible heating or cooling load in Btu/hr due to infiltration or ventilation
	1.10	→ 1.10 has units of Btu/hr per scfm × F 1.08 is often used for calculating heating load
	Δt	→ Inside-outside temperature difference in degrees F. Outside design conditions from Table 2.1. For cooling loads use Table 5.1 also.
	scfm	→ Q, the infiltration or ventilation in cfm
Latent cooling or humidification load due to infiltration or ventilation	$q_l = 4840 \times (\Delta W) \times \text{scfm}$	q_l → Latent load due to infiltration in Btu/hr
	4840	→ 4840 has units of Btu/hr per scfm per lb of water vapor
	ΔW	→ Inside-outside humidity ratio difference in lb of water vapor to lb of dry air
	scfm	→ Q, the infiltration or ventilation, in standard cfm

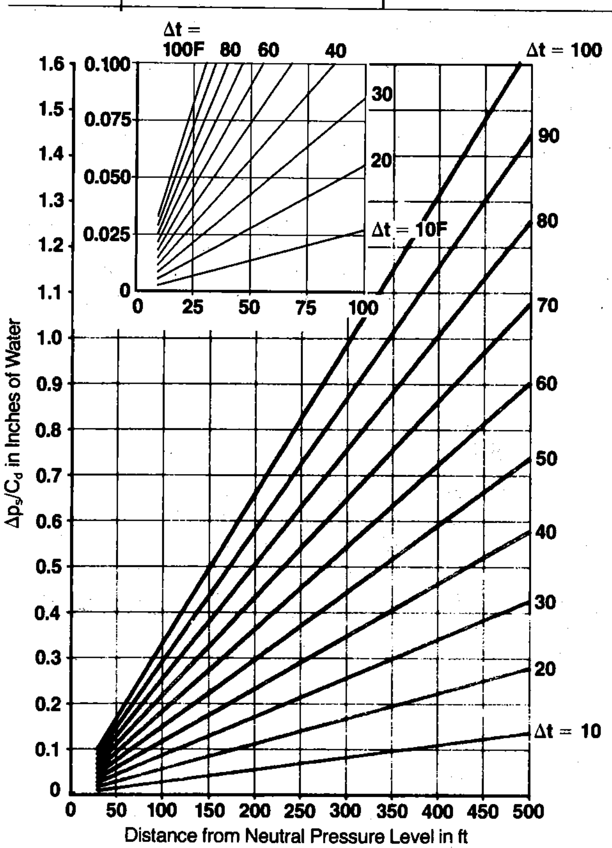


Fig. 5.1 Pressure Difference Due to Stack Effect

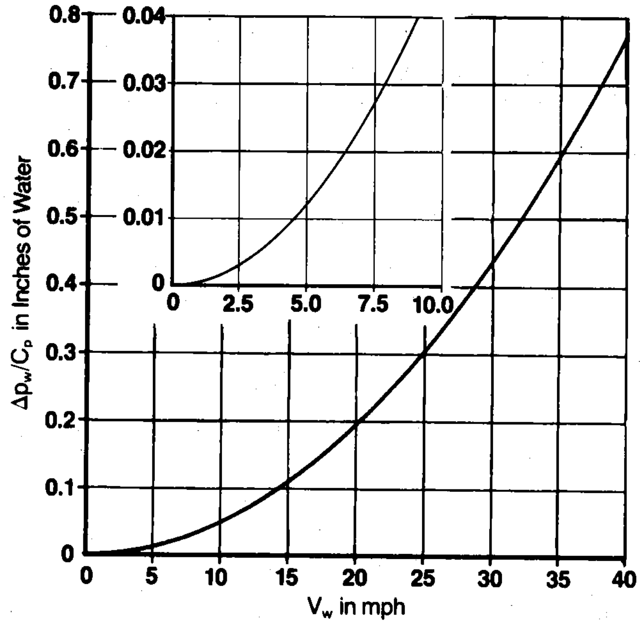


Fig. 5.2 Velocity Head vs Wind Velocity

5.2 VENTILATION AIR

Equation	Description and References
Q	→ Outdoor ventilation rate in cfm
$\frac{Q}{\text{Person}}$	→ Ventilation rate per person — Use Table 5.3 for various locations and activities
$Q = \frac{Q}{\text{Person}} \times$ no. of People	→ Number of people normally in conditioned space; should be known. If estimated number is needed use Table 5.3

Note: If adequate temperature regulation is provided and filtration restricts particulates to that listed in Table 5.2 (60 $\mu g/m^3$), the ventilating air may be reduced to 33% of the listed value in Table 5.3. Outdoor ventilation air not conforming to the remaining contaminants in Table 5.2 must be treated. In no case should the outdoor air quantity be reduced to less than 5 cfm per person.

Special Conditions

Some applications require special care in selecting outdoor design conditions. For example, hospitals or other applications with large quantities of outside air requirements are sensitive to outside conditions. In a location such as Los Angeles, the 2.5% design conditions from Table 2.1 are 80 F db/68 F wb. An occurrence of an outside temperature, for example, of 84 F db with an inside temperature of 78 F db would indicate (84 − 78)/(80 − 78) or 3 times the design ventilation load. For St. Louis where the design conditions are 94/75, an override of 4 deg F to 98 F db would indicate an increase of only 4/(94 − 78) or 25% in the ventilation sensible load. The difference in dry bulb temperature does not affect the other cooling loads as directly as it does the ventilation load, since the effect on the air is without any lag.

EXAMPLE 5.1

Determine the required amount of ventilation and its resultant cooling load for a 20 × 30 ft conference room at 1200, 1400 and 1600 hr. The design inside temperature is 78 F with 50% rh. The peak design outdoor temperature is 90 F db and 75 F wb and the daily temperature range is 25 deg F.

SOLUTION 5.1

The number of people is not given. Table 5.3 for conference rooms in office buildings lists

$$60 \text{ people}/1000 \text{ ft}^3 \text{ of floor area}$$

The floor area is $20 \times 30 = 600 \text{ ft}^2$, therefore the estimated number of people in the conference room is

$$\frac{60}{1000} \times 600 = 36 \text{ people}$$

Table 5.3 gives the minimum ventilation rate for a conference room to be

$$25 \text{ cfm/person}$$

The temperature of the ventilating air is to be controlled in this situation and the allowable contaminates listed in Table 5.2 are not exceeded. Therefore, the required ventilation may be reduced to a third, but no lower than 5 cfm/person

$$1/3 \times 25 = 8.33 \text{ cfm/person}$$

The required amount of outdoor ventilation is

$$Q = 8.33 \text{ cfm/person} \times 36 \text{ people} = 300 \text{ cfm}$$

Using Table 5.1 the peak temperature of 90 F occurs at 1500 hr. Using the daily range of 25 deg F the design temperature at 1200 hr is

$$90 - 6 = 84 \text{ F}$$

The sensible cooling load at 1200 hr is

$$q_s = 1.10 \times (\Delta t) \times \text{cfm}$$
$$= 1.10 \times (84 - 78) \times 300 = 1980 \text{ Btu/hr}$$

The sensible cooling load at 1400 and 1600 hr is

$$q_s = 1.10 \times (89 - 78) \times 300 = 3630 \text{ Btu/hr}$$

The amount of moisture usually does not change during the day. The humidity ratio at 90 F db and 75 F wb, $W_o = 0.0155$ lb/lb will be used for all 3 hr. At 78 F db and 50% rh, $W_i = 0.0102$ lb/lb, therefore the latent cooling load for 1200, 1400 and 1600 hr is

$$q_l = 4840 \times (\Delta W) \times \text{cfm}$$
$$= 4840 \times (0.0155 - 0.0102) \times 300 = 7700 \text{ Btu/hr}$$

5.3 CURTAIN WALL INFILTRATION PER FLOOR OR ROOM

Equation	Description and References
Q	Infiltration through curtain wall in cfm for one room or one floor only
A	Outside wall area in ft^2
$Q = A \times (Q/A)$	Q/A from Fig. 5.3 K, the wall leakage coefficient, use Table 5.4 Δp, the pressure difference across the outside wall. Use Fig. 5.1 and 5.2 and Table 5.5

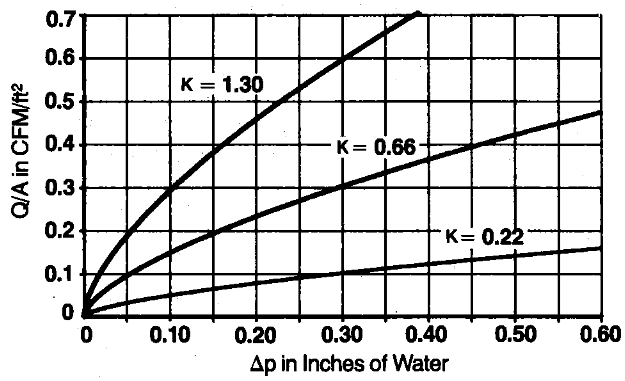


Fig. 5.3 Curtain Wall Infiltration For One Room or One Floor

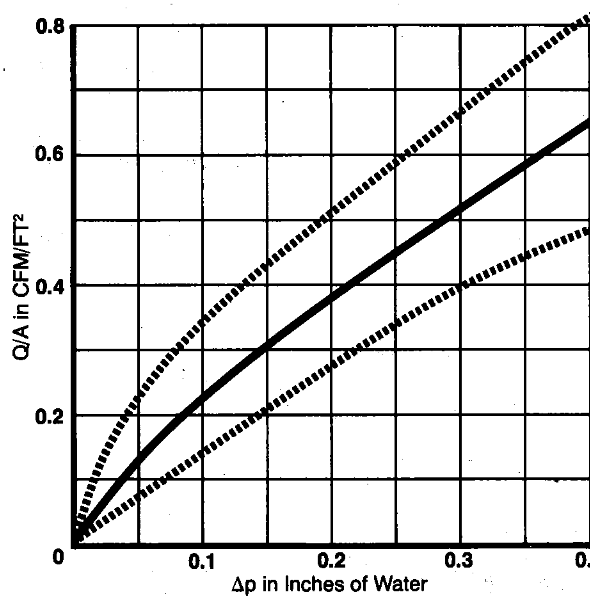


Fig. 5.4 Overall Leakage Rates for Seven Pressurized Curtain Wall Buildings — Includes leakage through doors, vents, equipment floors as well as walls. The solid line is the average of the seven buildings and the dotted lines are the extreme of the data.

EXAMPLE 5.2

Determine the design heating load due to air infiltration into an outside facing room on the 4th floor of a 20-story building. Each story is 10 ft high and the room width facing the outside is 15 ft. The design wind velocity is 10 mph and the room is on the windward side. The design outside temperature is 5 F and the design inside temperature is 72 F. The inside relative humidity is 30%. Assume that the curtain wall has average quality construction.

SOLUTION 5.2

From Table 5.5 the wind pressure coefficient for this room is

$$C_p = 0.95$$

From Fig. 5.2 a 10 mph wind gives

$$\frac{\Delta p_w}{C_p} = 0.048$$

$$\Delta p_w = C_p \times 0.048 = 0.95 \times 0.048 = 0.0456 \text{ in. of water}$$

The room is on the 4th floor which is 6 floors away from the 10th floor, the neutral pressure level of the building. The distance from the neutral pressure level is 6 × 10 = 60 ft and the inside-outside temperature difference is Δt = 72 - 5 = 67 deg F. Using this information and Fig. 5.1

$$\frac{\Delta p_s}{C_d} = 0.125$$

The value for C_d for office buildings is between 0.63 and 0.82. Assume $C_d = 0.80$ for this building.

$$\Delta p_s = C_d \times 0.125 = 0.80 \times 0.125 = 0.10 \text{ in. of water}$$

In the winter Δp_s is positive for the lower half of the building, that is, air leaks into the lower half, therefore assuming no pressurization the total pressure difference across the outside wall is

$$\Delta p = \Delta p_w + \Delta p_s = 0.0456 + 0.10 = 0.1456 \text{ in. of water}$$

From Table 5.4 assuming an average fitting wall

$$K = 0.66$$

Using $\Delta p = 0.1456$ and the $K = 0.66$ curve, Fig. 5.3 gives

$$\frac{Q}{A} = 0.19 \text{ cfm/ft}^2$$

thus $Q = A \times 0.19 = 10 \times 15 \times 0.19 = 28.5$ cfm

The sensible heating load is

$$q_s = 1.08\,(\Delta t)\,(\text{cfm}) = 1.08 \times 67 \times 28.5 = 2060 \text{ Btu/hr}$$

At 30% relative humidity and $t = 72$ F the psychrometric chart gives $W_i = 0.005$. Assuming saturated air at $t_o = 5$ F the chart gives $W_o = 0.001$.

If humidification is provided the humidification load is

$$q_l = 4840\,(\Delta W)\,\text{cfm} = 4840 \times (0.005 - 0.001) \times 28.5 = 552 \text{ Btu/hr}$$

EXAMPLE 5.3

Determine the cooling load of the top floor of a 20-story building due to air infiltration. Each story is 10 ft high and the floor area is 100 ft by 150 ft. There is a 10 mph wind acting normal to the long wall. The design outside db temperature is 90 F with 75 F wb and the design inside temperature is 78 F with 50% rh. Assume a thermal draft coefficient, C_d, of 0.80 and an average fitting curtain wall.

SOLUTION 5.3

From Fig. 5.2 a, 10 mph wind gives

$$\frac{\Delta p_w}{C_p} = 0.048$$

From Table 5.5 the pressure difference due to wind is

For the windward wall	$\Delta p_w = 0.95 \times 0.048 = 0.0456$
For the leeward wall	$\Delta p_w = -0.15 \times 0.048 = -0.0072$
For the side walls	$\Delta p_w = -0.40 \times 0.048 = -0.0192$

The 20th story is 10 stories from the neutral pressure level thus the distance from the neutral pressure level is 100 ft. The inside-outside temperature difference is $\Delta t = 90 - 78 = 12$ deg F. Using this information Fig. 5.1 gives

$$\frac{\Delta p_s}{C_d} = 0.030$$

$$\Delta p_s = 0.80 \times 0.030 = 0.024 \text{ in. of water}$$

In the summer Δp_s is positive for the upper half of the building (air leaking into upper half) thus the total pressure difference is

For the windward wall	$\Delta p = 0.0456 + 0.024 = 0.0696$
For the leeward wall	$\Delta p = -0.0072 + 0.024 = 0.0168$
For the side walls	$\Delta p = -0.0192 + 0.024 = 0.0048$

If any of these pressure differences would be negative it would mean the flow is exfiltrating through those walls and thus would not be causing a cooling load at that location.

From Table 5.4 and an average fitting wall

$$K = 0.66$$

Using the above values of Δp and the $K = 0.66$ curve, Fig. 5.3 gives

For the windward wall	$\frac{Q}{A} = 0.12$
For the leeward wall	$\frac{Q}{A} = 0.05$
For the side walls	$\frac{Q}{A} = 0.025$

The infiltration is

For the windward wall	$Q = 0.12 \times 150 \times 10 = 180$ cfm
For the leeward wall	$Q = 0.05 \times 150 \times 10 = 75$ cfm
For the side walls	$Q = 0.025 \times 100 \times 10 \times 2 = 50$ cfm

The total infiltration is

$$Q = 180 + 75 + 50 = 305 \text{ cfm}$$

The sensible cooling load is

$$q_s = 1.10\,(\Delta t)\,\text{cfm} = 1.10 \times 12 \times 305 = 4020 \text{ Btu/hr}$$

At 90 F db and 75 F wb, $W_o = 0.0155$ lb/lb and; at 78 F db and 50% rh, $W_i = 0.0102$ lb/lb.

The latent cooling load is

$$q_l = 4840\,(\Delta W)\,\text{cfm} = 4840 \times (0.0155 - 0.0102) \times 305 = 7820 \text{ Btu/hr}$$

For cooling load analysis the ventilation air is generally more important than the infiltration. To show this consider that the 20th floor is general office space. The floor area is 100 × 150 = 15,000 ft^2 thus Table 5.3 estimates 150 people on the floor. The minimum ventilation rate of 15 cfm/person is reduced to 5 cfm/person because the ventilating air is conditioned. The required outdoor ventilation for the floor is thus 5 × 150 = 750 cfm. Because the ventilating air is supplied to the conditioned space which has no comparable exhaust system, the ventilating air will pressurize the space and change the infiltration.

When the 20th floor is pressurized air will exfiltrate through the walls, lavatory vents, elevator shafts and stairshafts, the later two in turn exfiltrating air to the roof door, ground floor doors and equipment floors. In addition, of course, is the difference in pressure on each wall caused by the wind plus the stack effect pressure difference. To do an exact pressurization analysis would be very difficult even if all the important variables were known, thus the following method is suggested.

The results of pressurizing seven curtain wall office buildings without a wind or stack effect are shown in Fig. 5.4. The exfiltration is given as leakage per unit wall area but includes leakage through doors, vents, equipment floors, etc., in addition to walls. Using this leakage rate as the overall leakage rate for the condition space (the 20th floor wall area = (2 × 100 + 2 × 150) × 10 = 5000 ft^2) gives $Q/A = 750/5000 = 0.15$. Using Fig. 5.4 and

this Q/A the average curve gives a pressure difference of about 0.05 in. of water. On the other hand, if all the leaking air exfiltrates through the wall then Fig. 5.3 (for $K = 0.66$) gives a pressure difference of 0.10 in. of water.

If 0.05 is taken as the pressurization then the infiltration on the leeward and side walls would be prevented and the pressure difference on the windward side would be reduced from 0.0696 to 0.0196 in. of water. Using Fig. 5.3 and the $K = 0.66$ curve

$$Q/A = 0.05$$

Therefore

$$Q = 0.05 \times 150 \times 10 = 75 \text{ cfm}$$

The ventilation plus the infiltration is

$$750 + 75 = 825 \text{ cfm}$$

The sensible and latent cooling load for the total outside air entering the conditioned space is

$$q_s = 1.10 \times 12 \times 825 = 10900 \text{ Btu/hr}$$
$$q_l = 4840 \times (0.0155 - 0.0102) \times 825 = 21100 \text{ Btu/hr}$$

Note that is the pressurization were 0.10 in. of water then there would be no infiltration on any walls and the cooling load due to outside air would be just that due to the ventilating air.

5.4 CURTAIN WALL INFILTRATION FOR ENTIRE BUILDING DUE TO STACK EFFECT

Equation	Description and References
$Q = A \times K \times F_d \times (Q/AKF_d)$	Q → Infiltration through curtain wall in cfm for entire building due to stack effect with zero pressurization. A → Entire curtain wall area of building in ft^2 K → Curtain wall leakage coefficient — use Table 5.4 F_d → Thermal draft factor — use Fig. 5.5 Q/AKF_d → Q/AKF_d is from Fig. 5.6 Δt is the inside-outside temperature difference in degrees F The building height is in ft.

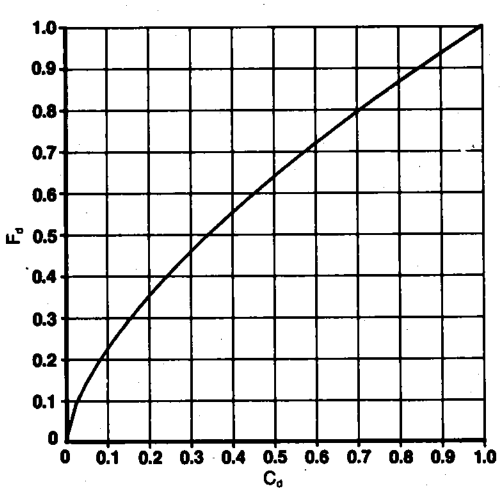


Fig. 5.5 Thermal Draft Factor vs Thermal Draft Coefficient

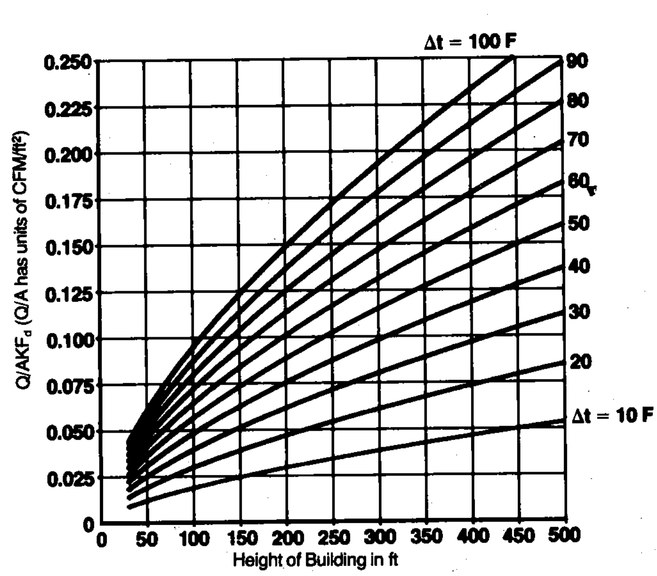


Fig. 5.6 Infiltration through Curtain Wall for Entire Building Due to Stack Effect and Zero Pressurization

EXAMPLE 5.4

Determine the infiltration through the walls of a modern 20-story office building. The exterior facing is pre-cast concrete panels and all construction procedures are conventional. The windows are non-operable. The floor area is 150 ft by 100 ft and the floor to floor height is 10 ft. The inside temperature is 72 F and the outside temperature is 5 F. No wind is blowing. Assume a thermal draft coefficient, C_d, of 0.80.

SOLUTION 5.4

From the description of the building and its construction the building envelope is a curtain wall with an average fitting wall. From Table 5.4

$$K = 0.66$$

Using $C_d = 0.80$ and Fig. 5.5, the thermal draft factor is

$$F_d = 0.87$$

The curtain wall area is

$$A = 2 \times (150 + 100) \times 200 = 100{,}000 \text{ ft}^2$$

For a building height of $20 \times 10 = 200$ ft and $\Delta t = 72 - 5 = 67$ deg F Fig. 5.6 gives

$$\frac{Q}{AKF_d} = 0.11$$

Substituting in the values for A, K and F_d, the infiltration for the entire curtain wall is

$$Q = 0.11 \times 100{,}000 \times 0.66 \times 0.87 = 6300 \text{ cfm}$$

Suppose the required ventilation air for the building is 30,000 cfm and the exhaust air is 7,000 cfm. The net inflow that will pressurize the building is

$$30{,}000 - 7{,}000 = 23{,}000 \text{ cfm}$$

To estimate the pressurization Q/A is needed. (See Example 5.3.)

$$Q/A = 23{,}000/100{,}000 = 0.23$$

Using Fig. 5.4, and the average curve, $Q/A = 0.23$ gives an approximate pressurization of 0.10 in. of water without the

stack effect. Using the same reasoning as in Example 5.3, that is, assuming that 0.10 pressurization holds when there is infiltration due to stack effect then Fig. 5.7 can be used. For a 200 ft high building, $\Delta t = 67$, Fig. 5.7 gives

$$\frac{Q}{AKF_d} = 0.022$$

Substituting in for A, K, and F_d as before, the infiltration for the entire curtain wall with 0.10 pressurization is

$$Q = 0.022 \times 100{,}000 \times 0.66 \times 0.87 = 1260 \text{ cfm}$$

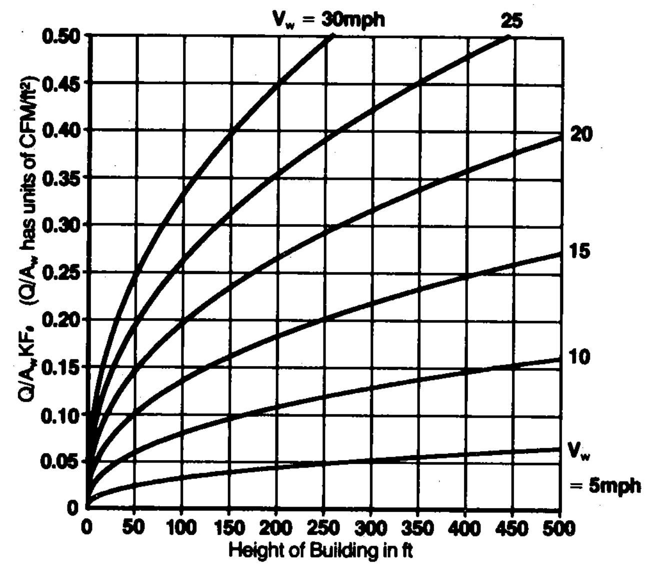


Fig. 5.8 Infiltration through Curtain Wall for Entire Building due to Wind and Zero Pressurization

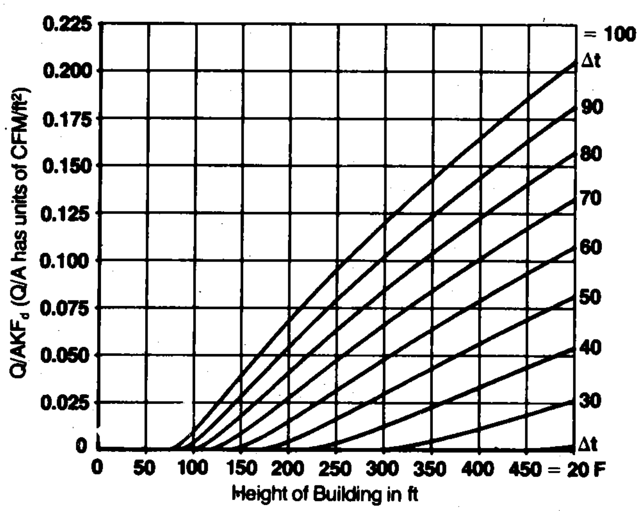


Fig. 5.7 Infiltration through Curtain Wall For Entire Building due to Stack Effect, C_d = 0.80, and a Pressurization of 0.10 in. of Water

5.5 CURTAIN WALL INFILTRATION FOR ENTIRE BUILDING DUE TO WIND

Equation	Description and References
Q	→ Infiltration through curtain wall in cfm for entire building due to wind blowing and with zero pressurization.
A_w	→ Curtain wall area of longest wall in ft² — building has rectangular floor plan
K	→ Curtain wall leakage coefficient — use Table 5.4
F_θ	→ Wind correction factor—use Fig. 5.9
$Q = A_w \times K \times F_\theta \times (Q/A_wKF_\theta)$	→ Q/A_wKF_θ is from Fig. 5.8
	V_w is the wind velocity in mph
	The building height is in ft

Note: For adjacent building acting as a shield for the wind, reduce Q by 60% if adjacent building is same height. Reduce Q by 20% if adjacent building is two-thirds as high and make no correction to Q if adjacent building is one-third as high.

EXAMPLE 5.5

Determine the infiltration through the walls of the building of Example 5.3 when a 15 mph wind is blowing normal to the 150-ft side of the building. The inside and outside temperatures are equal and there is no pressurization of the building.

SOLUTION 5.5

From Fig. 5.9 and the $W{:}l = 1{:}1.5$ graph, with $\theta = 0$ then

$$F_\theta = 1.0$$

The longest wall is the 150-ft wall thus

$$A_w = 150 \times 200 = 30{,}000 \text{ ft}^2$$

For a building height of 200 ft and $V_w = 15$ mph, Fig. 5.8 gives

$$\frac{Q}{A_wKF_\theta} = 0.18$$

Substituting in values for A_w and F_θ and for $K = 0.66$, the wind infiltration is

$$Q = 0.18 \times 30{,}000 \times 0.66 \times 1.0 = 3560 \text{ cfm}$$

If the wind is blowing normal to the 100 ft wall then $\theta = 90$ deg and from the $W{:}l = 1{:}1.5$ graph, Fig. 5.9, $F_\theta = 0.75$, thus

$$Q = 0.18 \times 30{,}000 \times 0.66 \times 0.75 = 2670 \text{ cfm}$$

Note that A_w is the longest wall and thus remains at 30,000 ft² for this situation.

If for this last case there is a nearby building 12 stories high and it is blocking the wind then the adjacent building about 2/3 as high and Q is reduced by 20%. The wind infiltration will be

$$Q = 2670 \times (1.0 - 0.20) = 2140 \text{ cfm}$$

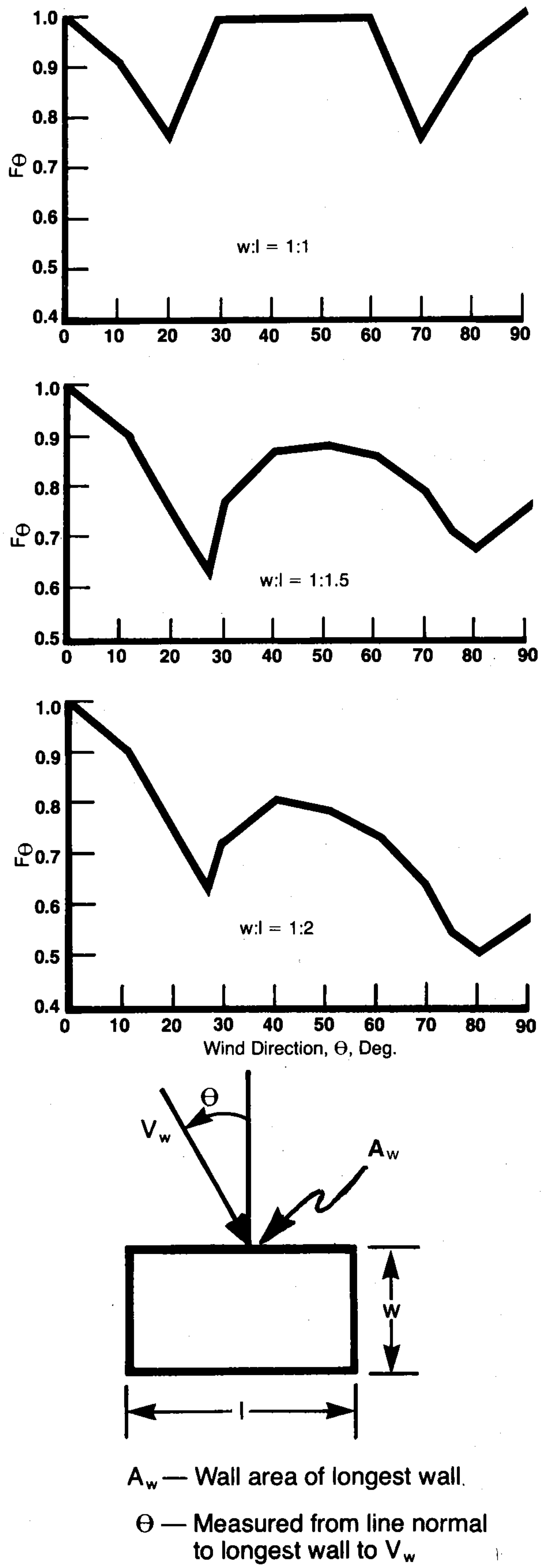


Fig. 5.9 Curtain Wall Infiltration Correction Factor Due to Various Wind Directions

5.6 CURTAIN WALL INFILTRATION FOR THE ENTIRE BUILDING DUE TO COMBINED WIND AND STACK EFFECT

Equation	Description and References
Q	→ Infiltration through curtain wall in cfm due to combined wind and stack effect for zero pressurization
Q_{large}	→ Larger value of Q due to stack effect acting alone or Q due to wind acting alone
$Q = Q_{large} \times \left(\frac{Q}{Q_{large}}\right)$	→ Q/Q_{large} is from Fig. 5.10 Q_{small} is the smaller value of Q due to stack effect acting alone or Q due to wind acting alone. Q_{small}/Q_{large} is a ratio of these two infiltrations.

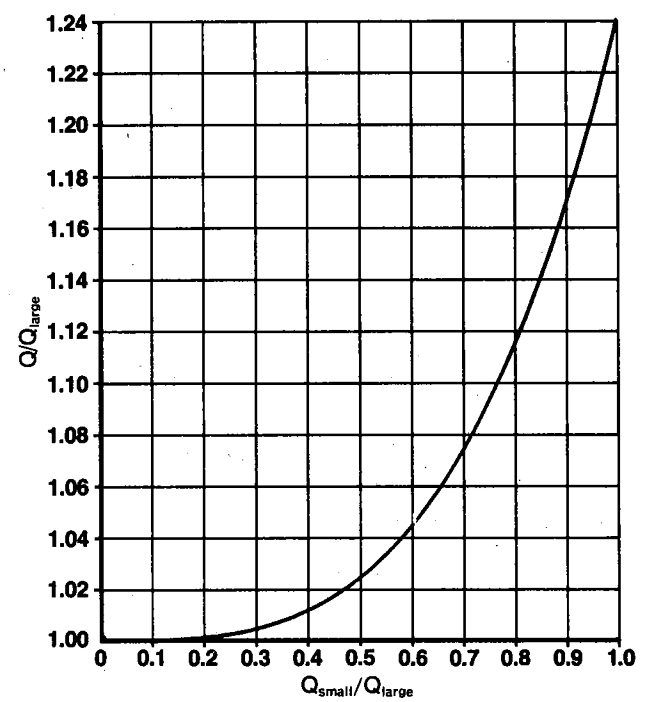


Fig. 5.10 Graph for Obtaining Curtain Wall Infiltration for Entire Building due to Combined Wind and Stack Effect With Zero Pressurization

EXAMPLE 5.6

Determine the infiltration through the walls of the building of Example 5.4 due to a wind of 15 mph blowing normal to the long wall and to an inside-outside temperature difference of $\Delta t = 67$ deg F.

SOLUTION 5.6

From Example 5.4 with zero pressurization

For stack effect alone $Q = 6300$ cfm

From Example 5.5

For wind acting alone $Q = 3560$ cfm

From the above definitions

$$Q_{small} = 3560$$
$$Q_{large} = 5740$$

Thus

$$Q_{small}/Q_{large} = \frac{3560}{6300} = 0.565$$

Using Fig. 5.10

$$Q/Q_{large} = 1.04$$

The combined wind and stack infiltration for the entire curtain wall is

$$Q = 1.04 \times Q_{large} = 1.04 \times 6300 = 6550 \text{ cfm}$$

Although the total infiltration is hardly changed there is a significant redistribution in leakage. In this example infiltration will increase on the windward side of the lower portion of the building but decrease on the upper portion.

5.7 CRACK INFILTRATION FOR WINDOWS AND RESIDENTIAL TYPE DOORS

Equation	Description and References
Q	→ Infiltration in cfm through perimeter gaps in windows and doors having a perimeter stop trim piece
P	→ Perimeter (total crack length) of windows or doors in ft
$Q = P \times (Q/P)$	→ Q/P is from Fig. 5.11 k, the perimeter leakage coefficient, for windows use Table 5.6, for doors use Table 5.7 Δp, the pressure difference across the window or door. Use Figs. 5.1 and 5.2 and Table 5.5

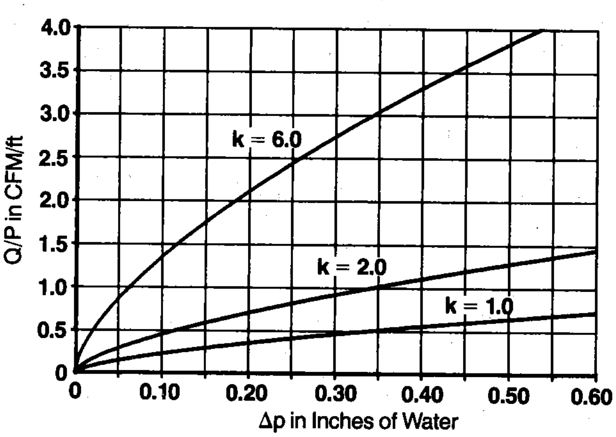


Fig. 5.11 Window and Residential Type Door Infiltration Characteristics

EXAMPLE 5.7

Determine the infiltration through a 3 by 5 ft new wood-plastic double hung window having small cracks between moving parts. The window is on the windward side of a house and the wind is blowing at 15 mph. For houses assume $C_p = 1.0$ for the windward side.

SOLUTION 5.7

Using 15 mph and Fig. 5.2

$$\frac{\Delta p_w}{C_p} = 0.105$$

For $C_p = 1.0$ then $\Delta p_w = 0.105$ in. of water

From Table 5.6 the plastic weatherstripped window is average fitting but with small cracks it will classify as tight fitting, that is, $k = 1.0$.

Using $\Delta p_w = 0.105$, $k = 1.0$ and Fig. 5.11 yields

$$\frac{Q}{P} = 0.25$$

P is the total length of the gap between movable sections of the window and the frame. For double hung window P includes the length of the meeting rail between the sashes.

$$P = (3 \times 3 + 2 \times 5) = 19 \text{ ft}$$

The infiltration through the window is

$$Q = 0.25 \times 19 = 4.75 \text{ cfm}$$

5.8 INFILTRATION THROUGH COMBINED STORM AND PRIME WINDOWS

Equation	Description and References
Q	→ Infiltration in cfm through combined storm and prime window
Q_p	→ Infiltration in cfm through prime window
$Q = Q_p \times (Q/Q_p)$	→ Q/Q_p is from Fig. 5.12 k_pP_p/k_sP_s where k_p and k_s are the perimeter leakage coefficients for the prime and storm windows, respectively, and P_p and P_s the perimeters of the prime and storm windows.

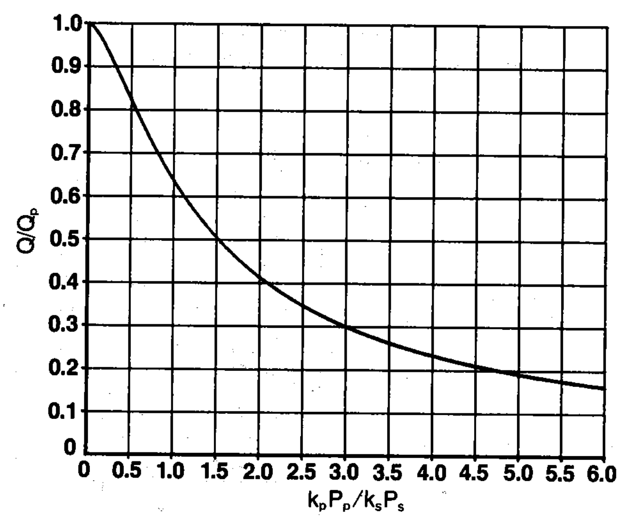


Fig. 5.12 Infiltration for Storm-Prime Combination Windows

EXAMPLE 5.8

Determine the infiltration through the window of Example 5.7 with the addition of a weatherstripped, double hung, aluminum storm window.

SOLUTION 5.8

Table 5.6 indicates this storm window is average fitting unless the gap between movable parts were 1/64 in. or less. Choosing to error on the high side of the infiltration estimate, $k = 2.0$ is chosen.

$$k_s = 2.0$$

Taking the perimeters to be equal ($P_p = P_s$) then

$$\frac{k_p \times P_p}{k_s \times P_s} = \frac{1.0 \times 19}{2.0 \times 19} = 0.50$$

Using this last result and Fig. 5.12

$$Q/Q_p = 0.825$$

$Q_p = 4.75$ cfm from Example 5.7, thus

$$Q = 0.825 \times 4.75 = 3.92 \text{ cfm}$$

5.9 INFILTRATION THROUGH COMMERCIAL TYPE SWINGING DOORS

Equation	Description and References
$Q = P \times (Q/P)$	→ Infiltration in cfm through cracks around swinging doors that are closed → Perimeter of door in ft → Q/P is given in Fig. 5.13 Δp is the pressure difference across the door — use Figs. 5.1 and 5.2 and Table 5.5 Average gap around door must be known.
Q	→ Infiltration in cfm through swinging doors under normal traffic conditions — Use Fig. 15.14. This figure is for one standard sized door thus is actually cfm per door. Δp, pressure difference across the door Use Figs. 5.1 and 5.2 and Table 5.5 C, the flow coefficient (Eq. A5.3). C is obtained from Fig. 15.15 knowing the people per hour and whether the door is single bank or double bank (vestibule)

The total infiltration through a swinging door is the addition of closed door infiltration and the normal traffic infiltration.

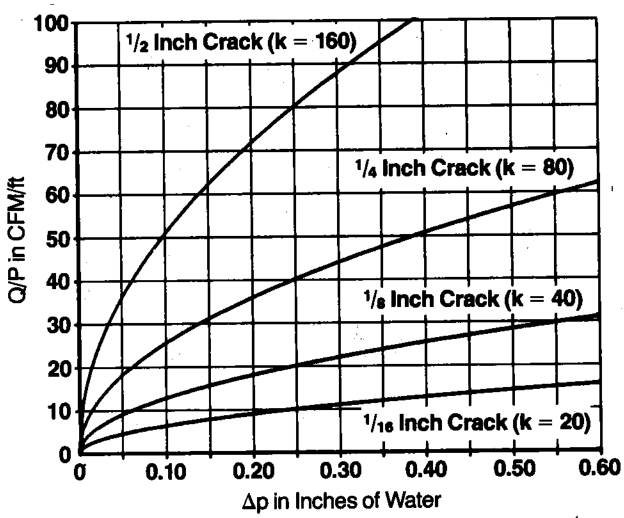


Fig. 5.13 Infiltration Through Closed Swinging Door Cracks

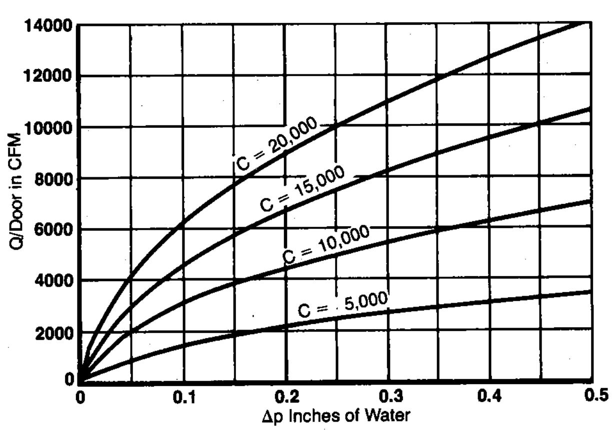


Figure 5.14 Swinging Door Infiltration Characteristics with Traffic

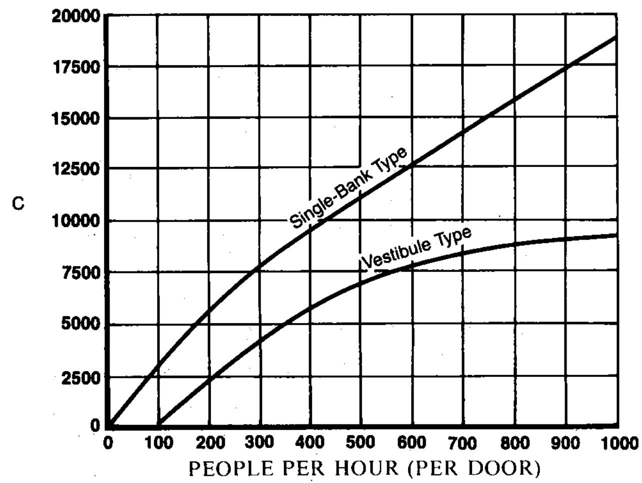


Fig. 5.15 Traffic Rate

EXAMPLE 5.9

The 20-story office building described in Example 5.4 has a two-door vestibule type entrance on the windward side (the 150 ft side) of the building. There are two single bank swinging doors on the leeward side, one of which carries no traffic. The other three doors handle 900 people per hour. There is a 1/8 in. perimeter air gap around each door. The wind is 15 mph and the inside-outside temperature difference is 67 deg F. The doors are 3 ft × 7 ft.

SOLUTION 5.9

The distance of the doors from the neutral pressure level is 10 × 10 = 100 ft and using $\Delta t = 67$ deg F and Fig. 5.1 yields

$$\frac{\Delta p_s}{C_d} = 0.2$$

Again taking C_d to be 0.8

$$\Delta p_s = 0.8 \times 0.2 = 0.16 \text{ in. of water}$$

From Fig. 5.2 and 15 mph

$$\frac{\Delta p_w}{C_p} = 0.11$$

From Table 5.5 the pressure difference due to wind is

For the windward doors $\Delta p_w = 0.95 \times 0.11 = 0.105$ in. of water

For the leeward doors $\Delta p_w = -0.15 \times 0.11 = -0.0165$ in. of water

Note: If this building were located such that the wind is blocked by other buildings then the effect of wind can be neglected. This would be true for doors in the middle of a side of a building that is located next to the street in a building crowded city center. If, on the other hand, buildings are offset from the street in the local area or the doors are on the corner of the building then it is possible that the doors could receive up to the full effect of the wind.

For a heated building, as in this case, Δp_s, is positive for the lower half of the building thus the total pressure difference is

For the windward door $\Delta p = 0.16 + 0.105 = 0.265$ in. of water

For the leeward door $\Delta p = 0.16 - 0.0165 = 0.1435$ in. of water

The infiltration for the doors when they are closed use Fig. 5.13, 1/8 in. crack, and the above Δp's.

For the windward door $Q/P = 20$
For the leeward door $Q/P = 15$

But the perimeter for each door is

$$P = (2 \times 3) + (2 \times 7) = 20 \text{ ft}$$

The infiltration for one windward closed door is

$$Q = 20 \times 20 = 400 \text{ cfm}$$

Note: This is high as the windward door is actually a vestibule type door. The infiltration for one leeward door is

$$Q = 15 \times 20 = 300 \text{ cfm}$$

The total infiltration for all four doors closed (2 windward and 2 leeward) is

$$Q = 2 \times 400 \times 2 \times 300 = 1400 \text{ cfm}$$

Assuming 300 people per hour for each of the 3 doors, Fig. 15.15 gives

$C = 7800$ for the single bank door
$C = 4200$ for the vestibule door

Using these values of C in Fig. 15.14 and the Δp's calculated previously

$Q/\text{Door} = 2000$ for $C = 4200$ and $\Delta p = 0.265$ windward door
$Q/\text{Door} = 3000$ for $C = 7800$ and $\Delta p = 0.1435$ leeward door

There are two windward vestibule doors and one single bank door with traffic thus the total infiltration due to traffic is

$$Q = 2 \times 2000 + 3000 = 7000 \text{ cfm}$$

The infiltration due to closed door leakage and due to traffic is

$$Q = 1400 + 7000 = 8400 \text{ cfm}$$

If these are the only doors in the lower half of the building then the total infiltration for the entire building is the curtain wall infiltration (Example 5.6) and the doors

$$Q = 6550 + 8400 = 14950 \text{ cfm}$$

If the building is pressurized to 0.10 in of water as done in Example 5.4, the pressure difference would be

For the windward door $\Delta p = 0.265 - 0.10 = 0.165$ in. of water
For the leeward door $\Delta p = 0.1435 - 0.10 = 0.0435$ in. of water

Repeating these calculations gives 5360 cfm for the total door leakage. The infiltration with pressurization in Example 5.4 of 1260 cfm is for a no wind condition. Using this value as an approximate curtain wall infiltration the wall and door infiltration with 0.10 pressurization is

$$1260 + 5360 = 7520 \text{ cfm}$$

This is a significant reduction from 14950 cfm but it took a net ventilation rate of 23,000 cfm to accomplish this. In general pressurizing buildings to reduce infiltration increases the heating or cooling load and should be done only to satisfy ventilation requirements.

5.10 INFILTRATION THROUGH REVOLVING DOORS

Equation	Description and References
Q	Infiltration in cfm through door seals when door is not revolving — Use Fig. 15.16 This figure is for one standard size door thus is actually cfm per door Δp, pressure difference across the door. Use Figs. 5.1 and 5.2 and Table 5.5
Q	Infiltration in cfm due to mechanical interchange of the air by revolving doors Use Fig. 15.17 or 15.18. Both figures are cfm per standard sized door. Δt is inside-outside temperature difference

The total infiltration through a revolving door is the addition of the non-revolving infiltration and the mechanical air interchange infiltration.

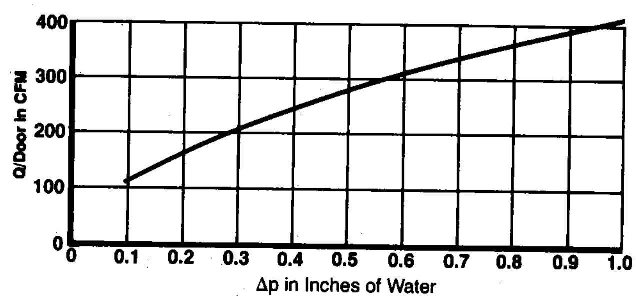


Fig. 5.16 Infiltration Through Seals of Revolving Doors Which are not Revolving

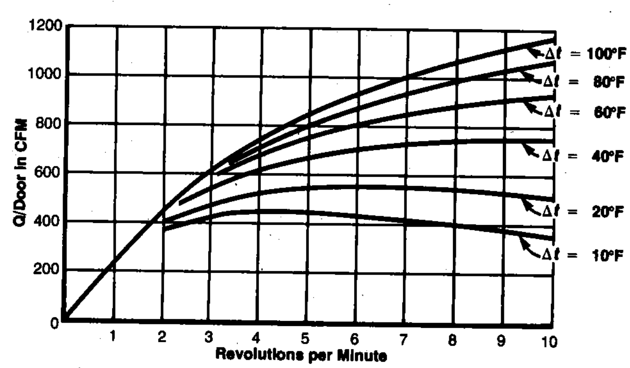


Fig. 5.17 Infiltration for Motor Operated Revolving Door

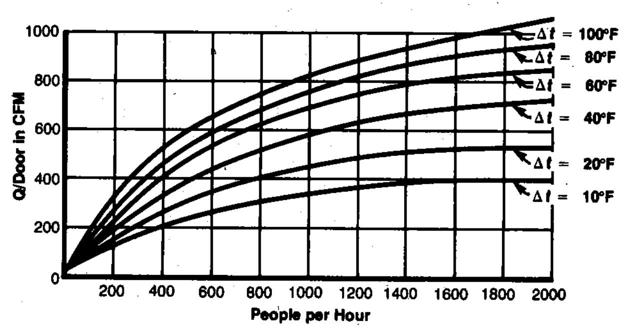


Fig. 5.18 Infiltration for Manually Operated Revolving Door

EXAMPLE 5.10

Replace the two vestibule doors of Example 5.9 with two manually operated revolving doors and determine the infiltration.

SOLUTION 5.10

From Example 5.9 the pressure difference across the windward doors is

$$\Delta p = 0.265 \text{ in. of water}$$

From Fig. 15.16 and $\Delta p = 0.265$ the infiltration through the seals is

$$Q/\text{door} = 200 \text{ cfm}$$

For both doors

$$Q = 2 \times 200 = 400 \text{ cfm}$$

For 300 people per hour and $\Delta t = 67$ deg F, Fig. 15.18 gives

$$Q/\text{door} = 360 \text{ cfm}$$

For both doors

$$Q = 2 \times 360 = 720 \text{ cfm}$$

The infiltration for leakage through the seals and for mechanical interchange of air is

$$Q = 400 + 720 = 1120 \text{ cfm}$$

Note: This is a significant reduction from the 4800 cfm calculated for the vestibule doors. Revolving doors, however, cannot handle the same traffic as swinging doors.

5.11 INFILTRATION FOR LOW-RISE COMMERCIAL AND LIGHT INDUSTRIAL BUILDINGS

Infiltration for low-rise buildings is difficult to assess. Traffic through normally closed doors or large open shipping or receiving doors with the wind blowing is the major source of infiltration. Unless the inside-outside temperature difference is extreme the stack effect can be neglected. Consider the following procedures as a guide for low-rise buildings. Any special or unusual design consideration will require separate analysis.

I. Low-Rise Commercial or Light Industrial Buildings with Tight Construction and No Open Doors and Having a Low Exhaust Air Rate

First determine the ventilation air rate required for people using Table 5.3. Secondly determine the infiltration due to wind blowing on one side of the building. Use Fig. 5.2 to obtain the pressure difference due to wind, and Figs. 5.11 through 5.18 and Tables 5.6 and 5.7 for windows and doors. Assume the wind pressure coefficient, C_p, is equal to 1.0 on the windward wall. An alternate approach is to assume 1/2 air change per hour. A low exhaust rate means that it is less than the infiltration due to the wind.

A. If the ventilation is less than the exhaust rate, then assume the total infiltration is equal to the infiltration due to wind plus the exhaust rate. Ventilation will be required only if the infiltration is not into the occupied space.

B. If the ventilation is greater than the exhaust rate but less than exhaust plus infiltration, then both ventilation and infiltration are considered as contributing to the load. When the value of the ventilation is close to the calculated infiltration then a reduced infiltration can be assumed.

C. If the ventilation is greater than the exhaust plus infiltration by 5% assume that the infiltration is offset and no infiltration takes place.

II. Low-Rise Light Industrial Building with Tight Construction and No Open Doors and Having a High Exhaust Rate

Make-up air equal to exhaust rate should be supplied. Check to see that make-up air exceeds ventilation requirements for people. For situations of this type wind infiltration can generally be neglected.

III. Low-Rise Commercial and Light Industrial Buildings with Open Doors

For buildings with one open door facing the wind, infiltration based on 5 air changes per hour is appropriate. If this is to be offset by ventilation air use 10% more than the calculated infiltration.

For buildings with open doors on more than one side of the building, it becomes economically impractical to design for periods of high wind, and other means must be employed. During periods of high wind, either close one door, provide air or plastic strip curtains, or suffer a variance from the design conditions.

EXAMPLE 5.11

A one-story retail store of tight construction has a floor area of 30,000 ft² and a height of 20 ft. There are four vestibule type doors having 1/8 in. perimeter cracks. The doors are expected to handle 800 people per hour and the normal maximum number of people in the store is about 400. The exhaust rate is 200 cfm. Determine the cooling load due to outside air entering the building. The design inside-outside temperature difference is 15 deg F and the design humidity ratio difference is 0.0050, both at 1400 hr.

SOLUTION 5.11

From Table 5.3 the minimum ventilation for sale floors in commercial buildings is 7 cfm/person. Because the air is conditioned this may be reduced to a third or 5 cfm/person, whichever is greater. The ventilation rate for the entire store is

$$400 \times 5 = 2000 \text{ cfm}$$

Assume a summer design wind velocity of 7.5 mph. Using Fig. 5.2 and $C_p = 1.0$ gives

$$\Delta p_w = 0.028 \text{ in. of water}$$

If the main doors are on the windward wall and if the traffic is equally divided for 200 people per vestibule door, Fig. 5.15 gives

$$C = 2200$$

Using $C = 2200$ and $\Delta p = 0.028$, Fig. 5.14 gives

$$Q/\text{door} = 300 \text{ cfm}$$

For the four doors the traffic infiltration is

$$4 \times 300 = 1200 \text{ cfm}$$

Using Fig. 5.13, $\Delta p = 0.028$, 1/8 in. crack curve, and assuming a single bank door

$$Q/P = 7$$

The perimeter for each standard size door is 20 ft

$$Q = 7 \times 20 = 140 \text{ cfm/door}$$

For the four doors the crack infiltration

$$Q = 4 \times 140 = 560 \text{ cfm}$$

The exhaust plus crack and traffic infiltration is

$$200 + 560 + 1200 = 1960 \text{ cfm}$$

If the ventilation exceeds the exhaust plus infiltration by more

than 5% then infiltration is offset. Adding 5% of 1960 onto 1960 gives

$$1960 + 0.05 \times 1960 = 2058 \text{ cfm}$$

Increasing the ventilation to this level will offset infiltration. The sensible and latent cooling load due to outside air entering the building at 1400 hr is

$$q_s = 1.10 \times 15 \times 2058 = 34000 \text{ Btu/hr}$$
$$q_l = 4840 \times 0.0050 \times 2058 = 49800 \text{ Btu/hr}$$

EXAMPLE 5.12

A one-story light machine shop of tight construction has a floor area of 5000 ft^2 and a height of 20 ft. There is one swinging door (1/8 in. crack) on the windward side of the building and there are no operable windows. About 10 people pass through the door per hour. There are three workers in the shop and there is just the one room in the building. The exhaust air rate is 300 cfm. Determine the cooling load of Δt = 12 deg F and ΔW = 0.0053 lb/lb at 1200 hr.

SOLUTION 5.12

From Table 5.3 for industrial and metalworking 40 cfm/person is recommended. The ventilation for the machine shop is thus

$$40 \times 3 = 120 \text{ cfm}$$

Assume a 7.5 mph wind is blowing. Using Fig. 5.2 and C_p = 1.0 gives

$$\Delta p_w = 0.028 \text{ in. of water}$$

For infiltration through swinging door cracks, Δp = 0.028, 1/8 in. crack and Fig. 5.13 gives

$$Q/P = 7$$

Taking the perimeter of the standard door to be 20 ft, then

$$Q = 20 \times 7 = 140 \text{ cfm}$$

Ten people is a bit low to use in Fig. 5.15 so work the problem through with 100 people and divide the end result by 10. For 100 people per hour Fig. 5.15 with single bank door gives

$$C = 3000$$

Using C = 3000 and Δp = 0.028, Fig. 5.14 gives

$$Q/\text{door} = 400 \text{ cfm}$$

For 10 people per hour this is

$$Q = 40 \text{ cfm}$$

The total infiltration due to wind is

$$140 + 40 = 180 \text{ cfm}$$

The ventilation is less than the exhaust, therefore the total infiltration is the infiltration due to wind and the exhaust air.

$$180 + 300 = 480 \text{ cfm}$$

Even when the wind is not blowing the ventilation requirement of 120 cfm is met. No special equipment to bring in ventilating air is necessary.

The sensible cooling load at 1200 hr is thus

$$q_s = 1.10 \times 10 \times 480 = 5280 \text{ Btu/hr}$$

The latent cooling load at 1200 hr is

$$q_l = 4840 \times 0.0053 \times 480 = 12300 \text{ Btu/hr}$$

Table 5.1 Decrease from Peak Design Outdoor db Temperature, F

Daily Range, F	hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10	9	9	10	10	10	10	9	8	7	6	4	2	1	0	0	0	1	2	3	5	6	7	8	8
15	13	14	14	15	15	15	14	13	11	8	6	3	2	0	0	0	2	3	5	7	9	10	11	12
20	17	18	19	20	20	20	19	17	14	11	8	5	2	1	0	1	2	4	7	9	12	14	15	16
25	22	23	24	25	25	25	23	21	18	14	10	6	3	1	0	1	3	5	9	12	15	17	19	21
30	26	28	29	30	30	30	28	25	21	17	12	7	3	1	0	1	3	6	10	14	17	20	23	25
35	30	33	34	35	35	35	33	29	25	20	14	8	4	1	0	1	4	7	12	16	20	24	27	29
Decrease From Peak in % of Daily Range	87	92	96	99	100	98	93	84	71	56	39	23	11	3	0	3	10	21	34	47	58	68	76	82

Table 5.2 Maximum Allowable Contaminant Concentrations for Ventilation Air

Contaminant	Annual Average Arithmetic Mean $\mu g/m^3$	Short-Term Level (not to be exceeded more than once a year) $\mu g/m^3$	Averaging Period, hr
Suspended Particulates	60	150	24
Sulfur Oxides	80	400	24
Carbon Monoxides	20,000	30,000	8
Photochemical Oxidant	100	500	1
Hydrocarbons (Not Including Methanes)	1,800	4,000	3
Nitrogen Oxides	200	500	24
Odor: Essentially Unobjectionable			
Other Contaminants: Not to exceed the current threshold limit value (TLV) of the American Conference of Government Industrial Hygienists.			

Table 5.3 Ventilation Requirements for Occupants

	Estimated persons/ 1000 ft^2 floor area.[g]	Required ventilation air, per human occupant: Minimum cfm	Recommended cfm
RESIDENTIAL			
Single Unit Dwellings			
General Living Areas, Bedrooms, Utility Rooms	5	5	7-10
Kitchens, Baths, Toilet Rooms[a]	—	20	30-50
Multiple Unit Dwellings and Mobile Homes			
General Living Areas, Bedrooms, Utility Rooms	7	5	7-10
Kitchens, Baths, Toilet Rooms[a]	—	20	30-50
Garages[b]	—	1.5[b]	2-3[b]
COMMERCIAL			
Public Rest Rooms	100	15	20-25
General Requirements—Merchandising (Apply to all forms unless specially noted)			
Sales Floors (Basement and Ground Floors)	30	7	10-15
Sales Floor (Upper Floors)	20	7	10-15
Storage Areas (Serving Sales Areas and Storerooms)	5	5	7-10
Dressing Rooms	—	7	10-15
Malls and Arcades	40	7	10-15
Shipping and Receiving Areas	10	15	15-20
Warehouses	5	7	10-15
Elevators	—	7	10-15
Meat Processing Rooms[c]	10	5	5
Pharmacists' Workrooms	10	20	25-30
Pet Shops[b]	—	1.0[b]	1.5-2[b]
Florists[d]	10	5	7
Greenhouses[d,e]	1	5	7-10
Bank Vaults	—	5	5
Dining Rooms	70	10	15-20
Kitchens[f]	20	30	35
Cafeterias, Short Order; Drive-Ins, Seating Areas	100	30	35
Bars (Predominantly Stand-Up)	150	30	40-50
Cocktail Lounges	100	30	35-40

	Estimated persons/ 1000 ft^2 floor area.[g]	Required ventilation air, per human occupant Minimum cfm	Recommended cfm
Hotels, Motels, Resorts			
Bedrooms	5	7	10-15
Living Rooms (Suites)	20	10	15-20
Baths, Toilets (attached to bedrooms)[a]	—	20	30-50
Corridors	5	5	7-10
Lobbies	30	7	10-15
Conference Rooms (Small)	70	20	25-30
Assembly Rooms (Large)	140	15	20-25
Cottages (treat as single-unit dwellings) (See also Food Services, Industrial, Merchandising, Barber and Beauty Shops, Garages for associated Hotel/Motel Services)			
Dry Cleaners and Laundries			
Commercial[f,g]	10	20	25-30
Storage/Pickup Areas	30	7	10-15
Coin-Operated[g]	20	15	15-20
Barber, Beauty, and Health Services			
Beauty Shops (Hairdressers)	50	25	30-35
Reducing Salons (Exercise Rooms)	20	25	30-35
Sauna Baths and Steam Rooms	—	5	5
Barber Shops	25	7	10-15
Photo Studios			
Camera Rooms, Stages[h]	10	5	7-10
Darkrooms	10	10	15-20
COMMERCIAL			
Shoe Repair Shops (Combined Workrooms/Trade Areas)	10	10	15-20
Garages, Auto Repair Shops, Service Stations			
Parking Garages (enclosed)[b]	—	1.5[b]	2-3[b]
Auto Repair Workrooms (general)[b]	—	1.5[b]	2-3[b]
Service Station Offices	20	7	10-15
Theaters			
Ticket Booths	—	5	7-10
Lobbies, (Foyers and Lounges)	150	20	25-30
Auditoriums (No Smoking)	150	5	5-10
Auditoriums (Smoking Permitted)	150	10	10-20
Stages (with Proscenium and Curtains)[h,j]	70	10	12-15
Workrooms	20	10	12-15
Ballrooms (Public)	100	15	20-25
Bowling Alleys (Seating Area)	70	15	20-25
Gymnasiums and Arenas			
Playing Floors-Minimal or No Seating	70	20	25-30
Locker Rooms[k]	20	30[k]	40-50[k]
Spectator Areas	150	20	25-30
Ramps, Foyers, and Lobbies	150	10	15-20
Amusement Parlors and Pool Rooms	25	20	25-30
Tennis, Squash, Handball Courts	—	20	25-30
Swimming Pools	25	15	20-25
Ice-Skating, Curling, and Roller Rinks	70	10	15-20
Transportation			
Waiting Rooms	50	15	20-25
Ticket and Baggage Areas, Corridors, and Gate Areas	50	15	20-25
Control Towers	50	25	30-35
Hangars[l]	2	10	15-20
Platform	150	10	15-20
Concourses	150	10	15-20
Repair Shops	—	10	15-20

	Estimated persons/ 1000 ft² floor area.[g]	Required ventilation air, per human occupant: Minimum cfm	Recommended cfm
Offices			
General Office Space	10	15	15-25
Conference Rooms	60	25	30-40
Drafting Rooms, Art Rooms	20	7	10-15
Doctors' Consultation Rooms	—	10	10-15
Waiting Rooms	30	10	15-20
Lithographing Rooms[g]	20	7	10-15
Diazo Printing Rooms[g]	20	7	10-15
Computer Rooms	20	5	7-10
Keypunching Rooms	30	7	10-15
Communication			
TV/Radio Broadcasting Booths, or Studios[h]	20	30	35-40
Motion Picture and TV Stages	20	30	35-40
Pressrooms	100	15	20-25
Composing Rooms	30	7	10-15
Engraving Shops	30	7	10-15
Telephone Switchboard Rooms (Manual)	50	7	10-15
Telephone Switchgear Rooms (Automatic)	—	7	10-15
Teletypewriter/Facsimile Rooms	—	5	7-10

INDUSTRIAL (including agricultural processing)

(Occupational safety laws in the various states usually regulate the ventilation requirements. These are almost always far in excess of the ventilation requirements for the occupants.) ASHRAE Standard 62-73 lists requirements for occupants only. In general, 25 cfm per occupant is recommended except for mining or metalworking, where 40 cfm is recommended.

INSTITUTIONAL

	Estimated persons/ 1000 ft² floor area.[g]	Minimum cfm	Recommended cfm
Schools			
Classrooms	50	10	10-15
Multiple Use Rooms	70	10	10-15
Laboratories[m]	30	10	10-15
Craft and Vocational Training Shops[m]	30	10	10-15
Music, Rehearsal Rooms	70	10	15-20
Auditoriums	150	5	5-7.5
Gymnasiums	70	20	25-30
Libraries	20	7	10-12
Common Rooms, Lounges	70	10	10-15
Offices	10	7	10-15
Lavatories	100	15	20-25
Locker Rooms[k]	20	30[k]	40-50[k]
Lunchrooms, Dining Halls	100	10	15-20
Corridors	50	15	20-25
Utility Rooms	3	5	7-10
Dormitory Bedrooms	20	7	10-15
Hospitals, Nursing and Convalescent Homes			
Foyers	50	20	25-30
Hallways	50	20	25-30
Single, Dual Bedrooms	15	10	15-20
Wards	20	10	15-20
Food Service Centers	20	35	35
Operating Rooms, Delivery Rooms[n]	—	20	—
Amphitheatres	100	10	15-20
Physical Therapy Areas	20	15	20-25
Autopsy Rooms	10	30	40-50
Incinerator Service Areas[o]	—	5	7-10
Ready Rooms, Recovery Rooms[n]	—	15	—
(For Shops, Restaurants, Utility Rooms, Kitchens, Bathrooms, and Other Service Items, see Hotels)			
Research Institutes			
Laboratories[m]	50	15	20-25
Machine Shops	50	15	20-25
Darkrooms, Spectroscopy Rooms	50	10	15-20
Animal Rooms[n]	20	40	45-50

	Estimated persons/ 1000 ft² floor area.[g]	Required ventilation air, per human occupant Minimum cfm		Recommended cfm	
Military and Naval Installations	20	7		10-15	
Barracks	100	15		20-25	
Toilets/Washrooms	100	10		15-20	
Shower Rooms	70	15		20-25	
Drill Halls	40	7		10-15	
Ready Rooms, MP Stations	70	20		25-30	
Indoor Target Ranges[p]					
Museums	70	7		10-15	
Exhibit Halls	10	10		15-20	
Workrooms	5	5		7-10	
Warehouses					
Correctional Facilities, Police and Fire Stations (see also Gymnasiums, Libraries, Industrial Areas)	20	7		10-15	
Cell Blocks	70	15		20-25	
Eating Halls	40	7		10-15	
Guard Stations					
Veterinary Hospitals	20	25		30-35	
Kennels, Stalls, Operating Rooms[n]	30	10		15-20	
Reception Rooms					
ORGANIZATIONAL					
Churches, Temples (see Theaters, Schools and Offices)					
Legislative Halls					
Legislative Chambers	70	20		25-30	
Committee Rooms and Conference Rooms	70	20		25-30	
Foyers, Corridors	50	20		25-30	
Offices	10	10		15-20	
Press Lounges	20	20		25-30	
Press/Radio/TV Booths	20	20		25-30	
Public Rest Rooms	20	15		20-25	
Private Rest Rooms	—	20		30-50	
(for Food Service, Utilities, etc. see Hotels)					
Survival Shelters[n]	—	5	2.5	—	—

[a]Installed capacity for intermittent use.
[b]cfm per sq ft of floor area.
[c]Spaces maintained below 50 F are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissable. When occupancy is intermittent, infiltration will normally exceed ventilation requirement.
[d]Maximum allowable concentration (MAC) for sulfur dioxide is 30 mmg/m³.
[e]Ventilation to optimize plant growth, temperature, and humidity will almost always be greater than shown.
[f]Exhaust to outside; source control as required.
[g]Installed equipment must incorporate positive exhaust and control (as required) of undesirable contaminants (toxic or otherwise).
[h]Thermal effects probably determine requirements.
[i]Stands where engines are run must incorporate systems for positive exhaust withdrawal.
[j]Special ventilation will be needed to eliminate stage effect contaminants.
[k]cfm/locker.
[l]Special solvent and exhaust problems handled separately.
[m]Special requirements control systems may be required.
[n]Special requirements or codes may determine requirements.
[o]Special exhaust systems required.
[p]Floor area behind firing line only.

Table 5.4 Curtain Wall Classification

Leakage Coefficient	Description	Curtain Wall Construction
$K = 0.22$	Tight Fitting Wall	Constructed under close supervision of workmanship on wall joints. When joints seals appear inadequate they must be re-done
$K = 0.66$	Average Fitting Wall	Conventional construction procedures are used
$K = 1.30$	Loose Fitting Wall	Poor construction quality control or an older building having separated wall joints

Table 5.5 Wind Pressure Coefficients For Curtain Wall Buildings

The table is for a rectangular floor-shaped building and for wind normal to windward side.

	C_p
Windward	0.95
Leeward	−0.15
Sides	−0.40

Table 5.6 Window Classification

	Wood Double-Hung (Locked)	Other Types
Tight Fitting Window $k = 1.0$	Weatherstripped Average Gap (1/64 in crack)	Wood Casement and Awning Windows; Weatherstripped Metal Casement Windows; Weatherstripped
Average Fitting Window $k = 2.0$	Non-Weatherstripped Average Gap (1/64 in. crack) or Weatherstripped Large Gap (3/32 in. crack)	All Types of Vertical and Horizontal Sliding Windows; Weatherstripped. Note: if average gap (1/64 in. crack) this could be tight fitting window Metal Casement Windows; Non-Weatherstripped Note: if large gap (3/32 in. crack) this could be a loose fitting window
Loose Fitting Window $k = 6.0$	Non-Weatherstripped Large Gap (3/32 in. crack)	Vertical and Horizontal Sliding Windows; Non-Weatherstripped

Table 5.7 Residential-Type Door Classification

Tight Fitting Door $k = 1.0$	Very small perimeter gap and perfect fit weatherstripping often characteristic of new doors
Average Fitting Door $k = 2.0$	Small perimeter gap having stop trim fitting properly around door and Weatherstripped
Loose Fitting Door $k = 6.0$	Large perimeter gap having poor fitting stop trim and weatherstripped or Small perimeter gap with no weatherstripping

CHAPTER 6

PSYCHROMETRIC PROCESSES — CALCULATIONS FOR EQUIPMENT SELECTION

After the cooling and heating loads are calculated, these loads must be picked up and applied to a specific system to be able to select the proper HVAC equipment. One of the most useful tools available for this step is the psychrometric chart. The psychrometric processes and the calculations can provide the data for equipment selection. Some examples are included in this part. A more complete discussion appears in Appendix A6.

The list below shows what factors are included in each example problem. Each example illustrates the calculation of the scfm required, the air conditions entering and leaving the coil and the coil load and the coil sensible heat ratio. All of the examples use the approximate method with scfm for the mass balance and the dry-bulb temperature for the enthalpy for mixing. In order to eliminate the use of trial and error solutions and also without the availability of data on coil characteristics, the example problems will be solved using the assumption that the air leaves the coil at 90% rh. This is a valid initial approximation for many cooling and dehumidifying coils.

Example	Conditions
6.1	No outside air, no fan or motor heat, no duct losses or gains — simple recirculating air system
6.2	All outside air
6.3	2500 scfm of outside ventilation air and the remainder return air
6.4	Supply duct heat gain and return duct heat gain
6.5	Fan and fan motor heat gain a. Draw-through fan b. Blow-through fan
6.6	Coil bypass control
6.7	Reheat
6.8	High latent heat load — low sensible heat ratio
6.9	Variable air volume
6.10	Plenum heat balance

The same design conditions and room loads will be used for all examples except as specifically noted.

Design conditions:

Time: 1500 hr solar time

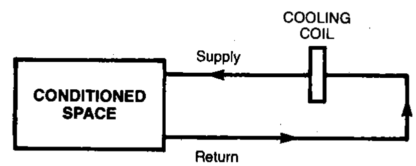
Outside: 95 F db and 75 F wb, standard barometer

Room: 78 F db and 50% rh

RSH: 200,000 Btu/hr including load from unvented lights

RLH: 50,000 Btu/hr

EXAMPLE 6.1 Recirculating Air

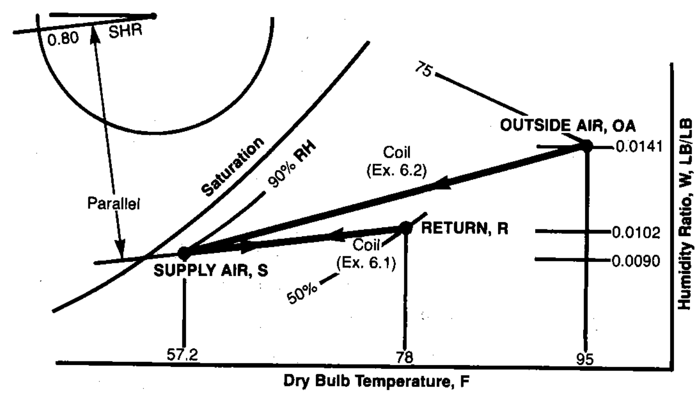


1. Plot room and outside design conditions on psychrometric chart
2. Room sensible heat ratio, RSHR

$$RSHR = RSH/RTH = 200{,}000/(200{,}000 + 50{,}000)$$

$$RSHR = 0.80$$

The value of 0.80 is found on the protractor, and a parallel line is drawn from *R* to the saturation line. The supply condition is found where the RSHR line crosses 90% rh. The room supply condition is the same as the condition leaving the coil. Point *R* represents the condition of the air entering the coil for this recirculating system with fan heat neglected.



Air entering coil: 78 F db and 50% rh which gives $W = 0.0102$
Air leaving coil: 57.2 F db and 90% rh

3. Required standard cubic feet per minute (scfm) of supply air:

$$\text{scfm} = q_s/1.10 \times (t_R - t_S)$$

$$= 200{,}000/1.10 \times (78 - 57.2)$$

$$= 8740 \text{ cfm}$$

In this example the coil load is equal to the room load.

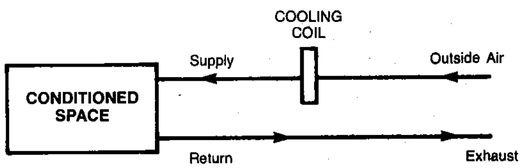
The humidity ratio of the air leaving the coil is

$$W_S = W_R - \frac{q_L}{4840 \times \text{scfm}}$$

$$W_S = 0.0102 - 50{,}000/(4840 \times 8740)$$
$$= 0.0090 \text{ lb/lb}$$

EXAMPLE 6.2 All Outside Air

All conditions are the same as in Example 6.1, except 100% *oa* is used as compared to 100% recirculated air.



1. Plot room and outside design conditions.
2. RSHR line: same as Example 6.1.
3. As in Example 6.1, the supply condition to the room is at 90% rh. This point is located on the RSHR line and becomes the condition of the air leaving the coil.
4. The air condition entering the coil is found at point *oa*, since 100% *oa* is used. See psychrometric sketch, Ex. 6.1.

Air entering coil: 95 F db and 75 F wb, and $W = 0.0141$ lb/lb
Air leaving coil: 57.2 F db and 90% rh, and $W = 0.0090$ lb/lb

5. Coil load:

$$q_s = 1.10 \times \text{scfm} \times \Delta t$$
$$q_L = 4840 \times \text{scfm} \times \Delta W$$

The total coil load is the sum of the sensible and latent loads, where the required scfm is the same as that in Example 6.1: 8740 cfm

$$q_s = 1.10 \times 8740 \times (95 - 57.2) = 363{,}000 \text{ Btu/hr}$$
$$q_L = 4840 \times 8740 \times (0.0141 - 0.0090) = 216{,}000 \text{ Btu/hr}$$
$$q_T = 363{,}000 + 216{,}000 = 579{,}000 \text{ Btu/hr}$$

Note that this is the same load as the room load plus the ventilation load due to the outside air.

Ventilation:

$$q_s = 1.10 \times 8740 \times (95 - 78) = 163{,}000 \text{ Btu/hr}$$
$$q_L = 4840 \times 8740 \times (0.0141 - 0.0102) = 165{,}000 \text{ Btu/hr}$$
$$q_T = 163{,}000 + 165{,}000 = 328{,}000 \text{ Btu/hr}$$

Room (as given):

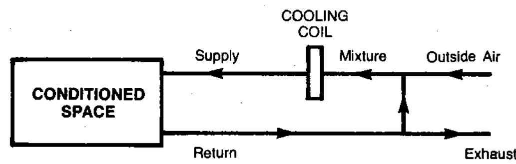
$$q_s = 200{,}000 \text{ Btu/hr}$$
$$q_L = 50{,}000 \text{ Btu/hr}$$
$$q_T = 250{,}000$$

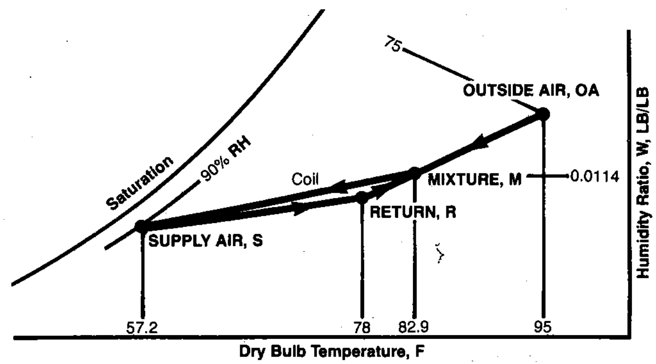
Coil Load = Ventilation Load + Room Load
= 328,000 + 250,000 = 578,000 Btu/hr

which agrees within the calculation accuracy of 579,000 Btu/hr.

EXAMPLE 6.3 Mixture of the Outside Air and Return Air

Room load, room air condition and room supply air condition and quantity are the same as before. With the introduction of 2500 scfm of *oa*, only the condition of the air entering the coil changes. Note that the mixture conditions and the entering coil conditions are at the same point in this example.





1. Mixture conditions:

$$t_M = t_R + \frac{\text{scfm of } oa}{\text{total scfm}}(t_{oa} - t_R)$$

$$T_M = 78 + \frac{2500}{8740}(95 - 78)$$

$$T_M = 82.9 \text{ F}$$

Point M is located at the intersection of this db with the line connecting points R and *oa* on the psychrometric chart.

rh = 47%; $W = 0.0114$ lb/lb

2. Coil load:

$$q_s = 1.10 \times 8740 \times (82.9 - 57.2) = 247{,}000 \text{ Btu/hr}$$
$$q_L = 4840 \times 8740 \times (0.0114 - 0.0090) = 101{,}000 \text{ Btu/hr}$$
$$q_T = 247{,}000 + 101{,}000 = 348{,}000 \text{ Btu/hr}$$

Once again, this can be checked by adding the ventilation load to the room load.

Ventilation:

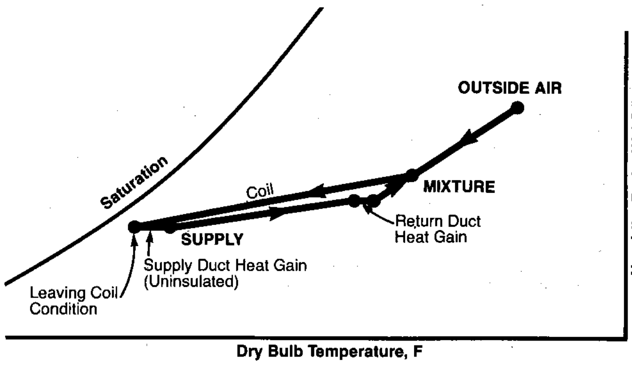
$$q_s = 1.10 \times 2500 \times (95 - 78) = 46{,}800 \text{ Btu/hr}$$
$$q_L = 4840 \times 2500 \times (0.0141 - 0.0102) = 47{,}200 \text{ Btu/hr}$$
$$q_T = 94{,}000 \text{ Btu/hr}$$

Room:

$$q_s = 200{,}000 \text{ Btu/hr}$$
$$q_L = 50{,}000 \text{ Btu/hr}$$
$$q_T = 250{,}000 \text{ Btu/hr}$$

Coil load = 94,000 + 250,000 = 344,000 Btu/hr which agrees quite well with 348,000 Btu/hr.

EXAMPLE 6.4 Duct Heat Gains



Determine the heat picked up in the supply and return ductwork of Example 6.3 with the following conditions:

Length: 75 ft supply run and 125 ft return through unconditioned space

Insulation: 2 in. (R-6) insulation on supply and 1 in. (R-3) insulation on return

Temperature surrounding ductwork: 95 F

Assume that the duct aspect ratio will be approximately 3:1 and that the duct velocity will be approximately 1500 fpm for both the supply and the return.

For 8740 scfm at 1500 fpm duct velocity, from Fig. 6.1 the rate of temperature rise in the duct will be 0.12 deg F per F difference per 100 ft.

Supply Duct

$$\text{Temperature Rise} = (0.12)\left(\frac{75\text{ ft}}{100\text{ ft}}\right)(95 - 57.2)\text{ F}$$

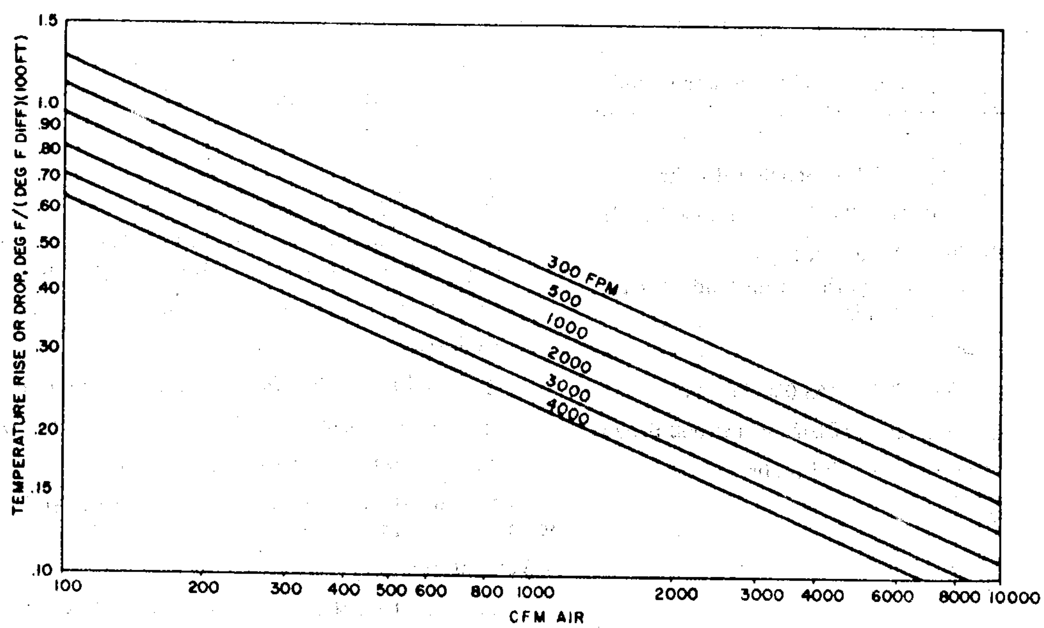
$$= 3.4\text{ deg F}$$

Correction factor for aspect ratio = 1.1 (Note 1 for Fig. 6.1)

Correction factor for duct insulation R-6 is equivalent to $U = .17$ (Note 2)

$$\text{Interpolation yields:}\quad 0.10 + \left(\frac{0.17 - 0.13}{0.27 - 0.13}\right) \times (0.185 - 0.10)$$

$$= 0.12 \text{ correction factor}$$



NOTES:

1. Based on bare rectangular duct with a 2:1 aspect ratio.

Aspect Ratio Correction

Aspect Ratio	Round	1:1	3:1	4:1	5:1	6:1	7:1	8:1	9:1	10:1
Correction	.83	.92	1.1	1.18	1.26	1.35	1.43	1.5	1.58	1.65

2. If duct is furred-in or insulated, use the following correction factors:
   Furred-in duct — .45
   Insulated (U = .27) — .185
   Insulated (U = .13) — .10

3. For air quantities greater than 10,000 cfm, divide air quantity by 100 and multiply degree change by 0.1.

(Permission: Carrier, System Design Manual, Part 2, 1968)

Fig. 6.1 Duct Heat Gain or Loss

Corrected temperature rise in supply duct = 3.4 × 1.1 × 0.12
= 0.4 deg F

This heat gain is added to the room sensible heat load

$$q = 1.10 \times 8740 \text{ scfm} \times 0.4 \text{ deg F} = 3800 \text{ Btu/hr}$$

It also will increase the supply air required.

The rise of 0.4 deg F compared to the total temperature difference between the original supply and room condition is

$$\frac{0.4}{78 - 57.2} \times 100\% = 2\%$$

If the supply duct were uninsulated, the temperature rise would be 3.4 F × 1.1 = 3.7 deg F.

The supply duct heat gain would then be

$$\frac{3.7}{78 - 57.2} \times 100\% = 18\% \text{ of the room sensible heat load}$$

This is one indication of the wide range of values that the supply duct heat gain can take with and without duct insulation.

The return duct heat gain is

$$(0.12)\left(\frac{125}{100}\right)(95 - 78) = 2.6 \text{ deg F}$$

Correction for aspect ratio = 1.1 (Note 1, Fig. 6.1)
Correction for insulation (Note 2)
$R = 3$ is equivalent to $U = 0.33$
Estimate the correction to be approximately 0.23
Temperature rise in return duct = 0.23 × 1.1 × 2.6 deg F
= 0.7 deg F

The heat gain on the return air side shows up in the equipment load but not in the room load nor in the supply air required.

EXAMPLE 6.5 Fan and Fan Motor Heat

Calculate the temperature rise of the air in Example 6.3 and the effect on the system when the fan is (*a*) a draw-through fan behind the coil and (*b*) a blow-through fan on the leaving side of the coil.

Assume the design total static pressure difference across the fan is 2 in. of water and that the fan efficiency is 75% and the motor efficiency is 85%. For these conditions Table 6.1 shows a temperature rise of the air of 1.0 deg F, if the motor is outside the air stream. When the motor is in the air stream, the combined efficiency is 0.75 × 0.85 = 0.64. The temperature rise is then 1.1 deg F. Compared to the supply air temperature difference, this represents 1.1/(78 − 57.2) × 100% or approximately 5% of the room sensible load.

If the temperature difference between the supply air and the room db is approximately 20 deg F and if the fan efficiency is 75%, then the fan heat gain as a percentage of the room sensible load would be approximately 2 1/2% per in. of water pressure difference across the fan.

The blow-through fan increases the wet-bulb temperature of the air as well as the dry bulb before the air enters the coil. In most cases this will improve the performance of the coil.

(*a*) The sensible load due to the draw-through fan and motor is generally added to the room sensible heat. In this case the new room sensible heat is increased by 5%.

$$q_s = (1.05)(200{,}000 \text{ Btu/hr})$$
$$= 210{,}000 \text{ Btu/hr}$$

$$\text{Room SHR} = 210{,}000/(210{,}000 + 50{,}000)$$
$$= 0.81$$

Table 6.1 Air Temperature Rise Through Fans, Deg F

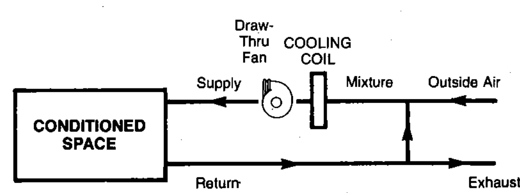
Fan or Combined* Motor and Fan Eff. %	Pressure Difference, In. of Water										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
50	0.7	1.1	1.5	1.8	2.2	2.6	2.9	3.3	3.6	4.0	4.4
55	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.6	4.0
60	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
65	0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.4
70	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6	2.9	3.1
75	0.5	0.7	1.0	1.2	1.5	1.7	1.9	2.2	2.4	2.7	2.9
80	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.1	2.3	2.5	2.7
85	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6
90	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
95	0.4	0.6	0.8	1.0	1.2	1.3	1.5	1.7	1.9	2.1	2.3
100	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.6	1.8	2.0	2.2

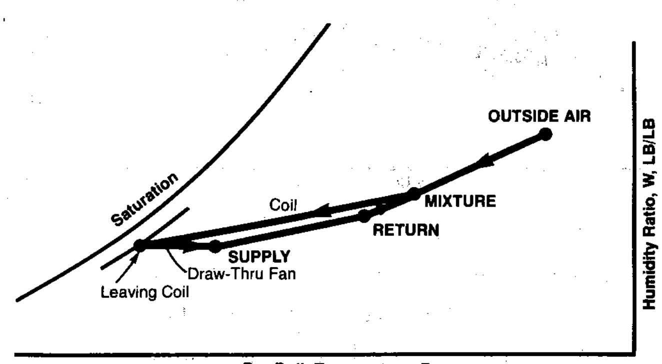
*Note: If fan motor is situated within the air stream, the combined efficiency is the product of the fan and motor efficiencies. If the motor is external to the air stream, then use only the fan efficiency.

Equation: $\Delta T = 0.363 \times \text{Press. Diff.}/(\% \text{ Eff}/100)$

Table 6.2 Water Temperature Increase Due to Pumping, Deg F

Pump Eff. (%)	Pump Head, Ft. of Water								
	40	60	80	100	120	140	160	180	200
40	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6
50	0.1	0.2	0.2	.0.3	0.3	0.4	0.4	0.5	0.5
60	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4
70	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4
80	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3
90	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3
100	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3





The supply air condition for this example is almost the same as in Example 6.1. Using the same supply temperature the supply air required is

$$\text{scfm} = 210{,}000/1.10 \times (78 - 57.2)$$
$$= 9180 \text{ cfm}$$

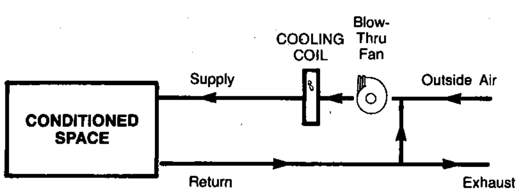
Mixture Conditions:

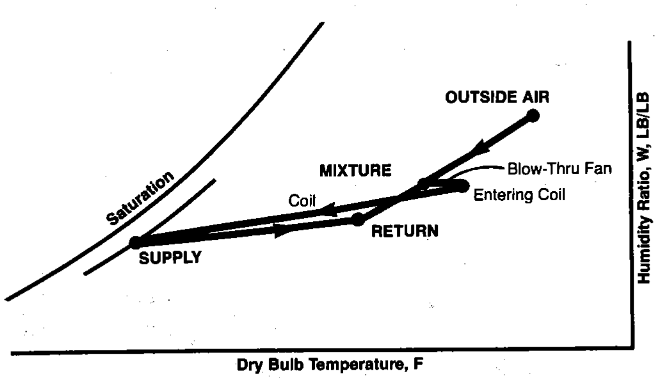
$$t_m = 78 + \frac{2500}{9180} \times (95 - 78)$$
$$= 82.6 \text{ F}$$
$$W_m = 0.0102 + \frac{2500}{9180} \times (0.0141 - 0.0102)$$
$$= 0.0113 \text{ lb/lb}$$

Coil Load:

$$q_s = 1.10 \times 9180 \times (82.6 - 57.2)$$
$$= 256{,}000 \text{ Btu/hr}$$
$$q_L = 4840 \times 9180 \times (0.0113 - 0.0090)$$
$$= 102{,}000 \text{ Btu/hr}$$
$$\text{Total } q = 358{,}000 \text{ Btu/hr}$$

(*b*) The additional load on the system due to the fan and fan motor are the same in both cases, but they are handled differently. The load of the draw-through fan generally is added into the room load. The effect of the blow-through fan is considered by changing the condition of the air entering the coil. These effects are exaggerated for clarity on the schematic psychrometric charts for Example 6.5 (*a*) and (*b*).





The mixture conditions from Example 6.3 are

82.9 F db and $W = 0.0114$ lb/lb

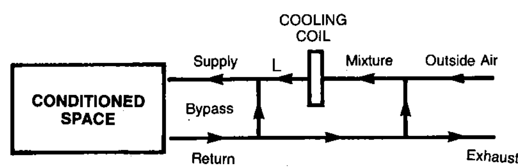
The temperature after the blow-through fan is

82.9 F + 1.1 deg F = 84.0 F

while the humidity ratio remains constant. The coil load is, therefore,

$$q_s = (1.10)\,(8740)\,(84.0 - 57.2)$$
$$= 258{,}000 \text{ Btu/hr}$$
$$q_L = (4840)\,(8740)\,(0.0114 - 0.0090)$$
$$= 101{,}000 \text{ Btu/hr}$$
$$\text{Total coil load} = 359{,}000 \text{ Btu/hr}$$

EXAMPLE 6.6 Coil Bypass Control



Bypass control of return air is used for partial load control of the room of Example 6.3. Assume the room sensible load can decrease by 50% with no change in the room latent load. Determine the final room conditions, if the condition of the air leaving the coil is the same as in Example 6.3.

$$\text{Partial load sensible heat} = 0.50 \times 200{,}000 \text{ Btu/hr}$$
$$= 100{,}000 \text{ Btu/hr}$$
$$\text{Partial load RSHR} = \text{RSH}/(\text{RSH} + \text{RLH})$$
$$= 100{,}000/(100{,}000 + 50{,}000)$$
$$= 0.67$$

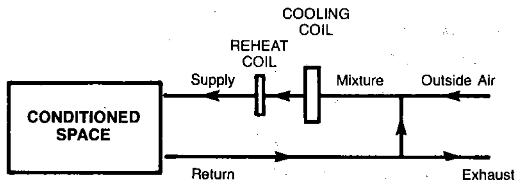
The line on the psychrometric chart between the condition of the room supply air and the room conditions is parallel to the RSHR of 0.67. The supply air condition is also on the line between the room air and the air leaving the coil, since this is a mixture of the bypassed return air and the air leaving the coil. Therefore, the slope of RSHR = 0.67 can be used directly from point *L*. So long as the room db remains the same and the db of the air leaving the coil remains the same, the increase in the supply air db will be proportional to the decrease in the room sensible load with a constant volume of supply air.

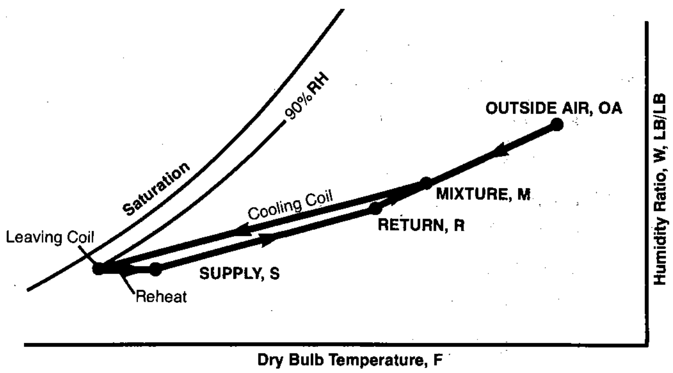
$$(t_R - t_S) = \text{RSH}/(1.10 \times \text{scfm})$$
$$t_S = 78 \text{ F} - (100{,}000 \text{ Btu/hr})/(1.10 \times 8740 \text{ cfm})$$
$$= (78 - 10.4) = 67.6 \text{ F}$$

The room conditions as located on RSHR = 0.67 from point *L* and at 78 F indicate a rh of approximately 55%. This points up the lack of control of the humidity with bypass control. If the air mixture after the introduction of outside air is bypassed, the room humidity may be even higher. Some multizone units and some double duct systems operate in a manner similar to bypass control systems.

In either case, however, the reduction of air flow across the coil permits greater dehumidification of the air through the coil under normal operating conditions. This partially compensates for the higher humidity of the bypassed air.

EXAMPLE 6.7 Reheat





Assume the conditions are the same as for Example 6.3 except that the room sensible heat has decreased from 200,000 Btu/hr down to 100,000 Btu/hr. The constant volume reheat system keeps the supply scfm at 8740 cfm. In order to maintain the desired room temperature of 78 F db, the supply air will be reheated in response to the space thermostat. Since the conditions of the air entering and leaving the coil are also the same, the coil load remains as in Example 6.3. The decrease in the room sensible heat requires an addition of heat at the reheat coil and thus increases the energy required by this system. This type of reheat system replaces the reduction in room sensible cooling load with energy supplied to the reheat coil.

EXAMPLE 6.8 High Latent Heat Load — Low Sensible Heat Ratio

Assume that the design latent load for Example 6.3 is increased from 50,000 Btu/hr to 120,000 Btu/hr. This results in a room sensible heat ratio of

$$\text{RSHR} = \frac{200{,}000}{200{,}000 + 120{,}000} = 0.63$$

The temperature at which the sensible heat ratio line crosses the saturation curve is the effective coil surface temperature or apparatus dew point (adp) if no outside air for ventilation is introduced. Usual design conditions for outside air will reduce this temperature. In this example, the RSHR just barely crosses the saturation line and the adp is approximately 37 F. The temperature of the chilled water and/or the refrigerant evaporating temperature would be lower than the adp, the exact value depending upon the coil selection. At lower refrigerant suction temperatures the capacity of a specific refrigeration system is lower and also requires more power per unit capacity. As an approximation only, the horsepower per ton for a compressor alone increases between 15 to 20% when the saturated suction temperature drops from 40 F to 30 F.

Two alternatives will be calculated in this example: (*a*) an assumed condition off the RSHR supply line with reheat and (*b*) a change in the room design conditions with no reheat.

(*a*) Schematically this system is similar to Example 6.7. However, for these conditions and for an initial trial, assume that the air will be supplied 20 deg F lower than the room. This locates the supply air on the RSHR line at 58 F db and the resulting $W = 0.0075$, as read from the psychrometric chart. By working back horizontally on the chart from the supply point through a reheat coil to the leaving conditions from the cooling coil of 90% rh, the dry bulb is approximately 52.5 F. The following calculations can then be made.

$$\text{Supply air required, scfm} = \frac{200{,}000}{1.10 \times (78 - 58)} = 9090 \text{ cfm}$$

Mixture of return air and 2500 scfm of outside air

$$T = 78 + \frac{2500}{9090} \times (95 - 78) = 82.7 \text{ F db}$$

$$W = 0.0102 + \frac{2500}{9090} \times (0.0141 - 0.0102) = 0.0113 \text{ lb/lb}$$

This is also the condition entering the cooling coil when fan heat and duct gains are not considered.

Load on cooling coil

$$q_s = 1.10 \times 9090 \times (82.7 - 52.5) = 302{,}000 \text{ Btu/hr}$$

$$q_L = 4840 \times 9090 \times (0.0113 - 0.0075) = 167{,}000 \text{ Btu/hr}$$

$$\text{Total } q = 469{,}000 \text{ Btu/hr}$$

Reheat required

$$q_s = 1.10 \times 9090 \times (58.0 - 52.5) = 55{,}000 \text{ Btu/hr}$$

Summary of Results in Btu/hr

	Room Load	Outside Air Load	Reheat Load	Cooling Coil Load
q_s	200,000	46,800	55,000	302,000
q_L	120,000	47,200	—	167,000
q_T	320,000	94,000	55,000	469,000
SHR	0.63	0.50	—	0.64

(*b*) If no reheat is supplied and the leaving coil condition is used for the supply condition, then the room relative humidity will be increased. If the room load is unchanged, the new conditions can be obtained as follows.

$$\text{Supply air scfm} = \frac{200{,}000}{1.10 \times (78 - 52.5)} = 7130 \text{ cfm}$$

$$\text{Room } W = 0.0075 + \frac{120{,}000}{4840 \times 7130} = 0.0110 \text{ lb/lb}$$

At 78 F db and 0.0110 lb/lb the relative humidity is approximately 53%. If these room conditions are acceptable, along with

the lower supply air conditions of 52.5 F db, then the cooling loads are reduced and also the supply air required is reduced.

Outside Air $q_L = 4840 \times 2500 \times (0.0141 - 0.0110)$

$= 37{,}500$ Btu/hr

Mixture $t = 78 + \frac{2500}{7130}(95 - 78)$

$= 84.0$ F

$W = 0.0110 + \frac{2500}{7130}(0.0141 - 0.0110)$

$= 0.0121$ lb/lb

Cooling Coil

$q_s = 1.10 \times 7130 \times (84.0 - 52.5)$

$= 247{,}000$ Btu/hr

$q_L = 4840 \times 7130 \times (0.0121 - 0.0075)$

$= 158{,}000$ Btu/hr

$q_T = 405{,}000$ Btu/hr

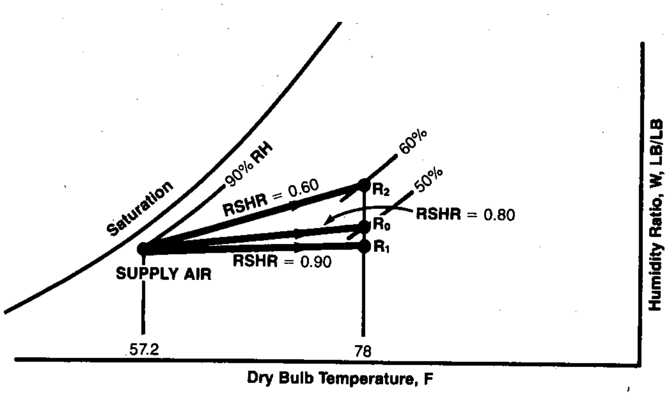
Summary of Results

	Room Load	Outside Air Load	Cooling Coil Load
q_s	200,000	46,800	247,000
q_L	120,000	37,500	158,000
q_t	320,000	84,300	405,000
SHR	0.63	0.56	0.61

When compared to part (*a*) which uses reheat, the results of (*b*) with a slightly higher room relative humidity indicate a significant reduction in the total cooling load from 469,000 to 405,000 Btu/hr of about 14%. The supply air was reduced from 9090 cfm to 7130 cfm or about 22%. While these values apply only to this example, it indicates what can be accomplished by some changes in design conditions.

EXAMPLE 6.9 Variable Air Volume (VAV)

There are many variations of VAV systems. However, this example will indicate operating conditions with a simple VAV system as used for cooling-only service. The supply air and room conditions will be as indicated in Example 6.3. The space cooling load can vary from the design loads both in magnitude and sensible heat ratio. The change in the space sensible cooling load is accommodated by the reduction in the supply air volume. The change in the SHR results in a higher or lower space relative humidity. If the SHR ranges from 0.60 to 0.90, the space rh will vary as shown in the schematic psychrometric chart. Calculations for these two conditions are shown below.



Solve first for the change in humidity ratio per ΔT between supply air and room temperature.

$$q_s/q_L = \text{SHR}/(1 - \text{SHR})$$

$$q_L = q_s \times (1 - \text{SHR})/\text{SHR}$$

$$(4840 \times \text{scfm} \times \Delta W) = (1.10 \times \text{scfm} \times \Delta t) \times (1 - \text{SHR})/\text{SHR}$$

$$\Delta W = \frac{1.10}{4840} = \frac{(1 - \text{SHR})}{\text{SHR}} \times \Delta t$$

$$= 0.000227 \times (1 - \text{SHR})/\text{SHR} \times \Delta t$$

For $\Delta t = (78 - 57.2)$ and SHR = 0.90

$$\Delta W = 0.000227 \times (0.10/0.90) \times (78 - 57.2)$$

$$= 0.0005 \text{ lb/lb}$$

At 78 F db and $W = (0.0005 + 0.0090)$ the relative humidity is approximately 46%.

For SHR = 0.60

$$\Delta W = 0.000227 \times (0.40/0.60) \times (78 - 57.2)$$

$$= 0.0032 \text{ lb/lb}$$

At 78 F db and $W = (0.0032 + 0.0090)$ the relative humidity is approximately 59%. Under these specific conditions the space relative humidities can vary from about 45% to approximately 60%.

EXAMPLE 6.10 Plenum Heat Balance

Determine the plenum temperature and the cooling load from the ceiling at various conditions with and without return air through plenum.

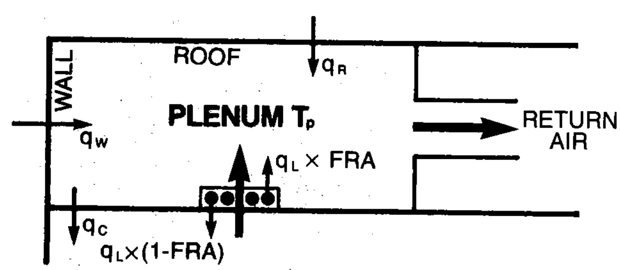
Location

Birmingham, Alabama 33 deg N latitude, Table 2.1
1600 hr design time
Summer Conditions (July) Table 2.1, 94 F db, 21 deg F Daily Range

Inside Conditions

78° F db/50% rh
Room sensible cooling load without loads from lights and ceiling is 40,000 Btu/hr

Construction and Details



FRA = Fraction of heat from lights to plenum

Plenum Height — 3 ft
Room Area — 20 ft × 100 ft
Wall Construction — 4 in. H. W. concrete + R-7 insulation, dark exterior surface
Roof Construction — 4 in. H. W. concrete + R-7 insulation, dark exterior surface
Ceiling Construction — Acoustic Tile

The room has one exposed wall: 100 ft side facing south.

Lights — recessed, 2 W/ft^2. Assume fraction of heat to plenum is 0.40 when unvented and 0.65 when vented to plenum. This is usually estimated from data from the manufacturers of lighting fixtures.

Heat Balance on Plenum

Heat into air flowing through plenum = Net Heat Transfer into plenum

$$q_{air} = q_R + q_W - q_C + (q_L \times FRA)$$

where

$q_{air} = 1.10 \times scfm \times (t_p - t_R)$

$q_R = (U \times A \times CLTD)_R$ Eq. (3.2) for Roof

$q_W = (U \times A \times CLTD)_W$ Eq. (3.2) for Wall

$q_C = U \times A \times (t_p - t_R)$ Eq. (3.1) for Ceiling

$q_L = 3.41 \times W$ Section 4.1

FRA = fraction of heat from lights to plenum from manufacturers' data.

The plenum temperature is the space temperature at the inside of the wall and roof. The CLTD and corrections are obtained from Tables 3.8, 3.10 and 3.12.

Color correction $K = 1.0$ for dark surface

Inside temperature correction = $(78 - t_p)$ Table 3.13

Outside temperature correction = OC. Table 3.13

Table value of CLTD corrected for outside conditions and latitude/month, $CLTD_o$ = CLTD + LM + OC

Substitute into equation for heat balance

$$(1.10 \times scfm) \times (t_p - t_R) = (UA)_R(CLTD_o + 78 - T_p)_R + (UA)_W(CLTD_o + 78 - T_p)_W - (UA)_C (t_p - t_R)C + q_L \times FRA$$

If the room temperature is 78 F, then rearrange the equation with terms involving $(T_p - 78)$ on left side

$$(t_p - 78)[(1.10\ scfm) + (UA)_C + (UA)_R + (UA)_W] = (UA \times CLTD_o)_R + (UA \times CLTD_o)_W + q_L \times FRA$$

$$t_p = 78 + \frac{(UA \times CLTD_o)_R + (UA \times CLTD_o)_W + q_L \times FRA}{1.10 \times scfm + (UA)_C + (UA)_R + (UA)_W}$$

If the average plenum temperature cannot be assumed to be equal to the return air temperature, t_p, then the equation is:

$$t_p = 78 + \frac{(UA \times CLTD_o)_R + (UA \times CLTD_o)_W + q_L \times FRA}{1.10 \times scfm + C[(UA)_C + (UA)_R + (UA)_W]}$$

where C represents the average temperature difference ratio between the plenum and the room as compared to $(t_p - 78)$. C is usually between 0.5 and 1.0.

For additional information refer to 1976 Systems Volume of the ASHRAE HANDBOOK, pages 3.5-3.7.

Item	Table	Explanation and Notes
U-Values Roof Wall Ceiling	Tables 3.1-3.5	Roof $R_T = R_o + R_{conc} + R_{ins} + R_i$ $= 0.25 + 0.71 + 7 + 0.92$ $= 8.88 \frac{(hr \cdot ft^2 \cdot F)}{Btu}$ $U = 1/8.88$ $= 0.11\ Btu/(hr \cdot ft^2 \cdot F)$ Wall $R_t = 0.25 + 0.71 + 7 + 0.68$ $= 8.64 \frac{(hr \cdot ft^2 \cdot F)}{Btu}$ $U = 0.12\ Btu/(hr \cdot ft^2 \cdot F)$ Ceiling $R_t = R_{fp} + R_{tile} + R_{fi}$ $= 0.17 + 1.25 + 0.92$ $= 2.34$ $U = 1/2.34$ $= 0.43\ Btu/(hr \cdot ft^2 \cdot F)$
UA Values		Roof $= (0.11\ Btu/(hr \cdot ft^2 \cdot F))\ (20\ ft \times 100\ ft)$ $= 220\ Btu/(hr \cdot F)$ Wall $= (0.12\ Btu/(hr \cdot ft^2 \cdot F))\ (3\ ft \times 100\ ft)$ $= 36\ Btu/(hr \cdot F)$ Ceiling $= (0.43\ Btu/(hr \cdot ft^2 \cdot F))\ (20\ ft \times 100\ ft)$ $= 860\ Btu/(hr \cdot F)$
CLTD — Roof	Table 3.8	The roof most nearly corresponds to roof number 9 in the table without a suspended ceiling. This is used because the plenum is considered and not the room. CLTD @ 1600 = 50 deg F
CLTD — Wall	Table 3.9 Table 3.10	The table indicates that a 4 in. H.W. concrete wall with 2 in. insulation is Group D CLTD @ 1600 facing south is 24 deg F
Color Correction	Table 3.10 Note 2	$K = 1.0$
Outside Correction	Table 3.13	At 94 F db with 21 F DR correction is −1 deg F
Latitude/ Month Correction	Table 3.13	For July and 32 deg north latitude + 1 deg F for the roof and − 3 deg F for south wall
$CLTD_o$	CLTD + OC + LM	Roof $CLTD_o = 50 + 1 - 1 = 50$ deg F Wall $CLTD_o = 24 - 3 - 1 = 20$ deg F
q_L, Lights		$q_L = 3.41 \times 2\ W/ft^2 \times (20\ ft \times 100\ ft)$ $= 13,640\ Btu/hr$

Sample Calculation with 1000 scfm through Plenum

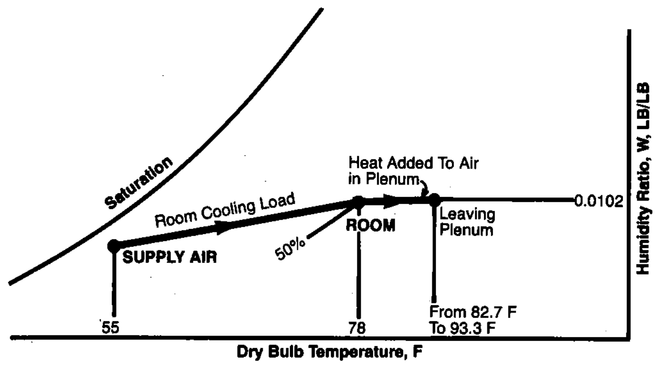
Item	Table	Explanation and Notes
Lights to Plenum		$q_L \times FRA = 13{,}640 \times 0.65$ $= 8866$ Btu/hr
Plenum Temperature t_P		$t_P =$ $78 + \frac{(220)(50) + (36)(20) + (8866)}{(1.10)(1000) + 220 + 36 + 860}$ $t_P = 78 + 9.3 = 87.3$ F
Ceiling, q_C		$q_C = (UA)_C \times (t_P - t_R)$ $= (860)(87.3 - 78)$ $= 8000$ Btu/hr
Room Sensible Cooling Load		$q_S = q_C + q_L(1 - FRA)$ $+ 60{,}000$ Btu/hr $= 8000 + (13640)(0.35) + 40{,}000$ $= 52770$ Btu/hr
Room Supply Air		$SCFM = q_S/(1.10 \times (\Delta t))$ Assume supply air temperature is 55 F. This will be determined by the type of HVAC system used. $scfm = 52770/(1.10 \times (78 - 55))$ $= 2086$ cfm

Discussion

When return air is pulled through a plenum space as in this example, the results indicate that:

1. The plenum air temperature is reduced. This also decreases the ceiling temperature and thus lowers the mean radiant temperature to the conditioned space. This provides greater comfort in the room without reducing the room air dry bulb.
   The lower plenum temperature does increase, somewhat, the heat gain through the roof and through the exterior wall of the plenum.
2. The net cooling load to the conditioned space is reduced appreciably. Much of the heat gain from lights, roof and plenum wall is picked up on the return air side. This decreases the supply air required by the room.
3. If some of the return air from the plenum is exhausted to the outside, then the part of the load picked up in the plenum is not loaded onto the cooling system.

If the plenum is located between two floors and both are conditioned, the procedure indicated in Example 4.2 of Chapter 4 may be used to calculate the effects on the cooling load.



Results

Plenum Air scfm/ft²	Plenum Air scfm	Plenum Temp. T_P	Heat Flow, Btu/hr: Ceiling q_C	From Lights to Room	From Lights to Plenum	Roof q_R	Wall q_W	Heat to Return Air, Btu/hr	Added Heat To Room Cooling Load Btu/hr	Supply Air scfm
0	0	93.3	13160	8184	5456	7630	170	0	21340	2425
0.5	1000	87.3	8000	4774	8866	8950	390	10230	12770	2086
1.0	2000	84.2	5330	4774	8866	9640	500	13640	10104	1980
1.5	3000	82.7	4040	4774	8866	9970	550	15510	8814	1930

CHAPTER 7

RESIDENTIAL HEATING AND COOLING LOADS

7.0 INTRODUCTION

The object of a residential heating and cooling load calculation is to provide the data for the selection of a system and equipment to provide comfort levels and to be consistent with efficient utilization of energy. In the process of making these calculations, some insight can be obtained for the reduction in the use of energy even though *a load calculation is not an energy calculation.* The end result of a load calculation is still a peak design capacity for the heating and/or cooling system.

Many applicable standards and codes have been adopted and are being proposed at the national, state and local levels which impact on these calculations. Two standards will be the major references cited here: (1) the Department of Housing and Urban Development-Minimum Property Standards (HUD-MPS) 4900.1 for One and Two Family Dwellings with the revisions up to May 1977; (2) ASHRAE Standard 90-75. Both of these standards, even at this writing, have revisions out for review. Therefore, it is important that any user of this Manual refer to the latest applicable standard or code.

7.1 RESIDENTIAL HEATING AND COOLING LOADS

Calculating a heating load involves estimating the maximum probable heat loss of each room or space to be heated while maintaining a selected indoor air temperature during periods of design outdoor weather conditions. The heat losses are mainly:

1. *Transmission* losses-heat transferred through the building envelope of glass, doors, walls, partitions, ceiling, floor, or other surfaces.
2. *Infiltration and ventilation* losses-energy required to heat up the outdoor air which comes in through cracks and crevices around windows, doors, fireplaces, pipes, wiring, and other openings in the building structure.

No credit is taken for periodic heat gains such as those due to internal loads or solar radiation in calculating the design peak heat loss. Also, the calculation is made with the assumption that the design conditions have reached a steady condition; the effect of the thermal inertia of the building and contents is not included.

For calculating a cooling load for a residential building, the procedures in the previous sections of this Manual are also applicable. However, as a result of research studies of five residences at the University of Illinois, taking into account the unique features of residential buildings and their systems, an all-industry residential cooling load calculation procedure was developed. The procedure was developed primarily for installers of residential equipment and systems, and its engineering basis is discussed here.

The unique features that distinguish residences from other types of buildings, with respect to cooling load calculation and equipment sizing, are:

1. Residences, unlike many other structures, are assumed to be occupied, and usually conditioned, for 24 hrs a day, every day of the cooling season.
2. Residential cooling system loads are primarily imposed by heat flow through structural components and by air leakage or ventilation. Internal loads, particularly those imposed by occupants and lights, are small in comparison to those in commercial or industrial installations.
3. Most residences are cooled as a single zone, since there is no means to redistribute cooling unit capacity from one area to another as loads change from hour to hour.
4. Most residential systems employ units of relatively small capacity (from about 20,000 to 60,000 Btu/hr) which have no means for controlling capacity except by cycling the condensing unit. Since cooling load is largely affected by outside conditions, and few days each season are design days, a partial load situation exists during most of the season. An oversized unit with no capacity control is detrimental to good system performance under these circumstances.
5. Dehumidification is achieved only during periods of cooling unit operation. Space condition control is usually restricted to use of room thermostats, essentially sensible heat-actuated devices.
6. Since many residential systems are operated 24 hr a day, full advantage can usually be taken of thermal flywheel effect of structural members and furnishings within the structure. (This accentuates the partial load effects mentioned in item 4, above).

The cooling load calculation consists of determining total sensible cooling load due to heat gain:

(1) through windows;
(2) through structural components (walls, floors, and ceiling areas);
(3) caused by infiltration and ventilation air; and
(4) due to occupancy and appliances and equipment.

The latent portion of the cooling load can be evaluated separately, but is usually computed as 0.3 times the calculated sensible load. For very dry climates, the factor can be reduced to 0.2.

The load can be calculated with the entire structure considered as a single zone; however, final equipment selection and system design is usually based on a room-by-room calculation, for several reasons: To properly design the distribution system, the designer must know how much conditioned air should be supplied to each room or area of the residence. In addition, the load varies significantly in different areas as a function of time of day. For example, the distribution system for a room facing west, with large, unshaded windows, may adequately handle morning load, but be totally inadequate when afternoon sun pours energy through the windows.

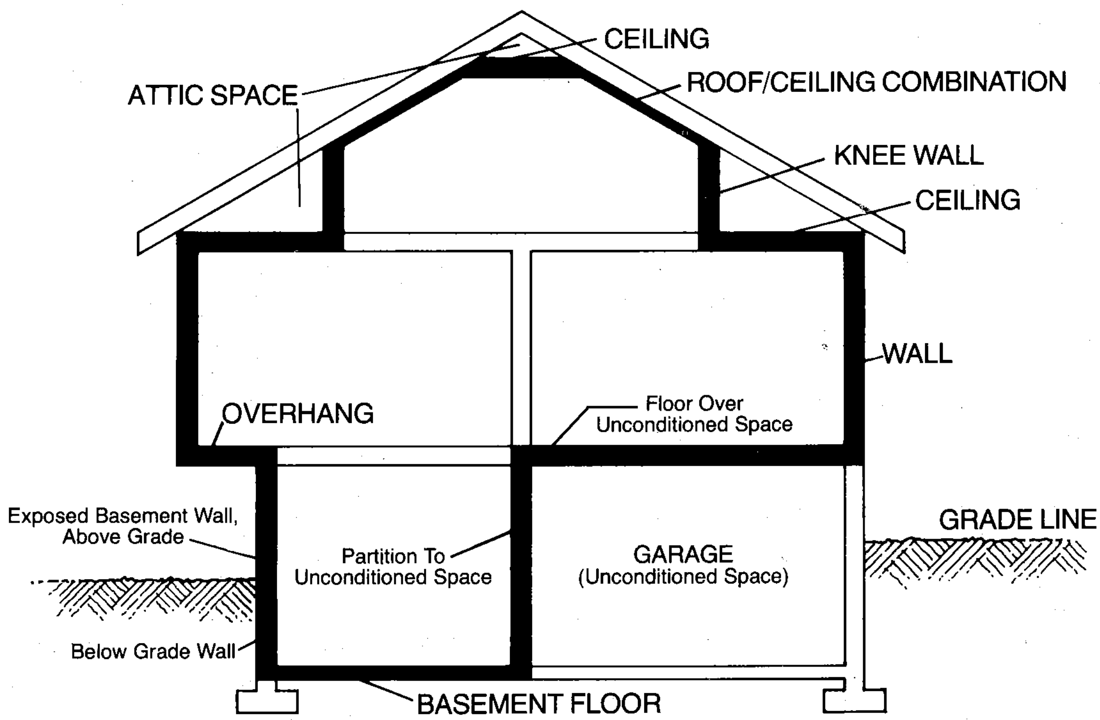


Fig. 7.1 Building Surfaces Next to Outside and to Unconditioned Spaces

Conversely, designing for very late afternoon solar gains inevitably results in excess capacity at other times. A good thermal design of the house will minimize these load extremes and the resulting problems. Dividing the structure into individually controlled zones can compensate in part for non-uniform load distribution.

When a residence is both cooled and heated, other imbalances may occur from room to room. For example, a room such as a finished basement which is essentially below-grade requires practically no cooling but may have a significant heating load. Some means of shifting the system balance from cooling mode to heating mode may be desirable as well.

Allowing for a "swing" in indoor temperature results in lower calculated peak cooling loads. Since, in reality, the indoor temperature does swing, such an allowance results in more economic selection of equipment capacity. Consequently, the tables presented in this section are based on an assumed indoor temperature swing of not more than 3 deg F on a design day, when the residence is conditioned 24 hr a day, and the thermostat setting is 75 F.

7.2 GENERAL PROCEDURE

To calculate a design heating or cooling load, detailed information about building design and weather data at design conditions is required as follows:

1. Select outdoor design weather conditions: summer and winter temperatures, wind speed, average winter outside air temperature and degree days. Climatic data are given in Tables 2.1 and 7.1.
2. Select the indoor air temperature to be maintained in each room.
3. Estimate temperatures in adjacent unconditioned spaces.
4. Select or compute heat transfer coefficients for outside walls and glass; for inside walls, non-basement floors, and ceilings, if these are next to unconditioned spaces; and the roof if it is next to conditioned spaces (see Fig. 7.1).
5. Determine net area of outside wall, glass, and roof next to conditioned spaces, as well as any walls, floors, or ceilings next to unconditioned spaces. Such determinations are made from building plans, or from the actual building, using inside dimensions.
6. Determine shaded and unshaded portions of glass areas.
7. Calculate heating and cooling loads according to procedure outlined in Table 7.2.
8. When positive ventilation using outdoor air is provided by an air-heating or air-conditioning unit, the energy required to warm the outdoor air room temperature must be provided by the unit. The principle for calculation of this load component is identical to that for infiltration. If mechanical exhaust from the room is provided in an amount equal to the outdoor air drawn in by the unit, the unit must also provide for the natural infiltration losses. If no mechanical exhaust is used, and the outdoor air supply equals or exceeds the amount of natural infiltration that would occur without ventilation, natural infiltration may be neglected.
9. Additional capacity may be required for intermittently cooled or heated buildings to bring the temperature of the air, confining surfaces, and building contents to the design indoor temperature within a specified time. Also, as residential buildings become better thermal structures, the design cooling and heating loads are lower. If the buildings are not operated as designed, that is with a constant setting of the temperature control, there may not be sufficient capacity for quick pickup or pulldown.

7.3 DESIGN CONDITIONS

Since the heating load and, to a somewhat lesser extent, the cooling load of residences are heavily influenced by outside conditions, the selection of design conditions materially affects the equipment size. A design for the extreme weather conditions will result in excessive capacity for most of the hours of operation. They usually result in higher energy consumption as well as higher first costs. For most types of new residential construction the design conditions listed in Table 7.3 should provide the basis for adequate sizing but not oversizing.

Estimation of Temperatures in Adjacent Unheated Spaces

The heat loss or gain from heated rooms to unheated rooms or spaces must be based on the estimated or assumed temperature in such unheated spaces. This temperature will lie in the range between the indoor and outdoor temperatures. If the respective surface areas adjacent to the heated room and exposed to the outdoors are the same, and if the heat transfer coefficients are equal, the temperature in the unheated space may be assumed to be almost equal to the mean of the indoor and outdoor design temperatures. If, however, the surface areas and coefficients are unequal, the temperature in the unheated space should be estimated by:

$$t_u = \frac{t_i(A_1U_1 + A_2U_2 + A_3U_3 + \text{etc.}) + t_o(2.16\dot{V}_o + A_aU_a + A_bU_b + A_cU_c + \text{etc.})}{A_1U_1 + A_2U_2 + A_3U_3 + \text{etc.} + 2.16\dot{V}_o + A_aU_a + A_bU_b + A_cU_c + \text{etc.}} \quad (7.1)$$

where

t_u = temperature in unheated space, Fahrenheit
t_i = indoor design temperature of heated room, Fahrenheit
t_o = outdoor design temperature, Fahrenheit
A_1, A_2, A_3, etc. = areas of surface of unheated space adjacent to heated space, square feet
A_a, A_b, A_c, etc. = areas of surface of unheated space exposed to outdoors, square feet
U_1, U_2, U_3, etc. = heat transfer coefficients of surfaces of A_1, A_2, A_3, etc.
U_a, U_b, U_c, etc. = heat transfer coefficients of surfaces of A_a, A_b, A_c, etc.
$\dot{V}_o$ = rate of introduction of outside air into the unheated space by infiltration and/or ventilation, cubic feet per minute

EXAMPLE 7.1

Calculate the temperature in an unheated space adjacent to a heated room having surface areas (A_1, A_2, and A_3) of 100, 120, and 140 ft^2, and overall heat transfer coefficients (U_1, U_2, and U_3) of 0.15, 0.20, and 0.25 Btu/(hr · ft^2 · F), respectively. The surface areas of the unheated space exposed to the outdoors (A_a and A_b) are 100 and 140 ft^2, respectively, and the corresponding overall heat transfer coefficients are 0.10 and 0.30 Btu/(hr · ft^2 · F). The sixth surface is on the ground and can be neglected for this example, as can the effect of introduction of outdoor air into the unheated space. Assume t_i = 70 F and t_o = −10 F

Solution 7.1: Substituting into Eq. (7.1)

$$t_u = \frac{70[(100 \times 0.15) + (120 \times 0.20) + (140 \times 0.25)] + (-10)[(100 \times 0.10) + (140 \times 0.30)]}{(100 \times 0.15) + (120 \times 0.20) + (140 \times 0.25) + (100 \times 0.10) + (140 \times 0.30)}$$

$t_u = 4660/126 = 37$ F

Temperatures in unheated spaces having large glass areas and two or more surfaces exposed to the outdoors, such as garages and sun parlors, are generally assumed to be the same as that of the outdoors.

Attic Temperature

Estimation of attic temperature is a special case of estimating temperature in an adjacent unheated space, and can be done using:

$$t_a = \frac{A_cU_ct_c + t_o(2.16\,A_c\dot{V}_c + A_rU_r + A_wU_w + A_gU_g)}{A_c(U_c + 2.16\,\dot{V}_c) + A_rU_r + A_wU_w + A_gU_g} \quad (7.2)$$

where

t_a = attic temperature, Fahrenheit
t_c = indoor temperature near top floor ceiling, Fahrenheit
t_o = outdoor temperature, Fahrenheit
A_c = area of ceiling, square feet
A_r = area of roof, square feet
A_w = area of net vertical attic wall surface, square feet
A_g = area of attic glass, square feet
U_c = heat transfer coefficient of ceiling, based on surface conductance of 2.20 Btu per (hour) (square foot) (degree Fahrenheit); 2.20 = reciprocal of one-half the air space resistance
U_r = heat transfer coefficient, of roof, Btu per (hour) (square foot) (degree Fahrenheit), based on surface conductance of 2.2 Btu per (hour) (square foot) (degree Fahrenheit) (lower surface)
U_w = heat transfer coefficient of vertical wall surface. Btu per (hour) (square foot) (degree Fahrenheit)
U_g = heat transfer coefficient of glass Btu per (hour) (square foot) (degree Fahrenheit)
$\dot{V}_c$ = rate of introduction of outside air into the attic space by ventilation per square foot of ceiling area, (cubic feet per minute per square foot)

EXAMPLE 7.2

Calculate the temperature in an unheated attic, assuming: t_c = 70 F; t_o = 10 F; A_c = 1000 ft^2; A_r = 1200 ft^2; A_w = 100 ft^2; A_g = 10 ft^2; U_r = 0.50 Btu/ (hr · ft^2 · F); U_c = 0.04 Btu/ (hr · ft^2 · F); U_w = 0.30 Btu/ (hr · ft^2 · F); U_g = 1.13 Btu/ (hr · ft^2 · F); $\dot{V}_c$ = 0.5 cfm/ft^2.

Solution 7.2: Substituting these values into Eq. (7.2)

$$t_a = \frac{(1000 \times 0.04 \times 70) + 10[(2.16 \times 1000 \times 0.5) + (1200 \times 0.50) + (100 \times 0.30) + (10 \times 1.13)]}{1000 \times [0.04 + (2.16 \times 0.5)] + (1200 \times 0.50) + (100 \times 0.30) + (10 \times 1.13)}$$

$t_a = 20{,}013/1761 = 11.4$ F

This result is so close to the outside temperature, t_o, that negligible error in heat transfer calculations would result from using $t_a = t_o$.

The value U_c = 0.04 is slightly higher than for the currently recommended use of R-30 insulation in the ceiling (U_c = 1/30 = .03). If the only change in the example data were to use U_c = 0.4,

as in an uninsulated ceiling, the calculated attic temperature would be $t_a = 21.3$ F and $t_a = t_o$ would then be an unacceptable approximation.

Eq. (7.2) includes the effect of air interchange that would take place through attic vents or louvers intended to preclude attic condensation. Test data indicate that reduction in temperature difference between attic air and outside air is linear, with attic ventilation rates between 0 and 0.5 cfm/ft^2 of ceiling area. When attic ventilation meets the requirements for moisture control, 0.5 cfm/ft^2 is the approximate ventilation rate under design conditions. Note that this reduction in temperature difference affects the overall heat loss of a residence with an insulated ceiling by only 1 or 2%.

Eq. (7.2) also does not take into consideration factors such as heat exchange between chimney and attic, or solar radiation to and from the roof. Because of these effects, attic temperatures are frequently higher than values calculated by using the equations. However, Eq. (7.2) may still be used to calculate attic temperature, because the resulting error for uninsulated ceilings will generally be considerably less than that introduced by neglecting the roof and assuming the attic temperature equal to the outdoor air temperature.

When relatively large louvers are installed (customary in southern states) the attic temperature is often assumed as the average between indoor and outdoor air temperatures.

For a shorter approximate method of calculating heat losses through attics, the combined ceiling and roof coefficient may be used.

Design Ground Temperature

Selecting the appropriate design temperature difference can be a problem. Although internal design temperature is given by basement air temperature, none of the usual external design air temperatures are applicable because of the heat capacity of the soil. However, ground surface temperature is known to fluctuate about a mean value by an amplitude A, which will vary with geographic location and surface cover. Thus, suitable external design temperatures can be obtained by subtracting A for the location from the mean annual air temperature, t_A. Values for t_A can be obtained from Table 7.1 or meteorological records, and A can be estimated from the map in Fig. 7.2. This map is part of one prepared in Ref. 7.10 giving annual ranges in ground temperature at a depth of 4 in.

EXAMPLE 7.3 Determine the Design Ground Temperature for Suburban Chicago, Illinois

Solution: From Table 7.1 the average winter temperature at Chicago's O'Hare Airport is 35.8 F. Fig. 7.2 indicates an amplitude $A = 22$ deg F at Chicago. Therefore $t_{bg} = t_A - A$ or 35.8 − 22 which is 13.8 F rounded off to 14 F. This temperature will be used for the external temperature for below-grade walls and floors.

7.4 WINDOWS

7.4.1 Heating Load

The heat loss by conduction and convection through windows and doors and other structural components is determined by the following equation

$$q = U \times (t_i - t_o) \times A \qquad (7.3)$$

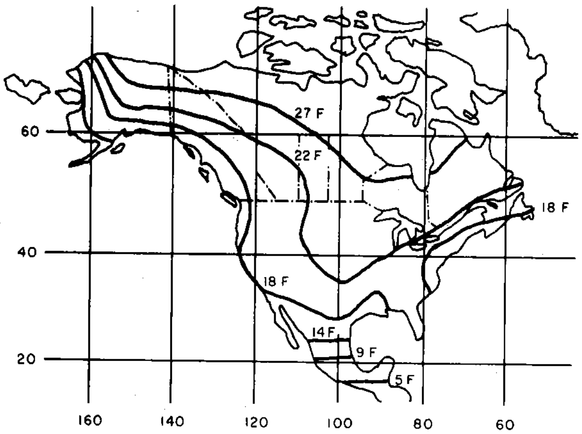


Fig. 7.2 Lines of Constant Amplitude of the Ground Temperature

where

q = heat transfer through the wall, roof, ceiling, floor, or glass, Btu per hour
A = area of wall, glass, roof, ceiling, floor, or other exposed surface, square feet
U = air-to-air heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit)
t_i = indoor air temperature near surface involved, Fahrenheit
t_o = outdoor air temperature, or temperature of adjacent unheated space, Fahrenheit

7.4.2 Cooling Load Due to Heat Gain Through Windows

Fenestration heat gains are discussed in detail earlier in this Manual. Direct application of these procedures for calculating cooling load due to heat gain for flat glass has resulted in unrealistically high cooling loads for residential installations. The data have, therefore, been interpreted to provide an average heat gain over the daylight hours rather than the peak instantaneous heat gain. Window factors for residential cooling load calculations (Table 7.6) have the following characteristics:

1. Different factors are presented for windows facing different directions.
2. The tabulated factors are averages for 5:30 a.m. to 6:30 p.m. at 30° and 40° N latitude. These are averages only in the sense that combining numbers in this manner results in accurate factors for calculating windows loads of residential structures. These factors include both the heat gain from solar radiation and the heat gain from the temperature difference between outside air and inside air dry bulb.
3. The tabulated factors for directions at equal angles from south have been combined.
4. The tabulated factors are applicable for an indoor design temperature of 75 F and for outdoor design temperatures as indicated. (Interpolate to obtain factors for outdoor design temperature other than those given.)
5. Effects of shading devices and different glass types are shown.

In using these factors, the area of each window is multiplied by the appropriate glass factor. Factors incorporating shading devices, such as roller shades half drawn, take into account both the shaded and unshaded portions of a window. When perma-

nent shading devices over windows are used, their effects must be considered separately in determining cooling load due to heat gain through windows. Glass protected by permanent shading, such as wide roof overhangs, is usually considered north-facing glass. Hence, the line of shadow from the overhang onto the window, the shade line, must be located.

Shade line factors are given in Table 7.7. These factors are expressed as the distance the shade line falls beneath the edge of the overhang width. The tabulated values are the average of the shade line values for the 5 hours of maximum solar intensity on each wall orientation shown, and for a solar declination of 18° N (August 1). Northeast- and northwest-facing windows are not effectively protected by roof overhangs and, in most cases, no credit should be taken for shading them.

7.5 STRUCTURAL COMPONENTS — DOORS, WALLS, FLOORS, CEILINGS

7.5.1 Heating Load

Except for loads from below-grade walls and floors the heating load for structural components is calculated by Eq. (7.3). For heat loss through ceilings into the attic and then through the roof, either of two methods may be used:

1. Use Eq. (7.3) with the ceiling area A, the indoor-outdoor temperature difference $(t_i - t_o)$ and the proper U-value:
   a. Flat Roofs. Select the heat transfer coefficient of the ceiling and roof from Table 3.2, or use appropriate coefficients in Eq. (7.2) if side walls extend appreciably above the ceiling of the floor below.
   b. Pitched Roofs. Select the combined roof and ceiling coefficient from Table 3.2, or calculate the combined roof and ceiling coefficient by means outlined in Chapter 3.
2. For pitched roofs, estimate the attic temperature (based on the indoor and outdoor design temperatures) using Eq. (7.2), and substitute for t_o in Eq. (7.3), thus obtaining the value of t_a, together with the ceiling area A and the ceiling U-value. In the case of flat roofs, it is not necessary to calculate the attic temperatures, as the ceiling-roof heat loss can be determined as suggested in (1a), above.

Generally, it is more convenient to use method 1. Also, with the increased use of insulation in the ceiling, it is sufficiently accurate to assume that the attic temperature is equal to the outside temperature and use the U-value of the ceiling alone.

Walls and Floors Below-Grade

The allowance made for basement heat loss depends on whether or not the basement is heated.

If the basement is heated to a specified temperature, heat loss is calculated in the usual manner, based on proper wall and floor U-values and outdoor air and ground temperatures. Heat loss through windows and walls above-grade is based on outdoor air temperatures and the air-to-air U-values. In addition, heat loss due to air leakage is calculated for this portion of the wall. Heat loss through basement walls below-grade is based on floor and wall U-values for surfaces in contact with the soil, and on the ground temperature.

Procedures have been established, by experiment and analysis, over the past 30 years, for heat loss through basements of residential buildings. Based on a study by the ASHVE Research Laboratory in 1942, it was felt adequate to adopt a uniform or average heat loss per square foot of wall of 0.2 Btu/(hr · ft^2) for each deg F of temperature difference between basement and ground water temperature.

Using a uniform heat loss factor does not indicate the greater heat loss through the wall near the ground surface relative to that through the lower parts. Consequently, accurate estimates of heat loss cannot be made, and it is impossible to estimate the depth below-grade to which it is economical to carry insulation. It has been shown that heat loss through the soil surrounding a house basement can be calculated on the basis of steady-state heat flow around concentric circular paths centered on the intersection of the ground surface and the basement wall. For the floor, these paths are continued around circular arcs centered on the intersection of the basement floor and wall.

As a result of such an analysis as above, Tables 7.10A and 7.10B have been developed for the heat loss for below-grade walls together with basement floors which are more than 3 ft below grade. Below-grade walls and basement floors 3 ft and less below-grade are usually treated as a slab-on-grade and Tables 7.9A and 7.9B are used for the heat loss.

Two types of concrete floors for slab-on-grade are: (1) unheated, relying for warmth on heat delivered above floor level by the heating system; and (2) heated, containing heated pipes or ducts that constitute a radiant slab or portion thereof for complete or partial heating of the house.

For Type 1 floors, floor heat loss may comprise only about 10% of total heat loss of the house. For comfort, however, it may be the most important, since houses with cold floors are difficult to heat. Note that a well-insulated floor does not in itself assure comfort if downdrafts from windows or exposed walls create pools of chilly air over considerable areas of the floor. Therefore, a Type 1 floor should not be used in a severe climate, except with a heating system that delivers enough heat near the floor to counteract the downdrafts of exterior walls and heat transmission through the floor.

Experiments with Type 1 unheated floor slabs indicate that heat loss from a concrete slab floor on grade is more nearly proportional to perimeter than to area of the floor and that the heat loss can be estimated by:

$$q = F \times P \tag{7.4}$$

where

q = heat loss of floor, Btu per hour.
F = heat loss coefficient, Btu per hour per linear foot of exposed edge.
P = perimeter or exposed edge of floor, linear feet.

Values of heat loss per linear foot of exposed edge given in Tables 7.9A and B are sufficiently accurate for design calculations. The insulation should extend under the floor horizontally for 2 ft; and can also be located along the foundation vertical wall with equal effectiveness if it extends 2 ft below floor level. HUD-MPS 4900.1, 607-3.7 specifies the minimum R-value perimeter insulation to be used.

Floors of Type 2, containing heating pipes or ducts, are in common use. Heat loss downward into the ground and outward through the edges of the floor is called reverse loss. Results of an investigation in which a warm air perimeter duct was embedded in four types of concrete floor slabs and foundation constructions verified that Eq. (7.4) can be used to calculate reverse loss when warm air perimeter heating ducts are used. To make results more applicable, values corresponding to those shown in Table 7.9A for unheated floors are in Table 7.9B for concrete floors with a warm air perimeter duct.

Desirability of edge insulation is apparent. The minimum

insulation that should be used is R-2.5 of water-resistant material, but R-5 is recommended. The values of edge loss in Table 7.9B indicate that reverse heat loss of heated slabs is likely to be 20% of total heat loss of many types of present-day houses, and may exceed 20% if only R-2.5 of insulation is used at the floor's edge.

The concrete floor slab is usually placed on a gravel fill 4 in. thick or more, to insulate the floor from the earth and to retard the rise of ground water by capillary action. A waterproof membrane should be installed over the gravel fill. Obviously, such floors must be laid several inches above grade, and effective subsoil drainage provided to avoid slabs soaked by rain or melting snow, and consequent excessive heat loss.

7.5.2 Cooling Load due to Heat Gain through Structural Components

The sensible cooling load due to heat gains through walls, floors, and ceiling areas of each room is calculated using the equivalent temperature differences (Table 7.8) and *U*-values for summer conditions. For ceilings under naturally vented attics, or beneath vented flat roofs, use the combined *U*-value for the roof, vented space, and ceiling. Where the design temperature difference (outdoor design temperature minus 75 F) is not an even increment of 5 deg F, the equivalent temperature difference should be corrected 1 deg F for each 1 deg F difference from the tabulated values.

Values for walls in Table 7.8 are based on the assumption of *dark walls*, believed desirable since wall color is an unpredictable variation in any residence. Roof color is more likely to remain constant, and can therefore be used as a design criterion.

Daily range (outdoor temperature swing on a design day) significantly affects equivalent temperature difference and hence the so-called *thermal flywheel* of the structure. Calculation and applicable range values are shown in Table 7.8 for daily temperature ranges classified as high, medium, and low. Table 2.1 lists outdoor daily ranges for many cities. Others can be estimated by using regional geographical and weather pattern characteristics such as altitude, proximity to large bodies of water, prevailing winds, etc. Care should be exercised, however, since climatological characteristics change rapidly within a distance of a very few miles.

No credit is taken for the possible cooling effect of below-grade walls or basement or slab floors.

7.6.1 Infiltration

The infiltration rate of outside air into a house is one of the most difficult quantities to predict accurately. The difficulty lies in the wide variation in the types and quality of construction, the shape and location of the house, the type of heating system, and the design variations in window and door construction. The two major forces which cause infiltration are the stack effect, caused by the inside-outside temperature difference, and the wind effect. Within present engineering accuracy, the combined effect from all sources of infiltration which includes that due to windows and doors can be represented by

$$ACH_{total} = A + (B \times \Delta t) + (D \times WS) \qquad (7.5)$$

where:

ACH = number of air changes per hour
Δt = inside-outside temperature difference in deg F
WS = wind speed in mph
A, B, D = experimentally determined coefficients

The above equation with coefficients based on reports in the literature was used to generate Tables 7.11B and 7.11C. The infiltration rates are listed for various design temperatures based upon the recommended winter and summer indoor design temperatures and wind velocities. Three classifications of workmanship are used, and the guidelines for their selection are listed in Table 7.11A. The infiltration rate measured in air changes per hour, is determined from either Table 7.11B (Heating) or Table 7.11C (Cooling) using the appropriate outdoor design temperature and the construction classification from Table 7.11A. The cfm/ft² of floor area is then obtained from Table 7.12 using the air changes/hour figure and the approximate ceiling height. The to2al cfm of air infiltration is given by this value times the *total* house floor area (found by measuring the floor area of *each* conditioned space and alding them together). The heat gain or loss due to infiltration is then given by

$$q_{sensible} = 1.1 \times \text{cfm} \times \Delta t \qquad (7.6)$$

where:

$q_{sensible}$ = sensible cooling load or heating load (Btu/hr).
cfm = total infiltration (cfm). Note that the infiltration rates are normally different in summer and winter.
Δt = design temperature difference, deg F, summer or winter.

Therefore, the calculation can be simplified still further by combining the factor $1.10 \times \text{cfm/ft}^2$ into a Btu/(hr · F) per ft² factor. The heating or cooling load factor for a particular residence then is

$$\text{LF} = \text{Btu/(hr} \cdot \text{F) per ft}^2 \times \Delta t$$

and

$$q_{sensible} = \text{LF} \times \text{Area} \qquad (7.7)$$

7.6.2 Ventilation Air

Mechanical ventilation may be provided in residential air-conditioning systems. It is not a code requirement in most localities, and only general guidance can be given in determining its desirability. Field experience indicates natural air leakage is adequate for sufficient ventilation in many cases. Nevertheless, the need for positive ventilation must be evaluated for each installation. Considerations include owner preference, entertaining by the owner, etc. In larger homes, ventilation should be provided. This ventilation air is usually introduced at the rate of about one air change/hr. It is considered desirable to install a manually operating, locking damper in the outdoor air duct, so the owner can have the option of positive ventilation or relying on natural air leakage. Generally, ventilation will impose a greater load than infiltration. Also, positive introduction of ventilation air during the summer can substantially eliminate natural air leakage.

7.7 PEOPLE, LIGHTS AND APPLIANCES

7.7.1 Heating Load

No credit is taken for internal heat gains to offset any heat loss when calculating the peak design heat loss; of course, these heat gains will be present and will reduce the energy required by the heating system. However, the extent of the heat gains present at the time of maximum heat loss which is often at night is usually small and often unpredictable.

7.7.2 Cooling Load

Even though occupant density is usually lower in residences than in many other structures, occupancy loads must be considered in residential cooling load calculations. Loads are generated by the occupants and by household appliances, and must usually be approximated, since occupancy and occupant activities are varied and unpredictable.

Heat release per occupant is usually assumed to be 225 Btu/hr of sensible heat gain. The number of occupants must be estimated as accurately as possible, with special attention paid to the owner's use of living or recreation rooms for entertaining large groups. When the owner does not indicate the need for special entertainment provisions, and the exact number of occupants is unknown, a convenient rule-of-thumb is to assume approximately twice as many occupants as the structure has bedrooms. The occupancy load should then be distributed about equally among the living rooms of the residence, because the maximum cooling load period occurs when most of the residents occupy the living rather than sleeping areas. In any case, care should be taken not to grossly overestimate the number of occupants which could lead to oversizing the cooling equipment.

In most cases, appliance loads should be limited to the kitchen. A value of 1200 Btu/hr of sensible heat gain released by kitchen appliances has been found satisfactory for residential cooling load calculations. Although this does not equal the load that can be imposed by even one top burner or element of a domestic range, such factors as intermittent use of appliances, flywheel effects, and kitchen ventilating fans make this a reasonable and practical value to use.

It may be necessary to include the loads imposed by other household appliances, particularly laundry equipment located within the conditioned space. These can be estimated from information in Tables 4.8 and 4.9. Appliances which are major sources of sensible and latent heat must be vented; for example, it is all but impossible to satisfactorily and economically overcome the load imposed by an unvented domestic clothes dryer.

7.8 LATENT HEAT GAINS OR LOSSES

7.8.1 Humidification — Heating

The trend to tighter and tighter construction of new residences along with greater use of vapor barriers generally has reduced the use of humidifiers. In fact, high humidities in residences is a growing concern. Therefore, no additional capacity is calculated for a humidification load.

7.8.2 Dehumidification — Cooling

The latent portion of a residential cooling load is usually estimated at 20 to 30% of the calculated sensible load. This is an approximation; moisture sources in a residence are numerous and, if taken individually, difficult to evaluate precisely. Furthermore, residential cooling equipment is controlled by one or more room thermostats, and humidity rarely affects a control device directly. The value of 20% is used for dry climates and a value of 30% for other regions.

7.9 DUCT HEAT GAINS/LOSSES AND OTHER CONSIDERATIONS

If all ducts are located within the conditioned space, distribution system design and equipment selection are based on the total calculated heating load or cooling load of each room. Whenever the distribution system is located outside the conditioned space—in attics, crawl spaces, or unconditioned rooms—heat gains to the ducts or pipes must be included in equipment load and considered in equipment selection. Table 7.13 provides some approximate allowance for duct heat gains and losses.

Another factor in equipment selection is the effect of outside conditions on unitary cooling equipment capacity. The rated capacity of unitary equipment is affected by standard test conditions and the properties and quantities of the fluids passing through the evaporator and condenser. One standard combination of test conditions cannot provide a meaningful capacity rating for all outside design conditions of dry-bulb temperature and daily temperature range. Whenever available, manufacturer's ratings at the appropriate outdoor conditions should be used. Furthermore, the inside design temperature swing materially affects the equipment requirement.

The cooling load calculation procedure is predicated on an inside temperature swing of 3 deg F. Engineers are not unanimous on the maximum acceptable temperature swing; other values, including 4.5 and 6 deg F, have been responsibly recommended. But 3 deg F is viewed as a practical mimimum; and equipment capacity selection on this basis is recommended here.

7.10 CALCULATION OF OVERALL U - VALUES AND EQUIVALENT BUILDING ENVELOPES

Standards such as HUD-MPS and ASHRAE 90-75 allow for either a prescriptive element by element requirement or some combination thermal requirement for buildings. This section will use some examples to illustrate the computations involved in such standards. The example building is assumed to have the following characteristics:

Ceiling attic roof 1000 ft²
Wall Area — above grade 700 ft² gross area
Window Area 10% of floor area (check HUD-MPS 4900.1 403-2.2) but not more than 15% of wall area (607-3.3)
Door Area 42 ft²
Floor over unheated garage 500 ft²

The building is located in a region that experiences an average of 5000 degree days.

7.10.1 U_o— For Walls, Windows and Doors

HUD-MPS 4900.1, 607-3.2 and 3.3

The maximum U-values for this example are:
Frame wall 0.08
Doors and Windows 0.69
Window Area = 0.10 × 1000 = 100 ft²

Window Area as a percentage of wall = $\frac{100}{700} \times 100\% = 14.3\%$

which is less than the 15% restriction of note (3) in HUD-MPS 4900.1, 607-3.3.

Therefore the maximum overall wall U_o
$$= [(0.08)(700 - 100 - 42) + (0.69)(100 + 42)]/700$$
$$= 0.204$$

According to ASHRAE 90-75, Fig. 1, the maximum U_o = 0.23.

The requirements can be met for example with the following combinations.

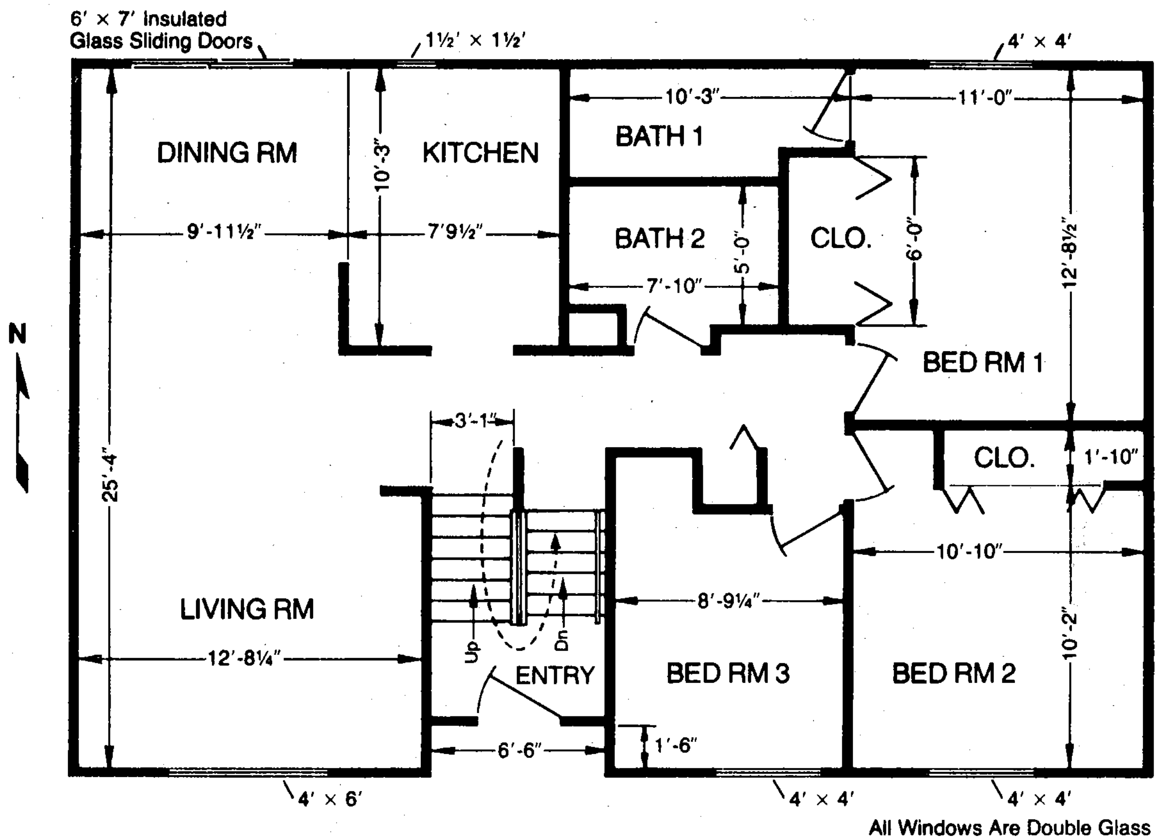


Fig. 7.3 First Floor Plan for Residence of Example 7.4.

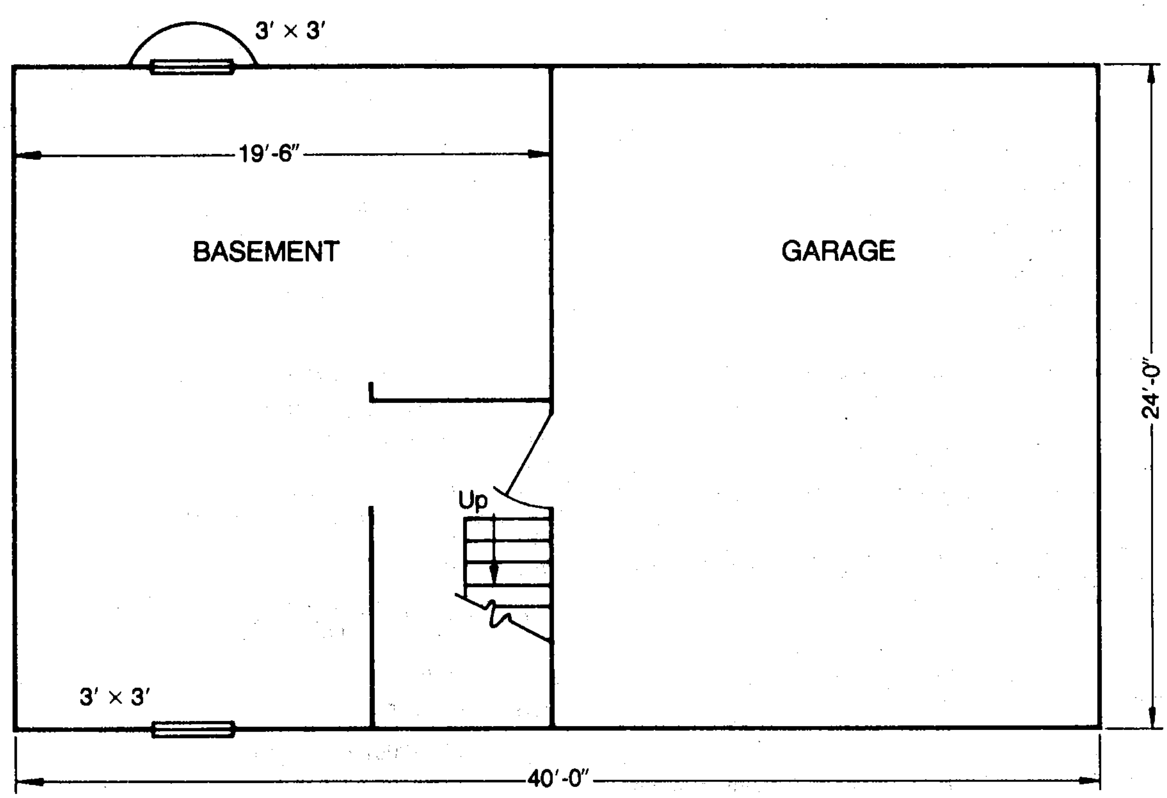


Fig. 7.4 Ground Floor Plan for Residence of Example 7.4.

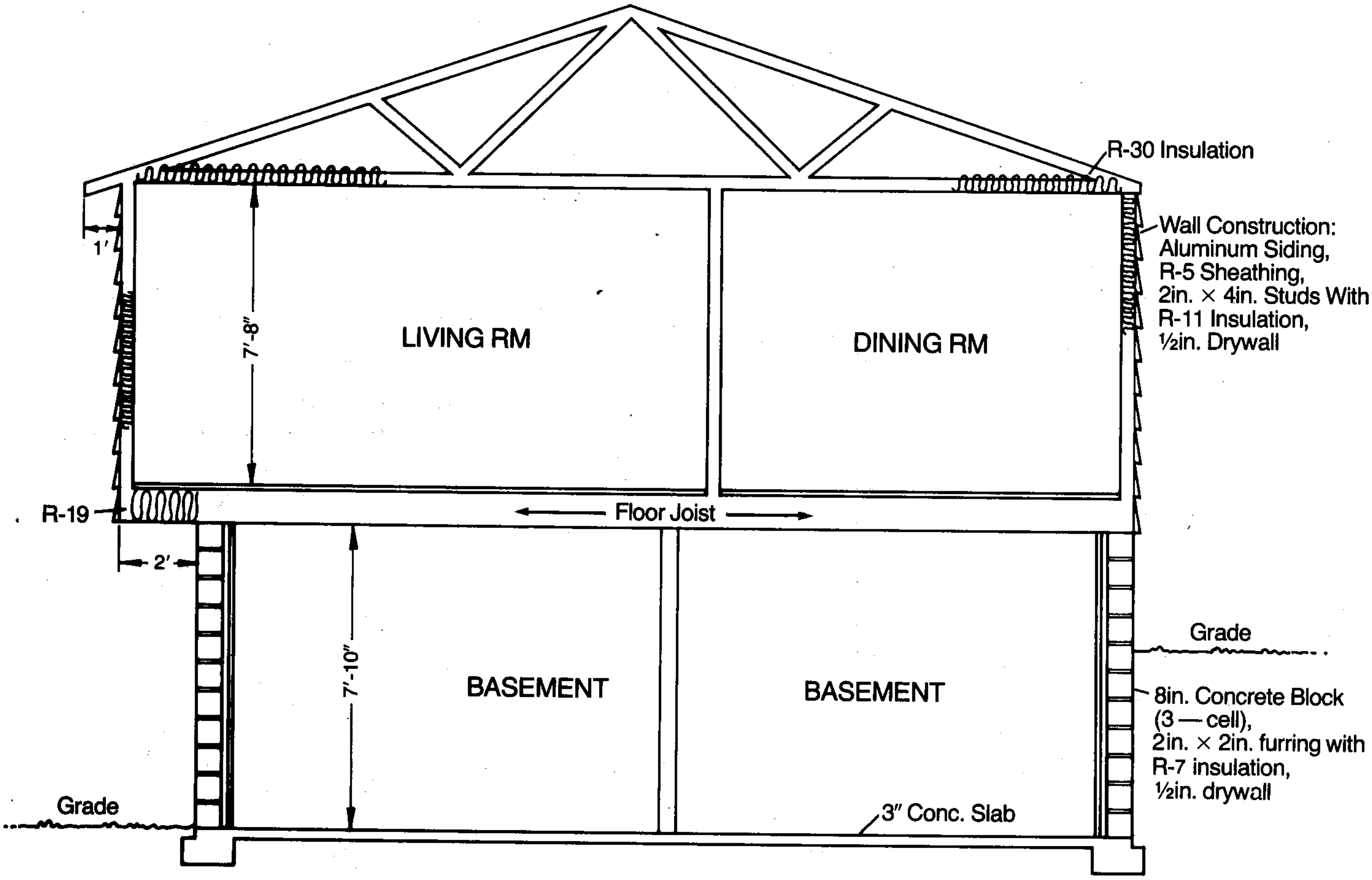


Fig. 7.5 Elevation for Residence of Example 7.4.

A. Assume that the doors are 1 1/4 in. wood doors with a metal storm door which has a U-value of 0.39. Assume that the windows are single with interior shades for a U-value of 0.83. Determine the necessary U-value of the wall to meet HUD-MPS and then ASHRAE 90-75 standards.

For $U_o = 0.204$

$$(0.204)(700) = (0.39)(42) + (0.83)(100) + U_w \times 558$$

$$U_w = \frac{142.8 - 16.4 - 83.0}{558}$$

$$= 0.078 \text{ Btu/(hr}\cdot\text{ft}^2\cdot\text{F)}$$

This would be the wall U-value before adjusting for framing, since such adjustment is not required by HUD-MPS.

For ASHRAE 90-75, $U_o = 0.23$

$$U_w = \frac{(0.23)(700) - 16.4 - 83.0}{558}$$

= 0.110 after adjusting for framing, as recommended by ASHRAE 90-75.

B. Assume that insulating double glass is used in part A. Determine the wall U-value

$U_o = 0.204$

The U-value for double glass with a 1/4 in. air space and interior shades is 0.48 uncorrected for type of sash.

$$U_w = \frac{(0.204)(700) - (0.39)(42) - (0.48)(100)}{558}$$

$$= 0.14$$

For $U_o = 0.23$

The U-value of double glass with wood sash has an adjustment multiplier of 0.95.

$$U_w = \frac{(0.23)(700) - 16.4 - (0.48 \times 0.95)(100)}{558}$$

= 0.177 adjusted for framing

7.10.2 U_o— Including Ceilings and Floors

HUD-MPS 4900.1, 607-3.3 and 3.4

Maximum U-values for

Ceiling 0.05

Floor 0.08

These are also the values from ASHRAE 90-75

Building Envelope U_o – value

HUD-MPS

$$U_o = \frac{(0.204)(700) + (0.05)(1000) + (0.08)(500)}{(700 + 1000 + 500)}$$

$$= 0.106$$

ASHRAE 90-75

$$U_o = \frac{(0.23)(700) + 50 + 40}{2200}$$

$$= 0.114$$

RESIDENTIAL COOLING & HEATING LOAD CALCULATIONS

Prepared For J. A. ARNØW Job No. 77-1030 Date 5/19/77

4920 MARGATE RØAD Prepared by RJW

Location PITTSBURGH, PA. 15261

Latitude 40° N

Summary of Load Calculations for Entire House	
(S1) Cooling	(S2) Heating
8918 Btu/hr Sensible	32519 Btu/hr
11593 Btu/hr Total	485 Btu/hr -F
0.97 Tons 1540 ft²/ton	21.8 Btu/hr -ft²

Design Conditions (1)	Summer	Winter
Outside Temp. db, F	86	5
Inside Temp. db, F	75	72
Difference	11	67

Daily Range, Deg. F 22

Temperature Swing 3 Deg. F.

Window Schedule (2)

Type	Description of Window	Description of Shades & Shading
A	4'x4' DØUBLE	SHADES
B	4'x6' DØUBLE	DRAPES
C	3'x3' DØUBLE	NØNE
D	1½'x1½' DØUBLE	NØNE
E	6'x7' DØUBLE DØØRS	DRAPES

Exterior Shading Calculation (3)

Type	A	B	C				
Orientation	S	S	S				
Shade Line Factor	2.6	2.6	2.6				
Overhang, ft	1	1	2				
Shade Length, ft	2.6	2.6	5.2				
Distance to Top of Window ft	1.0	1.0	1.0				
Shaded ht. of Window, ft	1.6	1.6	ALL				
Width of Window, ft	4.0	6.0					
Shaded Area, ft²	6.4	9.6	9.0				
Unshaded Area, ft²	9.6	14.4	—				

Work Sheet

	Living Room	Dining Room	Kitchen	Bedroom No. 1	Bedroom No. 2	Bedroom No. 3	Bath No. 1	BATH NO. 2	ENTRY	BASEMENT			UA Calculations (7): Entire House	U-Value	UxA	Load Factors: (10) Heating UxΔT	(11) Cooling
(4) WINDOW: Type A Facing S, ft²					16	16							32	0.46	14.6	30.8	27
WINDOW: B S, ft²	24												24	0.46	10.9	30.8	20
WINDOW: A N, ft²				16									16	0.46	7.3	30.8	15
WINDOW: D N, ft²			2.3										2.3	0.55	1.3	36.9	19
WINDOW: C N, ft²										9			9	0.55	5.0	36.9	19
WINDOW: C S, ft²										9			9	0.55	5.0	36.9	33
DOOR: 1" WITH METAL STØRM DØØR, ft²									21				21	0.39	8.2	26.1	5.7
DOOR: , ft²																	
DOOR: GLASS N, ft²		42											42	0.48	20.2	32.2	12
Subtotal Area, ft²	24	42	2.3	16	16	16			21	18			155	0.47	72.5		
(5) WALL: Exposed, Running ft.	29.2	20.3	7.8	23.8	22.9	10.3	10.3		6.5								
WALL: Gross Area, ft²	225	156	60	182	176	79	79		50	494			1501				
WALL: Above grade, ft²	201	114	58	166	160	63	79		29				870	0.061	53.1	4.1	0.89
WALL: CØNCRETE BLØCK, ft²										272			272	0.11	29.9	7.4	0.80
WALL: PARTITIØN, ft²										188			188	0.083	15.6	5.6	0.5
WALL: Below Grade, ft²										204			204	0.11	22.4		
WALL: , ft²																	
Subtotals	225	156	60	182	176	79	79		50				1485	X	171.1 (8)		
U_O-Value = Sum of UxA / Sum of A													X	0.115	X		
(6) ~~Roof~~/Ceiling TØ ATTIC, ft²	192	103	80	149	130	105	40	40	174				1013	0.038	38.5	2.5	1.33
, ft²																	
Floor, ØVERHANG, ft²	19				16	13							48	0.052	2.5	3.5	0.31
ØVER GARAGE, ft²				149	114	92	40	40	36				471	0.052	24.5	3.5	0.31
Totals													3221	X	259.0		
Overall U = Sum of UxA / Ref. Area													X	0.080	X (9)		

RESIDENTIAL HEATING AND COOLING LOAD CALCULATIONS

COOLING LOAD CALCULATION

	Description/ Orientation	Type	(C1) U-Value	Load Factor	(C6) Entire House Quant.	Entire House Btu/hr	Living Room Quant.	Living Room Btu/hr	Dining Room Quant.	Dining Room Btu/hr	Kitchen Quant.	Kitchen Btu/hr	Bedroom No. 1 Quant.	Bedroom No. 1 Btu/hr	Bedroom No. 2 Quant.	Bedroom No. 2 Btu/hr	Bedroom No. 3 Quant.	Bedroom No. 3 Btu/hr	Bath No. 1 Quant.	Bath No. 1 Btu/hr	BATH NO. 2 Quant.	BATH NO. 2 Btu/hr	ENTRY Quant.	ENTRY Btu/hr	BASEMENT Quant.	BASEMENT Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr
WINDOWS	S-SHADES	A	0.46	27	32	864							16	432	16	432														
WINDOWS	N-SHADES	A	0.46	15	16	240											16	240												
WINDOWS	S-DRAPES	B	0.46	20	24	480	24	480																						
WINDOWS	S-	C	0.55	33	9	297																			9	297				
WINDOWS	N-	C	0.55	19	9	171																			9	171				
WINDOWS	N-	D	0.55	19	2.3	44					2.3	44																		
DOORS	GLASS DOUBLE	E	0.48	12	42	504			42	504																				
DOORS	3'x7' WOOD		0.39	14.6 5.7	21	120																	21	120						
WALLS	R-11 FRAME		0.061	14.6 0.89	870	774	201	179	114	102	58	52	166	148	160	142	63	56	79	70			29	26						
WALLS	CONCRETE BLOCK		0.11	7.3 0.80	272	218																			272	218				
WALLS	PARTITION		0.083	6 0.50	188	94																			188	94				
ROOF	CEILING/ROOF		0.038	35 1.33	1013	1347	192	256	103	137	80	106	149	197	130	173	105	140	40	53	40	53	174	232						
ROOF																														
FLOOR	OVERGARAGE		0.052	6 0.31	471	146							149	46	114	35	92	30	40	12	40	12	36	11						
FLOOR	OVERHANG		0.052	6 0.31	48	15	19	6							16	5	13	4												
(C2)	People			225	6	1350	3	675	3	675																				
	Lights & Appliances					1200						1200																		
(C3)	Infilt./Ventil.	0.3		0.44	1481	652	192	85	103	45	80	35	149	66	130	57	105	46	40	18	40	18	174	77	468	206				
(C7)	Subtotal					8516		1681		1463		1437		889		844		516		153		83		466		986				
(C8)	Duct Heat Gain @ 5 %					426																								
(C9)	Room Sensible Cooling Load					8942																								

HEATING LOAD CALCULATION

	Description/ Orientation	Type	U-Value	Load Factor	Entire House Quant.	Entire House Btu/hr	Living Room Quant.	Living Room Btu/hr	Dining Room Quant.	Dining Room Btu/hr	Kitchen Quant.	Kitchen Btu/hr	Bedroom No. 1 Quant.	Bedroom No. 1 Btu/hr	Bedroom No. 2 Quant.	Bedroom No. 2 Btu/hr	Bedroom No. 3 Quant.	Bedroom No. 3 Btu/hr	Bath No. 1 Quant.	Bath No. 1 Btu/hr	BATH NO. 2 Quant.	BATH NO. 2 Btu/hr	ENTRY Quant.	ENTRY Btu/hr	BASEMENT Quant.	BASEMENT Btu/hr	Quant.	Btu/hr	Quant.	Btu/hr
WINDOW	TYPES A&B		0.46	30.8	72	2218	24	739					16	493	16	493	16	493												
WINDOW	TYPES C&D		0.55	36.9	20.3	749					2.3	85													18	664				
WINDOW	PATIO DOORS		0.48	32.2	42	1415			42	1415																				
	DOOR W/STORM DOOR		0.39	26.1	21	548																	21	548						
WALL	R-11 FRAME		0.061	4.1	870	3567	201	824	114	467	58	238	166	680	160	656	63	258	79	324			29	119						
WALL	CONCRETE BLOCK		0.11	7.4	272	2015																			272	2015				
WALL	PARTITION		0.083	5.6	188	1053																			188	1053				
ROOF	CEILING/ROOF		0.038	2.5	1013	2533	192	480	103	258	80	200	149	373	130	325	105	263	40	100	40	100	174	435						
ROOF																														
(C5) FLOOR	OVERHANG, OVERGARAGE		0.052	3.5	519	1817	19	67					149	522	130	455	105	368	40	140	40	140	36	126						
FLOOR	PERIM.			35	63	2205																			63	2205				
(C4)	Infilt./Ventil.	0.8		6.7	1481	9923	192	1286	103	690	80	536	149	998	130	871	105	704	40	268	40	268	174	1166	468	3136				
(C10)	Subtotal					28043		3396		2830		1059		3066		2800		2086		832		508		2394		9073				
(C11)	Duct (Piping) Heat Loss @ 15 %					4206																								
(C12)	Room Sensible Heat Loss					32249																								

A. Assume that the ceiling is to have a U-value of 0.032 unadjusted for framing and 0.038 adjusted. The floor is to have U-values of 0.08 adjusted or unadjusted.

Determine the allowable wall U-value if single glass and if insulating double glass is used.

For $U_o = 0.106$

Single Glass

$$U_w = \left(\frac{1}{558}\right) \times (0.106 \times 2200 - 0.032 \times 1000 - 0.30 \times 42 - 0.83 \times 100 - 0.08 \times 500)$$

$$= \frac{144.8 - (0.83)(100)}{558}$$

$= 0.111$ unadjusted

Double Glass

$$U_w = \frac{144.8 - (0.48)(100)}{558}$$

$$= 0.173$$

For $U_o = 0.114$

Single Glass

$$U_w = \left(\frac{1}{558}\right) \times (0.114 \times 2200 - 0.038 \times 1000 - 0.39 \times 42 - 0.08 \times 500 - U_G \times 100)$$

$$= \frac{156.4 - (0.83)(100)}{558}$$

$= 0.132$ adjusted for framing

Double Glass

$$U_w = \frac{156.4 - (0.48 \times 0.95)(100)}{558}$$

$= 0.199$ adjusted for framing

EXAMPLE 7.4 Residential Cooling and Heating Calculations

Sample residential cooling and heating load calculations are made based on:

- Floor plans and elevations as given in Figs. 7.3 through 7.5
- Location in suburban Pittsburgh as indicated on sample work sheet

The calculation includes references to the recommendations of publications by the Department of Housing and Urban Development (HUD-MPS 4900.1) with revisions to May, 1977 and to ASHRAE Standard 90-75. The procedure of calculations follows the indicated steps 1 through 11 on the Work Sheet, and then steps C1 through C12 of the Cooling and Heating Load Calculation forms as the cooling and heating load calculations for the entire house are completed. Summaries of sensible loads and total load, including latent load, are inserted on the Work Sheet as indicated by summaries S1 and S2 below the home-owner's address.

Sample calculations, listing of reference publications, tables used, and explanations are summarized for each item 1 through C12.

EXAMPLE 7.4 Residential Cooling and Heating Calculations

Item	Refer.	Explanation and Notes
Outside Design Conditions ①	Table 2.1 and HUD-MPS 615-3.1 and 615-4.2 (May 1977)	There are two weather stations listed for Pittsburgh, PA. at a latitude of 40°N: AP – for the Airport and CO – for an urban location. If the residence is located in suburban area represented by the airport weather, then this data should be used. Unless unusual design conditions are required, use the columns for 97 1/2% for the winter and 2 1/2% for the summer. Therefore, the winter db = 5 F and the summer db = 86 F with a summer daily range of 22 deg F.
	Table 7.1	The average winter temperature is 38.4 and a yearly total of 5987 degree days.
Inside Design Conditions ①		The recommended design conditions for load calculations, not necessarily for thermostat setting during actual operation, are 72 F for the winter and 75 F with a temperature swing of 3 deg F for the summer. The HUD-MPS provide for an inside design temperature of not less then 70 F.
Window Schedule and Description ②	Floor Plan or Survey	Use the floor plans or the survey to place the windows into similar type groups. For this example, there are three 4 ft × 4 ft insulated glass windows and two 3 ft × 3 ft windows. Two other types have one each. Insert the description in the window schedule.
Window Shading (omit if a cooling calculation is not to be made) ③	Table 7.7	Check the floor plans for overhangs or other exterior shading of glass areas. Complete the table for exterior shading. The shade line factors are given in Table 7.7. In this example, shading is available on the south windows in the living room and in bedroom 2 and bedroom 3 due to the roof overhang of 1 ft. The first floor overhang of 2 ft shades the basement window. The top of each of these window type A is: Shade length = Shade Line Factor × Overhang = 2.6 × 1.0 ft = 2.6 ft Shaded height of window = Shade length − distance to the top of the window = 2.6 ft − 1.0 ft = 1.6 ft Note: References are made to publications by the Department of Housing and Urban Development (HUD-MPS 4900.1) with revisions to May 1977 and ASHRAE Standard 90-75. More recent revisions and additions to these publications should be consulted. Shaded window area = 1.6 ft × 4.0 ft width = 6.4 ft² Unshaded area = Total window area − Shaded area = (4.0 × 4.0) − 6.4 ft² = 9.6 ft²

Item	Refer.	Explanation and Notes
Work Sheet — Window and door areas (4)	Plans & Survey	Insert window areas for each type and orientation into each room column. For example, the living room has one type *B*, 4 ft × 6 ft, window which faces south. When all of the windows and glass doors and skylights are tabulated, add across on each line for the entire house total. In this example, there are a total of 32 ft² of type *A* windows with 16 ft² in bedroom no. 2 and in no. 3. Also, total the window and door areas on exposed walls in the subtotal line. This is to be used for calculating the net exposed wall area. The total fenestration in the living room is just the one window area of 24 ft².
Walls — Exposed Perimeter (5)	Plans & Survey	It is usually convenient to calculate the gross exposed wall area and then subtract out the areas for windows and doors. When ceiling height is the same along the wall, determine the total exposed perimeter, referred to as running feet. For the living room it is 25 ft-4 in. minus 10 ft-3 in. along the west wall plus 12 ft.-8 in. along the south wall plus 1 ft-6 in. along entry. This is 29.2 ft. The other rooms are determined in a similar manner. Rounding off the dimensions will not generally incur great errors.
Gross Area		The gross area is obtained by multiplying the exposed running feet by the ceiling height. For the living room, the height is 7 ft-8 in. and the gross area = 29.2 × 7.7 = 225 ft²
Net Wall Area		The net wall areas are obtained by subtracting the fenestration subtotal from the gross area. Net = 225 − 24 = 201 ft² for the living room.
		For basement areas, it is necessary to split the walls into above-grade and below-grade walls. Also, if more than one type of wall construction is used, list their areas on separate lines. Insulated frame walls, insulated concrete block basement walls, and insulated partition walls to the garage are listed separately for above-grade walls.
Roof/ Ceilings and Floors (6)	Plans & Survey	The areas of ceiling surfaces to attics, unconditioned spaces or combination ceiling/roofs should be entered for each room. For the living room, the ceiling area is (25 ft-4 in. minus 10 ft.-3 in.) × 12 ft-8 1/4 in. which is 15.1 ft × 12.7 ft or 192 ft². The dining room area is 9 ft-11 1/2 in. or close enough to call 10.00 ft × 10.25 ft for 103 ft². Other rooms are similarly calculated.
		The garage is not heated. Since the garage door and most of the garage wall is above grade, the garage temperature will be assumed to be equal to outside conditions for design calculations. The use of insulated floors over the garage and insulated partitions between the basement and garage reduces the heat flow into the garage in winter and thus permits the temperature to drop. Therefore, the floor area over the garage is considered an exposed floor.

Item	Refer.	Explanation and Notes
		Also, a portion of the floor in the living room, bedroom no. 2 and bedroom no. 3 extends over the basement level. This overhang is to the outside air. In the living room the area is 1.5 ft × 12.7 ft or 19 ft². For the bedrooms, it is 16 and 13 ft². The basement floor will be treated separately as a slab on grade in the heating load calculation.
U-Values Windows and Doors (7)	Table 3.14	The *U*-values for various types of windows in combination with types of interior shading is listed in Table 3.14. For insulating double glass with a 1/4-in. air space, the tabulated winter *U*-value is 0.58 with no interior shade and 0.48 with interior shade. Table 3.1B indicates that an adjustment factor of 0.95 is to be used with wood frame double glass windows of 80% glass. The net values are 0.55 and 0.46. The glass patio doors have an adjustment factor of 1.0. Therefore the *U*-value is 0.48 with interior drapes.
	Table 3.6	One-inch door with metal storm door, $U = 0.39$.
	HUD-MPS 4900.1 607-3.3 (May 1977)	The Minimum Property Standards require a maximum value of 0.69, unadjusted for sash. These windows, therefore, meet that requirement.
U-Values Walls and Ceilings and Floors	Table 7.4 Tables 3.1-3.6	Obtain the *U*-values for each type of construction. Table 7.4 lists a few types of ceiling and wall constructions with the adjustment for framing and insulation. Chapters 3 and A3 provide details for calculation of *U*-values. Walls using 2 in. × 4 in., 16 in. O.C. studs have a wood area of 9.4% for studs alone. However, when all of the framing around windows, doors and corners, for example, are included, the percent framing area is approximately 20%. For frame wall with aluminum siding, sheathing of R-5, R-11 insulation, and gypsum wall board, the *U*-value in Table 7.4 is 0.061 assuming a 20% framing adjustment. The unadjusted value is 0.055.
	Table 7.1 & HUD-MPS 4900.1 607-3.2 & 3.3 (May 1977)	For Pittsburgh with average degree days of 5987, the HUD-MPS requirement is for a *U*-value for the frame wall of not more than 0.08 unadjusted. Therefore, this wall meets that requirement. A wall with ordinary sheathing would have an adjusted *U*-value of 0.081 and an unadjusted value of 0.069. This also could meet the maximum requirement. If it did not, then the overall heat loss may be checked for conformance to test for the reduction required. The outside masonry walls with R-7 in furred wall construction have a *U*-value of 0.098 unadjusted and 0.11 adjusted for 9.4% framing. This meets the HUD-MPS requirement of 0.10 unadjusted. The masonry partition has R-11 in furred wall.

Item	Refer.	Explanation and Notes
UA and U_o for Walls (8)	ASHRAE Standard 90-75	ASHRAE Standard 90-75 establishes a U_o overall value for the wall/window/door surface. This is obtained by multiplying each area by its appropriate U-value as indicated. Then the total is divided by the total area for U_o. In this case, the sum of all the wall element areas is 1485 ft² and the UA sum is 171.1. Then, $U_o = \frac{171.7}{1485} = 0.115$ Btu/(hr · ft² · F) ASHRAE 90-75 requires a maximum of 0.22 for 6000 degree days.
Roof/Ceiling U-Value (9)	Table 7.4 & HUD-MPS 4900.1 607-3.2 & 3.3 (May 1977)	The U-value for a ceiling to an unconditioned attic space with R-30 insulation is 0.038 adjusted for 9.4% framing of 2-in. × 8-in., 16-in. O.C. joists. The requirement for ASHRAE 90-75 is 0.08 and for the HUD-MPS is 0.05. Therefore, this construction meets both recommendations.
Floor U-Value	Table 7.4 & HUD-MPS 4900.1 607-3.4 (May 1977)	The floor over the unheated garage and the overhang has R-19 insulation. The U-value for this construction is 0.052. The requirement for HUD-MPS is a maximum value of 0.08 and is the same for ASHRAE 90-75. This floor construction meets both limits.
Overall U		The overall U-value of the building envelope is sometimes used as an indication of the thermal effectiveness of the building. The total of the areas is 3221 and the sum of $U \times A$ is 259.0 which yields an overall U of 0.08 per sq ft of building envelope. Another value might be obtained by dividing the $U \times A$ product by the heated floor area.
Heating Load Factors (10)		The heating load factor for exterior surfaces is equal to the product of $U \times \Delta t$. The Δt in these cases is the difference between the inside and outside design conditions. HLF = $U \times 67$ from (1) For window type A, the HLF = 0.46 × 67 = 30.8 Btu/(hr · ft²) Similar calculations are made for all other surfaces having a design temperature difference of 67 deg F. This includes the ceiling and the floor over the garage and the basement partition because of the assumption of outside temperature in the attic and garage for design calculations. The basement floor and below grade wall will be treated on the load calculation form.
Cooling Load Factors Windows (11)	Table 7.6 Design Conditions (1)	The cooling load factors are taken directly from Table 7.6 for an outside design of 86 F db. For regular double glass, unshaded, the CLF is 19 for a north window. For a north window with drapes, the CLF is 12 and with shades 15. For a south window with roller shades, the CLF is 27, with drapes 20, and unshaded 33.

Item	Refer.	Explanation and Notes
Cooling Load Factors Opaque Surfaces	Table 7.8 Daily Range (1)	The cooling load factors are the product of $U \times$ Design Equivalent Temperature Differences from Table 7.8. A daily range of 22 deg F is equivalent to a medium (M) value. For a dark roof over a naturally vented attic and ceiling, the design temperature difference is between 34 and 39 or approximately 35 deg F for an outside design of 86 F. The CLF = 0.038 × 35 = 1.33. The temperature difference for frame walls and wood doors is 13.6 + (18.6 − 13.6)/5 or 14.6 deg F. For masonry walls, the temperature difference is 6.3 + (11.3 − 6.3)/5 = 7.3 deg F. The temperature difference for the floors over the garage, garage to basement partition, and the overhang is 5.0 + (10.0 − 5.0)/5 or 6 deg F. The CLF are then calculated by multiplying by the respective U-values. Therefore, for: Frame Wall CLF = 0.061 × 14.6 = 0.89; Doors CLF = 0.39 × 14.6 = 5.7; Masonry Wall CLF = 0.11 × 7.3 = 0.80; Floor CLF = 0.052 × 6 = 0.31
Cooling Load Calculation (C1) Data from Work Sheet	Work Sheet	Transfer the data from the work sheet to the Load Calculation form for description of surfaces, type, U-values and Cooling Load Factors and Heating Load Factors. Also, transfer the areas of each item for each room.
(C2) People		Unless special provisions are to be made for entertaining large groups, it is customary to calculate for two people per bedroom — in this case, 6 people. The loads are then split between the living room and dining room.
(C3) Infiltration	Table 7.11A 7.11C & 7.12	The type of construction based on Table 7.11A will indicate the design air change infiltration rate to be used from Table 7.11C. Then, Table 7.12 can be used to determine the sensible heat gain from infiltration in Btu/hr per deg F temperature difference, inside to outside, per square foot of floor area for various ceiling heights.
	Table 7.11A Table 7.11C Table 7.12	Since this is a new house and is being constructed under tight standards, the design infiltration for a summer design temperature is 0.3 air changes per hour. For room with a ceiling height of 7 ft-8 in. the heat gain is 0.04 Btu/(hr · ft² · F). The cooling load factor is 0.04 × (86 − 75) or 0.44 Btu/(hr · ft²).
(C4) Infiltration - Heating	Table 7.11A and Table 7.11B and Table 7.12	The infiltration for heating at an outside design temperature of 5 F is between 0.7 and 0.8 air changes. From Table 7.12, the heat loss is between 0.09 and 0.11 Btu/(hr · ft² · F) for 7 ft-8 in and 0.10 to 0.12 for 8 ft-0 in. Therefore a value of 0.10 will be used for 7 ft-8 in. ceiling height. No controlled ventilation is designed for this house. Therefore, the infiltration is the only outside air load.

Item	Refer.	Explanation and Notes
(C5) Basement Floors and Walls	Tables 7.9A and 7.9B	The basement may be considered as a heated space whether or not it is initially a finished room. In many cases, this becomes a finished game room or family room and the heating system should account for the load. The basement is near grade level at the front of the house and slopes back along the west wall to approximately 4 ft at the north wall.
	Table 7.9A	Since most of the basement floor is less than 4 ft below grade, this will be treated as a slab-on-grade construction. The load factor is 35 Btu/hr per foot of slab perimeter for a slab with edge insulation of R-5. This would account for the heat loss through the wall and the floor. The basement perimeter is 19.5 ft + 24 ft + 19.5 ft for a total of 63 ft.
Cooling Load (C6) Btu/hr & (C7) Subtotal		The calculations are made by multiplying the cooling load factors by the appropriate quantities for the entire house and for room-by-room. The sensible heat gains are then subtotaled.
Duct Heat Gain (C8)	HUD-MPS 4900.1 515-3.1 (May 1977) ASHRAE 90-75 5.11 Table 7.13	The duct gain allows for any heat picked up when the ducts are run through unconditioned spaces such as attics or garages or crawl spaces. The heat gain is usually calculated for 5 to 10% when installed according to the recommended standards. An allowance of 5% will be made here for any runs through the garage. For the entire house this allowance is 0.05 × 8516 = 426

Item	Refer.	Explanation and Notes
Heating Load Subtotal (C10)		The sensible heat loss is calculated by multiplying the heat loss factor by each quantity for the entire house and room-by-room. The heat loss is subtotaled for each space.
Duct Heat Loss (C11)	Table 7.13 HUD-MPS 4900.1 515-3.1 (May, 1977) ASHRAE 90-75 5.11	The approximate heat loss per square foot of heated area is 28,043 Btu/hr divided by (1013 + 468) ft^2 for 18.9 Btu/(hr ft^2). The duct heat loss is, therefore, 15%. This assumes insulated duct runs through unconditioned spaces such as the garage as required to meet the standards. For this house, the duct heat loss is 0.15 × 28,043 = 4,206 Btu/hr
Room Sensible Heat Loss (C12), (S2)		The total for the entire house is 32,249 Btu/hr. Also, write this value in the load summary table on the work sheet side of the form at S2.
		The heat loss can also be reduced to 32,249 Btu/hr divided by (67 deg F temperature difference) or 481 Btu/(hr · F) Another check figure is obtained, 32,249 Btu/hr divided by (1013 + 468) ft^2 or 21.8 Btu/(hr · ft^2) These check figures also supply an indicator for comparing with other residences in a particular region.

Item	Refer.	Explanation and Notes
Cooling — Room Sensible Load (C9)		The total cooling sensible load for the house is 8516 + 426 = 8942 Btu/hr. Transfer this figure to the summary block on the work sheet side of the form in (S1).
Cooling — Total Load (S1)		The total cooling load = sensible × allowance factor for latent load. Since Pittsburgh is not a dry climate area the factor of 1.3 is used. Total load = 1.3 × 8942 = 11,625 Btu/hr
		Total load, tons = 11,625 Btu/hr ÷ 12,000 Btu/hr per ton = 0.97 tons
Note: 478 is sum of basement windows, concrete block above ground, and partition.		Total load, ft^2/ton = (1013 + 468/ft^2/ 0.97 tons = 1527 ft^2/ton if the basement is conditioned. Otherwise, the load is: 1013 ft^2/0.97 ton or 1045 ft^2/ton. This check figure of ft^2/ton provides some insight as to type of load when compared to other residences in a particular area. Experience will develop a set of guidelines for future comparisons.

References

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[4]Tamura, G.T., and Wilson, A.G., "Air Leakage and Pressure Measurements on Two Occupied Houses," ASHRAE JOURNAL, December 1963.

[5]Laschober, R.R., & Healy, J.H., "Statistical Analyses of Air Leakage in Split-Level Residences," ASHRAE TRANSACTIONS, Vol. 70, p. 364, 1964.

[6]Elkins, R.H., and Wensman, C.E., "Natural Ventilation of Modern Tightly Constructed Homes," Paper presented at the American Gas Association — Institute of Gas Technology, Conference on Natural Gas Research and Technology, Chicago, Illinois, Feb. 28 — March 3, 1971.

[7]Hunt, C.M., and Burch, D.M., "Air Infiltration Measurements in a Four-Bedroom Townhouse using Sulfur Hexafluoride as a Tracer Gas," ASHRAE TRANSACTIONS, Vol. 81, Part 1, 1975, p. 186.

[8]Tamura, G.T., "Measurement of Air Leakage Characteristics of House Enclosures," ASHRAE TRANSACTIONS, Vol. 81, Part 1, 1975, p. 202.

[9]Sepsy, C.F., et al., "Air Infiltration," The Ohio State University Environmental Control Group, 1976.

[10]ASHRAE HANDBOOK & Product Directory, — 1977 Fundamentals Volume, Chapters 21, 23, 24 and 25.

[11]ASHRAE HANDBOOK & Product Directory, — 1976 Systems Volume, Chapter 43.

Table 7.1 Average Winter Temperature and Yearly Degree Days for Cities in the United States and Canada [a,b,c] (Base 65 F)

State	Station		Avg. Winter Temp.[d] F	Degree-Days Yearly Total
Ala.	Birmington	A	54.2	2551
	Huntsville	A	51.3	3070
	Mobile	A	59.9	1560
	Montgomery	A	55.4	2291
Alaska	Anchorage	A	23.0	10864
	Fairbanks	A	6.7	14279
	Juneau	A	32.1	9075
	Nome	A	13.1	14171
Ariz.	Flagstaff	A	35.6	7152
	Phoenix	A	58.5	1765
	Tucson	A	58.1	1800
	Winslow	A	43.0	4782
	Yuma	A	64.2	974
Ark.	Fort Smith	A	50.3	3292
	Little Rock	A	50.5	3219
	Texarkana	A	54.2	2533
Calif.	Bakersfield	A	55.4	2122
	Bishop	A	46.0	4275
	Blue Canyon	A	42.2	5596
	Burbank	A	58.6	1646
	Eureka	C	49.9	4643
	Fresno	A	53.3	2611
	Long Beach	A	57.8	1803
	Los Angeles	A	57.4	2061
	Los Angeles	C	60.3	1349
	Mt. Shasta	C	41.2	5722
	Oakland	A	53.5	2870
	Red Bluff	A	53.8	2515
	Sacramento	A	53.9	2502
	Sacramento	C	54.4	2419
	Sandberg	C	46.8	4209
	San Diego	A	59.5	1458
	San Francisco	A	53.4	3015
	San Francisco	C	55.1	3001
	Santa Maria	A	54.3	2967
Colo.	Alamosa	A	29.7	8529
	Colorado Springs	A	37.3	6423
	Denver	A	37.6	6283
	Denver	C	40.8	5524
	Grand Junction	A	39.3	5641
	Pueblo	A	40.4	5462
Conn.	Bridgeport	A	39.9	5617
	Hartford	A	37.3	6235
	New Haven	A	39.0	5897
Del.	Wilmington	A	42.5	4930
D.C.	Washington	A	45.7	4224
Fla.	Apalachicola	C	61.2	1308
	Daytona Beach	A	64.5	879
	Fort Myers	A	68.6	442
	Jacksonville	A	61.9	1239
	Key West	A	73.1	108
	Lakeland	C	66.7	661
	Miami	A	71.1	214

State	Station		Avg. Winter Temp. F	Degree-Days Yearly Total
Fla. (Cont'd)	Miami Beach	C	72.5	141
	Orlando	A	65.7	766
	Pensacola	A	60.4	1463
	Tallahassee	A	60.1	1485
	Tampa	A	66.4	683
	West Palm Beach	A	68.4	253
Ga.	Athens	A	51.8	2929
	Atlanta	A	51.7	2961
	Augusta	A	54.5	2397
	Columbus	A	54.8	2383
	Macon	A	56.2	2136
	Rome	A	49.9	3326
	Savannah	A	57.8	1819
	Thomasville	C	60.0	1529
Hawaii	Lihue	A	72.7	0
	Honolulu	A	74.2	0
	Hilo	A	71.9	0
Idaho	Boise	A	39.7	5809
	Lewiston	A	41.0	5542
	Pocatello	A	34.8	7033
Ill.	Cairo	C	47.9	3821
	Chicago(O'Hare)	A	35.8	6639
	Chicago(Midway)	A	37.5	6155
	Chicago	C	38.9	5882
	Moline	A	36.4	6408
	Peoria	A	38.1	6025
	Rockford	A	34.8	6830
	Springfield	A	40.6	5429
Ind.	Evansville	A	45.0	4435
	Fort Wayne	A	37.3	6205
	Indianapolis	A	39.6	5699
	South Bend	A	36.6	6439
Iowa	Burlington	A	37.6	6114
	Des Moines	A	35.5	6588
	Dubuque	A	32.7	7376
	Sioux City	A	34.0	6951
	Waterloo	A	32.6	7320
Kans.	Concordia	A	40.4	5479
	Dodge City	A	42.5	4986
	Goodland	A	37.8	6141
	Topeka	A	41.7	5182
	Wichita	A	44.2	4620
Ky.	Covington	A	41.4	5265
	Lexington	A	43.8	4683
	Louisville	A	44.0	4660
La.	Alexandria	A	57.5	1921
	Baton Rouge	A	59.8	1560
	Lake Charles	A	60.5	1459
	New Orleans	A	61.0	1385
	New Orleans	C	61.8	1254
	Shreveport	A	56.2	2184
Me.	Caribou	A	24.4	9767
	Portland	A	33.0	7511
Md.	Baltimore	A	43.7	4654

[a] Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days,* 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 revisions to this publication, where available.

[b] Data for airport station, A, and city stations, C, are both given where available.

[c] Data for Canadian cities were computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating days data were obtained using the National Research Council computer and a method devised by H. C. S. Thom of the United States Weather Bureau. The heating days are based on the period from 1931 to 1960.

[d] For period October to April, inclusive.

Table 7.1 Average Winter Temperature and Yearly Degree Days for Cities in the United States and Canada (Base 65 F) (Continued)

State	Station		Avg. Winter Temp, F	Degree-Days Yearly Total
	Baltimore	C	46.2	4111
	Frederich	A	42.0	5087
Mass.	Boston	A	40.0	5634
	Nantucket	A	40.2	5891
	Pittsfield	A	32.6	7578
	Worcester	A	34.7	6969
Mich.	Alpena	A	29.7	8506
	Detroit(City)	A	37.2	6232
	Detroit(Wayne)	A	37.1	6293
	Detroit(Willow Run)	A	37.2	6258
	Escanaba	C	29.6	8481
	Flint	A	33.1	7377
	Grand Rapids	A	34.9	6894
	Lansing	A	34.8	6909
	Marquette	C	30.2	8393
	Muskegon	A	36.0	6696
	Sault Ste. Marie	A	27.7	9048
Minn.	Duluth	A	23.4	10000
	Minneapolis	A	28.3	8382
	Rochester	A	28.8	8295
Miss.	Jackson	A	55.7	2239
	Meridian	A	55.4	2289
	Vicksburg	C	56.9	2041
Mo.	Columbia	A	42.3	5046
	Kansas City	A	43.9	4711
	St. Joseph	A	40.3	5484
	St. Louis	A	43.1	4900
	St. Louis	C	44.8	4484
	Springfield	A	44.5	4900
Mont.	Billings	A	34.5	7049
	Glasgow	A	26.4	8996
	Great Falls	A	32.8	7750
	Havre	A	28.1	8700
	Havre	C	29.8	8182
	Helena	A	31.1	8129
	Kalispell	A	31.4	8191
	Miles City	A	31.2	7723
	Missoula	A	31.5	8125
Neb.	Grand Island	A	36.0	6530
	Lincoln	C	38.8	5864
	Norfolk	A	34.0	6979
	North Platte	A	35.5	6684
	Omaha	A	35.6	6612
	Scottsbluff	A	35.9	6673
	Valentine	A	32.6	7425
Nev.	Elko	A	34.0	7433
	Ely	A	33.1	7733
	Las Vegas	A	53.3	2709
	Reno	A	39.3	6332
	Winnemucca	A	36.7	6761
N.H.	Concord	A	33.0	7383
	Mt. Washington Obsv		15.2	13817
N.J.	Atlantic City	A	43.2	4812
	Newark	A	42.8	4589
	Trenton	C	42.4	4980
N.M.	Albuquerque	A	45.0	4348
	Clayton	A	42.0	5158
	Raton	A	38.1	6228
	Roswell	A	47.5	3793
	Silver City	A	48.0	3705
N.Y.	Albany	A	34.6	6875
	Albany	C	37.2	6201
	Binghamton	A	33.9	7286
	Binghamton	C	36.6	6451
	Buffalo	A	34.5	7062
	New York (Cent. Park)	C	42.8	4871
	New York (LaGuardia)	A	43.1	4811
	New York (Kennedy)	A	41.4	5219
	Rochester	A	35.4	6748
	Schenectady	C	35.4	6650
	Syracuse	A	35.2	6756
N. C.	Asheville	C	46.7	4042
	Cape Hatteras		53.3	2612
	Charlotte	A	50.4	3191
	Greensboro	A	47.5	3805
	Raleigh	A	49.4	3393
	Wilmington	A	54.6	2347
	Winston-Salem	A	48.4	3595
N. D.	Bismarck	A	26.6	8851
	Devils Lake	C	22.4	9901
	Fargo	A	24.8	9226
	Williston	A	25.2	9243
Ohio	Akron-Canton	A	38.1	6037
	Cincinnati	C	45.1	4410
	Cleveland	A	37.2	6351
	Columbus	A	39.7	5660
	Columbus	C	41.5	5211
	Dayton	A	39.8	5622
	Mansfield	A	36.9	6403
	Sandusky	C	39.1	5796
	Toledo	A	36.4	6494
	Youngstown	A	36.8	6417
Okla.	Oklahoma City	A	48.3	3725
	Tulsa	A	47.7	3860
Ore.	Astoria	A	45.6	5186
	Burns	C	35.9	6957
	Eugene	A	45.6	4726
	Meacham	A	34.2	7874
	Medford	A	43.2	5008
	Pendleton	A	42.6	5127
	Portland	A	45.6	4635
	Portland	C	47.4	4109
	Roseburg	A	46.3	4491
	Salem	A	45.4	4754
Pa.	Allentown	A	38.9	5810
	Erie	A	36.8	6451
	Harrisburg	A	41.2	5251
	Philadelphia	A	41.8	5144
	Philadelphia	C	44.5	4486
	Pittsburgh	A	38.4	5987
	Pittsburgh	C	42.2	5053
	Reading	C	42.4	4945
	Scranton	A	37.2	6254
	Williamsport	A	38.5	5934
R. I.	Block Island	A	40.1	5804
	Providence	A	38.8	5954
S. C.	Charleston	A	56.4	2033
	Charleston	C	57.9	1794
	Columbia	A	54.0	2484
	Florence	A	54.5	2387
	Greenville-Spartenburg	A	51.6	2980

Table 7.1 Average Winter Temperature and Yearly Degree Days for Cities in the United States and Canada (Base 65 F) (Continued)

State	*Station*		*Avg. Winter Temp, F*	*Degree-Days Yearly Total*
S. D.	Huron	A	28.8	8223
	Rapid City	A	33.4	7345
	Sioux Falls	A	30.6	7839
Tenn.	Bristol	A	46.2	4143
	Chattanooga	A	50.3	3254
	Knoxville	A	49.2	3494
	Memphis	A	50.5	3232
	Memphis	C	51.6	3015
	Nashville	A	48.9	3578
	Oak Ridge	C	47.7	3817
Tex.	Abilene	A	53.9	2624
	Amarillo	A	47.0	3985
	Austin	A	59.1	1711
	Brownsville	A	67.7	600
	Corpus Christi	A	64.6	914
	Dallas	A	55.3	2363
	El Paso	A	52.9	2700
	Fort Worth	A	55.1	2405
	Galveston	A	62.2	1274
	Galveston	C	62.0	1235
	Houston	A	61.0	1396
	Houston	C	62.0	1278
	Laredo	A	66.0	797
	Lubbock	A	48.8	3578
	Midland	A	53.8	2591
	Port Arthur	A	60.5	1447
	San Angelo	A	56.0	2255
	San Antonio	A	60.1	1546
	Victoria	A	62.7	1173
	Waco	A	57.2	2030
	Wichita Falls	A	53.0	2832
Utah	Milford	A	36.5	6497
	Salt Lake City	A	38.4	6052
	Wendover	A	39.1	5778
Vt.	Burlington	A	29.4	8269
Va.	Cape Henry	C	50.0	3279
	Lynchburg	A	46.0	4166
	Norfolk	A	49.2	3421
	Richmond	A	47.3	3865
	Roanoke	A	46.1	4150
Wash.	Olympia	A	44.2	5236
	Seattle-Tacoma	A	44.2	5145
	Seattle	C	46.9	4424
	Spokane	A	36.5	6655
	Walla Walla	C	43.8	4805
	Yakima	A	39.1	5941
W. Va.	Charleston	A	44.8	4476
	Elkins	A	40.1	5675
	Huntington	A	45.0	4446
	Parkersburg	C	43.5	4754
Wisc.	Green Bay	A	30.3	8029
	La Crosse	A	31.5	7589
	Madison	A	30.9	7863
	Milwaukee	A	32.6	7635
Wyo.	Casper	A	33.4	7410
	Cheyenne	A	34.2	7381
	Lander	A	31.4	7870
	Sheridan	A	32.5	7680

Prov.	*Station*		*Avg. Winter Temp, F*	*Degree-Days Yearly Total*
Alta.	Banff	C	—	10551
	Calgary	A	—	9703
	Edmonton	A	—	10268
	Lethbridge	A	—	8644
B. C.	Kamloops	A	—	6799
	Prince George*	A	—	9755
	Prince Rupert	C	—	7029
	Vancouver*	A	—	5515
	Victoria*	A	—	5699
	Victoria	C	—	5579
Man.	Brandon*	A	—	11036
	Churchill	A	—	16728
	The Pas	C	—	12281
	Winnipeg	A	—	10679
N. B.	Fredericton*	A	—	8671
	Moncton	C	—	8727
	St. John	C	—	8219
Nfld.	Argentia	A	—	8440
	Corner Brook	C	—	8978
	Gander	A	—	9254
	Goose*	A	—	11887
	St. John's*	A	—	8991
N. W. T.	Aklavik	C	—	18017
	Fort Norman	C	—	16109
	Resolution Island	C	—	16021
N. S.	Halifax	C	—	7361
	Sydney	A	—	8049
	Yarmouth	A	—	7340
Ont.	Cochrane	C	—	11412
	Fort William	A	—	10405
	Kapuskasing	C	—	11572
	Kitchner	C	—	7566
	London	A	—	7349
	North Bay	C	—	9219
	Ottawa	C	—	8735
	Toronto	C	—	6827
P.E.I.	Charlottetown	C	—	8164
	Summerside	C	—	8488
Que.	Arvida	C	—	10528
	Montreal*	A	—	8203
	Montreal	C	—	7899
	Quebec*	A	—	9372
	Quebec	C	—	8937
Sasks	Prince Albert	A	—	11630
	Regina	A	—	10806
	Saskatoon	C	—	10870
Y. T.	Dawson	C	—	15067
	Mayo Landing	C	—	14454

*The data for these normals were from the full ten-year period 1951-1960, adjusted to the standard normal period 1931-1960.

Table 7.2 Summary of Procedures for Residential Heating and Cooling Load Calculations

q = Sensible heating or sensible cooling load except for q_{total}, Btu/hr
Δt = Design temperature difference between inside and outside air except as noted otherwise, deg F
A = Area in square ft. of the applicable load source
U = U-values for the appropriate construction, Btu/(hr·ft²·F)

Load Source	Heating	Cooling
Glass and window areas	$q = U_G \times \Delta t \times$ Area $q = (HLF) \times A$ where $HLF = U_G \times \Delta t$ Solar effects are neglected for heating load considerations.	q = CLF × Area Glass Cooling Load Factors, CLF, are found in Table 7.6 according to window orientation, type of glass, type of interior shading, and outdoor design temperature. See Table 7 7 for the effect of shading due to overhangs. The CLF includes effects of both transmission and solar radiations.
Doors	$q = U_D \times \Delta t \times$ Area $q = (HLF) \times A$ where $HLF = U_D \times \Delta t$ Note: Glass in the doors should be treated as window area and the net door area used for this calculation.	q = (CLF) × Area Table 7.8 for Δt CLF = $U_D \times \Delta t$ Note: Glass in the doors should be treated as window area and the net door area used for this calculation.
Above-grade exterior walls	$q = U_W \times \Delta t \times$ Area $q = (HLF) \times A$ where $HLF = U_W \times \Delta t$ Table 7.4 for U_W	q = (CLF) × Area Tables 7.4 and 7.8 CLF = $U_W \times \Delta t$
Partitions to unconditioned space	$q = U_p \times A \times \Delta t$ where Δt is the temperature difference across the partition	$q = U_p \times A \times \Delta t$ where Δt is the temperature difference across the partition
Below-grade portions of exterior walls (with basement floor level more than 3 ft below grade)	$q = U_{bg} \times A \times \Delta t_{bg}$ Δt_{bg} : Below-grade temperature difference. The ground temperature (t_{bg}) is found by the equation $t_{bg} = t_A - A$ Temperature fluctuation amplitude for the region (Fig. 7.2) Average winter air temperature for the location (Table 7.1) Δt_{bg} is then given by $\Delta t_{bg} = t_{basement} - t_g$ A: Below-grade wall area U_{bg} : Average U-value for a below-grade insulated wall, (Table 7.10A) For an uninsulated wall use U = 0.60. However, this may not meet energy conservation standards.	Not applicable (In fact, some cooling is usually provided by the below-grade wall area)
Ceilings and roofs	$q = U_R \times \Delta t \times$ Area $q = (HLF) \times A$ where $HLF = U_R \times \Delta t$ Table 7.4 for U_R	q = (CLF) × Area Tables 7.4 and 7.8 CLF = $U_R \times \Delta t$
Exposed floors	$q = U_F = \Delta t \times$ Area $q = (HLF) \times A$ where $HLF = U_R \times \Delta t$	$q = U_F \times \Delta t \times$ Area = (CLF) × Area Table 7.8 for Δt
Basement floors (more than 3 ft below grade)	$q = HL \times \Delta t_{bg} \times$ Area Below-grade temperature difference. See "Below grade exterior walls" Section. Heat Loss rate from Table 7.10B	Not applicable
Slab floors (less than 3 ft below grade)	q = (HLF) × ft ft: Feet of exposed perimeter HLF: Heat Load Factor given in Table 7.9A or Table 7.9B	Not applicable
Infiltration	$q = 1.10 \times (cfm_H) \times \Delta t$ or q = HLF × Floor Area where Δt is the design indoor-outdoor temperature difference for heating. Tables 7.11A, 7.11B and 7.12	$q = 1.10\ (cfm_C) \times \Delta t$ or q = CLF × Floor Area where Δt is the summer design indoor-outdoor temperature difference. Tables 7.11A, 7.11 C and 7.12
Internal loads - people, appliances and lights	Not applicable	225 Btu/hr per person, divided evenly among the rooms not used as bedrooms. If the number of occupants is not known, assume 2 people per bedroom. 1200 Btu/hr is usually added to the kitchen load for appliances.
Total loads	q_{total} = sum of the individual sensible heating loads	q_{total} = (1.3 or 1.2) × (sum of individual sensible cooling loads) For arid climates, use 1.2. For all other applications use a value of 1.3. This factor allows for the latent cooling loads as a fraction of the sensible cooling load.

Table 7.3 Design Conditions

Item	Heating	Cooling
Outdoor Design Temperatures[2]	Table 2.1 97 1/2% values	Table 2.1 2 1/2% values
Design Wind Speeds	15 mph	7 1/2 mph
Indoor Design Conditions	72 F dry bulb. If humidification is provided, it shall be designed to a maximum relative humidity of 30%	75 F dry bulb with a temperature swing of 3 deg F
Design Temperature Difference	[Indoor Design Temp.] − [Outdoor Design Temp.]	[Outdoor Design Temp.] − [Indoor Design Temp.]
Mean Daily Range Classifications		Table 2.1 Represents the difference between the average daily maximum and average daily minimum temperatures for each station Low (L) - Less than 15 deg F daily range Medium (M) - 15 deg F to 25 deg F daily range High (H) - More than 25 deg F daily range
Average Winter Air Temperature	Table 7.1	Not Applicable
Degree Days	Base 65 F, Table 7.1	

[1]ASHRAE Standard 90-75 and HUD/MPS Revision 5a; May, 1977.
[2]Adjustments may be made to reflect local climates which differ from the tabulated data, and local weather data may be used for locations not listed.

Table 7.4 Adjusted U-Value for Some Insulated Walls and Roofs with Wood Framing Members (Winter Conditions)

Construction	Wood Members, Nominal Sizes	U-Value At Wood Section	% Wood Framing For Surface	Air Space	Between Studs or Joists or Furring R 7	R 11	R 19	R 30	R 38
Roof/Ceiling, Combined Asphalt shingles, felt membrane, plywood sheathing, gypsum wallboard, with foil backing	2-in.×4-in., 16-in. o.c.	0.145	*	0.213	0.086	0.074			
			9.4	0.207	0.092	0.081			
			15	0.203	0.095	0.085			
	2-in. × 6-in. 16-in. o.c.	0.106	*	0.213	0.086	0.064	0.046		
			9.4	0.203	0.088	0.068	0.052		
			15	0.197	0.089	0.070	0.055		
Ceiling Metal lath & plaster, joists, no floor above	Joists 2-in.×8-in., 16-in. o.c.	0.093	*	0.592	0.115	0.079	0.048	0.032	0.025
			9.4	0.545	0.113	0.080	0.052	0.038	0.029
			15	0.517	0.112	0.081	0.055	0.041	0.031
Frame Wall Wood siding, sheathing, framing, gypsum wall board or plaster (approximately the same values can be used for brick veneer and for metal siding with insulated frame walls)	2-in. × 4-in. 16-in. o.c.	0.128	*	0.225	0.087	0.069			
			9.4	0.216	0.091	0.074			
			15	0.210	0.093	0.078			
			20	0.206	0.095	0.081			
	2-in. × 4-in. 16-in. o.c. with insulated sheathing of $R = 5$	0.087	*	0.123	0.066	0.055			
			9.4	0.120	0.068	0.058			
			15	0.118	0.069	0.060			
			20	0.116	0.070	0.061			
	2-in. × 6-in. 24-in. o.c.	0.097	*	0.225	0.087	0.069	0.045		
			6.3	0.217	0.088	0.071	0.048		
			10	0.212	0.088	0.072	0.050		
			15	0.206	0.089	0.073	0.053		
Masonry Wall 8-in. concrete block, furring, dry wall with foil backing	2-in.×1-in., 16-in. o.c. (Flat)	0.240	*	0.167	0.098				
			9.4	0.174	0.111				
	2-in.×2-in., 16-in. o.c.	0.196	*	0.176	0.098	0.070			
			9.4	0.178	0.107	0.082			

*U-Values for the section between wood members.

Table 7.5 Approximate Thickness of Insulation for Thermal Resistances, in.

Thermal Resistance of Insulation	Batts or Blankets		Loose Fill			Boards and Slabs	
	Glass Fiber	Rock Wool	Glass Fiber	Rock Wool	Cellulosic	Polyurethane	Cellular Glass
R-7	2 1/4 to 2 3/4	2	3 to 4	2 to 3	2	1	2 5/8
R-11	3 1/2 to 4	3	5	4	3	1 3/4	4 1/4
R-13	3 5/8	3 1/2	6	4 to 5	4	2	5
R-19	6 to 6 1/2	5 1/4	8 to 9	6 to 7	5	3	7 1/4
R-22	6 1/2	6	10	7 to 8	6	3 1/2	8 3/8
R-30	9 1/2 to 10 1/2	9	13 to 14	10 to 11	8	4 3/4	11 3/8
R-38	12 to 13	10 1/2	17 to 18	13 to 14	10 to 11	6	14 1/2

Table 7.6 Design Cooling Load Factors Through Glass

Outdoor	Regular Single Glass						Regular Double Glass						Heat Absorbing Double Glass						Clear Triple Glass		
Design Temp	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95
No Awnings or inside Shading																					
North	23	27	31	35	39	44	19	21	24	26	28	30	12	14	17	19	21	23	17	19	20
NE and NW	56	60	64	68	72	77	46	48	51	53	55	57	27	29	32	34	36	38	42	43	44
East and West	81	85	89	93	97	102	68	70	73	75	77	79	42	44	47	49	51	53	62	63	64
SE and SW	70	74	78	82	86	91	59	61	64	66	68	70	35	37	40	42	44	46	53	55	56
South	40	44	48	52	56	61	33	35	38	40	42	44	19	21	24	26	28	30	30	31	33
Horiz. Skylight	160	164	168	172	176	181	139	141	144	146	148	150	89	91	94	96	98	100	126	127	129
Draperies or Venetian Blinds																					
North	15	19	23	27	31	36	12	14	17	19	21	23	9	11	14	16	18	20	11	12	14
NE and NW	32	36	40	44	48	53	27	29	32	34	36	38	20	22	25	27	29	31	24	26	27
East and West	48	52	56	60	64	69	42	44	47	49	51	53	30	32	35	37	39	41	38	39	41
SE and SW	40	44	48	52	56	61	35	37	40	42	44	46	24	26	29	31	33	35	32	33	34
South	23	27	31	35	39	44	20	22	25	27	29	31	15	17	20	22	24	26	18	19	21
Roller Shades Half-Drawn																					
North	18	22	26	30	34	39	15	17	20	22	24	26	10	12	15	17	19	21	13	14	15
NE and NW	40	44	48	52	56	61	38	40	43	45	47	49	24	26	29	31	33	35	34	35	35
East and West	61	65	69	73	77	82	54	56	59	61	63	65	35	37	40	42	44	46	49	49	50
SE and SW	52	56	60	64	68	73	46	48	51	53	55	57	30	32	35	37	39	41	41	42	43
South	29	33	37	41	45	50	27	29	32	34	36	38	18	20	23	25	27	29	25	26	26
Awnings																					
North	20	24	28	32	36	41	13	15	18	20	22	24	10	12	15	17	19	21	11	12	13
NE and NW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
East and West	22	26	30	34	38	43	14	16	19	21	23	25	12	14	17	19	21	23	12	13	14
SE and SW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
South	21	24	28	32	36	41	13	15	18	20	22	24	11	13	16	18	20	22	11	12	13

Table 7.7 Shade Line Factors

Direction Window Faces	N Latitude, Deg						
	25	30	35	40	45	50	55
E/W	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SE/SW	1.9	1.6	1.4	1.3	1.1	1.0	0.9
S	10.1	5.4	3.6	2.6	2.0	1.7	1.4

Note: Distance shadow line falls below the edge of the overhang equals shade line factor multiplied by width of overhang. Values are averages for 5 hr of greatest solar intensity on August 1.

Table 7.8 Design Equivalent Temperature Differences

Design Temperature, deg F	85		90			95			100		105	110
Daily Temperature Range [a]	L	M	L	M	H	L	M	H	M	H	H	H
WALLS AND DOORS												
1. Frame and veneer-on-frame	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
2. Masonry walls, 8-in. block or brick	10.3	6.3	15.3	11.3	6.3	20.3	16.3	11.3	21.3	16.3	21.3	26.3
3. Partitions, frame	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
masonry	2.5	0	7.5	3.5	0	12.5	8.5	3.5	13.5	8.5	13.5	18.5
4. Wood doors	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
CEILINGS AND ROOFS [b]												
1. Ceilings under naturally vented attic or vented flat roof—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
2. Built-up roof, no ceiling—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
3. Ceilings under unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
FLOORS												
1. Over unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
2. Over basement, enclosed crawl space or concrete slab on ground	0	0	0	0	0	0	0	0	0	0	0	0
3. Over open crawl space	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0

[a] Daily Temperature Range
L (Low) Calculation Value: 12 deg F. Applicable Range: Less than 15 deg F.
M (Medium) Calculation Value: 20 deg F. Applicable Range: 15 to 25 deg F.
H (High) Calculation Value: 30 deg F. Applicable Range: More than 25 deg F.

[b] Ceiling and Roofs: For roofs in shade, 18-hr average = 11 deg temperature differential. At 90 deg F design and medium daily range, equivalent temperature differential for light-colored roof equals $11 + (0.71)(39 - 11) = 31$ deg F.

Table 7.9A Heat Loss of Concrete Floors at or Near Grade Level per Foot of Exposed Edge (less than 3 ft Below Grade)

Outdoor Design Temperature, F	Heat Loss per Foot of Exposed Edge, Btu/(hr·ft) R = 5.0 Edge Insulation	R = 2.5 Edge Insulation	No Edge Insulation [a]
-20 to -30	50	60	75
-10 to -20	45	55	65
0 to -10	40	50	60
+10 to 0	35	45	55
+20 to +10	30	40	50

[a] This construction not recommended; shown for comparison only.

Table 7.9B Floor Heat Loss to be Used When Warm Air Perimeter Heating Ducts Are Embedded in Slabs[a] [Btu/hr per (linear foot of heated edge)]

Outdoor Design Temperature, F	Edge Insulation: R = 2.5 Vertical Extending Down 18 in. Below Floor Surface	R = 2.5 L-Type Extending at Least 12 in. Deep and 12 in. Under	R = 5 L-Type Extending at Least 12 in. Down and 12 in. Under
-20	105	100	85
-10	95	90	75
0	85	80	65
10	75	70	55
20	62	57	45

[a] Factors include loss downward through inner area of slab.

Table 7.10A Heat Loss for Below-Grade Walls with Insulation on Inside Surface — (For walls extending more than 3 ft below grade) Average Btu/(hr·ft²·F)

Distance Wall Extends Below-Grade,* ft	Insulation Over Full Surface			Wall Insulated to a Depth of Two Feet Below Grade		
	R-4	R-8	R-13	R-4	R-8	R-13
4	0.110	0.075	0.057	0.136	0.102	0.090
5	0.102	0.071	0.054	0.128	0.100	0.091
6	0.095	0.067	0.052	0.120	0.097	0.089
7	0.089	0.064	0.050	0.112	0.093	0.086

* For a depth below-grade of 3 feet or less, treat as a slab on grade.

Table 7.10B Heat Loss Through Basement Floors (For Floors more than 3 ft below grade) Btu/(hr·ft²·F)

Depth of Foundation Wall Below Grade,* ft	Width of House, ft			
	20	24	28	32
4	0.035	0.032	0.027	0.024
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

*For a depth below-grade of 3 feet or less, treat as a slab on grade.

Table 7.11A

Construction Type	Description
Tight	New buildings where there is close supervision of workmanship and special precautions are taken to prevent infiltration. Descriptions for tight windows and doors are given in Tables 5.6 and 5.7.
Medium	Building is constructed using conventional construction procedures. Medium fitting windows and doors are described in Tables 5.6 and 5.7.
Loose	Buildings constructed with poor workmanship or older buildings where joints have separated. Loose windows and doors are described in Tables 5.6 and 5.7.

Table 7.11B Design Infiltration Rate, Winter (Heating) (Air Changes/hr) Wind speed = 15 mph

Type of Construction	Winter Outdoor Design Temperature, deg F									
	50	40	30	20	10	0	-10	-20	-30	-40
Tight	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1.0
Medium	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4
Loose	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.8	1.9

Table 7.11C Design Infiltration Rate, Summer (Cooling) (Air Changes/hr) Wind Speed = 7.5 mph

Type of Construction	Summer Outdoor Design Temperature, deg F					
	85	90	95	100	105	110
Tight	0.3	0.3	0.3	0.4	0.4	0.4
Medium	0.4	0.4	0.5	0.5	0.5	0.6
Loose	0.4	0.5	0.6	0.6	0.7	0.8

Table 7.13 Duct Heat Gain and Loss Allowance

Duct Description	Cooling — Heat Gain, %	Heating — Heat Loss, %			
		Design Heat Loss Btu/(hr·ft²)	Outside Design Temp. F		
			Below 0	0 to +15	Above +15
Located in attic or crawl space and with duct insulation* of R-5 or more	10	Less than 35	20	15	10
		35 and over	15	10	5
Unconditioned basement	5	Less than 35	20	15	10
		35 and over	10	10	5

*Check appropriate standards for insulation required.

Note: Since new residential structures are being built to tighter thermal standards and older structures are being improved thermally, the duct heat loss or gain can become a more significant fraction of the total load. Care must be exercised to reduce duct air leakage as well as duct heat losses or gains. This is particularly true when runs are made through attic spaces, crawl spaces, and unconditioned spaces such as garages and through outside wall stud spaces.

Table 7.12 Infiltration per Square Foot of Floor Area

Ceiling Height	Air Changes Per Hour																	
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
	cfm/ft²																	
7 ft - 6 in.	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.24	0.25
8 ft - 0 in.	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.16	0.17	0.19	0.20	0.21	0.23	0.24	0.26	0.27
8 ft - 6 in.	0.04	0.06	0.07	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.27	0.28
9 ft - 0 in.	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.27	0.29	0.30
	Btu/(hr·ft²·F)																	
7 ft - 6 in.	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.14	0.15	0.16	0.18	0.20	0.20	0.22	0.23	0.24	0.26	0.27
8 ft - 0 in.	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.14	0.16	0.17	0.19	0.22	0.22	0.23	0.24	0.26	0.27	0.29
8 ft - 6 in.	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18	0.20	0.23	0.23	0.24	0.26	0.28	0.29	0.30
9 ft - 0 in.	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.16	0.18	0.19	0.21	0.24	0.24	0.26	0.28	0.29	0.31	0.32

A1 EXAMPLE PROBLEMS AND CHECK FIGURES

Example A1 Cooling and Heating Load for Corner, Top Floor Office Module

Calculate the cooling and heating load for a corner office module on the *top floor* of a building with the following description and conditions:

Inside Design: 75F, 50% RH, all interior spaces adjacent to the office are also conditioned; 72 F winter
Month: September (Cooling); 97.5% winter design
Location: Birmingham, Alabama (industrial area)
Office Dimensions: 13.5 ft × 13.5 ft with a roof/ceiling height of 10 ft.
Roof: Flat, built-up roofing (3/8 in.)
Rigid roof deck insulation ($R = 4.17$)
Concrete slab, lightweight aggregate, 4 in.
Suspended ceiling with 8 in. air space
Metal lath and 3/4 in. L.W. aggregate plaster
Still air inside
East Outside Wall: 10 ft × 13.5 ft
8 in. L.W. concrete block (L.W. agg.) + R-7 insulation + surface finish
East Window Unit: 7-1/2 ft high × 11 ft with glass flush in wall, metal sash
Two (2) 7 ft high × 5 ft double insulating and reflecting glass panes —
1/4 in. clear inner pane
1/2 in. air space
1/4 in. outer pane with 0.60 emittance coating
No interior or exterior shading
South Outside Wall: Same as east outside wall with 4 in. face brick added
South Window Unit: 7 1/2 ft high × 11 ft with glass recessed 8 in. due to concrete framework, no visible metal sash
Two (2) 7 ft high × 5 ft double insulating glass panes —
1/4 in. clear inner and outer panes
1/2 in. air space
Light color Venetian blinds, no exterior shade
Lights: 3 fixtures of 2-40 W fluorescent tubes, each on at 8:00 A.M., off at 10:00 P.M.; recesses; not vented.
People: Two enter at 8:30 A.M., leave at 5:00 A.M.
Equipment: 1 electric typewriter
Ventilation: As needed, neglect infiltration

Some preliminary observations about the relative magnitude of some of the loads and when their individual maximum values occur may reduce the time span which must be considered in determining load peak.

- There is a large glass area, 140 ft² total. The maximum glass solar heat gain is higher per square foot than the conduction gain for glass, roof, or walls. The solar heat gain peaks in mid-morning for East glass and at noon for South glass.
- The roof area of 182.5 ft² is only slightly larger than the glass area and has considerably less heat gain per square foot. Peak roof gain is in late afternoon.
- The North and West partition walls and the floor contribute no load because adjacent spaces are conditioned.
- The combined internal cooling load from 6-40 watt fluorescent lights, two people, and one typewriter, will peak in late afternoon, but will be small compared to glass load.
- Ventilation load will peak in the afternoon because the outdoor air temperature peaks at 1500 hr.

As a result of the above observations, it is expected that overall peak cooling load will occur about noon or early afternoon. An hourly analysis will be made from 1000 to 1500.

Item	Table/Graph	Explanation and Notes	Resistance (R)	Heat Capacity Btu/ft²·F
a) Roof $q = A \times U \times CLTD$		Cooling Load for Roof		
Climatic Conditions	Table 2.1	Col.1: Alabama Birmingham; Col. 2: 33°30′N; Col. 6: 94/75; Col. 7: 21		
U and Heat Capacity	Tables 3.1 and 3.2	Flat masonry roof with built-up roofing, suspended ceiling, *summer conditions, downward flow.*		
		Construction (Heat flow down)	Resistance (R)	Heat Capacity Btu/ft²·F
	Table 3.3	1. Inside surface (still air, horiz.)	0.92	—
	Table 3.1	2. Metal lath and 3/4 in. lightweight aggregate plaster	0.47	0.57
	Table 3.2	3. Suspended ceiling with 8 in. air space	0.93	—
	Tables 3.1,	4. Concrete slab, 30 lb/ft³ lightweight aggregate, 4 in.	4.44	$6.0(\frac{4}{12}) = 2.0$
	Tables 3.1,	5. Built-up roofing (3/8 in.)	0.33	0.77
	Given	6. Rigid roof insulation	4.17	—
	Table 3.3	7. Outside surface	0.25	—
		Total (sum)	11.51	3.3
		$U = 1/R_t = 1/11.51 = 0.09$ Btu/(hr·ft²·F) Heat capacity = 3.3 Btu/(ft²·F)		
A		$A = (13.5)(13.5) = 182.3$ ft²		
UA Factor		$UA = 0.09(182.3) = 16.4$ Btu/(hr·F)		
Corrections to be made to CLTD	Notes Table 3.8			

LOAD CALCULATIONS FOR: CONEMAUGH, INC.

Date 12/6 19 77 Sheet No 1 of 1

Client ______ Job No 77-114

Drawing No ______

Computed By KJR Checked By BIL Approved By ______

DESIGN CONDITIONS FOR BIRMINGHAM, ALA.
LATITUDE 30°30' N DB DAILY RANGE 21 F

	SUMMER MONTH SEPT. DB	WB	W	WINTER DB	W
OUTSIDE	94	75	0.0146	21	–
INSIDE	75	–	0.0092	72	–
DIFFER.	19	–	0.0054	51	–

EXTERNAL COOLING LOADS

CONDUCTION

ITEM	ORIENTATION	U BTU/(HR-FT²-F)	AREA FT²	U×A BTU/(HR-F)	CLTD TABLE VALUES 10 HR	12 HR	14 HR	ADJUST FOR LATIT & MONTH	COLOR CORR. K	ADJUST FOR INSIDE OUTSIDE TEMP	CLTD. CORRECTED 10 HR	12 HR	14 HR	COOLING Q-SENSIBLE, BTU/HR 10 HR	12 HR	14 HR	HEATING U BTU/(HR-FT²-F)	U×A BTU/(HR-F)	Q-SENSIBLE BTU/HR @ ΔT = 51
ROOF		0.09	182.3	16.4	16	25	35	-6	–	1.5	11	20	30	180	328	492	0.09	16.4	836
ROOF																			
WALL	E	0.10	52.5	5.25	26	36	37	-2.3	–	1.5	25	35	36	131	184	189	0.10	5.25	268
WALL	S	0.09	65.0	5.85	11	11	12	8	–	1.5	21	21	22	123	123	129	0.09	5.85	298
WALL																			
WALL																			
GLASS	E	0.61	82.5	50.3	4	9	13	–	–	1.5	6	11	15	302	553	755	0.52	42.9	2188
GLASS	S	0.52	70.0	36.4	4	9	13	–	–	1.5	6	11	15	218	400	546	0.42	29.4	1499

ITEM	U	AREA	U×A ×	ΔT
PARTITION				
CEILING				
FLOOR				
FLOOR				
	SUM			

Heating sum: 5089

SOLAR

ITEM		ORIENTATION	TOTAL AREA	SHADE COEFF. ×	MAX SHG BTU/(HR-FT²) ×	10 HR AREA ×	CLF	12 HR AREA ×	CLF	14 HR AREA ×	CLF	Q-SENSIBLE 10 HR	12 HR	14 HR
GLASS	UNSHADED	E	70	0.55	213	70	0.57	70	0.42	70	0.32	4674	3444	2624
	SHADED													
GLASS	UNSHADED	S	70	0.51	179	51.6	0.58	60	0.83	51.6	0.68	2735	4548	3204
	SHADED	N		0.51	32	18.4	0.80	10	0.89	18.4	0.86	240	145	258
GLASS	UNSHADED													
	SHADED													
GLASS	UNSHADED													
	SHADED													

SUBTOTAL: 8603 | 9725 | 8197

INTERNAL COOLING LOADS

LIGHTS

TYPE	TOTAL HOURS ON	START TIME	WATTS TO BTU/HR ×	BALLAST AND USE FACTOR ×	TOTAL WATTAGE ×	CLF 10 HR	12 HR	14 HR	Q-SENSIBLE 10 HR	12 HR	14 HR
FLUOR.	14	800	3.41	1.20	240	0.72	0.73	0.75	707	717	737
			3.41								

PEOPLE

HRS. IN SPACE	TIME ENTER	NO. OF PEOPLE	Q_s BTU/HR-P	NO. × Q_s ×	CLF 10 HR	12 HR	14 HR	Q-SENSIBLE 10 HR	12 HR	14 HR
8	800	1	485	485	0.61	0.72	0.80	296	350	388

EQUIPT.

HRS. ON	START TIME	HOODED YES/NO	Q_s	CLF 10 HR	12 HR	14 HR	Q-SENSIBLE 10 HR	12 HR	14 HR
–	–	NO	350	1.0	1.0	1.0	350	350	350

MISC.

INFILT. AIR – SCFM × 1.10 × ΔT: – | – | – → – | – | –

F–FACTOR=1–.02×(SUM OF U×A OF EXT. WALL AND GLASS)/EXT. PERIMETER= 0.9

HEAT TO RETURN AIR(A) 3.41 BTU/HR PER WATT× ______ WATTS × ______ FRACTION TO RETURN AIR

VENTILATION AIR 10 SCFM × 1.10 × ΔT: 8 | 14 | 18

	10 HR	12 HR	14 HR
SUBTOTAL ROOM Q-SENSIBLE	9956	11142	9672
SUBTOTAL × F-FACTOR	8960	10028	8705
SUPPLY DUCT 5 % LEAKAGE + 5 % HEAT GAIN	896	1003	870
ROOM SUBTOTAL	9856	11031	9575
DEDUCT FROM ROOM			
NET ROOM SENSIBLE	9856	11031	9575
VENTILATION AIR	88	154	198

LATENT LOAD

ITEM	Q_l/ITEM	NUMBER OF EACH ITEM 10 HR	12 HR	14 HR
PEOPLE	445	1	1	1
EQUIPMENT				
EQUIPMENT				
	FACTOR ×	SCFM ×	ΔW	
INFILT. AIR	4840			
VENT. AIR		10	0.0054	

Q-LATENT, BTU/HR	10 HR	12 HR	14 HR
	445	445	445
Q-LATENT SUBTOTAL	445	445	445
5 % DUCT LEAKAGE	22	22	22
ROOM Q-LATENT	467	467	467
ROOM SENSIBLE + ROOM LAT.	10323	11498	10042
ROOM SENSIBLE HEAT RATIO	0.96	0.96	0.96

SUPPLY AIR CFM BASED ON A SUPPLY TEMP. OF ___F IS: (ROOM Q-SENSIBLE) / 1.10 × (T_{ROOM} – T_{SUPPLY})

COOLING LOAD SUMMARY

	Q-SENSIBLE 10 HR	12 HR	14 HR	Q-LATENT 10 HR	12 HR	14 HR
VENTILATION LOAD	88	154	198	261	261	261
ROOM SUBTOTAL	9856	11031	9575	467	467	467
ADD HEAT TO RETURN AIR(A)	–	–	–	–	–	–
RETURN DUCT GAIN 5 %	493	552	479	23	23	23
COOLING EQUIPMENT LOAD	10349	11583	10054	751	751	751
SAFETY FACTOR 0 % / 0 %	–	–	–	–	–	–
TOTAL: QS / QL	10349	11583	10054	751	751	751
GRAND TOTAL = QS + QL	11188	12488	11003			

HEATING

INFILT/VENT AIR: CFM 10 → 561

TOTAL 5650

SAFETY FACTOR 0 % 0

PICK-UP FACTOR –

GRAND TOTAL 5650

INTERNAL LOADS SUBTOTAL 1817

RATIO OF INTERNAL TO GRAND TOTAL 0.322

HUMIDIFICATION @ΔW= ______

CFM	BTU/HR

Item	Table/Graph	Explanation and Notes
Inside and Outside Design	Table 3.13	Correction for inside design = 3 F Correction for outside design = −1.5 F (94 F dry bulb, 21 F daily range)
Color		No color correction; industrial area
Month-latitude	Table 3.12	North Lat 32 Deg (34 Deg) 40 Deg Month Hor Hor March/Sept −5 (−6 approx) −8 (32 deg N is close enough to 33 deg N could use −5 F instead of interpolating)
Total Correction		Total Corr. = 3 − 1.5 − 6 = −4.5 = −5 F rounded
Equivalent Roof	Table 3.7 Table 3.8 (Note 4)	Roof No. 4 with suspended ceiling and 1 in. insulation. Peak CLTD occurs 1 hour later than actual construction (No. 3) without insulation according to Note 4, Table 3.8.
CLTD Corrections		Roof No. 4 — Solar time, hr with suspended ceiling: 10 12 14
$CLTD_{uncorr}$	Table 3.8	$CLTD_{uncorr}$ 16 25 35
$CLTD_{corr}$	(Subtract 5)	$CLTD_{corr}$ 11 20 30
$q = U \times A \times CLTD$	(Mult. by 16.4)	q 180 328 492
b) East Wall $q = U \times A \times CLTD$		Cooling Load for East Wall
U and Heat Capacity	Table 3.9	8 in. L.W. concrete block + R-7 insulation + surface finish Construction — Resistance (R) — Heat Capacity Btu/ft²·F
	Table 3.11	1. Inside surface (still air) 0.68 2. Surface finish (code no. E1) 0.15 $1.25(\frac{0.75}{12}) = 0.08$
	Given Table 3.11	3. R-7 insulation 7.00 0.07 4. 8 in. L.W. concrete block (lt.wt.agg) 2.02 5.1 5. Outside surface 0.25
		Total (sum) 10.1 5.25 $U = 1/R_t = 1/10.1$ $= 0.10$ Btu/(hr·ft²·F)
A		$A = 10(13.5)$ − window area $= 135 - 82.5 = 52.5$ ft²
UA		$UA = 0.10(52.5) = 5.25$ Btu/(hr·F)
CLTD corrections	Notes for Table 3.10	
Corr. for Temp.		Same as for roof = +1.5 F
Corr. for Color		None needed — industrial area
Month-latitude	Table 3.12	North Lat. 32 deg (34 deg) 40 deg Month E E March/Sept −2 (−2.3 approx) −3
Total Correction		Total Corr. = 1.5 − 2.3 = −0.8 = −1 F rounded off
Equivalent Wall	Table 3.9	L.W. and H.W. Concrete Block + (Finish)

Item	Table/Graph	Explanation and Notes
		Group D (with 1 in. insulation)
$CLTD_{uncorr}$	Table 3.10 and Note 4	R-7 is equivalent to 2 in. insulation. Therefore for the additional insulation use Group E
		N. Lat. Wall — Solar time, hr Group E Walls: 10 12 14
		E 26 36 37
$CLTD_{corr}$	(Subtract 1)	$CLTD_{corr}$ 25 35 36
$q = U \times A \times CLTD_{corr}$	(Mult. by $UA = 5.25$)	q 131 184 189
c) South Wall		Cooling Load for South Wall
U and Heat Capacity	(Adjusting calculation for East Wall)	Construction — Resistance (R) — Heat Capacity Btu/ft²·F
		East Wall + 10.1 5.25
	Table 3.1 or Table 3.11	4 in. Brick 0.79 8.0 Total (sum) 10.9 13.25
		$U = 1/R_t = 1/10.9 = 0.09$ Btu/(hr·ft²·F)
A		$A = 10(13.5)$ − south window unit area $= 135 - 70.0 = 65.0$ ft²
UA		$UA = 0.09(65.0) = 5.85$ Btu/(hr·F)
CLTD Corrections		
Corr. for Temp.		Same as for East Wall = +1.5 F
Corr. for Color		None needed — industrial area
Month-latitude	Table 3.12	North Lat. 32 deg (34 deg) 40 deg Month S S March/Sept 7 (8 approx) 10
Total Correction		Total corr = 1.5 + 8 = 9.5 = 10 F
Equivalent Wall	Table 3.9	4 in. face brick + 2 in. insulation + 8 in. L.W. block Group B
$CLTD_{uncorr}$		N. Lat. Wall — Solar time, hr Group B walls: 10 12 14
		S 11 11 12
$CLTD_{corr}$	(Add 10)	$CLTD_{corr}$ 21 21 22
$q = U \times A \times CLTD$	(Mult. by 5.85)	q 123 123 129
d) East Window $q = A \times U \times CLTD$		Conduction Cooling Load for East Window
A_{unit}		$A_{unit} = (7.5)(11) = 82.5$ ft², glass and sash
A_{glass}		Two 5 ft × 7 ft panes; $A_{glass} = 2(5)(7) = 70$ ft², glass
% glass		$\% \text{ glass} = \frac{A_{glass}(100)}{A_{unit}} = \frac{70(100)}{82.5}$ $= 84.84 = 85\%$

Item	Table/Graph	Explanation and Notes
U, no adjustment for framing	Table 3.14A	*Exterior Vertical Panels* Flat Glass — *Summer* Insul. glass, double — *No Indoor Shade* 0.500 in. air space, $e = 0.60$ — 0.51
U, adjusted for framing	Table 3.14B (Caution: Read notes carefully, especially if metal sash)	Adjustment Factor Windows — Double or Triple Glass Metal sash; 80% glass — 1.20* *Assumes no thermal break $U_{adj} = 1.20\ (0.51) = 0.61$ Btu/(hr · ft² · F)
UA Factor		$UA = 0.61\ (82.5) = 50.3$ Btu/(hr · F)
Corrections to be made to CLTD? Total correction?	Table 3.23 Notes Table 3.13	$\text{Total}_{corr} = 3 - 1.5 = 1.5$ $= 2$ F rounded off
$CLTD_{uncorr}$	Table 3.23	Hour — 10 — 12 — 14 CLTD, F — 4 — 9 — 13
$CLTD_{corr}$	(add 2)	$CLTD_{corr}$ — 6 — 11 — 15
$q = U \times A \times CLTD$	(Mult. by 50.3)	q — 302 — 553 — 755
e) South Window $q = A \times U \times CLTD$		Conduction Cooling Load for South Window
A_{glass}		$A_{glass} = 70$ ft² glass,
U, no adjustment for framing	Table 3.14A	*Exterior Vertical Panels* *Summer* *Indoor Shade* Flat glass Insul. glass, double 0.500 in. air space — 0.52
U, adjusted for framing	Table 3.14B	Adjustment Factor Double or Triple Glass All Glass — 1.00 $U_{adj} = 0.52$ Btu/(hr · ft² · F)
UA Factor		$UA = 0.52\ (70) = 36.4$ Btu/(hr · F)
$CLTD_{uncorr}$		Same conduction as for East Window Hour — 10 — 12 — 14
$CLTD_{corr}$		$CLTD_{corr}$ — 6 — 11 — 15
$q = A \times U \times CLTD$	(Mult. $CLTD_{corr}$ by 36.4)	q — 218 — 400 — 546

Item	Table/Graph	Explanation and Notes
f) East Window Solar $q = A(SC)(SHGF)(CLF)$	($A = 70$ ft², glass)	Glass Solar Cooling Load, applied separately to shaded and unshaded glass $q = q_{unsh} + q_{sh}$
SC	Table 3.18	Insulating Glass Heat absorb out — Nom. thick — $h_o = 4.0$ Clear in — 1/4 in. — 0.55
$SHGF_{max,unsh}$ (East)	Table 3.25	No external shading, do not need $SHGF_{max,sh}$ 32 deg N Lat — (34) — 36 deg N lat E — — E Sept. 215 — (213) — 210 $SHGF_{max,unsh} = 213$ Btu/(hr · ft²)
CLF	Table 3.27	*without interior shading* North Lat Facing — Room Const. — Time, hr 10 — 12 — 14 E — L — 0.57 — 0.42 — 0.32
$q = 70(0.55)(213) \times CLF = 8200 \times CLF$		q_{solar} — 4674 — 3444 — 2624
g) South Window Solar	($A = 70$ ft² glass)	Insulating Glass; Light Venetian Blinds
SC	Table 3.18	Clear out — Nom. Thick — $h_o = 4.0$ Clear in — 1/4 in. — 0.51
$SHGF_{max,unsh}$ (South)	Table 3.25	32 deg N Lat — (34) — 36 deg N Lat N S — N S — N S Sept 33 171 — (32) (179) — 31 187
$SHGF_{max,sh}$ (North) N Lat > 24 deg	Table 3.25	$SHGF_{max,unsh} = 179$ Btu/(hr · ft²) $SHGF_{max,sh} = 32$ Btu/(hr · ft²)
CLF	Table 3.28	*with interior shading* North Lat. Facing — Room Const — Solar time, hr. 10 — 12 — 14 S — L — 0.58 — 0.83 — 0.68 N(SH) — L — 0.80 — 0.89 — 0.86

$SC(CLF)(SHGF_{max,unsh}) = 0.51\ (179)(CLF) = 91.3\ CLF = (q/A)_{unsh}$
53.0 at 10; 75.8 at 12; 62.1 at 14

$SC(CLF)(SHGF_{max,sh}) = 0.51\ (32)(CLF) = 16.3\ CLF = (q/A)_{sh}$
13.0 at 10; 14.5 at 12; 14.0 at 14

Item	Table/Graph	Explanation and Notes
S_H/P and S_W/P_V	Table 3.29	Shadow length and shadow width, each per ft of projection are as in Example A3.4
	Fig. 3.4	Sept., South facing, 34 deg North Lat
		Time: 10 — 12 — 14 S_H/P — 1.5 — 1.5 — 1.5 S_W/P_V — 1.05 — 0 — 1.05 Right Fin — — Left Fin
	with $P = P_V = 2/3$ ft	S_H — 1.0 — 1.0 — 1.0 S_W — 0.70 — 0 — 0.70 Right Fin — — Left Fin

Item	Table/Graph	Explanation and Notes			
$A_{unshaded}$ and A_{shaded}		$A_{unsh,gl} = (7 - S_H)(5 - S_W)(2 \text{ panes})$ $= (7 - 1)(5 - S_W)(2) = 12(5 - S_W)$ $A_{sh,gl} = 2(7)(5) - A_{unsh,gl} = 70 - A_{unsh,gl}$ at 1000: $A_{unsh,gl} = 12(5 - 0.7) = 51.6\ ft^2$ $A_{sh,gl} = 70 - 51.6 = 18.4\ ft^2$			
		Time	10	12	14
		$A_{unsh,gl}$	51.6	60	51.6
		$A_{sh,gl}$	18.4	10	18.4
$q_{unsh} = q/A_{unsh}\ (A_{unsh})$		q_{unsh}	2735	4548	3204
$q_{sh} = (q/A)_{sh} A_{sh}$		q_{sh}	240	145	258
$q_{solar} = q_{unsh} + q_{sh}$		q_{solar}	2975	4693	3462
$q_{total,external}$ $= q_{roof} + q_{E.W.}$ $+ q_{S.W.} + q_{cond,\ E.gl.}$ $+ q_{cond,\ S.gl.} + q_{solar,\ E.gl.}$ $+ q_{solar,\ S.gl.}$		Time	10	12	14
		q_{roof}	180	328	492
		$q_{E.W.}$	131	184	189
		$q_{S.W.}$	123	123	129
		$q_{cond,\ E.gl.}$	302	553	755
		$q_{cond,\ S.gl.}$	218	400	546
		$q_{solar,\ E.gl.}$	4674	3444	2624
		$q_{solar,\ S.gl.}$	2975	4693	3462
		$q_{total,\ external}$	8603	9725	8197
h) Lights $q_s = 3.41\ q_u F_u$ F_s CLF		Cooling Load Equation for Lights			
q_i		$q_i = 3(2)(40) = 240$ w total wattage			
F_u		$F_u = 1.0$, all on at a time			
F_s	Table 4.1	$F_s = 1.20$, fluorescent lights, 2 lamps/fixture for ballast			
CLF	Table 4.2	"*a*" for: Recessed, not vented, low air supply rate "*a*" = 0.45			
	Table 4.3	Assume 8 in. concrete floor with tile "*b*" = *D*			
	Table 4.4 "CLF... for 14 hours" Since lights on at 8:00 A.M.	No. hrs. after lights turned on	2	4	6
		"*a*" 0.45 *D*	0.72	0.73	0.75
		Time	10	12	14
$q_s = 3.41\ (240)(1)(1.2)$ CLF $= 982.$ CLF		$q_s =$	707	717	737
i) People $q_s = CLF(q_s/N)\ N$ $q_l = (q_l/N)N$		Sensible Cooling Load for People (*N* = number of people having the same activity classification) Sensible Latent Load for People			
$q_{s,N}$ and $q_{l,N}$	Table 4.5 (Assume 1 writing 1 typing)		$q_{s/N}$	$q_{l/N}$	
		Seated, writing	230	190	Btu/hr
		Seated, typing	255	255	Btu/hr

Item	Table/Graph	Explanation and Notes			
CLF	Table 4.6	For Sensible Load Only Time in space = 8:30 A.M. to 5:00 P.M. = 8 1/2 hr Round off to 8 hr			
		Total hr in Space	Hours after entry 2	4	6
		8	0.61	0.72	0.80
		Time	10	12	14
		CLF	0.61	0.72	0.80
q_s = CLF (230 + 255) = 485 × CLF		q_s	296	350	388
$q_l = 190 + 255 = 445$		q_l	445	445	445
j) Equipment (Typewriter)	Table 4.9	Assume same as magnetic card typewriter and CLF = 1.0; $q_s = 350$ Btu/hr			
$q_{total,\ internal}$ $= q_{lights}$ $+ q_{s,\ people}$ $+ q_{l,\ people}$ $+ q_{type}$		Time	10	12	14
		q_{lights}	707	717	737
		$q_{s,\ people}$	296	350	388
		$q_{l,\ people}$	445	445	445
		q_{type}	350	350	350
		$q_{total,\ internal,\ s}$	1353	1417	1475
		$q_{total,\ internal,\ l}$	445	445	445
k) $q_{total,\ s} =$ $q_{internal,\ s}$ $+ q_{external,\ s}$		Time	10	12	14
		$q_{internal,\ s}$	1353	1417	1475
		$q_{external,\ s}$	8603	9725	8197
		$q_{total} =$	9956	11142	9672
l) *F*-factor		*F*-factor = 1 − 0.02 (Sum of $U \times A$ of ext. wall and glass)/ext. perimeter = 1 − 0.02 (5.25 + 5.85 + 50.3 + 36.4)/(13.5 + 13.5) = 0.9			
m) Net Room Sensible		Time	10	12	14
		Subtotal × *F*-factor	8960	10028	8705
		10% duct losses	896	1003	870
		Net room sensible	9856	11031	9575
n) Ventilation $q_s = 1.10(\Delta t)$CFM $q_l = 4840(\Delta w)$CFM		Sensible and Latent Cooling Loads Δt = Inside − Outside temp. diff. Δw = Inside − Outside humidity ratio diff., lb water vapor to lb dry air CFM = standard ft^3 per minute			
Δw	Table 2.1 (Climatic table)		Col. 6	Col. 7	Col. 8
		Alabama Birmingham	Design DB & Mean Coinci-dent W.B.	Mean Daily Range	Design W.B.
			2.5%		2.5%
			94/75	21	77
	Psychro-metric Chart and Table 2.1	at 94 db, 75 wb; $w_{outside} = 0.0146$ lb/lb at 75 db, 50% RH; $w_{inside} = 0.0092$ lb/lb $\Delta w = 0.0146 - 0.0092 = 0.0054$ lb/lb			

Item	Table/Graph	Explanation and Notes			
t_o	Table 5.1	Time	10	12	14
		$94 - t_o =$	11	5	1
		t_o	83	89	93
CFM required for occupants	Table 5.8		Per Person		
		Offices	Min. CFM	Recommended CFM	
		General Office Space	5	15 - 25	
		Assume minimum CFM per person			
		CFM = 5 (2 people) = 10			
Ventilation q_s	$q_s = (1.10)(10)(t_o - 75)$	Time	10	12	14
		q_s	88	154	198
q_l	$q_l = (4840)(10)(0.0054)$	q_l	261	261	261
o) Room q-Latent		Time	10	12	14
		People	445	445	445
		5% duct loss	22	22	22
		Total	467	467	467
p) Sensible Heat Ratio		Time	10	12	14
		$q_s + q_l$	10323	11498	10042
		q_s	9856	11031	9575
		SHR	0.96	0.96	0.96
q) Total Load $(q_s + q_l)$		Time	10	12	14
		Vent Load, s	88	154	198
		Vent Load, l	261	261	261
		Room Sub, s	9856	11031	9575
		Room Sub, l	467	467	467
		5% Air Leakage, s	493	552	479
		5% Air Leakage, l	23	23	23
		Total Load =	11188	12488	11003
r) $q_{tot,\,max}$		$q_{tot,\,max}$ = 12500 Btu/hr at about noon			
Heating Load $q = U \times A \times \Delta T$					
a) ΔT Climatic Conditions (Winter)	Table 2.1	Col. 1	Col. 2	Col. 5 97.5%	
		Alabama Birmingham	33° 30′N	21	
Indoor Design Temperature	Given	72F			
$\Delta T = T_{in} - T_{out}$		$\Delta T = 72 - 21 = 51$ F			
$U \times A$		*Note - $U \times A$ will be used as calculated in the cooling load section of this example for parts $b - d$.			

Item	Table/Graph	Explanation and Notes	
b) Roof		$q = 16.4 \times 51 = 836$	
c) East Wall		$q = 5.25 \times 51 = 268$	
d) South Wall		$q = 5.85 \times 51 = 298$	
e) East Window A_{unit}		$A = 70$ ft²	
U, no adjustment for framing	Table 3.14A	Flat glass Insul. glass, double 0.500 in. air space, $e = 0.60$	*Exterior Vertical Panels Winter No Indoor Shade* 0.43
U, adjusted for framing	Refer to cooling section of this example	$U_{adj} = 1.20(0.43) = 0.52$ Btu/(hr · ft² · F)	
$U \times A$		$UA = (0.52)(82.5) = 42.9$ Btu/(hr · F)	
q		$q = 42.9 \times 51 = 2188$ Btu/hr	
f) South Window A_{glass}		$A_{glass} = 70$ ft² glass	
U, no adjustment needed for framing		Flat Glass Insul. glass, double 0.500 in. air space	*Exterior Vertical Panels Winter Indoor Shade* 0.42
$U \times A$		$UA = (0.42)(70) = 29.4$ Btu/(hr · F)	
q		$q = (29.4) \times 51 = 1499$ Btu/hr	
g) Vent. Air $q = 1.10 (\Delta T)$CFM		ΔT = Inside − Outside Temp. Diff. CFM = 10 (as previously stated) $q = 1.10(10)(57) = 627$ Btu/hr	
h) q_{total}		q_{roof}	836
		$q_{E.\,wall}$	268
		$q_{S.\,wall}$	298
		$q_{E.\,window}$	2188
		$q_{S.\,window}$	1499
		$q_{vent.\,air}$	627
		q_{total}	5716 Btu/hr
i) $q_{sensible\ internal}$	From cooling example (no CLF applies)	q_{lights}	818
		q_{people}	230, 255
		q_{equip}	350
		$q_{sensible\ internal}$	1653 Btu/hr
j) Internal/Trans. Ratio	Divide by 5716	Internal Load = 1653 Btu/hr Ratio = 0.289	

Example A 1.1 Design Data Collected For Birmingham, Alabama

From Table 2.1

	Summer	Winter
Outside Design db Temp, F	94	22
Daily Range, db Temp, F	21	
Outside Wet Bulb Temp, F	78	
Wind Speed		⩽ 7 mph
Humidity Ratio, lb/lb	0.0146	

From Table 2.1

Design Data For Birmingham, Ala.

Latitude 33°34′ N

Longitude 86° 45′ W

Elevation 610 ft

Inside Design db Temp. 78 F
Inside Humidity Ratio 0.0102

***From Table 5.1* — Design Day Temperature For 94 DB and 21 DR**

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
DB	77	76	75	74	73	74	75	77	80	83	86	89	92	93	94	93	92	90	87	85	82	80	79	78

From Table 2.2 Cooling Outside Design			Outside Temp *From Table 3.13*	Adjustments (F) to CLTD Tables for 32° N Latitude and Month *(From Table 3.12)*									
	DB	WB		N	NNE/N	NE/NW	ENE/WNW	E/W	SE/SW	SE/SW	SSE/SSW	S	HOR
Jan	67	62	–28	–5	–7	–9	–11	–8	–4	2	9	12	–15
Feb	72	63	–23	–4	–6	–7	–8	–4	–2	4	8	11	–10
Mar	76	64	–19	–3	–4	–4	–4	2	–1	3	5	7	–5
Apr	83	67	–12	–2	–2	–1	–2	0	–1	0	1	1	–1
May	91	71	–4	1	1	1	0	0	–1	–1	–3	–3	1
June			–1	1	2	2	1	0	–2	–2	–4	–4	2
July			–1	1	1	1	0	0	–1	–2	–3	–3	1
Aug			–1	–2	–2	–1	–2	–1	–1	0	0	0	–2
Sept			–1	–3	–4	–4	–5	–2	–1	2	4	6	–6
Oct	84	69	–11	–4	–6	–7	–8	–5	–2	3	7	11	–11
Nov	74	64	–21	–5	–7	–9	–11	–8	–4	2	8	12	–15
Dec	68	60	–27	–5	–7	–10	–11	–8	–5	2	9	12	–17

***From Table 3.25* — Maximum Solar Heat Gain For 32° N Latitude**

	N	NNE/NNW	NE/NW	ENE/WNW	E/W	ESE/WSW	SE/SW	SSE/SSW	S	HOR.
Jan.	24	24	29	105	175	229	249	250	246	176
Feb.	27	27	65	149	205	242	248	232	221	217
Mar.	32	37	107	183	227	237	227	195	176	252
Apr.	36	80	146	200	227	219	187	141	115	271
May	38	111	170	208	220	199	155	99	74	277
June	44	122	176	208	214	189	139	83	60	276
July	40	111	167	204	215	194	150	96	72	273
Aug.	37	79	141	195	219	210	181	136	111	265
Sep.	33	35	103	173	215	227	218	189	171	244
Oct.	28	28	63	143	195	234	239	225	215	213
Nov.	24	24	29	103	173	225	245	246	243	175
Dec.	22	22	22	84	162	218	246	252	252	158

Table A1.1 Cooling Load Check Figures

Classifications	Occupancy Sq Ft/Person			Lights Watts/Sq Ft			Refrigeration Sq Ft/Ton‡			Air Quantities CFM/Sq Ft East-South-West			North			Internal		
	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi
Apartment, High Rise	325	175	100	1.0	2.0	4.0	450	400	350	0.8	1.2	1.7	0.5	0.8	1.3	-	-	-
Auditoriums, Churches, Theaters	15	11	6	1.0	2.0	3.0	400	250	90	-	-	-	-	-	-	1.0	2.0	3.0
Educational Facilities	30	25	20	2.0	4.0	6.0	240	185	150	1.0	1.6	2.2	0.9	1.3	2.0	0.8	1.2	1.9
Schools, Colleges, Universities																		
Factories Assembly Areas	50	35	25	3.0†	4.5†	6.0†	240	150	90	-	-	-	-	-	-	2.0	3.6	5.5
Light Manufacturing	200	150	100	9.0†	10.0†	12.0†	200	150	100	-	-	-	-	-	-	1.6	2.5	3.8
Heavy Manufacturing★	300	250	200	15.0†	45.0†	60.0†	100	80	60	-	-	-	-	-	-	2.5	4.0	6.5
Hospitals Patient Rooms*	75	50	25	1.0	1.5	2.0	275	220	165	0.33	0.55	0.67	0.33	0.50	0.67	-	-	-
Public Areas	100	80	50	1.0	1.5	2.0	175	140	110	1.0	1.25	1.45	1.0	1.1	1.2	0.95	1.0	1.1
Hotels, Motels, Dormitories	200	150	100	1.0	2.0	3.0	350	300	220	1.0	1.40	1.5	0.9	1.2	1.4	-	-	-
Libraries and Museums	80	60	40	1.0	1.5	3.0	340	280	200	1.0	1.6	2.1	0.9	1.1	1.3	0.9	1.0	1.1
Office Buildings*	130	110	80	4.0	6.0†	9.0†	360	280	190	0.25	0.5	0.9	0.25	0.5	0.8	0.8	1.1	1.8
Private Offices*	150	125	100	2.0	5.8	8.0	-	-	-	0.25	0.5	0.9	0.25	0.5	0.8	-	-	-
Stenographic Department	100	85	70	5.0†	7.5†	10.0†	-	-	-	-	-	-	-	-	-	0.9	1.3	2.0
Residential Large	600	400	200	1.0	2.0	4.0	600	500	380	0.8	1.2	1.6	0.5	0.8	1.3	-	-	-
Medium	600	360	200	0.7	1.5	3.0	700	550	400	0.7	1.1	1.4	0.5	0.7	1.2	-	-	-
Restaurants Large	17	15	13	1.5	1.7	2.0	135	100	80	1.8	2.4	3.7	1.2	1.6	2.1	0.9	1.1	1.4
Medium							150	120	100	1.5	2.0	3.0	1.1	1.4	1.8	0.9	1.0	1.3
Shopping Centers, Department Stores and Specialty Shops																		
Beauty and Barber Shops	45	40	25	3.0†	5.0†	9.0†	240	160	105	1.5	2.6	4.2	1.1	1.7	2.6	0.9	1.3	2.0
Department stores Basement	30	25	20	2.0	3.0	4.0	340	285	225	-	-	-	-	-	-	0.7	1.0	1.2
Main Floors	45	25	16	3.5	6.0†	9.0†	350	245	150	-	-	-	-	-	-	0.9	1.4	2.0
Upper Floors	75	55	40	2.0	2.5	3.5†	400	340	280	-	-	-	-	-	-	0.8	1.0	1.2
Dress Shops	50	40	30	1.0	2.0	4.0	345	280	185	0.9	1.2	1.6	0.7	1.0	1.4	0.6	0.8	1.1
Drug Stores	35	23	17	1.0	2.0	3.0	180	135	110	1.8	2.3	3.0	1.0	1.4	1.8	0.7	1.0	1.3
5¢ and 10¢ Stores	35	25	15	1.5	3.0	5.0	345	220	120	0.7	1.4	2.0	0.6	1.2	1.6	0.5	0.9	1.1
Hat Shops	50	43	30	1.0	2.0	3.0	315	270	185	1.0	1.3	1.9	0.7	1.0	1.5	0.6	0.8	1.2
Shoe Stores	50	30	20	1.0	2.0	3.0	300	220	150	1.2	1.6	2.1	1.0	1.4	1.8	0.8	1.0	1.2
Malls	100	75	50	1.0	1.5	2.0	365	230	160	-	-	-	-	-	-	1.1	1.8	2.5
Refrigeration for Central Heating and Cooling Plant																		
Urban Districts							475	380	285									
College Campuses							400	320	240									
Commercial Centers							330	265	200									
Residential Centers							625	500	375									

Refrigeration and air quantities for applications listed in this table of cooling load check figures are based on all-air system and normal outdoor air quantities for ventilation except as noted.

Notes:

‡ Refrigeration loads are for entire application

† Includes other loads expressed in Watts/sq ft.

★ Air quantities for heavy manufacturing areas are based on supplementary means to remove excessive heat.

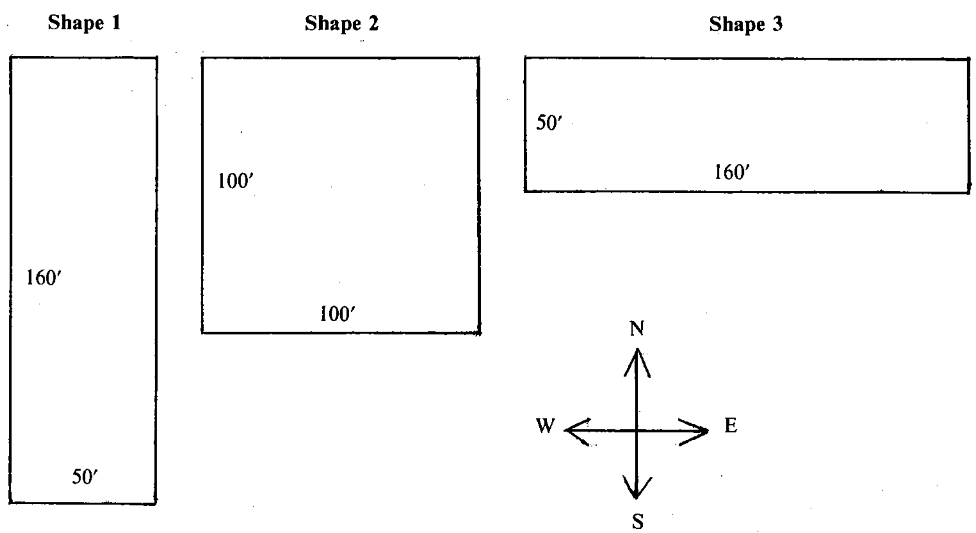
* Air quantities for hospital patient rooms and office buildings (except internal areas) are based on induction (air-water) system.

Table A1.2 Glass and the Cooling Load; Load and Air Quantity

Item	Bldg. Shape	Glass Area-% Wall Area 0%	20%		40%		60%		80%		100%	
			Shading (venetian blinds)									
			With	Without	With	Without	With	Without	With	Without	With	Without
Refrigeration	1	320	292	286	264	252	236	218	208	184	180	150
Load*	2	330	304	298	278	266	252	234	226	202	200	170
(sq ft/ton)	3	322	296	290	270	258	244	226	217	193	190	160
Air†	1	1.20	1.46	1.52	1.72	1.84	1.98	2.16	2.24	2.48	2.50	2.80
Quantity	2	1.05	1.25	1.30	1.45	1.55	1.65	1.80	1.85	2.05	2.05	2.30
(cfm/sq ft)	3	1.15	1.35	1.41	1.55	1.67	1.75	1.93	1.95	2.29	2.15	2.45

*Refrigeration load based on 100 sq ft/person, 6 watts/sq ft, .15 cfm outdoor air/sq ft, wall U=.32; roof U=.10, single glazing, 10-story building, 40° N latitude, 12-hour operation.

†Air quantity is average for entire building and is based on use of an all-air system.



Case	Area Sq. Ft.	% Glass	Shading	Bldg. Shape	Tonnage	Cfm
1	30,000	20	Yes	1	100	44,000
2	30,000	60	Yes	1	127	59,500
3	30,000	60	Yes	3	123	52,500
4	30,000	60	No	1	137	65,000

Examples of Using Tables

The ratio of glass to wall in the exterior module affects significantly the cooling load. Clear glass transmits over 90% of the solar heat impinging. One hundred square feet of glass increases the cooling load about one ton. With heat abosrbing sections the heat gain is less. The chart at the top of the page shows the magnitude of the solar heat load. In buildings with 50% or more glass, the sun heat becomes the dominant factor when sizing and selecting room equipment. Heat is also generated by people, by lights and other electrical equipment. Heat flows through walls, glass and roof. When the outside temperature is above the inside, the heat flows inward; when below, the heat flows outward. The net effect of positive internal heat and a loss due to the transmission may require that supplementary heat be added. The need may occur on mild days when 60° F outside temperature or it may not be essential until the outside temperature is in the thirties or lower. This reversal of the load from heating to cooling or vice versa occurs during the intermediate season and is the reason some systems do not perform as well as others. The problem is more acute as the glass ratio increases.

Lights produce considerable heat which may be utilized in various ways for heating. Picked up at the troffers in return air, it can be transferred to outside offices where needed. Also, when absorbed by air returning through ceiling fixtures, it does not add heat to the room and less air is required to maintain comfort.

A3 External Load Factors

A3.0 EXTERNAL LOAD FACTORS

Outside weather conditions and the sun combine to produce a cooling or heating load through the building envelope. The load depends upon: (a) the thermal characteristics of the walls, roof, fenestration, floor and of the interior building furnishing, and construction, and (b) the driving force which is the result of the difference between the outside conditions (including solar) and the inside conditions. For example, the heat transferred through the roof shown in Fig. A3.1 is determined by the temperature of the top surface of the built-up roofing and the inside surface of the suspended ceiling. The temperature of the outside surface depends upon the solar radiation absorbed by the surface, whether heat is convected to or from the outside air, the amount of radiation from the surface to the sky and surroundings and the amount of heat conducted into the roof construction. A similar analysis of the inside surface shows the surface temperature depends on the amount of heat conducted or convected from the roof/ceiling construction, the amount of heat convected to the inside air, the radiation from the surface to the inside enclosure and furnishings, and the amount of radiation from internal sources such as lights.

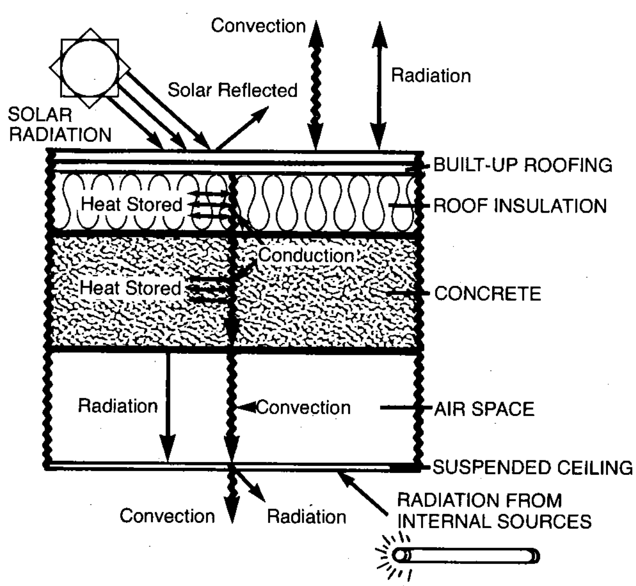


Fig. A3.1 Heat Transfer through a Typical Roof

The heat flow through the roof construction usually will not be constant since the outside conditions, and often the scheduled inside conditions, vary with the time of day and day of the week and year.

For example, with an increase in solar radiation and/or an increase of the outside air temperature, the outside surface temperature increases. After the first layer is heated up or cooled down, the next layer feels the effect of the change of temperature, and on through the complete roof or wall. The rate at which heat flows through the structure and the time delay before a change at the outside affects the inside surface are functions of the thermal characteristics of each layer. The resistance to the heat flow per unit area is proportional to the thickness of the layer divided by the thermal conductivity. The heat stored per unit area is proportional to the density and the thickness, i.e., mass per unit area, and the specific heat of each layer.

The heat transferred through transparent surfaces such as glass is more a function of the thermal radiation characteristics of the glass and less dependent upon the thermal storage capacity of such materials.

To obtain an accurate estimate of the heat transfer through both opaque and transparent surfaces by manual calculations would be unwieldy without some simplification. Therefore, this section will discuss the procedures used to simplify the calculation process. First, the variables which affect the cooling or heating load will be analyzed. Then, the inclusion of these variables in the final calculation procedure will be discussed. A summary of the factors affecting each component is listed below.

A. Heat Transferred to or from Outside Surface
- 1.0 Amount of solar radiation absorbed
  - 1.1 Solar radiation incident to a surface
    - Latitude, month,* solar time of day*
    - Orientation of surface
    - Exterior shading of surface
    - Reflection from adjacent surfaces
  - 1.2 Absorptance, reflectance and transmittance of surface or material
  - 1.3 Atmosphere through which solar radiation passes*
    - Haze, water vapor, dust, smoke
- 2.0 Radiation from the surface to the sky and to other surrounding surfaces
  - 2.1 Orientation of surface (i.e., horizontal, vertical and southeast)
  - 2.2 Temperature of surface*
  - 2.3 Cloud cover*
- 3.0 Convection to or from outside surface
  - 3.1 Temperature* of the air and surroundings compared to surface temperature
  - 3.2 Wind speed* at the surface
  - 3.3 Type of surface such as smooth or rough stucco
- 4.0 Conduction into the construction
  - 4.1 Temperature profile* throughout the various construction layers (history of heat flow prior to time considered)
  - 4.2 Thermal resistance of the construction (thickness and conductivity or conductance)
  - 4.3 Heat capacity of construction (thickness, density and specific heat)

B. Heat Transferred to or from Inside Surface
   1.0 Conduction from the construction (same as 4.0 above)
   2.0 Convection to/from surface
      2.1 Inside air velocity* across surface
      2.2 Temperature* of inside air
   3.0 Radiation to or from the surface
      3.1 Temperature* of the furniture, the partitions, other inside surface
      3.2 Temperature* of the internal sources such as the lights, the equipment or people
      3.3 Type of other interior surfaces and their orientation with respect to the roof or the wall or fenestration

*Represent those factors which are variable. The other parameters are usually fixed for a particular location or configuration or construction.

A3.1 HEAT TRANSMISSION THROUGH WALLS, ROOFS AND OTHER OPAQUE SURFACES

The relative simplicity of the equation for steady-state heat transfer by conduction makes it useful as a basis for many other calculations as well. It has been used, with some adjustment, to calculate the heat transfer under varying temperatures and heat flows such as with Total Equivalent Temperature Differences (TETD) and now with Cooling Load Temperature Difference (CLTD).

In steady-state conduction heat flow through a flat wall or roof of uniform composition, the heat flow does not vary with time. Also, for flat construction the cross-sectional area along the heat flow path is constant. The rate of heat conduction through the wall is expressed as

$$q_k = \frac{Ak}{L}(t_{hot} - t_{cold}) = \frac{A(\Delta t)}{L/k} = A\frac{\Delta t}{R_k} = AC_k\,\Delta t \qquad \text{For Pure Conduction} \qquad (A3.1)$$

where

q_k = steady-state conduction rate, Btu/hr.
A = cross-sectional area measured perpendicularly to the one-dimensional direction of flow, ft^2.
L = wall thickness, in.
$(t_{hot} - t_{cold}) = \Delta t$, the total difference in temperature through the wall in the direction of heat flow, deg F
k = average thermal conductivity, Btu-in./$(hr \cdot ft^2 \cdot F)$. Note that many tables of properties list the thermal conductivities per foot thickness, that is Btu/(hr · ft · F). In such a case the thickness, L, should be in units of ft also.
$R_k = L/k$ = thermal resistance, $(hr \cdot ft^2 \cdot F)$/Btu, analogous to electrical resistance of direct current flow.
$C_k = 1/R_k$ = thermal conductance, Btu/$(hr \cdot ft^2 \cdot F)$.

Often the flat wall layer is not of uniform composition—for example, a concrete block wall in which heat transfer is dependent upon the combined effects of convection within the air spaces and conduction through concrete. The last two forms of Eq. (A3.1) are used for such cases by dropping the subscript k to show that the heat flow is no longer by pure one-directional conduction.

$$q = \frac{A(\Delta t)}{R} = AC\,(\Delta t) \qquad \text{Non-uniform composition wall layer} \qquad (A3.1a)$$

and

$$R = \frac{1}{C}$$

By use of an analogy to direct current flow of electricity, pure heat conduction flow may be analyzed through a series of flat wall layers, each of which is of uniform composition. Fig. A3.2 shows the approximate temperature distribution and thermal circuit as an electrical analog for heat flow in steady-state pure conduction heat flow through a 3-layered series wall, that is, the same fixed heat flow rate through each layer. Eq. (A3.2) expresses q_k for the case of Fig. A3.2 in several equivalent forms.

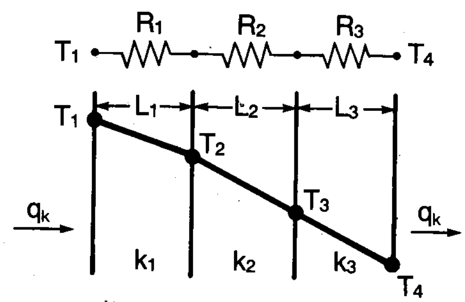


Fig. A3.2 Approximate Steady-State Temperature Distribution and Thermal Circuit for Conduction Heat Flow Through a Series of Flat Wall Layers, Each of Uniform Composition.

$$q_k = A\frac{(t_1 - t_2)}{R_1} = A\frac{(t_2 - t_3)}{R_2} = A\frac{(t_3 - t_4)}{R_3} = A\frac{(t_1 - t_4)}{R_1 + R_2 + R_3} = A\frac{(t_1 - t_4)}{R_t} \qquad (A3.2)$$

where

$R = \frac{L}{k}$, thermal resistance of each layer, $(hr \cdot ft^2 \cdot F)$/Btu.
R_t = total thermal resistance, the sum of individual thermal resistances of all layers, $(hr \cdot ft^2 \cdot F)$/Btu.
A = cross-sectional area, ft^2, constant and the same for all layers.

The calculation for a series of uniform flat layers assumes knowledge of the exposed surface temperatures. It is more likely that only the temperature of the air on each side of the two exposed surfaces is known. In that case, convection from the air on one side to the composite wall and convection to the air from the composite wall must be considered.

The rate of heat transfer by convection between a surface and a fluid directly contacting it is calculated by the relation

$$q_c = h_c A\,(t_{surface} - t_{fluid}) \qquad (A3.3)$$

where

q_c = convective heat rate, Btu/hr.
h_c = average convective heat transfer coefficient on the surface of area A, h_c being in units of Btu/$(hr \cdot ft^2 \cdot F)$ and A in ft^2.

and q_c is *from* the surface if $t_{surface}$ is greater than t_{fluid}, or *to* the surface if $t_{surface}$ is less than t_{fluid}.

It is convenient to write Eq. (A3.3) in the resistance form

$$q_c = \frac{A(\Delta t)}{R_c} \qquad (A3.3a)$$

where

$R_c = 1/h_c$ is the thermal resistance due to the fluid film on the surface, and
Δt = temperature difference across that film; $\Delta t = t_{surface} - t_{fluid}$.

When the convective effects are considered on the surfaces, Fig. A3.2 is replaced by Fig. A3.3. Here the thermal resistances on the surfaces due to convection are included.

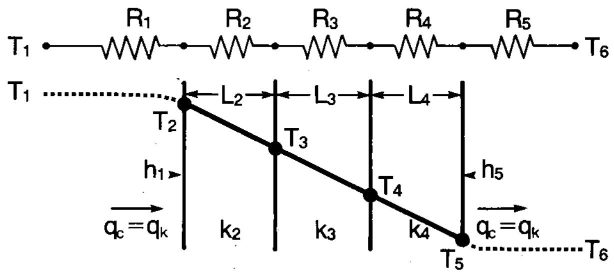


Fig. A3.3 Approximate Steady-State Temperature Distribution and Thermal Circuit for Combined Convection and Conduction Heat Flow Through a Series of Flat Wall Layers, Each of Uniform Composition.

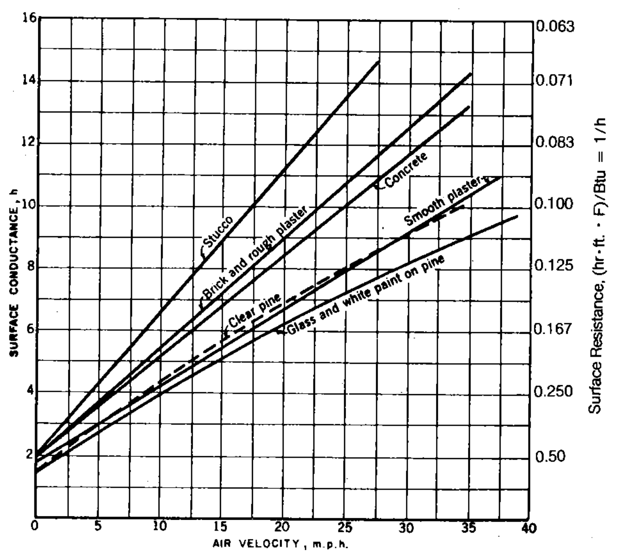


Fig. A3.4 Surface Conductance and Surface Resistance as Affected by Air Movement, Including Radiation.

For Fig. A3.3, $q = q_c = q_k$ and can be expressed as in Eq. (A3.4)

$$q = q_c = q_k = \frac{A(t_1 - t_2)}{R_1} = \frac{A(t_2 - t_3)}{R_2} = \frac{A(t_3 - t_4)}{R_3}$$
$$= \frac{A(t_4 - t_5)}{R_4} = \frac{A(t_5 - t_6)}{R_5} = \frac{A(t_1 - t_6)}{R_t} \qquad (A3.4)$$

where

$R_1 = 1/h_1$
$R_5 = 1/h_5$

and R_2, R_3, and R_4 are of the form $R = L/k$ for pure conduction.

It is customary to use an alternate notation to that of the overall thermal resistance R_t as in Eq. (A3.4). For the case of Fig. A3.3, an overall coefficient of heat transmission, U, is defined as the reciprocal of R_t:

$$q = UA(t_1 - t_6) = \frac{A(t_1 - t_6)}{R_t}; \text{ where } U = 1/R_t \qquad (A3.5)$$

Radiation on opaque surfaces also must often be considered. Sometimes it is superimposed on the convection transfer by replacing the convective heat transfer coefficient, h_c, with a combined coefficient for convection and radiation, h as in Eq. (A3.6).

$$q_{c+r} = q = hA\,(t_{surface} - t_{fluid}) = \frac{A(\Delta t)}{R} \qquad (A3.6)$$

where

q = combined convective and radiative heat rate, Btu/hr, from a surface contacting a fluid.
$h = h_c + h_r$, Btu/(hr · ft² · F); see Fig. A3.4 and Tables 3.3 and 3.4.
$R = 1/(h_c + h_r)$, (hr · ft² · F)/Btu; see Fig. A3.4.

This is usual for the common applications for air apaces and also for air films except for the case when solar radiation is present.

When radiation and convection occur across an air space between wall layers, Eq. (A3.6) is modified to

$$q_s = h_s\,A(\Delta t)_s = \frac{A(\Delta t)_s}{R_s} \qquad (A3.7)$$

where

q_s = combined convective and radiative heat rate across an air space, Btu/hr
$R_s = 1/h_s$ = thermal resistance across the air space, (hr · ft² · F)/Btu.
and $(\Delta t)_s$ = temperature difference across the air space, deg F

Overall Coefficients, U

One method for determining the heat transmission coefficient, U, for a given building section of area A, is to test a representative section. However, it is not practical to test all the combinations which may be of interest in building construction. Experience has indicated that U values for many constructions can be calculated to an adequate degree of accuracy if the following items are considered.

1. Use the most accurate property values available for component materials as obtained from guaranteed data of the manufacturer or from unbiased test data.
2. Make corrections for framing member properties when significantly different from the materials between the framing members. One example is a wall with air spaces or insulation between framing members.
3. Make special adjustments for lateral heat flow when panels with internal metallic structure are bonded on one or both sides to a metal skin or covering.
4. Special attention must be given to the use of vapor barriers because moisture may change the thermal properties of insulation or other construction materials.
5. Where reflective air spaces are involved in building construction, and where their thermal resistance values constitute a major share of the installed resistance of the insulation, U-values may change up to 10 percent for applications where heat flow is horizontal or upward, and up to 20 percent where heat flow is downward.
6. Use tabulated U values for identical or similar composite constructions only after carefully comparing conditions upon which the tables were based to those conditions actually existing.

Calculation of *UA* Factors

For a wall made up of a series of uniform layers, as in Fig. A3.3, the area, A, is constant and R_t is found as the sum of the resistances of individual layers. The transmission coefficient, U, is obtained from R as defined in Eq. (A3.5). Tables 3.1 through 3.4 provide useful data for calculating the U-values.

Table 3.1 lists the properties of typical building and insulating materials.

Table 3.2 illustrates the procedure for determining U values for many types of construction.

Table 3.3 lists the thermal resistance and conductance properties for air films.

Table 3.4 provides the thermal properties for air spaces.

Table 3.5 gives the effective thermal resistance of attics under summer conditions.

U-values for various window and door constructions are given in Tables 3.6, 3.14, 3.15, and 3.16. Table A3.1 gives the adjusted U-value when additional thermal insulation of resistance R is added to a given building section. Table A3.2 is a conversion table for wall U-values for various wind speeds.

Table A3.1 Determination of U-Values, Btu/(hr·ft²·F) Resulting From Addition of Thermal Insulation to any Given Building Section

GIVEN BLDG SECTION PROPERTY		ADDITIONAL THERMAL INSULATION, R[a, b], (hr·ft²·F)/Btu														
U	*R*	1	2	3	4	5	6	7	9	11	13	15	17	19	30	38
0.08	12.5	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.047	0.043	0.039	0.036	0.034	0.032	0.024	0.020
0.10	10.0	0.091	0.083	0.077	0.071	0.067	0.063	0.059	0.053	0.048	0.043	0.040	0.037	0.034	0.025	0.021
0.12	8.3	0.107	0.097	0.088	0.081	0.075	0.070	0.065	0.058	0.052	0.047	0.043	0.039	0.037	0.026	0.022
0.14	7.1	0.123	0.109	0.099	0.090	0.082	0.076	0.071	0.062	0.055	0.050	0.045	0.041	0.038	0.027	0.022
0.16	6.3	0.138	0.121	0.108	0.098	0.089	0.082	0.075	0.066	0.058	0.052	0.047	0.043	0.040	0.028	0.023
0.18	5.6	0.153	0.132	0.117	0.105	0.095	0.087	0.080	0.069	0.060	0.054	0.049	0.044	0.041	0.028	0.023
0.20	5.0	0.167	0.143	0.125	0.111	0.100	0.091	0.083	0.071	0.063	0.056	0.050	0.045	0.042	0.029	0.023
0.22	4.5	0.180	0.153	0.133	0.117	0.105	0.095	0.087	0.074	0.064	0.057	0.051	0.046	0.042	0.029	0.024
0.24	4.2	0.194	0.162	0.140	0.122	0.109	0.098	0.090	0.076	0.066	0.058	0.052	0.047	0.043	0.029	0.024
0.26	3.8	0.206	0.171	0.146	0.127	0.113	0.102	0.092	0.078	0.067	0.059	0.053	0.048	0.044	0.030	0.024
0.28	3.6	0.219	0.179	0.152	0.132	0.117	0.104	0.095	0.080	0.069	0.060	0.054	0.049	0.044	0.030	0.024
0.30	3.3	0.231	0.188	0.158	0.136	0.120	0.107	0.097	0.081	0.070	0.061	0.055	0.049	0.045	0.030	0.024
0.40	2.5	0.286	0.222	0.182	0.154	0.133	0.118	0.105	0.087	0.074	0.065	0.057	0.051	0.047	0.031	0.025
0.50	2.0	0.333	0.250	0.200	0.167	0.143	0.125	0.111	0.091	0.077	0.067	0.059	0.053	0.048	0.031	0.025
0.60	1.7	0.375	0.273	0.214	0.176	0.150	0.130	0.115	0.094	0.079	0.068	0.060	0.054	0.048	0.032	0.025
0.70	1.4	0.412	0.292	0.226	0.184	0.156	0.135	0.119	0.096	0.080	0.069	0.061	0.054	0.049	0.032	0.025

[a] If the insulation occupies a previously considered air space, an adjustment must be made in the given building section R-value.
[b] Adjust for furring or framing sections as necessary, separately.

Table A3.2 Conversion Table for Wall U Values for Various Wind Speeds

WIND SPEED (MPH)	*U*-VALUE, Btu/(hr·ft²·F)																	
STILL	0.077	0.096	0.114	0.132	0.149	0.167	0.184	0.201	0.217	0.233	0.249	0.265	0.281	0.296	0.311	0.326	0.340	0.410	0.475
5.0	0.079	0.098	0.118	0.137	0.156	0.175	0.194	0.213	0.231	0.250	0.268	0.287	0.305	0.323	0.341	0.359	0.377	0.464	0.549
7.5	0.079	0.099	0.119	0.138	0.158	0.177	0.197	0.216	0.235	0.255	0.274	0.293	0.312	0.331	0.350	0.369	0.388	0.481	0.573
10.0	0.080	0.099	0.119	0.139	0.159	0.178	0.198	0.217	0.237	0.256	0.276	0.295	0.315	0.334	0.353	0.372	0.392	0.487	0.581
15.0	0.080	0.100	0.120	0.140	0.160	0.180	0.200	0.220	0.240	0.260	0.280	0.300	0.320	0.340	0.360	0.380	0.400	0.500	0.600
20.0	0.080	0.100	0.120	0.141	0.161	0.181	0.201	0.222	0.242	0.262	0.283	0.303	0.324	0.344	0.364	0.385	0.406	0.509	0.612
25.0	0.080	0.101	0.121	0.141	0.161	0.182	0.202	0.223	0.243	0.264	0.284	0.305	0.326	0.346	0.367	0.388	0.409	0.514	0.620

Since the tables for the thermal properties of air spaces and air films include the effect of radiation, it is necessary to use a radiation property, the emittance, E. Emittances for some common construction materials are listed in Tables A3.3 and 3.3B. The values in the second column of Table 3.3B are for the surface with air films. The last two columns of values of Table 3.3B are used for enclosed air spaces with one or both surfaces consisting of the itemized material. The combined emittance for air spaces for other combinations can be calculated by

$$\frac{1}{E_S} = \frac{1}{E_1} + \frac{1}{E_2} - 1 \qquad \text{(A3.8)}$$

where

E_S = combined emittance of air space.
E_1, E_2 = emittances of each bounding surface.

Parallel Heat Flow

Some applications use combinations of series and parallel heat flow paths. The concrete block layer has convective transfer in the air spaces and conduction transfer through the concrete in a parallel, side by side, path. When such a non-uniform layer exists in a layered wall, Eq.(A3.5) still applies if an experimental $R = 1/C$ has been determined for the non-uniform layer (See Eq. A3.1a). In other cases of parallel flow an experimental R (or C) may not be available. For example, some outer wall construction may be in series with the parallel paths produced by a layer of 2 × 4 wood studs or 2 × 2 wood furring strips with either air spaces or insulation between the studs. In such a case Eq. (A3.5) is modified to

$$q = (U_s A_s)\,\Delta t + (U_i A_i)\,\Delta t$$
$$q = (U_s A_s + U_i A_i)\,\Delta t \qquad \text{(A3.5a)}$$
$$q = (U_{av})\,(A)\,\Delta t$$

where

A_s = area backed by framing members (studs or furring strips, for example) in a representative wall section, ft^2.
A_i = area of insulation (or air spaces) between framing members in the representative wall section, ft^2.
$A = A_s + A_i$ = representative wall section area, ft^2.
U_s = overall coefficient of heat transfer for the flow path through the framing members, Btu/(hr · ft^2 · F).
U_{av} = the average overall coefficient of heat transfer for the total representative area A, Btu/(hr · ft^2 · F).

From comparision of the last two forms of Eq. (A3.5a),

$$U_{av} = \frac{U_s A_s + U_i A_i}{A}$$

Using $A_i = A - A_s$,

$$U_{av} = \left(\frac{A_s}{A}\right) U_s + \left(\frac{A - A_s}{A}\right) U_i$$

$$U_{av} = \left(\frac{S}{100}\right) U_s + \left(1 - \frac{S}{100}\right) U_i \qquad \text{(A3.9)}$$

where

$S = \left(\frac{A_s}{A}\right)(100)$ = percentage of area backed by framing members.

The series thermal circuit of Fig. A3.3 is no longer adequate because of the insertion of the parallel combination. Fig. A3.5 shows a typical construction and the thermal circuit of the electrical analog. The actual dimensions of a common 2×4 pine stud, 1 1/2 in. × 3 1/2 in., are used 16 in. on centers with insulation between studs.

R_{t_s}, the total resistance through the pine framing area $A_s = A_p$, is given by

$$R_{t_s} = R_{1p} + R_{2p} + R_{3p} + R_{4p} + R_{5p} + R_{6p} = \frac{1}{U_s}$$

Similarly, the total resistance through the insulation area A_i is

$$R_{ti} = R_{1i} + R_{2i} + R_{3i} + R_{4i} + R_{5i} + R_{6i} = \frac{1}{U_i}$$

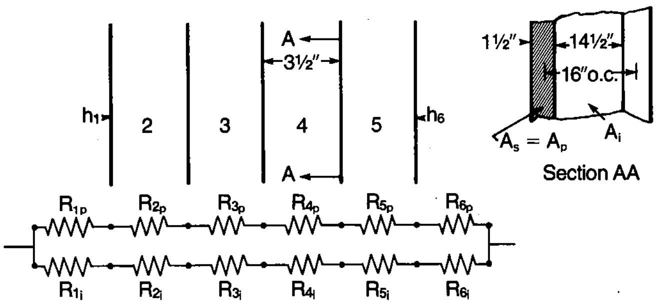
Table A3.3 Emittances for a Few Surfaces [b, c]

Class	Surfaces	Total Normal Emittance [a] At 50-100 F	At 1000 F
1	A small hole in a large box, sphere, furnace, or enclosure	0.97 to 0.99	0.97 to 0.99
2	Black non-metallic surfaces such as asphalt, carbon, slate, paint, paper	0.90 to 0.98	0.90 to 0.98
3	Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc.)	0.85 to 0.95	0.75 to 0.90
4	Yellow and buff brick and stone, firebrick, fire clay	0.85 to 0.95	0.70 to 0.85
5	White or light-cream brick, tile, paint or paper, plaster, whitewash	0.85 to 0.95	0.60 to 0.75
6	Window glass	0.90	....
7	Bright aluminum paint: gilt or bronze paint	0.40 to 0.60	....
8	Dull brass, copper, or aluminum; galvanized steel; polished iron	0.20 to 0.30	0.30 to 0.50
9	Polished brass, copper, monel metal	0.02 to 0.05	0.05 to 0.15
10	Highly polished aluminum, tin plate, nickel, chromium	0.02 to 0.04	0.05 to 0.10
11	Selective Surfaces		
	Stainless steel wire mesh	0.23 to 0.28	....
	White painted surface	0.92	....
	Copper treated with solution of $NaClO_2$ and NaOH	0.13	....
	Copper, nickel, and aluminum plate with CuO coating	0.09 to 0.21	....

[a] Hemispherical and normal emittance are not equal in many cases. The hemispherical emittance may be as much as 30 percent greater for polished reflectors to 7 percent lower for non-conductors
[b] See Table 3.3B, also.
[c] Adapted from Table 3, page 2.9, Chapter 2, ASHRAE 1977 HOF.

Eq. (A3.9) is often written in the dimensionless form

$$\frac{U_{av}}{U_i} = \left(\frac{S}{100}\right)\left(\frac{U_s}{U_i}\right) + \left(1 - \frac{S}{100}\right) \qquad \text{(A3.9a)}$$



Subscript p relates to "pine"; subscript i relates to "insulation"; in the thermal circuit these subscripts are used in layers 1 through 6 to indicate that the path is in series with either the pine or insulation.

Fig. A3.5 Series-Parallel Path Wall Construction and Thermal Circuit When Layer 4 is 2 in. × 4 in. Pine Studs on 16 in. Centers with Insulation Between Studs.

Conduction Through Interior Partitions, Ceilings and Floors

Heat flow through the interior building construction (partitions, ceilings and floors) is caused by a difference in temperature of the air on both sides of the structure. This temperature difference is essentially constant through the day or some fairly specific fractions of the day and can be used in the steady-state equation for the heat transfer rate, q, in Btu/hr:

$$q = UA\ (t_b - t_i) \qquad \text{(A3.10)}$$

where

U = coefficient of overall heat transfer between the adjacent and the conditioned space, Btu/(hr · ft² · F).
A = area of separating section, ft².
t_b = air temperature in adjacent space, F.
t_i = air temperature in conditioned space, F.

The temperature t_b may have any value over a considerable range, according to conditions in the adjacent space. The temperature in a kitchen or boiler room may be as much as 15 to 50 deg F above the outdoor air temperature. It is recommended that actual temperatures be measured in adjoining spaces wherever practicable. Where nothing is known, except that the adjacent space is of conventional construction and contains no heat sources, it is recommended that the difference ($t_b - t_i$) be taken as the difference between the outdoor air and conditioned space design dry-bulb temperatures minus 5 deg F. In some cases, the air temperature in the adjacent space will correspond closely to the outdoor air temperature at all times.

For floors directly in contact with the ground, or over an underground basement that is neither ventilated nor warmed, the heat transfer may be neglected for cooling load estimates.

Conduction Through Glass (Fenestration)

Whether or not there is sunlight, heat flows through fenestration by thermal conduction as given by the expression:

Conduction Heat Flow	=	Overall Coefficient of Heat Transfer	×	Outdoor-Indoor Temperature Difference

or

$$q/A = U(t_o - t_i) \qquad \text{(A3.11)}$$

where

q/A = the instantaneous rate of heat transfer through fenestration Btu/(hr · ft²).
U = overall coefficient of heat transfer for the glazing, Btu/(hr · ft² · F).
t_o = outside air temperature, F.
t_i = inside air temperature, F.

When the outdoor temperature, t_o, is higher than the indoor temperature, t_i, the conduction heat flow is inward; otherwise the conduction is outward. This is true even though solar radiation is coming into the conditioned space. Values of the overall coefficient of heat transfer for a number of widely used fenestrations are given in Tables 3.6, 3.14, 3.15, and 3.16.

For the conduction gain, the overall coefficient of heat transfer accounts for the following heat transfer processes: convection for the outside and inside surfaces and the conduction through the fenestration material and air spaces.

Table A3.4 gives indoor radiation and convection resistances, R_i for still air and various glass surfaces emittances. The quantity R_i is the inner surface resistance which is one part of the total resistance, R_t. Hence, R_i influences U which is the reciprocal of R_t. In Table A3.4 R_i is defined in terms of $h_c + h_r$, but with zero indoor air velocity.

Table 3.15 gives U factors for summer conditions for double glass types with indoor air velocity.
The convection component, h_c, is given by the equation

$$h_{c_i} = 0.99 + 0.21v \qquad \text{(A3.12)}$$

where

h_{c_i} = inside glass surface convection coefficient, Btu/(hr · ft² · F).
v = air velocity on inner surface, fps.

A3.2 UNSTEADY-STATE HEAT FLOW AND COOLING LOAD TEMPERATURE DIFFERENCE (CLTD)

The calculation of the heat gain or loss at the inside surface of some structure under all the varying conditions indicated in section A3.0 has been simplified by the use of Total Equivalent Temperature Differences (TETD). The TETD method has been used extensively in previous publications. However, it still required an additional procedure to convert the heat gain to the cooling load. Now this has been accomplished in a one step procedure by using the Transfer Function Method to compute the transient heat gain together with a room transfer function to convert load thus obtained in Btu/(hr · ft²) by the steady-state U-value for each roof or wall. The units obtained are in degrees F and are referred to as the equivalent Cooling Load Temperature difference (CLTD) and are used in a similar manner to the TETD

$$\text{CLTD} = q/UA; \quad q = UA(\text{CLTD}) \qquad \text{(A3.13)}$$

where

q = transient cooling load, Btu/hr.

Table A3.4 Indoor Radiation and Convection Coefficient (h_i) (Still Air Conditions), Btu/h·ft²·F, and Resistance ($R_i = 1/h_i$) for Various Glass Surface Emittances

Room Temp. (deg F)	Glass Temp. (deg F)	Temp Diff. (Δt)	Indoor Coefficient [a] h_i Indoor Glass Surface Emittance e_g 0.05	0.10	0.20	0.40	0.84	0.90	Indoor Resistance [b] R_i Indoor Glass Surface Emittance e_g 0.05	0.10	0.20	0.40	0.84	0.90
70	65	5	0.45	0.51	0.61	0.81	1.25	1.31	2.22	1.96	1.64	1.22	0.80	0.76
	60	10	0.53	0.58	0.68	0.88	1.31	1.37	1.89	1.73	1.47	1.14	0.76	0.73
	50	20	0.62	0.67	0.75	0.96	1.38	1.44	1.61	1.49	1.31	1.04	0.72	0.69
	40	30	0.68	0.73	0.81	1.01	1.42	1.48	1.47	1.37	1.22	0.99	0.71	0.68
	30	40	0.73	0.77	0.86	1.04	1.44	1.50	1.37	1.30	1.16	0.96	0.70	0.67
	20	50	0.76	0.81	0.90	1.07	1.46	1.51	1.31	1.22	1.11	0.94	0.69	0.66
	10	60	0.79	0.84	0.92	1.10	1.47	1.52	1.27	1.19	1.09	0.90	0.68	0.66
75	135	60	0.81	0.88	1.00	1.25	1.79	1.87	1.22	1.14	1.00	0.80	0.56	0.54
	125	50	0.78	0.84	0.96	1.20	1.73	1.80	1.28	1.19	1.04	0.83	0.58	0.56
	115	40	0.74	0.80	0.91	1.15	1.66	1.73	1.35	1.25	1.10	0.87	0.60	0.58
	105	30	0.69	0.75	0.86	1.09	1.59	1.66	1.45	1.33	1.16	0.92	0.63	0.60
	95	20	0.63	0.68	0.79	1.02	1.50	1.57	1.59	1.47	1.27	0.98	0.67	0.64
	85	10	0.53	0.59	0.70	0.91	1.39	1.45	1.89	1.70	1.42	1.10	0.72	0.71
	80	5	0.46	0.51	0.62	0.83	1.30	1.36	2.18	1.96	1.61	1.21	0.77	0.74

[a] $h_i = h_c + h_r = 0.27\,(\Delta t)^{0.25} + \dfrac{e_g\,\sigma\,(T_g^4 - T_i^4)}{T_g - T_i}$

[b] $R = 1/h_i$

but with *UA* calculated as for steady-state heat flow.

The base tabulated values were generated for the conditions listed below.

Outdoor Conditions

- July 21, 40 deg N latitude
- No exterior shading
- Ground reflectance of 0.20
- Clear sky with a clearance number of 1.0
- Outside surface of roofs and walls with a ratio of the absorptance to the film coefficient (α/h) of 0.30
- Outside air maximum dry bulb temperature of 95 F with a daily range of 21 F and a profile similar to Table 5.1

Inside Conditions

- Room dry bulb temperature constant at 78 F
- Inside film coefficient for still air
- Interior furnishings and construction as follows
  - Light: Frame exterior wall, 2 in. concrete floor slab, approximately 30 lb of material/sq ft of floor area
  - Medium: 4 in. concrete exterior wall, 4 in. concrete floor slab, approximately 70 lb. of material/sq ft floor area
  - Heavy: 6 in. concrete exterior wall, 6 in. concrete floor slab, approximately 130 lb of material/sq ft floor area

Adjustments for conditions other than these base values are listed in the notes which accompany each table of values for the CLTD. For example, the adjustment for the effect of the change in solar radiation due to calculation for other months or for other latitudes is given by Table 3.12. The adjustment is given in degrees F.

Absorptance, α, of several materials to solar radiation is given in Table A3.5. These values will be helpful in predicting the actual absorptance to film coefficient ratio, α/h.

Table A3.5 Absorptance of Materials to Solar Radiation[1]

Material	Solar Absorptance	Material	Solar Absorptance
Asbestos Cement		Paints	
White to Red	0.42 - 0.70	Dark (red, brown, green)	0.65 - 0.80
Aged	0.61 - 0.83	Light (yellow, buff)	0.30 - 0.50
		White	0.23 - 0.49
Black, non-metallic surfaces			
		Roofing	
Asphalt, carbon, slate, paint, paper	0.82 - 0.98	Aluminized	0.40
		Green, bituminous felt, black	0.86 - 0.97
Bricks			
		Tiles	
Purple, blue	0.77 - 0.89		
Light buff, red	0.50 - 0.77	Concrete, uncolored to black	0.65 - 0.91
White, cream	0.26 - 0.50		
		Red to dark purple	0.43 - 0.81
Glass	0.93		
		Wood, smoothly planed	0.78
Granite, Marble, Sand	0.41 - 0.68		
Gravel, Limestone, Sandstone	0.29 - 0.76		

[1]Abstracted from Thermal Radiation Properties Survey (Honeywell Research Center, Minneapolis, Minnesota, 1966), pp. 245-248 and from Table 3, page 2.9, Chapter 2, 1977 ASHRAE HANDBOOK, Fundamentals Volume.

A3.3 GLASS SOLAR LOAD

Solar radiation transmitted directly through glass or other fenestration material is often one of the largest contributions to the cooling load. It reduces the actual heating load, but is not usually considered in the design for peak heating loads for equipment selection.

The total instantaneous rate of heat gain through a glazing material can be obtained from the heat balance between a unit area of fenestration and its thermal environment.

Total heat transmission through glass	=	Radiation transmitted through glass	+	Inward flow of absorbed solar radiation
	+	Heat flow due to outdoor-indoor temperature difference		(A3.14)

In this equation, the first two terms of the right-hand side are present only when the fenestration is irradiated by direct or diffuse sunshine, and so, are related to the incident solar radiation. The third term occurs whether or not the sun is shining since it represents the heat flow through fenestration by thermal conduction. Eq. (A3.14) can be simplified to:

$$\text{Total heat transmission through glass} = \text{Solar heat gain} + \text{Conduction heat gain} \qquad (A3.15)$$

In this way the glass heat gain is divided into two components: one, the heat gain due to transmitted and absorbed solar energy, and two, the conduction heat gain or loss due to differences in outdoor and indoor air temperature (Eq. A3.11).

Since the Solar Heat Gain (SHG) is present only when the fenestration is irradiated by direct or diffuse sunshine, it is a direct function of the total radiation, I_t, as given by:

$$\text{SHG} = F \times I_t, \ \text{Btu/(hr} \cdot \text{ft}^2) \qquad (A3.16)$$

where F, the ratio of solar heat gain to incident solar radiation (dimensionless), depends on the type of fenestration and the incident angle of radiation.

Solar Heat Gain

Direct use of Eq. (A3.16) was found impractical because of the infinite variety of combinations in type of fenestration, shading devices, incident angle and solar radiation intensity. Instead, ASHRAE developed a method for calculating solar heat gains through fenestrations based on a reference glazing material: Double strength (1/8″) sheet glass.

The method is summarized as follows:

1. Solar Heat Gain Factors (SHGF) are defined as the solar heat gain (SHG) through double strength sheet glass (DS, 1/8″) having no external or internal shading. These account for both direct and diffuse irradiation.
2. Tables of SHGF values were generated, Chapter 26, 1977 HOF, for
   - North latitudes, 0 through 64 degrees, in 8 degree intervals
   - Daylight hours of the 21st day of each month
   - 17 different orientations: N, NNE, ... NNW and horizontal surfaces
3. Shading Coefficients (SC) relate the solar heat gain through a specific glazing system to the solar heat gain through the reference glazing material under the same specific set of conditions.

$$\text{SC} = \frac{\text{Solar Heat Gain of Fenestration}}{\text{Solar Heat Gain of Double-Strength Glass}} \qquad (A3.17)$$

Glass Solar Cooling Load Without External Shading, Cooling Load Factor

The calculated SHGF were used as the "heat gain" input for determining glass solar cooling load in the absence of external shading. This required the introduction of two new, independent variables into the calculations:

1. Type of interior construction considered in the space: light (L), medium (M), or heavy (H).
2. Presence or absence of an interior shading device for the glass which affects the time lag between the entrance of radiant solar energy into the space and its appearance as cooling load. For example, the lag is different when energy is absorbed by interior draperies from the situation where it is absorbed by the floor.

For different orientations and latitudes, the SHGF for a particular month were divided by the maximum value, SHGF_{max}, reached in that month. Results for $\text{SHGF}/\text{SHGF}_{max}$ for different months were compared and were observed to be of very similar profiles. Thus, the set of $\text{SHGF}/\text{SHGF}_{max}$ values for July at 40 deg North latitude were considered as representative. These representative values were used as dimensionless heat gain input data for a computerized calculation of Cooling Load Factors (CLF).

Tables 3.27 and 3.28 give values of the CLF for use with and without interior shading devices, but without external shading. The effect of external shading is calculated separately. The CLF is used to obtain cooling load, q, as follows:

$$q_{unsh} = A \times SC \times \text{SHGF}_{max.\ unsh} \times \text{CLF}_{unsh} \qquad (A3.18)$$

where, the subscript "unsh" has been added here to signify "unshaded *externally*", and

A = net glass area
SC = shading coefficient, as defined in Eq. (A3.17)
$\text{SHGF}_{max.\ unsh}$ is found from Table 3.25
and CLF_{unsh} is found in either Table 3.27 (without internal shading) or Table 3.28 (with internal shading).

Eq. (A3.18) can be used directly when external shading is uniform over the entire fenestration, as with exterior horizontal louvered sun screens for which shading coefficients are defined. However, external shading resulting from overhangs, vertical side fins, or mullion and transom cannot effectively be handled by the SC concept and is discussed in a later section.

Shading Coefficients for Typical Fenestrations

The top, central portion of Table 3.18 gives Shading Coefficients for commonly used types of flat glass with no interior shading, classified in terms of their thickness and normal incidence solar-radiation transmittance. The values are applicable to both sunlit and shaded glass, since the distinctions between Glass in Sun and Glass in Shade are no longer made. Solar transmittances are for normal incidence. The values of SC given in this portion of Table 3.18 are based on still air (natural convection) at the inner surface of the fenestration and a 7.5 mph wind at the outer surface. For these conditions, h_i is about 1.46 Btu/(hr · ft² · F) and h_o is 4.0, so the inward-flowing fraction of the absorbed heat for single glazing (neglecting resistance of the glass) is:

$$N_i = h_i/(h_i + h_o) = 1.46/(5.46) = 0.267 \qquad (A3.19)$$

For other indoor and outdoor conditions, the surface coefficients will vary over a considerable range, and N_i will also change. For comparison, the top, central portion of Table 3.18 also lists shading coefficients for $h_o = 3.0$. The designer should be aware of possible increases or decreases in the Shading Coefficient for any fenestration which result when the surface conditions vary from still air and for a 7.5 mph wind at the inner and outer surfaces, respectively. The Shading Coefficient for any fenestration will rise above the tabulated values when the inner surface coefficient is increased because of forced air flow

over the surface and when the outer surface coefficient is decreased by lower wind velocity. Conversely, the Shading Coefficient will fall somewhat below the tabulated values when the air at the inner surface is still and the outside wind speed rises above 7.5 mph.

Most of the Shading Coefficients given in the "no interior shading" portion of Table 3.18 are for uncoated single glass, in which the reflectance ranges downward from 0.08 for double-strength sheet to 0.05 for 1/4 in. heat-absorbing plate/float. If solar-reflective films or coatings are used, the absorptance will be reduced for any given value of the transmittance. The values given in the table, including reflective coated glass, are typical of the glazing materials in common use in 1977. Development of new materials will be accompained by lower values of SC and *U*. Generally, the manufacturers of such materials can supply appropriate values of their Shading Coefficients.

Interpolation of the tabulated values in Table 3.18 for insulating glass may be used when the inner light is clear sheet or plate glass. When heat-absorbing glass is used in double glazing, it should be installed in the outer light, so that the absorbed heat can be more readily dissipated to the atmosphere.

Shading Coefficients for Fenestration with Internal Shading — Draperies, Venetian Blinds, and Roller Shades.

The effectiveness of any internal shading device is dependent upon its ability to reflect the incoming solar radiation back through the fenestration before it can be absorbed and converted into heat within the building. When internal shading devices are used with glass fenestration, small differences in glass properties become unimportant from a practical point of view.

The top, right portion of Table 3.18 gives Shading Coefficients for Venetian blinds and roller shades when used with single glazing of four different transmittance ranges. These values apply when the fenestration is sunlit and also when it is on the shaded side of the building. The tabulated values apply specifically to horizontal Venetian blinds, but they may be used with good accuracy for vertical blinds when the blinds are adjusted so that no direct solar radiation can enter through them. The lower, right portion of Table 3.18 gives Shading Coefficients for Venetian blinds and roller shades when used with insulating glass. The first line applies for windows in which both lights are high-transmittance glass, while the second line applies when the outer light is heat-absorbing and the inner light is clear glass. The designer should bear in mind the fact that blinds, roller shades, and drapes will generally not be tightly closed on the shaded exposures of a building.

The wide variety of glasses available today makes it imperative that the manufacturer be consulted for more precise data on a given product. The Shading Coefficient with no interior shading is included for each classification of single and insulating glasses in order to give the designer a reference point in understanding the effect of the interior shading device upon the Shading Coefficient. This will allow him to estimate the benefit to be derived from the use of a common type of interior shading with a specific glazing. Such an added benefit decreases considerably as the performance of the glazing itself increases. Similarly, the flexibility of the fenestration system decreases as the performance of the glazing increases. This is due to the extremely low transmittances encountered and the inability of the occupant of the space to change this factor, as he can with the use of indoor shading devices in combination with higher transmittance glazing.

For a single-glazed fenestration which is shaded on the indoor side by a fabric drape, the Shading Coefficient can be found by use of Fig. 3.1 accompanying Table 3.20.

While flat-fabric properties of reflectance and transmittance are used to enter this figure, the resulting Shading Coefficient is for the selected type of glass in combination with a loose-hanging drape with 100% fullness where the fabric width is twice the width of the window opening.

The solar-optical properties of drapery fabrics can be determined accurately by laboratory tests, and manufacturers can usually supply values of the transmittance and reflectance of their products for solar radiation. In addition to these properties, the Openness Factor, which is the ratio of the open area between the fibers to the total area of the fabric, is a useful property that can be measured exactly. The Openness Factor can also be estimated by inspection, since the human eye can readily distinguish between tightly woven fabrics which permit very little direct radiation to pass between the fibers and loosely woven fabrics which allow the sun's rays to pass freely.

Drapery fabrics may be classified in terms of their solar-optical properties as having specific values of fabric transmittance and reflectance. Fabric reflectance is the controlling factor in determining the ability of a fabric to reduce solar heat gain. Based on their appearance to the eye, draperies can also be classified by yarn color as dark, medium, and light, and by weave as closed, semiopen and open. The apparent color of a fabric is determined by the reflectance of the yarn itself. The yarn reflectance can be found by reference to Fig. 3.1. Fig. 3.2 shows a classification chart for drapery fabrics in which nine types are rated in terms of their Openness Factors and yarn reflectances. Openness Factor is designated by Roman numerals, with I referring to open-weave materials, II to semiopen, and III to closed-weave fabrics. The range of Openness Factors to which these designations apply is also shown. Yarn reflectance is designated by capital letters, with D for dark, M for medium, and L for light. The ranges of yarn reflectance to which these color designations apply are also shown.

Fig. 3.2, with the aid of Fig. 3.1 and Table 3.20, is a guide to the designer in estimating the probable Shading Coefficient for a fabric-glass combination when the solar-optical properties are not known exactly. Whenever possible, fabric reflectance and transmittance values should be obtained from the manufacturer so that more accurate estimates of the Shading Coefficients can be made using Fig. 3.1. Visual estimations of openness and yarn reflectance interpreted through Fig. 3.1 or Fig. 3.2 are valuable in judging the effectiveness of drapes for protection against excessive radiant energy from either sunlight or sunheated glass, for brightness control, for providing either outward view or privacy, and for sound control.

The fabric reflectance vs. fabric transmittance coordinates are best adapted to accurate determination of the Shading Coefficient. However, because they do not reveal the environmental effects of draperies, the yarn reflectance vs. fabric openness coordinates must be used, as depicted in Fig. 3.2. Both systems may be shown on the same chart, together with reference to various glass types as well as drapery types. Translation of information between the two systems is accomplished by the use of Fig. 3.1.

Shading Coefficients and Solar Heat Gain with External Shading

The most effective way to reduce the solar load on fenestration is to intercept direct radiation from the sun before it reaches the glass. Windows fully shaded from the outside will have a reduction in solar heat gain of as much as 80%. In one degree or another fenestration can be shaded by roof overhangs, vertical and horizontal architectural projections, awnings, heavily proportioned exterior louvers, insect screening and patterned fiberglass screening having an increased number of strands for

sunlight interception, or by sun screens of miniaturized fixed metal louvers. In all exterior shading structures it is important that a free movement of air be allowed to carry away the heat absorbed in them. Effectiveness of screening and, to a lesser extent, miniaturized louvers is reduced when installed too close to the glazing. Refer to the manufacturer's instructions regarding the need for ventilation space. It is also important to consider the geometry of the structures relative to the changing sun position so that the times and quantities of direct sunlight penetration may be determined.

The ability of horizontal panels or louvers to intercept the direct component of solar radiation depends upon their geometry and the profile or shadow-line angle. (See Table 3.21)

When the profile angle for slat-type sunshades is above the cutoff angle, the highest angle shown in Table 3.21, for example, straight-through transmission of direct radiation is completely eliminated but the transmitted diffuse and the reflected-through components remain. Their magnitude depends chiefly upon the reflectance of the surfaces of the sunshade.

When horizontal louvers are fabricated in conventional width-spacing ratios but are reduced to diminutive dimensions and framed as window screens they retain their shading characteristics while gaining in effective transparency by eliminating the coarse striation pattern of large louvers. Table 3.21 gives shading coefficients for several types of louvered sun screens.

Glass Solar Cooling Load with External Shading; Roof Overhangs — Horizontal and Vertical Projections — Window Reveal

During certain seasons of the year and for some exposures, horizontal projections can result in considerable reductions in solar heat gain by providing shade. This is particularly applicable to South, Southeast and Southwest exposures during the late spring, summer, and early fall. On East and West exposures during the entire year, and southerly exposures during the winter, horizontal projections would have to be excessively long to be effective. The horizontal projection, P, required to produce a given shadow length, S_H, on a window or wall for any time of day or year is obtainable from the left side of Table 3.29.

It is advantageous to lay out a vertical section view of a wall or window and an architecturally desirable projection, adding a line from the tip of the projection to the bottom of the window or desired shadow. (See Fig. 3.5, left side). All times of day and year when the desired shadow will be achieved can be readily observed by scanning the applicable column of the left side of Table 3.29 for the times when the actual S_H/P exceeds the required S_H/P.

A vertical fin or projection, P_V, required to produce a given shadow width, S_W, on a window or wall for any given time of day and year is obtainable from the right side of Table 3.29. Application of S_W/P_V is similar to that for S_H/P. (See Fig. 3.5, right side).

For windows, the glass area which is used in calculations is likely to be significantly lower than the total window area, and the effect of the opaque areas must be borne in mind by the designer (Table 3.14B). A window with a significant depth of reveal will generally have part of the glass area shaded by the mullions and transoms. The area that is shaded varies throughout the day, but it can be estimated by treating mullions and transoms as vertical and horizontal projections.

Consider only the left portion of Fig. 3.5, which deals with horizontal projections. It is important to observe and to carefully apply the physical distinction between the unprimed quantities (P, for example) and the primed quantities (P', for example). P is the total horizontal projection from the surface in question and S_H is its total resultant shadow length. In Section AA, where the recessed window is not involved, the application of S_H/P from the left side of Table 3.29 is straightforward, $S_H = (S_H/P) \times P$. In Section BB, where the recessed window is involved, the shadow line may fall above the window, on the window, or below the window. For the first case shown in Section BB, low S_H/P, although $S_H/P = S_H'/P'$, it is the primed ratio, and not the unprimed, which is important in the analysis of the glass solar load. P' is the "horizontal projection" when shading on the glass results only from the window recess, and S_H' is the corresponding actual shadow length, measured only from the top of the recession.

In the second case of Section BB, projection P includes the window recess, and S_H includes shaded glass and shaded wall above the glass. This is a unique case in which the same sunray passes the edge of the major overhang and the edge of the projection from the window recess. Although P' and S_H' are not marked here, they are defined as before and $S_H/P = S_H'/P'$ as in the first case.

In the third case of Section BB, the projection, P, major overhang plus window recess, produces the shadow on the window, but the height of shaded glass is again less than S_H. Further, P' is not defined.

In the fourth, and final case, of Section BB, high S_H/P, the entire glass is in shadow and P is only the major overhang projection.

Consider only the right portion of Fig. 3.5, which deals with vertical projections. A left and a right side fin are shown, but only one of these at a given time can be producing a shadow on the wall and/or window between them. The examples shown use the prime symbols somewhat differently than they were used for the left side of the figure which dealt with the horizontal projections. Here P_V' is the actual projection producing a shadow line on the glass, being sometimes the window recess depth and sometimes the sum of side fin projection and window recess. S_W' always corresponds to P_V'. Unprimed symbols, P and S_W, are reserved to relate only to shading on wall surface area.

After the locations of shadow lines on the glass have been found by use of the left and/or right sections of Table 3.29, the glass solar cooling load is calculated separately for the externally unshaded and externally shaded portions by Eq. (A3.20):

$$q_{unsh} = A_{unsh} \times SC \times SHGF_{max.\,unsh} \times CLF_{unsh}$$
$$q_{sh} = A_{sh} \times SC \times SHGF_{max.\,sh} \times CLF_{sh} \qquad (A3.20)$$

The total glass solar cooling load is given by Eq. (A3.21):

$$q = q_{unsh} + q_{sh} \qquad (A3.21)$$

In applying Eqs. (A3.20) and (A3.21),

1. Unshaded and shaded glass areas must add to total glass area, A_g, and A_{sh} is calculated from the location of the glass relative to shade producing members by use of S_H/P and S_W/P_V values from Table 3.29.
2. $SHGF_{max,unsh}$ is found in Table 3.25. $SHGF_{max,sh}$ is found from Table 3.26 for latitudes 0 to 24 deg North, using true window orientation. For North latitudes greater than 24 deg, $SHGF_{max,sh}$ is found from Table 3.25, using North orientation. The $SHGF_{max,sh}$ of Table 3.26 are the maximum monthly diffuse components of $SHGF_{unsh}$, thus being consistent with the fact that shaded glass has no direct component irradiation falling on it. The $SHGF_{max,\,unsh.\,N}$ of Table 3.25 are adequate replacements for $SHGF_{max,sh}$ at any orientation for North latitudes greater than 24 deg, because calculations have shown 1) that North facing surfaces receive little direct sunlight at such latitudes, and

2) that diffuse components of irradiation are not strongly orientation dependent.

3. Cooling Load Factor, CLF, is found in either Table 3.27 (without internal shading) or Table 3.28 (with internal shading). For CLF_{unsh}, the true window orientation is used. For CLF_{sh}, which is used in conjunction with $SHGF_{sh}$, the CLF for the North orientation should be used regardless of the actual orientation. The use of CLF_{sh} as approximately equal to $CLF_{unsh, N}$ is entirely consistent with the handling of $SHGF_{max, sh}$ for latitudes greater than 24 deg North. For North latitudes less than 24 deg, it is not as good an approximation, but is sufficiently accurate.
4. Shading Coefficient, SC, is obtained for the glass unit, sun shades, or internal shading devices as discussed earlier in this section. If several SC values apply in the same application, these are multiplied together.

A3.4 CALCULATION OF EXTERNAL COOLING LOAD; GENERAL AND SPECIFIC PROCEDURES

In order to calculate a design external cooling load, detailed information about the design of the building and the weather data at design conditions are required. The following procedure should be followed:

a. Obtain characteristics of the building. Building materials, component size, and shape are usually determined from building plans and specifications.
b. Determine building location, orientation, and external shading. Plans and specifications will have this information. Shading from adjacent buildings can be determined by a site plan or by visiting the proposed building site.
c. Obtain appropriate weather data and outdoor design conditions. Weather data may be obtained from local weather stations or from the National Climatic Center, Asheville, North Carolina 28801. Outdoor design conditions for a large number of weather stations are given in Table 2.1.
d. Decide on indoor design conditions such as indoor dry-bulb temperature, and indoor wet-bulb temperature.
e. Decide upon the time of day and day of month of year to do the external cooling load calculation. Frequently several different times on a given day are required. The particular day and month are quite often dictated by the peak solar conditions.

Summary of Combining Conduction, Convection, and Radiation Effects for Determination of External Cooling Load

The variables affecting external cooling load calculations are numerous, often difficult to define precisely, and always intricately interrelated. Components due to conduction through external walls and roofs vary in magnitude over a wide range during a 24-hr period because of the variable effects of solar radiation and changes in outdoor temperature. Components due to conduction through fenestration, though analogous to those through external walls and roofs, must be handled separately. Direct radiation gain through fenestration has no equivalent in opaque walls and roofs.

Since cyclic changes in external cooling load components are generally not in phase with each other, a detailed analysis is required to establish the resultant external maximum cooling load for a building or zone. A zoned system, that is, one serving several areas, each of which has its own temperature control, must often handle peak loads in different hours. Also, at certain times of the day during the heating season, some perimeter zones may require heating and other perimeter zones may require cooling.

Finally, although the sample calculations given in this Chapter relate to external cooling load components, or to steps toward such component calculations, non-external cooling load components may sometimes be more important in determining the peak time of the space cooling load and the cooling equipment design.

EXAMPLE A3.1 — *UA* Factor for a Composite Wall Structure — Requiring Parallel Heat Flow Analysis

Calculate the *UA* factor for a 30 ft by 10 ft vertical composite wall:

Outside surface (summer conditions)
4 in. yellow face brick
3/4 in. air space
8 in. H.W. concrete block (3 oval core)
Furring 1 × 2 in. at 16 in. O.C.; 1 in. polystyrene between (3.5 lb/ft³)
1/2 in. gypsum wall board, painted white
Inside surface (still air)

Item	Table/Graph	Explanation and Notes
$q = U \times A \times CLTD$	Table 1.2	Cooling Load Equation; *UA* Factor to be calculated
Area, A		$A = 10 \times 30 = 300$ ft^2
Surface Emittance, E	Table A3.1	Class 4, for yellow brick between 50 and 100 F, $E = 0.85$ to 0.95; Use $E_o = E_{1s} = 0.90$ as an average value Class 11, for white painted surface between 50 and 100 F, $E = 0.92$. Use $E_i = 0.92$. Class 3, for concrete between 50 and 100 F, $E = 0.85$ to 0.95 Use $E_{s2} = 0.90$
Effective Emittance, E_s, Air Space	Eq. A3.8	$1/E_s = 1/E_{1s} + 1/E_{2s} - 1$ $E_s = 0.82$
Resistance, R_s, Air Space	Table 3.4	Vertical air space, horizontal heat flow, 3/4 in. width; $E_s = 0.82$. For summer conditions use an approximate air space temperature of 90° F with a Δt across the air space of $\Delta t = 10$ F. For these conditions the tabulated value of $R = 0.84$ (hr · ft^2 · F)/Btu
Resistances of air films	Table 3.3	Any position surface (7.5 mph wind) any direction of heat flow; $E_o = 0.90$; $R_o = 0.25$ (hr · ft^2 · F)/Btu Vertical surface (still air) Horizontal direction of heat flow; $E_i = 0.90$; $R_i = 0.68$ (hr · ft^2 · F)/Btu
Resistance of Wall Layers	Table 3.1	Face brick; $R_{inch} = 0.11$ $R_1 = 4(0.11) = 0.44$ (hr · ft^2 · F)/Btu 8 in. H.W. concrete block (oval core), sand and gravel agg.: $R_2 = 1.11$ (hr · ft^2 · F)/Btu 1/2 in. gypsum wall board: $R_4 = 0.45$ (hr · ft^2 · F/Btu
Dimensions, furring strips		Nominal: 1 in. × 2 in. Actual: 3/4 in. × 1 1/2 in.

Item	Table/Graph	Explanation and Notes
Resistance of layers 3 (3_i = insulated path) (3_s = furring path)	Table 3.1	Layer 3 involves parallel flow paths. Two U values will be calculated: U_i through insulated path, and U_s through furring path. Then, U_{av} is based on weighting procedure (Eq. A3.9). R_{3i}: Polystyrene (R-12 exp): 3.5 lb/ft^3 $R_{inch} = 5.26$ $R_{3i} = 5.26\ (3/4) = 3.95$ (hr · ft^2 · F)/Btu R_{3s}: Softwoods: $R_{inch} = 1.25$ $R_{3s} = 1.25\ (3/4) = 0.93$ (hr · ft^2 · F)/Btu
Total Resistances R_{ti}, R_{ts}		Series path through insulation: $R_{ti} = R_o + R_1 + \ldots + R_{3i} + \ldots + R_i$ $R_{ti} = 0.25 + 0.44 + 0.84 + 1.11 + 3.95 + 0.45 + 0.68 = 7.72$ Series through furring strips: (replace R_{3i} by R_{3s}) $R_{ts} = R_{ti} - R_{3i} + R_{3s}$ $R_{ts} = 7.72 - 3.95 + 0.93 = 4.70$
Transmission Coefficients, U_i, U_s		$U_i = 1/R_{ti} = 1/7.72$ $= 0.13$ (hr · ft^2 · F)/Btu $U_s = 1/R_{ts} = 1/4.70$ $= 0.21$ (hr · ft^2 · F)/Btu
S, percentage of area backed by furring strips		Strips are 1.5 in. wide on 16 in. centers $S = (1.5/16)(100) = 9.4\% = 10\%$
Transmission Coefficient, U_{av}	Eq. A3.9	$U_{av} = (S/100)\ U_s + (1 - \frac{S}{100})\ U_i$ $U_{av} = 0.1(0.21) + (0.9)\ (0.13)$ $U_{av} = 0.138$ Btu/(hr · ft^2 · F)
UA Factor		$UA = 0.138(300) = 41.4$ Btu/(hr · F)

EXAMPLE A3.2 Calculation of *UA* Factor for Single and Double Glass Windows, With and Without Internal Shading and Inside Air Velocity

Calculate the *UA* factors for the following window construction and conditions:

(A) Single regular plate glass vertical window, (3 ft × 5 ft)
No inside shades
Still air inside; 7.5 mph outdoor wind velocity
Summer conditions
Wood framing for glass, unit size 3.5 ft × 5.5 ft

(B) Same window and conditions as (A) except that dark colored, closed-weave drapes are used on the inside and kept fully closed. Assume average space between drapes and glass is 1 1/2 in. thick and has a mean air temperature of 85 F with room temperature of 75 F and outdoor temperature of 95 F.

(C) Conditions as in (A), but with inside air velocity on the single pane of glass changed from 0 to 200 fpm.

(D) Double insulating glass in the window unit of (A), 1/2 in. air space, low emittance coating of E = 0.20 on the outer glass surface facing the air space; all other glass surfaces uncoated. No inside shades. Inside air velocity across window of 200 fpm.

Item	Table/Graph	Explanation and Notes
$q = U \times A \times CLTD$	Table 1.2	Cooling Load Equation. UA to be calculated.
Area, A glass		$A_{glass} = 5 \times 3 = 15$ ft^2
Part (A) U, no adjustment for framing	Table 3.14A	Exterior, vertical, summer, no shade, flat glass, single $U = 1.04$ Btu/(hr · ft^2 · F)
U adjusted for wood framing	Table 3.14B	$A_{unit} = 3.5 \times 5.5 = 19.25$ ft^2 % glass $= 100 \times A_g/A_{unit}$ $= (15/19.25)(100) = 78\%$ Adjustment factor (wood sash with 80% single glass) = 0.90 $U = 1.04(0.90) = 0.94$
UA		$UA = 0.94(15) = 14.1$ Btu/(hr · F)
Part (B) U adjusted for inside shading	Table 3.14A	As in (A) except indoor shade $U = 0.81$ Btu/(hr · ft^2 · F)
U adjusted for wood framing	Table 3.14B	As in (A), adjustment factor = 0.90 $U = 0.81(0.90) = 0.73$
UA		$UA = 0.73(15) = 11.0$ Btu/(hr · F)
Part (C) U, no adjustment for framing nor for inside air velocity		U not adjusted; $U = 1.04$, as in (A)
R_t, still air		R_t, still air $= 1/1.04$ $= 0.96$ (hr · ft^2 · F)/Btu
R_i, inside film; V = 200 fpm		$R_i = 1/(h_{c_i} + h_{r_i})$ Eq. (A3.6) $h_{ci} = 0.99 + 0.21\ V$ Eq. (A3.12) where h_{ci} = inside glass surface convection coeff., Btu/(hr · ft^2 · F) V = air velocity, ft/sec $h_{ci} = 0.99 + 0.21(200$ fpm$)/(60$ sec/min$)$ $= 1.69$ at $V = 200$ fpm $R_i = 1/(1.69 + h_{ri})$; $V = 200$ fpm
R_i, inside film; still air	Table 3.3A	$E_i = 0.90$, still air, vert, surface, hor. heat flow $R_i = 0.68 = 1/(0.99 + h_{ri})$ at $V = 0$
h_{ri}		Assume h_{ri}, radiation film coefficient, is independent of velocity. (See Chapter 26, 1977 HOF, for exact treatment.) $0.99 + h_{ri} = 1/0.68 = 1.46$ $h_{ri} = 0.47$ Btu/(hr · ft^2 · F)
R_i; V = 200 fpm		$R_i = 1/(1.69 + 0.47) = 0.46$
R_t; V = 200 fpm		Outside resistance unchanged from Part (A) $R_t = R_{t(A)} - R_{i(A)} + R_{i(C)}$ $= 0.96 - 0.68 + 0.46$ $= 0.74$
U_{adj} for vel.		$U = 1/0.74 = 1.35$ Btu/(hr · ft^2 · F) as compared to 1.04 for still air inside. This represents an increase of 30% due to the increase in the inside velocity over single glass.

Item	Table/Graph	Explanation and Notes
U_{adj} for wood framing	Table 3.14B	As in (A), adjustment factor = 0.90 $U = 1.35(0.90) = 1.22$ Btu/(hr · ft² · F)
UA		$UA = 1.22(15) = 18.3$ Btu/(hr · F)
Part (D) Surface Emittances	Table A3.1 Class 6	Normal emittance window glass, 50-100 F $E = 0.90$ (uncoated surfaces) Given in problem statement $E = 0.20$ for inner surface of outer glass
Effective Emittance Air Space, E_s	Eq. (A3.8)	$\frac{1}{E_s} = \frac{1}{0.90} + \frac{1}{0.20} - 1$ $E_s = 0.20$
Resistance of Air Space, R_s	Table 3.4	$E_s = 0.20$, Vert. 1/2 in. thick space, hor. flow direction, air space temp. 90 F, air difference 10 deg F. $R_s = 1.67$(hr · ft² · F)/Btu
Outside Surface Resistance, R_o	Table 3.3	With $E_o = 0.90$, and for window outer surface, any position and direction of heat flow, at 7.5 mph wind, $R_o = 0.25$ (hr · ft² · F)/Btu
R_i, inside film $V = 200$ fpm		From Part (C), $R_i = 0.46$ at $V = 200$ fpm
R_t		Neglecting resistances of glass layers, $R_t = R_o + R_s + R_i$ $R_t = 0.25 + 1.67 + 0.46 = 2.38$
U adjusted for velocity		$U = 1/R_t = 0.42$ Btu/(hr·ft²·F) as compared to 1.35 for single glass, 200 fpm inside. The use of double glass represents a decrease of approximately 70%.
U adjusted for wood framing	Table 3.14B	Wood sash – 80% glass – double glass Adjustment factor = 0.95 $U = 0.42(0.95) = 0.40$ Btu/(hr · ft² · F)
UA		$UA = 0.40(15) = 6.0$ Btu/(hr · F)

EXAMPLE A3.3 — CLTD and q/A for a Typical Roof Construction from Table 3.8 (Roof No.9, Table 3.7) With and Without Correction

Determine the CLTD and q/A for a 4 in. H.W. concrete flat roof with 2 in. of roof insulation having manufacturer's specification of resistance of 3.33 (hr · ft² · F)/Btu per inch as given in Table 3.8 and corrected as necessary for the following conditions:

(A) Outdoor Design Correction Only

Time: 1700 (17 hr)
Inside Design: 78 F db
Month: July
Roof: Dark-colored, without suspended ceiling, no attic
Location: Beatrice, Nebraska (rural area)

(B) Color Correction and Outdoor Design

Time: 1100 (11 hr)
Inside Design: 78 F db
Month: July
Roof: Permanently light-colored, with suspended ceiling (air space resistance of 1.00 (hr · ft² · F)/Btu and acoustic tile, 1/2 in. (18 lb/ft³), no attic
Location: Same as in (A)

(C) Outdoor Design, Month-Latitude and Color Correction

Time: 2000 (20 hr)
Inside Design: 78 F db
Month: October
Roof: Same as in (B)
Location: Tulsa, Oklahoma (rural area)

Item	Table/Graph	Explanation and Notes			
				Summer	
Climatic Conditions	Table 2.1	**Col. 1**	**Col. 2**	**Col. 6**	**Col. 7**
		State — Station	Latitude (North)	Design db/wb 2-1/2%	Daily Range, F
Parts A & B		Nebraska Beatrice	40° 20′	95/74	24
Part C		Oklahoma Tulsa AP	36° 10′	98/75	22

Item	Table/Graph	Explanation and Notes
(A) Roof Construction	Table 3.7 & 3.11	Roof No. 9; 4 in. H.W. with 2 in. insulation. Table 3.7 gives code no. of layers as A_0, E_2, E_3, B_5, C_5, E_0, when 1 in. insulation. B_5 is replaced by B_6 for 2 in. insulation. Table 3.11 gives description for each of these code numbers. Check on the density of the concrete for such a roof, since a lighter density concrete, 80 lb/ft³, for example, has greater resistance, resulting in lower U.
Resistances, R		Thermal properties in Table 3.11 are representative only. Use actual conditions to get resistances from basic sources as follows:
	Table 3.3	Outside surface, $R_0 = 0.25$ (summer; 7.5 mph wind)
	Table 3.1	1/2 in. slag or stone, $R_1 = 0.08$ per 1 in. $R_1 = 0.5 \times 0.08 = 0.04$
	Table 3.1 Insulation Spec.	3/8 in. felt and membrane, $R_2 = 0.33$ (built-up roofing 0.375 in.); $R_3 = 2$ in. $\times$ 3.33 = 6.66
	Table 3.1	4 in. H.W. concrete, $R_4 = 0.08$ per in. (140 lb/ft³; not dried) $R_4 = 4 \times 0.08 = 0.32$
	Table 3.3	Inside surface, $R_i = 0.92$ (still air horizontal surface $E = 0.90$)
$R_t = R_0 + \ldots + R_i$		$R_t = 0.25 + 0.04 + 0.33 + 6.66 + 0.32 + 0.92$ $R_t = 8.52$ (hr · ft² · F)/Btu
$U = 1/R_t$		$U = 1/8.52 = 0.177$ Btu/(hr · ft² · F)
$CLTD_{uncorrected}$	Table 3.8 Upper Section	For Roof No. 9 at 1700 without a suspended ceiling CLTD = 53 deg F
Corrections to be made CLTD?	Table 3.8 Notes	Note (1) Explains general use of Table 3.8 Note (2) Adjustments
Indoor Design?	Table 3.13 Part a	No correction; $t_R = 78$ F, Table 3.13, part a) lists 0 correction
Outdoor Design?	Table 3.13 Part b	−2 F correction from Table 3.13, part b) interpolating at 95 F design db 24 deg F daily range

Item	Table/Graph	Explanation and Notes
Attic?		Not applicable; no attic, $f = 1.0$
Color?		No correction; dark roof, $K = 1.0$
Month-Latitude?	Table 3.12	No correction, July at 40 deg North latitude
$CLTD_{corrected}$	Table 3.8 Note (2)	$CLTD_{corr} = [(CLTD + LM) \times K + (78 - t_R) + (t_o - 85)] \times f$ $CLTD_{corr} = [(53 + 0) \times 1.0 + 0 - 2] \times 1.0$ $CLTD_{corr} = 51$ deg F
$q/A = U \times CLTD$		$q/A = (0.117)(51) = 6.0$ Btu/(hr·ft^2)
(B) Roof Construction	Table 3.7	Same as part (A) except with suspended ceiling
Resistance and U $R_t = R_o + \ldots + R_i$	$R_t = R_t(A) + R_{at} + 1.00$	As compared to (A) has two additional R terms: R_{at} for acoustic tile and 1.00 for the air space.
	Table 3.1	For 1/2 in. thick acoustic tile, 18 lb/ft^3, $R_{at} = 1.25$ (hr·ft^2·F)/Btu $R_t = 8.52 + 1.25 + 1.00 = 10.77$
$U = 1/R_t$		$U = 1/10.77 = 0.092$ Btu/(hr·ft^2·F)
$CLTD_{uncorrected}$	Table 3.8 Lower Section	For Roof No. 9 at 1100 with a suspended ceiling CLTD = 22 deg F
Corrections to be made to CLTD?	Table 3.8 Notes	Outdoor design correction = −2 F as in (A) Note (2b) Factor $K = 0.5$, permanently light-colored roof, rural area
$CLTD_{corrected}$	Table 3.8 Notes	$CLTD_{corr} = CLTD \times K + (t_o - 85)$ $= 22(0.5) - 2 = 9$ deg F
$q/A = U \times CLTD$		$q/A = 0.092(9) = 0.83$ Btu/(hr·ft^2)
(C) Roof Construction $U = 1/R_t$		Same as part (B) $U = 0.092$ Btu/(hr·ft^2)
$CLTD_{uncorrected}$	Table 3.8 Lower Section	For Roof No. 9 at 2000 with a suspended ceiling CLTD = 38 deg F
Corrections to be made to CLTD?	Table 3.8 Notes	
Outdoor Design?	Table 3.13 Part b	+2 F correction from Table 3.13, Part b) at 98 F design db, 22 deg F daily range
Color?		$K = 0.5$ as in part (B)
Month-Latitude?	Table 3.12	Correction given by Table 3.12 at October, 36 deg North latitude, horizontal
		Table 3.12 Month and Latitude Correction Lat. / Month / Hor. 32 / Oct. / −10 (36) / (Oct.) / (−12) 40 / Oct. / −14
		Month-Latitude Correction = −12 deg F

Item	Table/Graph	Explanation and Notes
$CLTD_{corrected}$	Table 3.8 Note (2)	$CLTD_{corr} = [(CLTD + LM) \times K + (t_o - 85)]$ $CLTD_{corr} = [(38 - 12)(0.5) + 2]$ $CLTD_{corr} = 15$ deg F
$CLTD_{corrected}$ Alternate	Table 2.2 replacing Table 3.13, Part b for outdoor design correction	Table 2.2 gives outdoor design temperature, t_o, for specific months for certain weather stations. For Tulsa, Oklahoma in October, $t_o = 86$ F. Then, $t_o - 85 = 1$ deg F as compared to 2 deg F from Table 3.13, Part b. $CLTD_{corr} = [(38 - 12)(0.5) + 1]$ $= 14$ deg F
$q/A = U \times CLTD$		Using Table 3.13, Part b for outdoor design correction, $q/A = 0.092(15) = 1.38$ Btu/(hr·ft^2) Using Table 2.2 for outdoor design temperature, $q/A = 0.092(14) = 1.29$ Btu/(hr·ft^2)

EXAMPLE A3.4 — Calculation of Maximum Total Cooling Load (Conduction Plus Solar) for a Recessed Window-Unit with Insulating Glass and Indoor Air Velocity

Calculate the maximum total cooling load, Btu/hr (conduction plus solar) for the following window unit and conditions:

Unit size 4 ft wide by 6 ft high, vertical, facing south; recessed 8 in. from wall
Wood sash
Unobstructed glass size, 43 3/4 in. wide by 67 1/8 in. high
Insulating double glass, 1/4 in. clear inner, 1/4 in. clean outer, 1/2 in. air space.
Summer conditions
Internal air velocity sweeping window, approximately 275 fpm.
Light room construction
Inside design: 76 F
Month: September
Location: Birmingham, Alabama (industrial area)

Item	Table/Graph	Explanation and Notes
$q = U \times A \times CLTD$	Table 1.2	Glass Conduction Cooling Load
$q = A(SC)(SHGF)(CLF)$		Glass Solar Cooling Load, applied separately to shaded and unshaded glass $q = q_{unsh.} + q_{sh}$
$q_{total,max}$		$q_{total,max} = (q_{cond} + q_{solar})_{max}$
Climatic Conditions Location Latitude (N or S) Outside Design Daily Range	Table 2.1	*Summer* **Col. 1** State and Station / **Col. 2** Latitude (North or South) / **Col. 6** Design db/wb (2 1/2%) / **Col.7** Daily Range, F Alabama Birmingham / 33°30″(N) (34 deg N) / 94/75 / 21
A_{glass}		$A_{glass} = (43.75 \times 67.125)$in.^{2} × (1 ft^2/144 in.^{2}) = 20.4 ft^2

Item	Table/Graph	Explanation and Notes
% glass		% glass = (20.4/24) (100) = 85%
U, no adjustment for framing.	Table 3.15	U-Factor for summer, double glass Type — Indoor Velocity CL & CL — 275 fpm 0.658 — $U = 0.658$
U, Adjusted for framing	Table 3.14B (Caution: Read notes carefully, especially if metal sash)	Windows — Double or Triple Glass All glass — 1.00 Wood sash – 80% glass — 0.95 (Wood sash, 85% glass = 0.96) U, adjusted for framing = 0.658 (0.96) = 0.63 Btu/(hr·ft²·F)
UA Factor		$UA = 0.63(20.4) = (12.85)$ Btu/(hr · F) (A = net glass area)
$CLTD_{uncorrected}$	Table 3.23	Hour . . . 12 13 14 15 16 17 CLTD, F 9 12 13 14 14 13 Maximum q, conduction plus solar, may not occur when CLTD is maximum
Corrections to be made to CLTD?	Table 3.23 Notes	
Inside and Outside Design?	Table 3.13a Table 3.13b	Inside temperature correction = 2 F Outdoor design correction = −1.5 F, say −2 F (94 F outside, 21 F daily range)
Color?		No color correction; industrial area
Month-Latitude?	Table 3.12; September	For South facing: Month-Lat. corr. N. Lat. 32 deg = 7 deg F N. Lat. 40 deg = 10 deg F For 34 deg N. Lat., Correction = 8 deg F
Total Correction		Total Corr. = 2 − 2 + 8 = 8 deg F
$CLTD_{corrected}$		Add 8 deg F to all values from Table 3.23 above Hour . . . 12 13 14 15 16 17 $CLTD_{corr, F}$ 17 20 21 22 22 21
$q_{conduction}$		$q_{cond} = UA(CLTD) = 12.85$ (CLTD) $q_{cond\ at\ 1200} = 12.85(17) = 218$ Btu/hr Hour . . . 12 13 14 15 16 17 q_{cond} 218 257 269 282 282 269
$SHGF_{max,\ unsh}$ (South) $SHGF_{max,\ sh}$ (North) N. Lat > 24 deg	Table 3.25	32 Deg. N. Lat — (34) — 36 Deg. N. Lat Sept. N 33, S 17 — N (32), S (179) — N 31, S 187 $SHGF_{max,\ unsh} = 179$ Btu/(hr · ft²) $SHGF_{max,\ sh} = 32$ Btu/(hr · ft²)
SC	Table 3.18A Insulating Glass	Type — Nom. Thickness — $h_o = 4.0$ Clear out Clear in — 1/4 in. each — 0.81

Item	Table/Graph	Explanation and Notes
CLF	Table 3.27 CLF_{unsh} CLF_{sh}	*without interior shading* North Lat Facing — Room Const. — *Solar time, hr* 12 13 14 15 16 S — L — 0.59 0.65 0.65 0.59 0.50 N — L — 0.76 0.80 0.82 0.82 0.79
S_H/P (Shade from top of recess; overhang)	$P = 8/12$ ft Fig. 3.4 Left Table 3.29, Left	For 34 deg N Lat interpolate between 32 and 40. Shadow Length, ft, per ft projection Table 3.29 Left *32 deg N Lat* (34) *40 deg N Lat* Time S — S Time *March Sept.* 800 1.6 (1.5) 1.2 1600 900 1.6 — 1.2 1500 1000 1.6 — 1.2 1400 1100 1.6 — 1.2 1300 1200 1.6 (1.5) 1.2 1200 S — S South facing for the month of Sept. yields the untypical condition that shade from overhang does not vary through the sunlit hours.
S_W/P_V (Shade from side of recess; side fin)	$P_V = 8/12$ ft Fig. 3.4, Right Table 3.29, Right	Shadow Width ft, per ft projection Table 3.29 Right *32 deg N Lat* (34) *40 deg N Lat* Glass Time S — S Time *March Sept.* 800 3.3 (3.15) 2.7 1600 900 1.9 (1.83) 1.6 1500 1000 1.1 (1.05) 0.9 1400 1100 0.5 (0.48) 0.4 1300 1200 0.0 (0.0) 0.0 1200 S — S Line in above tables shows right side shades in the morning, left side in the afternoon, with no shade from either side at noon.

The raw data needed to determine the maximum total cooling load (conduction plus solar) has been collected. At a given time of day, $q_{total} = q_{cond} + q_{solar,\ unsh} + q_{solar,\ sh}$. The results for q_{cond} show it peaking at 1600 with only a slightly higher value than at 1400. The results for the horizontal and vertical shadow lines show that the least shading of glass will occur at 1200, while the CLF Table 3.27 shows $CLF_{max,\ unsh}$ occurring at 1300 or 1400. Consider the solar load at each hour from 1200 to 1400 and add on the conduction load.

Item	Table/Graph	Explanation and Notes			
$A_{unshaded}$ and A_{shaded}		Assume % glass in total unit applies to unshaded part of unit (85%)			
		$A_{unsh. glass} = (6 - S_h)(4 - S_W)(0.85)$			
		$A_{sh. glass} = 20.4 - A_{unsh. glass}$			
		Using $P = P_V = 8$ in. $= 2/3$ ft;			
		$S_H = 2/3\ (S_H/P)$ and $S_W = 2/3\ (S_W/P_V)$			
		Time	12	13	14
		S_H/P	1.5	1.5	1.5
		S_H	1.0	1.0	1.0
		S_W/P_V	0.0	0.48	1.05
		S_W	0	0.32	0.70
		$A_{unsh. gl}$	17.00	15.64	14.03
		$A_{sh. gl}$	3.40	4.76	6.37
q_{unsh} and q_{sh}		$q_{unsh} = A_{unsh}\ SC(SHGF_{max. unsh})(CLF)_{unsh}$ $= SC(SHGF_{max. unsh})(A_{unsh})(CLF)_{unsh}$ $= (0.81)(179)(A_{unsh})(CLF)_{unsh}$			
		$q_{sh} = (0.81)(32)(A_{sh})(CLF)_{sh}$			
		Time	12	13	14
		q_{unsh}	1454	1474	1322
q_{cond} previously calculated		q_{sh}	67	99	135
		q_{cond}	218	257	269
q_{total}, solar and conduction		(add)	1739	1830	1726
		$q_{max. total} = 1830$ Btu/hr at 1300			

A4 INTERNAL LOADS

A4.1 LIGHTING

An accurate estimate of the space cooling load imposed by lights is essential in the design of air-conditioned systems since often it is the major component of the space load. Calculation of this load component is not straightforward; the rate of heat gain to the air from lights can be quite different from the power supplied to them.

Some of the energy emanating from lights is in the form of radiation which only affects the air after it has been absorbed by walls, floor and furniture and has warmed them to a temperature that is higher than the air temperature. This absorbed energy stored by the structure contributes to the space cooling load after a time lag and is present after the lights are switched off. This lag effect should be taken into account in the calculation of the cooling load since this is lower than the instantaneous heat gain and may affect the peak load significantly.

The instantaneous rate of heat gain from electrical lights is

$$q_{inst} = 3.41 \times q_i \times F_u \times F_s \qquad \text{(A4.1)}$$

where

- q_{inst} = instantaneous rate of heat gain in Btu/hr.
- 3.41 = conversion factor from watts to Btu/hr.
- q_i = summation of all incandescent light and fluorescent lamp wattages in conditioned space.
- F_u = use factor—the ratio of wattage in use to total installed wattage.
- F_s = special allowance factor—for fixtures which require more power than their rated wattage. For fluorescent fixtures F_s accounts for ballast losses.

The amount of q_{inst} which is transferred to the air is entirely a sensible cooling load. This is given by

$$q_s = \text{CLF} \times q_{inst} \qquad \text{(A4.2)}$$

where

- q_s = sensible cooling load in Btu/hr
- CLF = cooling load factor. CLF is a function of the mass of the building, floor covering, ventilation rate, type of light fixture and time.
- q_{inst} = instantaneous rate of heat gain in Btu/hr

The value of CLF is obtained by identifying the proper "a" and "b" classifications as described in Tables 4.2 and 4.3 and then using these classifications in Table 4.4. The "a" classification depends on the location of the light fixture relative to the return air stream and the nature of the return air in the ceiling (ducted or unducted). The numerical value of "a" is actually the fraction of the light power convected to the air but this value is not to be used in any calculations. The "b" classification depends on the construction of the building, which is given as weight of floor, the room air circulation and the type of supply and return system.

The value of CLF × q_{inst} is the energy convected directly from the lights to the air plus the portion of the radiated energy that has been absorbed previously by the mass of the building and is now being convected to the air. It is this last portion which builds up with time when the lights remain on. When the lights are just turned on the CLF is the convected fraction of the total light wattage direct from the lights plus the convected fraction of the heat held in the building from the previous day. Note that the value of "a" is the jump in the CLF after the lights have been on for 1 hr. The numerical values of CLF in Table 4.4 were obtained by a combination of experimental and analytical studies done at the National Research Council.[1]

There are actually five separate tables under the Table 4.4 listing. The tables are for 8, 10, 12, 14 and 16 hr of continuous lighting use. The one table which best fits the situation should be used. If the lights are on only 4 hr a day, then strictly speaking the tables are not applicable. The tables are based on the fact that the conditioned space temperature is maintained at a constant temperature when the lights are off. If the cooling system is to be operated only during the period when the lights are on then Tables 4.2 through 4.4 are not to be used and the CLF should be taken as 1.0. The idea here is that if the portion of the heat from the lights that goes into the structure is not removed during non-occupied hours it must be removed the following day. Another way of stating this would be, if the cooling system is to operate on a 24-hr basis then part of the heat from the lights is removed during the occupied hours and the remainder during the non-occupied hours. In this case the use of Tables 4.2 through 4.4 will prevent the oversizing of the cooling equipment. The situation described here is shown schematically in Fig. A4.1.

When the lights are on 24 hr a day, use a CLF of 1.0. If a portion of the lights are on one schedule and another portion is on another lighting schedule, then work out both portions separately and add the results together.

For cases where the return air flows through the light fixture into a ceiling space or duct, the convected portion of the heat directly from the lights does not enter the conditioned space.

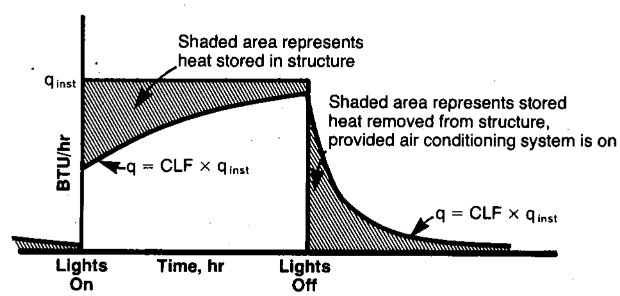


Fig. A4.1 The Effect of Thermal Storage on the Cooling Load Due to Lights

The radiated portion enters the conditioned space, increases the temperature of the mass of the building and convects heat to the air as previously described. This latter portion of heat is drawn out the return duct and combined with the convected portion directly from the lights thus the cooling load felt at the cooling coil is found as before (Eq. A4.2). The cooling load in the conditioned space, however, is CLF × q_{inst} minus the convected portion that goes directly into the return air. This convected portion is a function of the quantity of flow through the fixture, the type of fixture and for a ceiling space return, the type of suspended ceiling and the construction of the floor above. The fraction of heat removed by the air flowing through vented lights, the convected portion, with two types of return air systems is shown in Fig. 4.1. The curve for the return air through the ceiling space is lower because a portion of the heat removed from the light re-enters the conditioned space through the ceiling and also goes to the floor above. Although venting the lights does not alter the coil cooling load, it significantly reduces the space cooling load and therefore reduces the required supply air to those spaces.

For a more complete and detailed analysis of the heat balance for vented lighting fixtures and plenum temperatures refer to Chapter 3, pages 3.5-3.7 1976 Systems, ASHRAE HANDBOOK & Product Directory.

A4.2 PEOPLE

The rates at which heat and moisture are given off by human beings depend on the type of activity, mode of dress and various environmental conditions. Some practical values for these rates are given in Table 4.5 for the approximate conditions, activity and dress appropriate to the applications listed and which are commonly encountered.

The latent heat gain from people can be considered as an instantaneous cooling load, but the total sensible heat gain is not converted directly to cooling load. The radiant portion is first absorbed by the surroundings and then convected to the room at some later time depending upon the thermal characteristics of the room. The radiant portion of the sensible heat loss from men and women is generally near 70% and varies only a few percent from that value. This value of 70% was used to generate the cooling load factors in Table 4.6.

If the space temperature is not maintained constant during the 24-hr period, that is, if the cooling system is shut down during the night for example, then a CLF of 1.0 should be used. This pulldown load is a result of not removing the stored sensible heat in the structure and thus reappears as a cooling load when the system is started the next day.

If there is a high people density such as occurs in theaters and auditoriums, there is a reduced quantity of radiation to the walls and room furnishings. A CLF of 1.0 should be used in this situation.

A4.3 APPLIANCES AND LABORATORY EQUIPMENT

The most common types of heat producing appliances found in the conditioned area are those used in food preparation in commercial and industrial food service establishments. Laboratory tests have shown that appliance surfaces contribute most of the heat in these situations. When the appliance is installed under an effective exhaust hood only the radiant portion of the heat stays in the conditioned space, the convected and latent heat being removed with the exhaust air.

The instantaneous rate of heat gain for hooded appliances and laboratory equipment is

$$q_{inst} = q_r \times F_u \times F_R \times F_G \qquad (A4.3)$$

where

q_{inst} = instantaneous rate of heat gain in Btu/hr
q_r = manufacturer's input rating in Btu/hr
F_u = use factor. Because of the diversity of appliance use and the on-off effect of thermostatic controls, a use factor of 0.50 should be used for commercial kitchens. Table 4.7 uses $F_u = 0.50$.
F_R = radiant fraction for hooded appliances that stays in condition space. Table 4.7 uses $F_R = 0.32$.
F_G = special factor for hooded gas appliances. Gas fired appliance surfaces require considerable more heat to attain the same temperature as would be achieved by electric or steam. Because the radiant heat depends on the surface temperature and not upon q_r, F_G will be less than 1.0. Table 4.7 uses $F_G = 0.625$ for gas and, of course, $F_G = 1.0$ for electric or steam.

For hooded appliances, q_{inst} is all sensible heat and

$$q_s = \text{CLF} \times q_{inst} \qquad (A4.4)$$

where

q_s = sensible cooling load in Btu/hr for hooded appliances
CLF = cooling load factor
q_{inst} = instantaneous cooling load in Btu/hr from Eq. (A4.3)

For unhooded appliance and laboratory equipment all the heat stays in the conditioned space, thus only a use factor is needed.

$$q_{inst} = q_r \times F_u \qquad (A4.5)$$

where

q_{inst} = instantaneous rate of heat gain in Btu/hr
q_r = manufacturer's input rating in Btu/hr
F_u = use factor. Table 4.7 uses $F_u = 0.50$

For unhooded kitchen appliances (Table 4.7) 66% of q_{inst} is assumed to be sensible and the remaining 34% latent load, thus

$$q_s = 0.66 \times \text{CLF} \times q_{inst}$$
$$q_l = 0.34 \times q_{inst} \qquad (A4.6)$$

where

q_s = sensible cooling load in Btu/hr for unhooded appliances
q_l = latent cooling load in Btu/hr for unhooded appliances
CLF = cooling load factor
q_{inst} = instantancous cooling load in Btu/hr from Eq. (A4.5)

Tables 4.8 and 4.9 are, for the most part, based on Eq. (A4.3) and (A4.5) and for unhooded conditions the 2/3 and 1/3 split between sensible and latent heat gain. The column titled "probable maximum hourly input" is the manufacturer's input rating times the use factor, generally about 0.50. Recent research[2] has

been using "actual input energy required to maintain appliance surface temperatures" as a substitute for "probable maximum hourly input." In some cases, such as electric griddles, fryers and steam cookers these inputs are considerably lower than the manufacturer's input rating times a use factor of 0.50.

A4.4 POWER EQUIPMENT

When equipment of any sort is operated within the conditioned space by electric motors the heat equivalent of this operation must be considered in the heat gain. Motors are rated by the power delivered by the shaft. Equipment attached to the motor will absorb the shaft power and then transfer this power as heat gain to the conditioned space. When the motor is outside the conditioned space or air stream and the equipment within the conditioned space, the instantaneous heat gain is

$$q_{inst} = 2545 \times hp \times F_L \qquad (A4.7)$$

where

q_{inst} = instantaneous heat gain in Btu/hr
2545 = horsepower to Btu/hr conversion factor
hp = horsepower rating of motor in units of hp
F_L = load factor

The load factor is the fraction of the rated shaft horsepower being delivered to the equipment. Like all power delivering apparatus it is important to appreciate that the rated horsepower is a maximum (nominal) rating and that this power is not being delivered just because the motor is running. The load factor can very from zero to as high, in some cases, as 1.4 (overload). Some typical motor overload limits are given in Table 4.13. Overloading motors is allowed only when they have an intermittent duty cycle.

When both the motor and the equipment are in the conditioned space then the heat given off due to the inefficiencies in the motor must be added to that delivered to the equipment. The instantaneous heat gain for this condition is

$$q_{inst} = 2545 \times F_L \times hp \times \frac{1}{\eta_p} \qquad (A4.8)$$

where

η_p = motor efficiency = motor shaft power divided by the power input to the motor

When the motor is inside the conditioned space and the power absorbing equipment is outside, the instantaneous heat gain is

$$q_{inst} = 2545 \times F_L \times hp \times \frac{1 - \eta_p}{\eta_p} \qquad (A4.9)$$

Typical values of η_p are given in percent in Table 4.12. These values of η_p are used to calculate the instantaneous heat gains, with $F_L = 1.0$, in Columns A (Eq. A4.8), B (Eq. A4.7) and C (Eq. A4.9). When motor loads are an appreciable portion of the total cooling load, motor efficiencies should be obtained from the manufacturer and then applied to Eq. (A4.7), (A4.8) or (A4.9). Also the efficiencies given in Table 4.12 are for a load factor of one. Efficiencies decrease significantly with decreasing load factor. For example, a motor which has a efficiency of 87% at full load might only have an efficiency of 60% at a load factor of 0.10. If the equipment is used on an intermittent schedule, then an appropriate usage factor must be applied to these equations.

For power equipment there is no latent cooling load component, thus

$$q_s = CLF \times q_{inst} \qquad (A4.10)$$

where

q_s = sensible cooling load in Btu/hr
CLF = cooling load factor. Use Table 4.11 (appliances without hoods)
q_{inst} = instantaneous cooling load in Btu/hr (from Eq. (A4.7), (A4.8) or (A4.9)

If the cooling system is shut down after working hours then use CLF = 1.0.

REFERENCES

[1] Mitalas, G.P., "Calculating Cooling Load Caused by Lights," ASHRAE JOURNAL, June 1973.
[2] Talbert, S.G., Flanigan, L.J., and Eibling, "An Experimental Study of Ventilation Requirements of Commercial Electric Kitchens," ASHRAE TRANSACTIONS, Vol. 79, Part I, 1973, p. 34.

A5 INFILTRATION AND VENTILATION

The equations which represent infiltration are complex and difficult to use, but it is possible to put these equations in convenient table and graphical form. Much of the following material describes how the graphs were made and the restrictions placed upon them.

A5.1 INFILTRATION AND VENTILATION

Infiltration is the uncontrolled and often undesired leakage of air into a building through cracks in the walls and ceilings and through the perimeter gaps of windows and doors. The flow of the air into a building through doorways resulting from normal opening and closing is also generally considered infiltration. The flow of air leaving the building by these means is called exfiltration. Ventilation, either natural or forced by fans, is the intentional movement of air into and out of a building through specified openings.

For summer conditions the infiltrating and ventilating air has to be cooled to the desired space temperature. This represents a cooling load and must be included in the total equipment or room cooling load depending on where the air is introduced. The equation for this load is

$$q_s = 1.10 \times \Delta t \times \text{cfm} \tag{A5.1}$$

A more complete explanation of this equation is given in A6. By a similar analysis Eq. (A5.1) can be used to determine the heating load caused by infiltrating and ventilating air. For low humidity winter weather at standard conditions, the value of 1.10 is usually replaced by 1.08.

For summer conditions some of the water vapor of the infiltrating and ventilating air is usually condensed on the cooling system coils and thus constitutes a part of the total cooling load. The equation for this latent load is

$$q_l = 4840 \times \Delta W \times \text{cfm} \tag{A5.2}$$

A complete explanation of Eq. (A5.2) is given in A6.

If humidification of a space is required such as in the heating season or to maintain higher humidities, heat must be supplied to a humidifier to vaporize the amount of water that is deficient in the infiltrating or ventilating air. Eq. (A5.2) gives this required latent heating load for humidification.

Ventilation air for human occupancy is introduced into a conditioned space to maintain the oxygen level and to dilute odors and other contaminants given off by people. Ventilation requirements for a wide range of living and working conditions are given in Table 5.3. These data are abstracted from ASHRAE Standard 62-73 which is based on controlling contaminants given off by people. The standard does not specify the required ventilation air for diluting domestic and industrial contaminants.

It is possible that the outside air based on the ventilation requirements obtained from Table 5.3 will be inadequate for another reason. When air is exhausted from a conditioned space, such as from kitchen or laboratory hoods or washrooms, then additional make-up air will be required if the amount of exhausted air exceeds the ventilation given by Table 5.3.

Special fire and safety regulations or codes should be consulted for ventilation requirements in applications such as hospitals or laboratories. For some situations air flow from adjoining spaces is not permitted. Also, many states have or are enacting energy conservation regulations which will impact on the design of ventilation systems.

Infiltration is caused by a greater air pressure on the outside of the building than on the inside. The quantity of the infiltrated air depends on this pressure difference; the number, the size, and the shape of the cracks involved; the number, the length and width of the perimeter gaps of windows and doors; and the nature of the flow in the crack or gap (laminar or turbulent). The relation connecting these quantities is

$$Q = C(\Delta p)^n \tag{A5.3}$$

where

- Q = quantity flow rate of leaking air.
- Δp = pressure difference between the air pressure inside the building and the air pressure outside the building. When the outside pressure is greater than the inside then Q, a positive value, is the quantity flow rate of air leaking into the building. For this case Q is called infiltration. If the inside pressure exceeds the outside pressure then Q, is the quantity flow rate of exfiltrating flow and called exfiltration.
- n = flow exponent. If the flow in the crack is laminar then $n = 1.00$; if turbulent then $n = 0.50$. Usually the flow will be part laminar and part turbulent, thus n will be between 0.5 and 1.0. Small hairline cracks tend to have values of n of 0.8 to 0.9, whereas cracks or openings of 1/8 in. or greater will have complete turbulent flow thus n will be 0.5.
- C = flow coefficient. C is determined experimentally. The value of C is that when Δp is in inches of water, Q will be in cubic feet per minute.

The pressure difference, Δp, is equal to

$$\Delta p = \Delta p_s + \Delta p_w + \Delta p_p \tag{A5.4}$$

where

- Δp_s = the pressure difference caused by the stack effect
- Δp_w = the pressure difference caused by wind
- Δp_p = the pressure difference caused by pressurizing the building

Δp_s, Δp_w, and Δp_p are positive when each, acting separately, would cause infiltration.

The stack effect occurs when the air densities are different on the inside and outside of a building. The air density decreases with increasing temperature and decreases slightly with increasing humidity. Because the pressure of the air is due to the weight

of a column of air, on winter days the air pressure at ground level will be less inside the building due to warm inside air than the cold air outside the building. As a result of this pressure difference air will infiltrate into a building at ground level and flow upward inside the building. Under summer conditions when the air is cooler in the building, outside air enters the top of the building and flows downward on the inside.

Under the influence of the stack effect there will be a vertical location in the building where the inside pressure equals the outside pressure. This location is defined as the neutral pressure level of the building. In theory, if cracks and other openings are uniformly distributed vertically then the neutral pressure level will be exactly at the mid-height of the building. If larger openings predominate in the upper portions of the building this will tend to raise the neutral pressure level and likewise large openings in the lower part will lower the neutral pressure level. Unless there is information to the contrary it is assumed that the neutral pressure will be at the building mid-height when under the influence of the stack effect acting alone.

The theoretical pressure difference resulting from the stack effect can be found using

$$\Delta p_{s_t} = 0.52 \times p_{psi} \times h \times \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \qquad (A5.5)$$

where

Δp_{s_t} = theoretical pressure difference between the inside and outside air pressures due to the stack effect in inches of water
p_{psi} = outside (absolute) pressure in pounds per square inch
h = vertical distance from neutral pressure level in feet
T_o = outside temperature in absolute Fahrenheit
T_i = inside temperature in absolute Fahrenheit

Fig. A5.1 shows the stack effect pressure variations for cold outside air. When the outside pressure is greater than the inside pressure–as in the lower half of the building, Δp_{s_t} is positive and the air flow is into the building. When the outside temperature is greater than the inside air then the situation is reversed and p_{s_t} is positive for the upper half of the buuilding.

The Δp_{s_t} given by Eq. (A5.5) is valid only for buildings with no vertical separations, that is, no floors as for example with an auditorium. Floors in conventional buildings offer a resistance

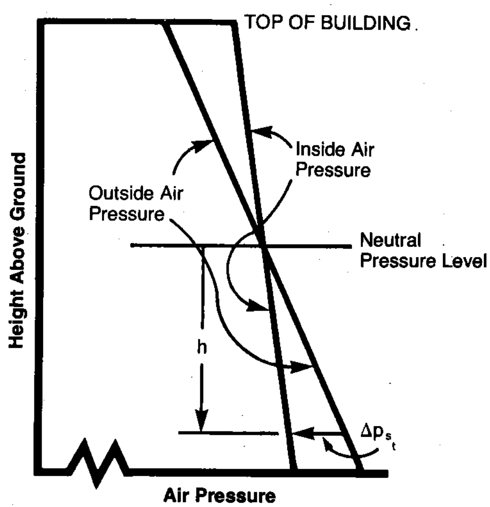


Fig. A5.1 Winter Stack Effect Showing Theoretical Pressure Difference vs Height

to the vertical flow of air caused by the stack effect. There are pressure drops between each floor at stairwell and elevator doors resulting from the air passing from one story to the next. If these resistances such as doors can be assumed uniform for every floor, then a single correction, called the thermal draft coefficient, C_d, can be used to connect Δp_{s_t} with Δp_s, the actual pressure difference.

$$C_d = \frac{\Delta p_s}{\Delta p_{s_t}} \qquad (A5.6)$$

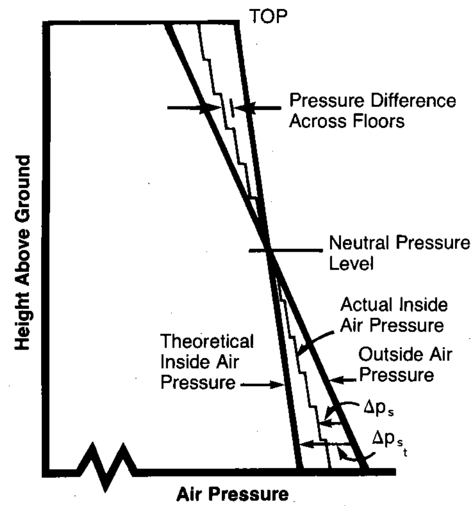


Fig. A5.2 Winter Stack Effect Showing Actual Pressure Difference vs Height for a 12-story Building

Insert Figure A5.2

Fig. A5.2 shows the effect of these pressure drops between floors for winter conditions. The flow of air upward through the building causes the pressure to decrease at each floor. For this reason Δp_s is less than Δp_{s_t} and thus C_d will be a number less than 1.0. Note that the slope of the actual inside pressure within each floor is the same as the theoretical curve.

Eqs. (A5.5) and (A5.6) are combined to yield

$$\frac{\Delta p_s}{C_d} = 0.52 \times p_{psi} \times h \times \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \qquad (A5.7)$$

Eq. (A5.7) is plotted in Fig. 5.1 with an inside temperature of 75 F and p_{psi} = 14.7 (sea level pressure). The values of Δt were obtained by using decreasing values of T_o, that is, for winter conditions. Fig. 5.1 can, however, be used for the summer stack effect with little loss in accuracy.

The value the thermal draft coefficient, C_d, depends on the resistance to the vertical flow of air, that is, the tightness of stair doors, etc., and to the quantity of vertical air flow. In this last regard the larger the vertical flow, the larger the pressure drop per floor and thus the smaller the value of C_d (see Fig. A5.2). For this reason loose fitting exterior walls which produce large amounts of infiltration and thus vertical flow, tend to lower the values of C_d, whereas loose fitting stair doors, etc., tend to raise the value of C_d by reducing pressure drops. With no doors in the stairwells C_d has a value of 1.0. Values of C_d determined experimentally for a few modern office buildings ranged from 0.63 to 0.82.[1] Values of C_d for apartment buildings are not available but because of fewer elevator shafts which means a tighter vertical resistance, and looser fitting exterior walls and with operable windows, the values of C_d will probably be lower than those for office buildings.

The pressure caused by the wind is given by

$$\Delta p_{w_t} = \frac{1}{2} \times \rho \times V_w^2 \qquad (A5.8)$$

where

Δp_{w_t} = maximum theoretical pressure difference caused by the wind.
ρ = density of the air.
V_w = wind velocity.

For sea level air density, Δp_{w_t} in inches of water and V_w in mph Eq. (A5.8) becomes

$$\Delta p_{w_t} = 0.000482 \times V_w^2 \qquad (A5.9)$$

The full force of the wind does not act on the side of a building, because even on the windward side the air maintains some velocity in order to pass around the building. For this reason the following definition is made

$$C_p = \frac{\Delta p_w}{\Delta p_{w_t}} \qquad (A5.10)$$

where

C_p = the pressure coefficient
Δp_w = actual pressure difference caused by the wind.

The pressure coefficient will always have a value less than 1.0. It can have any value less than zero, that is, negative values when the wind causes pressures that are below atmospheric.

Eqs. (A5.9) and (A5.10) are combined to obtain

$$\frac{\Delta p_w}{C_p} = 0.000482 \times V_w^2 \qquad (A5.11)$$

This equation is plotted in Fig. 5.2.

The building will be pressurized if the rate of ventilation air is greater than the exhaust air rate. Δp_p will be negative for this case and will reduce infiltration.

A5.3 CURTAIN WALL INFILTRATION PER FLOOR OR ROOM

The flow coefficient, C, in Eq. (A5.3) has a particular value for each crack and each window and door perimeter gap. Although values of C are determined experimentally for window and door gaps, this same procedure will not work for cracks. Cracks occur at random in fractures of building materials and at the interface of similar or dissimilar materials. The number and size of the cracks depend on the type of construction, the workmanship during construction and the maintenance of the building after construction. To determine a value of C for each crack would be impractical, however an overall leakage coefficient can be used by changing Eq. (A5.3) into the following form

$$Q = K \times A \times (\Delta p)^n \qquad (A5.12)$$

where

A = wall area
K = leakage coefficient ($C = K \times A$)

Eq. (A5.12) is applied to a wall area having cracks and the leakage coefficient, K, can then be determined experimentally. If very large wall areas are used in the test, then advantage is made of the averaging effect of a very large number of cracks. Tests have been made on entire buildings by pressurizing them with fans. Measurements are made of the flow through fans, which is equal to the exfiltration, and the pressure difference due to pressurization.[2,3] Air leakage through doors and other openings were not included in the wall leakage. The seven, tall, office-type buildings tested were of curtain wall construction of metal or precast concrete panels and had non-operable windows. The results of these tests are contained in Table 5.4 and Fig. 5.3. The equation of the three curves in Fig. 5.3 is $Q/A = K(\Delta p)^{0.65}$ for K = 0.22, 0.66 and 1.30. One masonry building was tested and was found to obey the relation $Q/A = 4.0(\Delta p)^{0.65}$, which is for a very loose fitting wall. Because only one of these buildings was tested, this equation was not plotted in Fig. 5.3. The pressurization curves for the seven buildings including leakage through doors, vents, equipment floors, etc., as well as the curtain walls is given in Fig. 5.4.[3] There was negligible wind and stack effect when the tests were run. The solid line is the average of the seven buildings and the dotted lines are the extremes of the data. If the wall construction is tight fitting, the lower dotted line should be used; if loose fitting, the upper dotted line. The total exfiltration rate is given as leakage per unit wall area. Fig. 5.4 is useful for estimating the pressurization of curtain wall buildings.

The pressure difference, Δp, needed in order to use Fig. 5.3, is found using Eq. (A5.4). The explanation for Δp_s, Δp_w and Δp_p is given in Section A5.1. The wind pressure coefficient, C_p, needed to obtain Δp_w is given in Table 5.5. These values of C_p were obtained from wind tunnel tests and computer studies.[4] The pressure coefficient is actually a variable on the windward wall thus 0.95 represents an average value for the entire windward wall. On the sides and leeward walls, C_p is approximately constant. Also incorporated into these C_p's is the fact that when the wind blows normal to one wall the low pressure on the remaining walls lowers the pressure inside the building by about $\Delta C_p = 0.3$. This increases infiltration through the windward wall from 0.64, the previously accepted value, to about 0.95, and correspondingly decreases the exfiltration on the remaining walls. The computer analysis is for an open floor model, that is, the floor is not subdivided into rooms. If the room or office separations are tight this will act as a horizontal resistance to the infiltrating and exfiltrating air due to wind. The windward wall will have a C_p lower than 0.95 because the windward room will have a pressure slightly higher than the average of the entire floor. This will reduce the infiltration due to wind. Stating this another way, the estimates of infiltration based on Table 5.5 will be high if there are tight internal wall separations. The C_p given in Table 5.5 also assumes no pressurization to the ventilation fans.

A5.4 CURTAIN WALLS INFILTRATION FOR ENTIRE BUILDING DUE TO STACK EFFECT

Determination of Q, the infiltration, through the walls of a building due to stack effect cannot be made with simple mathematics. Although Δp_s varies linearly with height, because $Q = KA(\Delta p)^{0.65}$, Q is non-linear. Fig. A5.3 describes this situation.

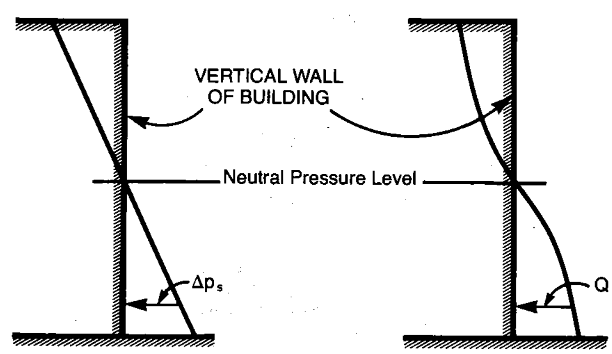


Fig. A5.3 Diagram Showing Linear Distribution of Δp_s and Non-Linear Distribution of Q for Winter Conditions

The infiltration through the curtain wall for an entire building due to stack effect and zero pressurization is expressed by Eq. (A5.13). This equation is restricted to:

a. Buildings with constant floor area with varying height, that is, vertical walls with no offsets
b. Uniform distribution of the wall leakage coefficient with height
c. The flow exponent is $n = 0.65$
d. Inside temperature is $t_i = 72$ F
e. The neutral pressure level is at the mid-height of the building

$$Q = 0.01225 \times K \times A \times (C_d)^{0.65} \times \left(\frac{\Delta t}{\Delta T_o}\right)^{0.65} \times H^{0.65} \quad \text{(A5.13)}$$

where

Q = infiltration in cfm
K = wall leakage coefficient
A = curtain wall area of entire building in ft^2
C_d = thermal draft coefficient
Δt = inside-outside temperature difference in F
T_o = outside temperature in absolute Fahrenheit
H = height of the building in ft

In order to reduce the complexity of Eq. (A5.13), a thermal draft factor, F_d, is defined as

$$F_d = (C_d)^{0.65} \quad \text{(A5.14)}$$

This equation is plotted in Fig. 5.5
Eqs. (A5.13) and (A5.14) are combined to obtain

$$\frac{Q}{AKF_d} = 0.01225 \times \left(\frac{\Delta t}{T_o}\right)^{0.65} \times H^{0.65} \quad \text{(A5.15)}$$

This equation is plotted on Fig. 5.6 with decreasing 10-deg. increments of T_o for winter conditions. Fig. 5.6 can be used for the summer stack effect with little loss in accuracy. Fig. 5.6 does not account for the situation when the building has an equipment floor between the ground and the building mid-height or for summer conditions between the mid-height and the top of the building. Use of Fig. 5.6 requires that the restrictions placed on Eq. (A5.13) be met. If it is not possible to meet all these then the infiltration must be determined floor by floor. Fig. 5.6 does not assume operable windows and doors. Infiltration through the window and door perimeter gaps must be handled as separate cases.

Fig. 5.7 is similar to Fig. 5.6 except that the building is pressurized to 0.10 in. of water. The curve could only be made for a specific value of the thermal draft coefficient. C_d equal to 0.8 was chosen as typical.

A5.5 CURTAIN WALL INFILTRATION FOR ENTIRE BUILDING DUE TO WIND

As with the stack effect the infiltration into an entire building due to the wind cannot be analyzed with simple math. This analysis, for example, assumes the wind velocity profile in open flat land as a function of height, Z is

$$V = (\text{const}) \times Z^{1/3} \quad \text{(A5.16)}$$

This is shown in Fig. A5.4.

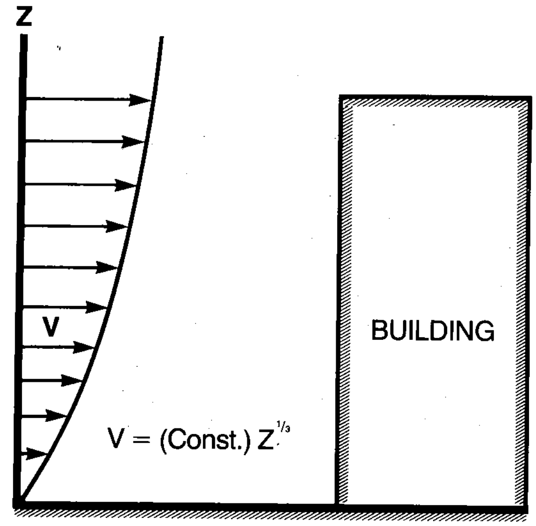


Fig. A5.4 Wind Velocity Distribution for Building in Open Areas

A rectangular floor building was tested in a wind tunnel having this ground velocity profile and the average pressure coefficient on the sides of the building measured for wind directions taken every 15 deg.[4] These pressure coefficients were then put into a computer program that determined the pressure difference across the walls of a building having an average fitting wall and no stack effect nor pressurization. The pressure difference on the walls with infiltration were used along with Eqs. (A5.12) and (A5.16) to obtain

$$\frac{Q}{A_w K F_0} = 0.0005375 \times H^{0.435} \times V_w^{1.30} \quad \text{(A5.17)}$$

where

Q = infiltration in cfm
A_w = curtain wall area of longest wall in ft^2
K = wall leakage coefficient
F_0 = correction factor for various wind directions. This factor is based on experimental data along with computer analysis and is given in Fig. 5.9.
H = height of the building in ft
V_w = wind velocity in mph at a point 32 ft above the ground

Eq. (A5.17) is plotted on Fig. 5.8. Because the velocity varies with height, the point 32 ft above the ground[1] is chosen to represent the wind velocity, V_w. This means that tall buildings will have most of its wind above the value of V_w, while a four-story building will have most of its wind below the value of V_w. The computer analysis also uses the same open floor model as explained in Section A5.3. The infiltration estimates given by Eq. (A5.17) (Fig. 5.8) will be high if the building has rooms on all floors having inside tight walls. Fig. 5.8 assumes a uniform distribution of leakage with height and that the wind is steady. One report[5] indicates that the gustiness of the wind, that is, an unsteady wind, increases infiltration over similar steady wind conditions.

A5.6 CURTAIN WALL INFILTRATION FOR ENTIRE BUILDING DUE TO COMBINED WIND AND STACK EFFECT

The combined infiltration of the wind and stack effect cannot be found by adding together the two infiltrations found separately. Eq. (A5.4) shows that the Δp's can be added together but does not indicate the same summation for infiltration. For a tall building under winter conditions, for example, the Δp's for the wind and stack effect add together on the windward and lower half of the building thus increasing the infiltration there. On the

windward side and upper half of the building the Δp's subtract thus decreasing the infiltration there. The net effect of this is a small increase in total infiltration. This is much less than adding together the two infiltrations determined independent of each other. Fig. 5.10 was obtained by solving for the infiltration due to combined wind and stack effect on the computer with the same input information that was used to develop Eqs. (A5.15) and (A5.17). The results were plotted on a graph and the best curve drawn through the points. The best fit curve is in Fig. 5.10. This procedure allows the user to obtain from graphs the same information as would be obtained from complex computer programs.

A5.7 CRACK INFILTRATION FOR WINDOWS AND RESIDENTIAL TYPE DOORS

Infiltration through windows and all types of doors can be determined by altering Eq. (A5.3) to the form

$$Q = k \times P \times (\Delta p)^n \qquad \text{(A5.18)}$$

where

P = perimeter of the window or door in ft
k = perimeter leakage coefficient ($C = k \times P$)

Experiments are carried out on windows and residential type doors and the values of the leakage coefficient, k, and the exponent, n, are determined using Eq. (A5.18). The results of these tests are contained in Tables 5.6 and 5.7 and Fig. 5.11.[6,7] The equation of the three curves in Fig. 5.11 is $Q/P = k(\Delta p)^{0.65}$ for k = 1.0, 2.0 and 6.0. Note in Table 5.6 that weatherstripped windows are considered tight fitting unless they are vertical or horizontal sliding windows. These latter two types can be tight fitting if there is a very good fit between moving parts. Some carefully constructed casement and awning windows have leakage rates less than that given by the tight fitting classification. New windows should not have a loose fitting classification. If the description of a window appears to be between two types of window fitting classification then a perimeter leakage coefficient, k can be choosen accordingly. For example, a new, wood, non-weatherstripped double-hung window that appeared to have loose tracks would probably be somewhat looser than an average fitting window. A selection of $k = 3.0$ would be appropriate for this situation.

A5.8 INFILTRATION THROUGH COMBINED STORM AND PRIME WINDOWS

In order to reduce infiltration the storm window must completely cover the entire prime window, including, of course, the cracks. When this is true Fig. 5.12 can be used. The curve in this figure is given by

$$Q/Q_P = \left[\frac{1.0}{\left[\frac{k_p P_p}{k_s P_s}\right]^{1/0.65} + 1.0}\right]^{0.65} \qquad \text{(A5.19)}$$

A5.9 INFILTRATION THROUGH COMMERCIAL TYPE SWINGING DOORS

The equation for the three curves in Fig. 5.13 is $Q/P = k(\Delta p)^{0.50}$ for k = 20, 40, 80 and 160. The corresponding crack width is given opposite each value of k. Note also that for these large cracks the exponent is $n = 0.50$.

The equation for the four curves in Fig. 5.14 is $Q = C(\Delta p)^{0.50}$ (Eq. A5.3) for flow coefficients C = 5,000, 10,000, 15,000 and 20,000. With $n = 0.50$ this is the same equation as would be used for flow through a sharp edged orifice. The flow coefficient, C, as a function of traffic rate for two kinds of doors is given in Fig. 5.15. These values of C were obtained from model tests and observing traffic under actual conditions.[8] The values of C obtained from Fig. 5.15 are based on a standard sized (3 by 7 ft) door.

There is no published information on automatically operated doors but automatic doors do stay open often twice and in many cases several times longer than manually operated doors. A reasonable estimate would be to multiply the infiltration from traffic for the single bank doors by a factor based on the increased time the automatic doors will be open. Under the action of long opened doors, such as might occur with automatic doors, the benefits of a vestibule arrangement are negated.

The total infiltration is the infiltration through the cracks when the door is closed added to the infiltration due to traffic.

A5.10 INFILTRATION THROUGH REVOLVING DOORS

Fig. 5.16 is the infiltration due to a pressure difference across the door seals of a standard sized revolving door.[9] The results are for seals that are typically worn but have good contact with adjacent surfaces.

Figs. 5.17 and 5.18 account for infiltration due to a mechanical interchange of air caused by the rotation of the standard sized door.[9] The amount of air interchanged depends on the inside-outside temperature difference and the rotational speed of the door.

The total infiltration is the infiltration due to leakage through the door seals plus the infiltration due to the mechanical interchange of air due to the rotation of the door.

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A6 PSYCHROMETRIC PROCESSES – CALCULATIONS FOR EQUIPMENT SELECTION

A6.0 PSYCHROMETRICS AND PSYCHROMETRIC PROCESSES

Psychrometrics and psychrometric processes are used in the conversion of the cooling and heating loads into equipment loads for system design and optimization. It enables the designer to determine air quantities and air conditions which can be used for equipment selection and duct and piping design. This section deals with the fundamental properties of moist air and the basic processes used in HVAC systems. More detailed information is available in the ASHRAE Handbook and Product Directory series, particularly the Fundamentals and the Systems Volumes.

The psychrometric chart is not only convenient for making calculations, it can be a valuable visual aid in displaying the processes in the HVAC system. Fig. A6.1 is the abridged ASHRAE Psychrometric Chart for the normal temperature of air conditioning applications and for a standard barometric pressure of 29.921 in. of mercury. Charts for other temperature ranges and other altitudes are also available. Fig. A6.2 is a schematic version of the chart with some exaggeration to show the properties more clearly. Fig. A6.3 indicates some of the basic air conditioning processes. Other processes that are used in HVAC systems can be analyzed by combination of these basic processes.

EQUATIONS FOR SYSTEM DESIGN CALCULATIONS

Basic Calculations

Basic calculations for air system loads, flow rates and psychrometric processes are based on mass flow and enthalpy. However, volume values are required for selecting coils, fans, ducts, etc. Also, dry bulb temperatures are much more

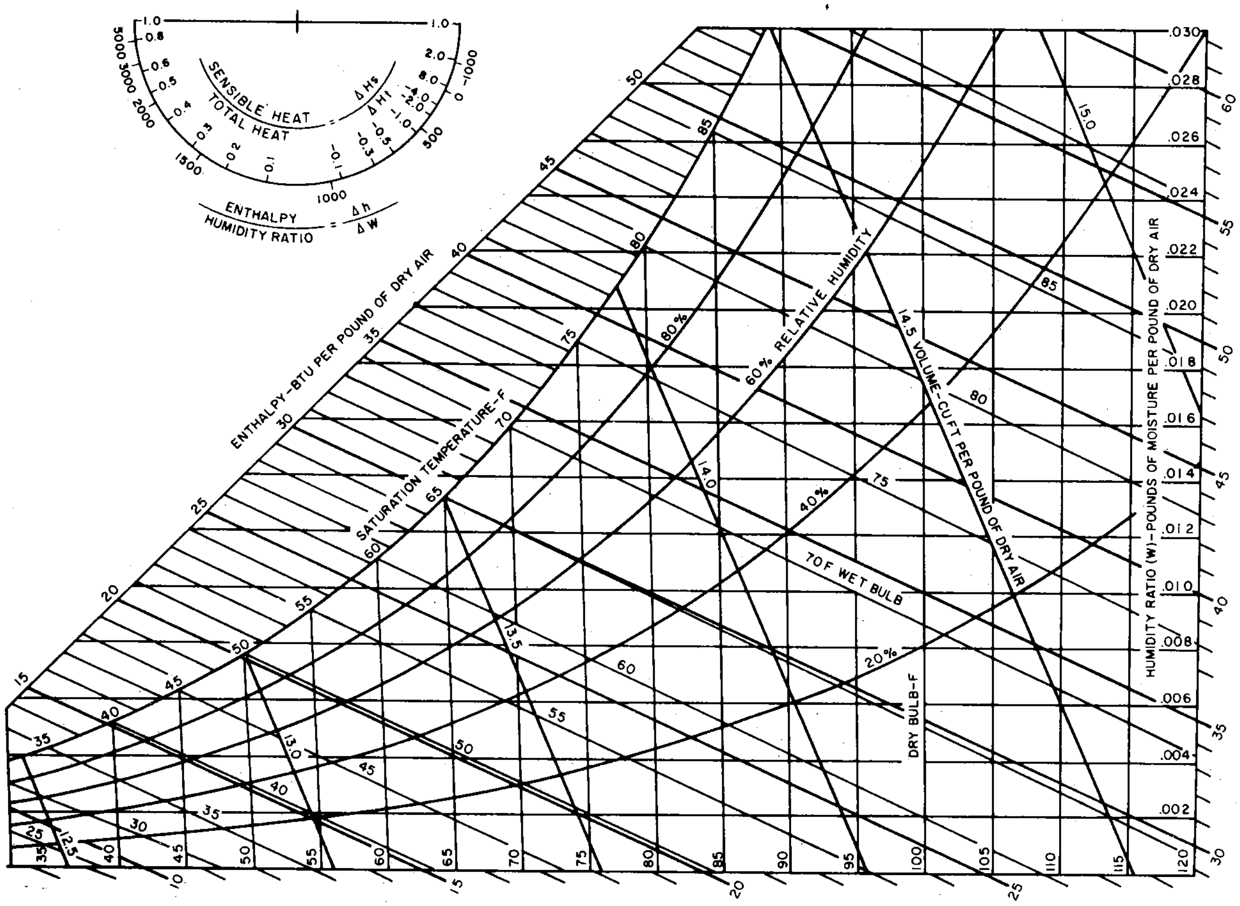

Fig. A6.1 Abridged ASHRAE Normal Psychrometric Chart (29.921 in. Hg.)

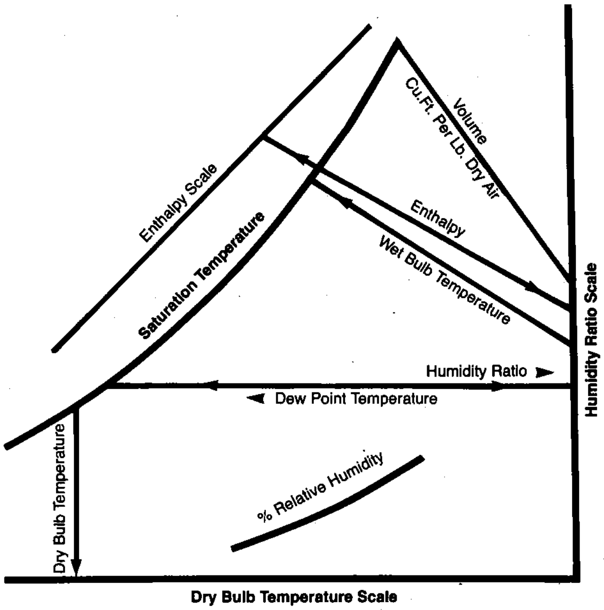

Fig. A6.2 Schematic ASHRAE Psychrometric Chart

convenient to use than enthalpy. A practical method of using volume, but still including mass so that accurate results are obtained, is the use of volume values based on measurement at ASHRAE standard conditions. The value considered standard is 0.075 lb of dry air/ft^3 (13.33 ft^3/lb of dry air), which corresponds to approximately 60 F at saturation or to dry air at 69 F (at 14.7 psia). Thus, in the range at which the air usually passes through the coils, fans, ducts, etc., its density is close to standard, and is not likely to require correction. When the air flow is to be measured at any particular condition or point, such as at a coil entering or leaving condition, the corresponding specific volume can be taken from the psychrometric chart, and the standard volume multiplied by the ratio of the actual specific volume divided by 13.33. To illustrate: assume the outdoor air at ASHRAE standard conditions is 1000 scfm. The actual outdoor air condition is 95 F db and 75 F wb (14.3 ft^3/lb). The measured rate at that condition would be $1000 \times (14.3/13.33) = 1070$ cfm.

The use of standard cubic feet per minute (scfm) along with some of the other assumptions indicated below yields more convenient forms of the equations. The general use of these equations may result in an error usually less than 2 or 3 percent, which is normally acceptable for general HVAC calculations.

Sensible Heat

The sensible heat gain in Btu/hr as a result of a difference in temperature (Δt) between the incoming air and leaving air flowing at ASHRAE standard conditions is:

$$q_s = \text{cfm}\ (60)\ (0.075)\ (0.24 + 0.45\ W)\ \Delta t \qquad \text{(A6.1)}$$

where

60 = minutes per hour
0.075 = pounds of dry air per cubic foot
0.24 = specific heat of dry air, Btu per pound per deg F temperature change
0.45 = specific heat of water vapor, Btu per pound per deg F temperature change
W = humidity ratio, pounds of water vapor per pound of dry air.

(The specific heats are for a range from about −100 F to +200 F.)

The value of (60) (0.075) (0.24 + 45 W) varies with W. When $W = 0$, the value is 1.08; when $W = 0.01$, the value is 1.10; when $W = 0.02$, the value is 1.12; and when $W = 0.03$, the value is 1.14. Since a value of $W = 0.01$ approximates conditions found in many air conditioning problems the sensible heat gain is approximated by:

$$q_s = 1.10\ (\text{cfm})\ \Delta t \qquad \text{Air Conditioning} \qquad \text{(A6.2)}$$

During the heating season the humidity ratio is usually quite low and the sensible heat equation is:

$$q_s = 1.08\ (\text{cfm})\ \Delta t \qquad \text{Heating Season} \qquad \text{(A6.3)}$$

By using Eq. (A6.2) for all seasons then a difference of only 2 percent occurs.

Latent Heat

As a result of a difference in humidity ratio (ΔW) between the incoming and leaving air flowing at ASHRAE standard condition the latent heat gain in Btu/hr is:

$$q_L = \text{cfm}\ (60)\ (0.075)\ (1076)\ \Delta W \qquad \text{(A6.4)}$$

where 1076 is the approximate energy content of 50% relative humidity vapor at 75 F, less the energy content of water at 50 F. The 50% rh at 75 F is a common design condition for the space, and 50 F is common condensate temperature from cooling and dehumidifying coils. Combining the three values, the latent heat gain is:

$$q_L = 4840\ (\text{cfm})\ \Delta W \qquad \text{(A6.5)}$$

Total Heat

Total heat, q_t, is the sum of sensible heat, q_s, and latent heat, q_L, so that

$$q_t = q_s + q_L \qquad \text{(A6.6)}$$

The total heat gain in Btu/hr as a result of a difference in enthalpy (Δh) between the incoming and leaving air flowing at ASHRAE standard condition is:

$$q_t = \text{cfm}(60)\ (0.075)\ [\Delta h - \Delta W \times h_f] \qquad \text{(A6.7)}$$

The term, $\Delta W \times h_f$, involving the enthalpy of the condensed water or the enthalpy of the evaporated water, is generally small. Therefore, the equation is simplified by considering only the change in enthalpy of the moist air.

If the product of the two constants is used as a single number, the total energy exchange is:

$$q_t = 4.5\ (\text{cfm})\ \Delta h \qquad \text{(A6.8)}$$

The values 1.10, 4840 and 4.5 in Eqs. (A6.2), (A6.5) and (A6.8), respectively, are useful in air conditioning calculations for an atmospheric pressure of approximately 14.7 psia and normal temperatures and moisture ratios. For other conditions, calculations should use more precise values. For frequent computations at other altitudes, it may be desirable to calculate new values in the same manner. For an altitude of 5000 ft (12.2 psia), for example, the values are 0.92, 4020, and 3.73, respectively.

Air Mixtures

General equations for the resulting state of air when the standard flow rate CFM_1 at a temperature t_1 and a humidity ratio W_1 mixes with CFM_2 at t_2 and W_2 to yield a mix condition of CFM_m at t_m and W_m are

$$CFM_m = CFM_1 + CFM_2 \quad (A6.9)$$

$$t_m = t_2 + (t_1 - t_2)(CFM_1/CFM_m) \text{ or} \quad (A6.10a)$$

$$t_m = t_1 - (t_1 - t_2)(CFM_2/CFM_m) \quad (A6.10b)$$

$$W_m = W_2 + (W_1 - W_2)(CFM_1/CFM_m) \text{ or} \quad (A6.11a)$$

$$W_m = W_1 - (W_1 - W_2)(CFM_2/CFM_m) \quad (A6.11b)$$

Such mixtures, plotted on a standard pyschrometric chart, are considered to fall on a straight line drawn between states 1 and 2. Thus, solving any of Eqs. (A6.10a) to (A6.11b) will automatically locate the mixture state, m, on a psychrometric chart representation. Proportionally dividing the line will accomplish the same result. When lines are steep, it is preferable to use Eq. (A6.11a) and (A6.11b).

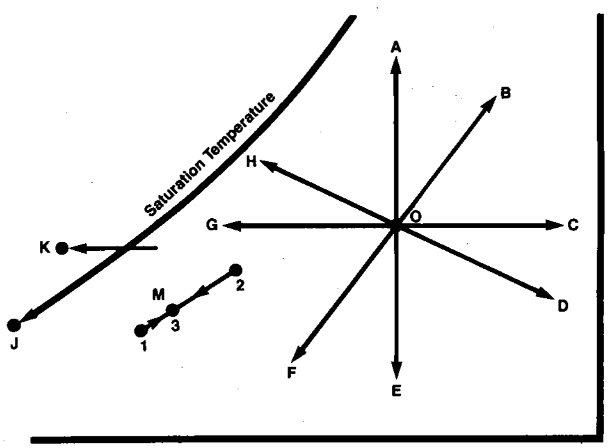

Fig. A6.3 Basic Air Conditioning Processes

A6.1 BASIC AIR CONDITIONING PROCESSES

The basic air conditioning processes are shown in Fig. A6.3. More complex processes that may be used in various types of HVAC systems can be analyzed by combinations of the basic processes.

Any change in air condition can be broken down into a latent heat change and a sensible heat change on the psychrometric chart.

- Humidifying Only (A) and Dehumidifying Only (E) show an increase and decrease, respectively, in humidity ratio with no change in dry bulb temperature. These are pure latent heat processes.
- Sensible Heating Only (C) and Sensible Cooling Only (G) show an increase and decrease, respectively, in dry bulb temperature with no change in humidity ratio. These are pure sensible heat processes.
- The combination of Cooling and Dehumidifying (F) results in a reduction of both the dry bulb temperature and the humidity ratio. Cooling coils generally perform this type of process. Heating and Humidifying (B) increases both the dry bulb temperature and the humidity ratio.
- Evaporative Cooling Only (H) is an adiabatic heat transfer process in which the wet bulb temperature of the air remains constant but the dry bulb temperature drops as the humidity rises. Since it is adiabatic (no net heat transfer), it is the same as removing energy in the form of sensible cooling along direction (G) with the sensible energy going to vaporize an additional amount of water added at constant dry bulb temperature (latent heat addition). The magnitude of sensible energy cooling is identical to the magnitude of latent energy heating when the process of Evaporative Cooling Only is taking place. This is a process upward and to the left along a constant wet bulb temperature line as shown on Fig. A6.1. This is nearly identical to a constant enthalpy process. The deviation of the two processes, that is, of constant enthalpy and constant wet bulb temperature, is the enthalpy deviation.
- Chemical Dehumidifying (D) is a process in which moisture from the air is absorbed or adsorbed by a hydroscopic material. Generally, the process essentially occurs at constant enthalpy with the latent cooling associated with a nearly equal sensible heating.
- Adiabatic Mixing (M) of air at one condition with air at some other condition is represented on the psychrometric chart by a straight line connecting the two points representing the two air conditions. Mixing occurs in almost every air conditioning system. The fundamental equations applying to the adiabatic mixing are: conservation of total enthalpy, conservation of total air mass, and conservation of total water vapor mass. Solution of these conservation equations forces the final mixture to lie on the straight line between the points and determines the position based on proportions of the masses of *dry air* mixed. Thus, if points 1 and 2 represent the two moist air conditions before mixing and point 3, or point M, the final mixed moist air condition, the masses of dry air are related to line segments as follows:

$$m_{a,1} = 32 \text{ or } m_{a,1} = 32 \text{ or } m_{a,2} = 13$$
$$m_{a,2} = 13 \text{ or } m_{a,3} = 12 \text{ or } m_{a,3} = 12$$

A more detailed treatment of adiabatic mixing will be given later.

- Dehumidification by Cooling Below Dewpoint (J) occurs when the moist air is brought into contact with a surface having a temperature lower than the dewpoint temperature of the air. In such a case constant-pressure cooling (with constant humidity ratio) will occur until the adiabatic saturation temperature is reached (the dewpoint where the horizontal part of the total process intersects the saturation curve). Further cooling then results in condensation and a lowering of the humidity ratio by following precisely along the saturation curve when the cooling process is slow enough that effective equilibrium can be maintained.
- Constant Pressure Fog Condition (K) occurs when the cooling process at constant pressure, as just described, occurs in such a way that water droplets remain suspended in the air in a non-equilibrium condition after the dewpoint is reached. The line condition to (K) then replaces the previous path downward along the saturation curve toward (J). If all the condensed liquid remains suspended along with remaining water vapor, the humidity ratio remains fixed. Energy and mass balance equations must be examined.

A general fog condition exists when the condition is to the left of the saturation curve regardless of how that condition was attained. All that is inferred is that liquid water droplets remain suspended in the air rather than dropping out as required by total equilibrium concepts. This two-phase region represents a

mechanical mixture of saturated moist air and liquid water with the two components in thermal equilibrium. Isothermal lines in the fog region are coincident with extensions of thermodynamic wet bulb temperature lines.

A6.2 BASIC EQUATIONS BASED ON MASS AND ENTHALPY

Process	Equation	Explanation and Notes
General (O→) Fig. A6.3		Starts from specified point 0 on psychrometric chart schematic of Fig. A6.3 where moist air has enthalpy h_o, Btu/lb.d.a., humidity ratio W_o, lb/lb, and m of dry air per hour. Ends at specified point after specified type of process.
Sensible Heating, Heat added (O→ C)	$q = m\,(h_C - h_o)$	W constant, db temperature increases
Heating and Dehumidifying, Heat added (O→ D)	$q = m\,(h_D - h_o) - m\,h_f\,(W_D - W_o)$	W decreases, db temperature increases, h_f is enthalpy of saturated liquid water, Btu/lb
Dehumidifying Only Heat removed (O→ E)	$q = m\,(h_o - h_E) - m\,h_f\,(W_o - W_E)$	db temperature constant, W decreases
Cooling and Dehumidifying, Heat removed (O→ F)	$q = m(h_o - h_F) - m\,h_f\,(W_o - W_F)$	db temperature decreases, W decreases
Sensible Cooling Heat removed (O→ G)	$q = m\,(h_o - h_G)$	W constant, db temperature decreases
Cooling and Humidifying, Heat removed (O→ H)	$q = m\,(h_o - h_H) - m\,h_f\,(W_o - W_H)$	db temperature decreases, W increases; If $q = 0$, evaporative cooling with wb temperature constant
Humidifying Only Heat added (O → A)	$q = m\,(h_A - h_o) - m\,h_f\,(W_A - W_o)$	db temperature constant, W increases
Heating and Humidifying, Heat added (O→ B)	$q = m\,(h_B - h_o) - m\,h_f\,(W_B - W_o)$	db temperature increases, W increases

A6.3 AIR CONDITIONING EQUIPMENT AND PROCESSES

Air processing equipment consists basically of three types: coils, sprays, and sorbent dehumidifiers. These may be used singly or in combination to control temperature and humidity. Ordinarily, performance requirements are first established, and, then, equipment components are chosen to 1) meet the performance requirements and 2) provide a practical system having economical owning and operating costs.

The cooling load and psychrometric conditions to be maintained within the conditioned space must be satisfied in any case.

A6.3-1 COIL CHARACTERISTICS

Cooling coils are used with or without dehumidification. They are basically of two types — bare tubes or pipe, and extended or finned surfaces. The usual cooling media in extended surface coils are chilled water or direct expansion refrigerants.

Heating coils may also be used but without the possibility of simultaneous dehumidification due to the coil action alone.

The proper selection of coils requires an understanding of the requirements in each case, and should be based on an economic analysis of the plant design as a whole. While no general rule can be established for the selection of cooling coils, it is possible to point out the limits of usual practice and to indicate the influence of the variables involved in the coil selection.

Coil Application Range

Based on information in ARI Coil Standard 410-64, dry surface (sensible cooling) coils and dehumidifying coils which accomplish both cooling and dehumidification, particularly for field-assembled coil banks or factory-assembled coil banks or factory-assembled central station type air conditioners using different combinations of coils, are *usually* rated within the following limits:

Entering Air Dry-Bulb; 65 to 100 F
Entering Air Wet-Bulb; 60 to 85 F
Air Face Velocity; 300 to 800 fpm (sometimes as low as 200 and as high as 1500)
Direct Expansion Refrigerant Saturation Temperature; 30 to 55 F at coil suction outlet (refrigerant vapor superheat is 6 deg F or higher)
Entering Liquid Temperature; 35 to 65 F
Water Quantity; 1.2 to 6 gpm per ton (equivalent to a water temperature rise of from 4 to 20 deg F)
Water Velocity; 1 to 8 fps

Steam and hot water coils for heating are usually rated within the following limits which may be exceeded for special applications:

Air Face Velocity; 200 to 1500 fpm, based on air at standard density of 0.075 lb per cu ft.
Entering Air Temperature; Minus 20 F to 100 F for steam coils; 0 F to 100 F for hot water coil.
Steam Pressures; 2 to 250 psig at the coil steam supply connection (pressure drop through the steam control valve must be considered).
Hot Water Temperatures; 120 F to 250 F.
Water Velocities; 0.5 to 8 fps.

A6.3-2 EXAMPLES OF BASIC AIR-CONDITIONING PROCESSES

The psychrometric chart diagram in Example 6.3 shows an idealization of a typical air conditioning process for air conditioning a space. Outdoor air (OA) is mixed with return air from the room (R) and enters the air conditioning apparatus (M). Air flows through the conditioning apparatus (M-S) and is supplied to the space (S). The air supplied to the space moves along line (S-R) as it picks up the room loads, and the cycle is repeated. Normally most of the air supplied by the air conditioning system is returned to the apparatus. There, it is mixed with outdoor air required for ventilation. The mixture then passes through the apparatus where heat and moisture are added or removed, as required, to maintain the desired conditions. Full understanding of such a cycle depends upon understanding the basic air conditioning processes.

Pure Sensible Heating (or Cooling)

Fig. A6.4 shows schematically a pure sensible heating coil and the process on a psychrometric chart. A medium such as hot water or steam circulating inside the tubes serves as the heat source. Sensible cooling would occur if the coil surface temperature were cooler than the inlet dry-bulb temperature but higher than the dewpoint temperature of the inlet moist air. If the coil surface is cooler than the inlet dewpoint temperature, cooling and dehumidification results.

For the assumption of pure sensible heating, the humidity ratio, W, remains constant as the process line 12 is followed on the psychrometric chart.

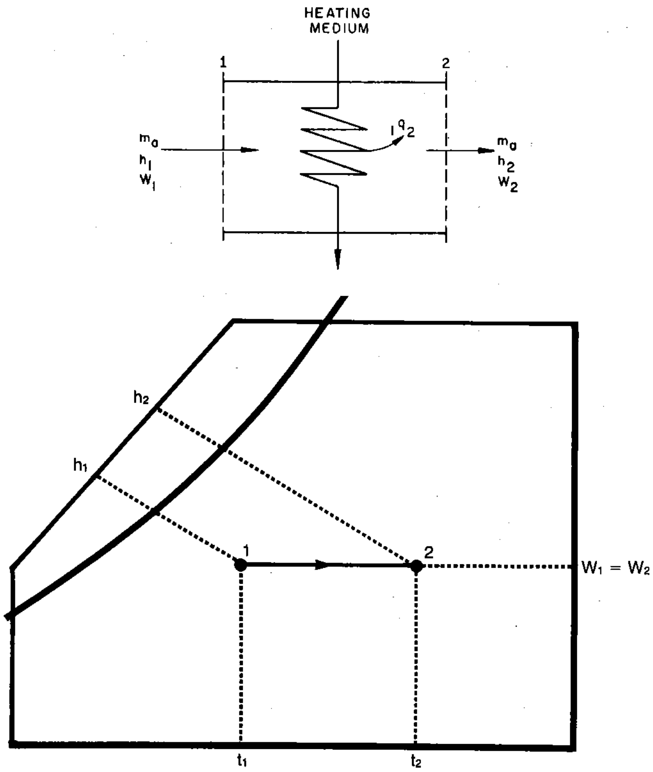

Fig. A6.4 Schematic Pure Sensible Heating Coil and Psychrometric Process

Example A6.1 Sensible Heating

Moist air enters a steam heating coil at 45 F db and 40 F wb. The air is heated sensibly to 70 F db. Determine the leaving conditions and the heat required for the stated temperature rise. From the psychrometric chart, Fig. A6.1, proceeding as in Fig. A6.4:

$$\text{db } t_1 = 45 \text{ F; wb } t_1 = 40 \text{ F; } h_1 = 15.2 \text{ Btu/lb d.a.}$$

With sensible heating (horizontal line on chart) to discharge condition 2:

$$\text{db } t_2 = 70 \text{ F; wb } t_2 = 52 \text{ F; } h_2 = 21.4 \text{ Btu/lb d.a.}$$

The sensible heat added to the system per pound of dry air is from Eq. (A6.8)

$$q_s = h_2 - h_1 = 21.4 - 15.2 = 6.2 \text{ Btu/lb d.a.}$$

The alternate approach which does not use enthalpies is that of Eq. (A6.1)

$$q_s = (0.24 + 0.45\ W)\ \Delta t$$

$$q_s = (0.24 + 0.45 \times 0.0042)\ (70 - 45) = 6.05 \text{ Btu/lb d.a.}$$

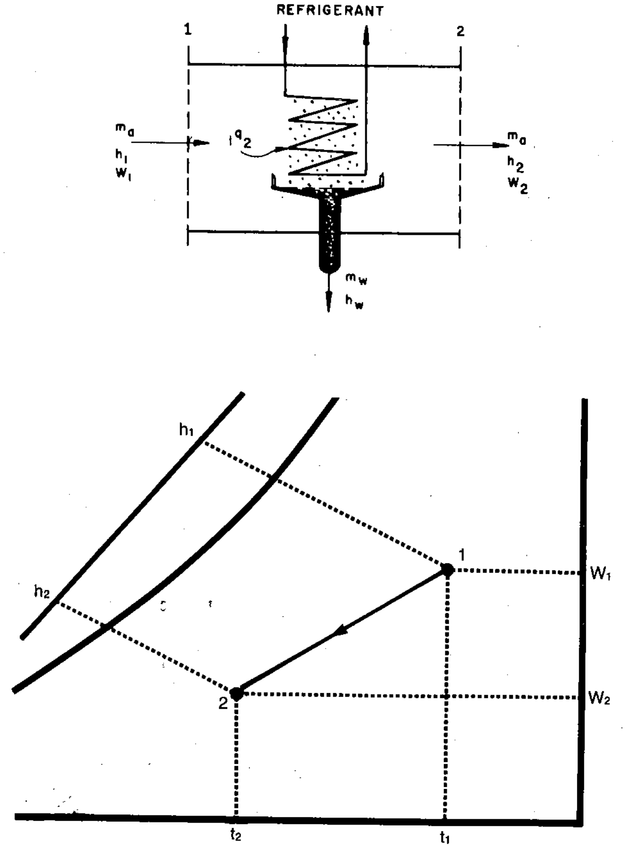

Fig A6.5 Schematic and Psychrometric Performance of a Cooling and Dehumidifying Coil

REFRIGERATION LOAD (COOLING AND DEHUMIDIFYING COIL)

Fig. A6.5 shows the schematic and psychrometric performance of a cooling and dehumidifying coil.

The line from 1 to 2 on the psychrometric chart shows the effective process on the air. If only the total refrigeration load, q_t, of the cooling and dehumidifying coil per lb of dry air is desired, it may be calculated according to Eq. (A6.7), by

$$q_t = (h_1 - h_2) - (W_1 - W_2)\ h_{f3}$$

where h_1 and h_2 are enthalpies of air (Btu for moist air per lb of dry air) at points 1 and 2, respectively;

W_1 and W_2 are humidity ratios at points 1 and 2, respectively,
$(W_1 - W_2)$ is the mass of water removed per pound of dry air,
h_{f3} is the enthalpy of saturated liquid water at the final temperature of the condensate, t_3,
$(W_1 - W_2)\ h_{f3}$ is the thermal energy content of the leaving condensate per pound of dry air, and
q_t is directed into the refrigerant, a heat loss from the air.

Within the normal air conditioning range, precise values of t_3 are not necessary since the enthalpy of the condensate, $(W_1 - W_2)\ h_{f3}$, removed from the air is usually about 0.5 to 1.5 percent of the refrigeration load. In practice, t_3 is frequently the same as the leaving wet bulb temperature of the air.

$$q_t = h_1 - h_2 \text{ (omitting the enthalpy of the condensate)}$$

Example A6.2 Cooling and Dehumidifying by Coil, Without and With Nomograph of Standard ASHRAE Psychrometric Chart

Moist air enters a cooling coil at 70 F wb and 60% rh. It is cooled to 60 F db while the humidity ratio is decreased by 30%. Determine the inlet and outlet conditions, db and wb temperatures, and the amount of heat removed from the air, a) without nomograph and b) with nomograph of the standard ASHRAE psychrometric chart.

a) From the psychrometric chart
Entering: at intersection of given wb and rh condition

db t_1 = 80.4 F; wb t_1 = 70 F; h_1 = 34 Btu/lb d.a.;

W_1 = 0.0134 lb/lb d.a.

Decreasing W by 30% yields:

W_2 = 0.0094 lb/lb d.a.

Leaving: at intersection of given db and calculated W_2 condition

W_2 = 0.0094; db t_2 = 60 F; wb t_2 = 57.2 F;

h_2 = 24.6 Btu/lb d.a.

Heat removed: by Eq. (A6.7) with h_{f3} = 25 Btu/lb

$q_t = 34.0 - 24.6 - (0.0134 - 0.0094)(25) = 9.4 - 0.1$

q_t = 9.4 Btu/lb d.a., omitting the enthalpy of the condensate.

q_t = 9.3 Btu/lb d.a. when the enthalpy of the condensate is considered.

b) In a) the enthalpies h_1 and h_2 were obtained by using a straight edge matching up the state-point with the left and right edge enthalpy scales. The value of h_{f3} was obtained from Tables in the 1977 Handbook of Fundamentals. The nomograph on the standard psychrometric chart permits an alternate approach. That nomograph is given here as Fig. A6.6 since Fig. A6.1 does not include it. Thus $h_1 = h^*_{s1} + D_1$ where h^*_{s1} is the enthalpy of saturated moist air at the thermodynamic wet bulb temperature (70 F) and D_1 is the enthalpy deviation given by the nomograph. From Fig. A6.1, h^*_{s1} = 34.1 Btu/lb d.a. and h^*_{s2} (at 57.2 F wb) = 24.6.

From the nomograph

$D_1 = -0.1$

$D_2 = 0.0$

$h_1 = 34.1 - 0.1 = 34.0$ Btu/lb d.a.

$h_2 = 24.6 - 0 = 24.6$ Btu/lb d.a.

Water temp. = 57 F

$W_1 h_{f3} = 0.32$; $W_2 h_{f3} = 0.22$

Using Eq. (A6.7) for heat removed (negative of heat gain),

$q_t = h_1 - h_2 - (W_1 h_{f3}) - (W_2 h_{f3})$

$q_t = 34.0 - 24.6 - 0.32 + 0.22 = 9.3$ Btu/lb d.a. as in a)

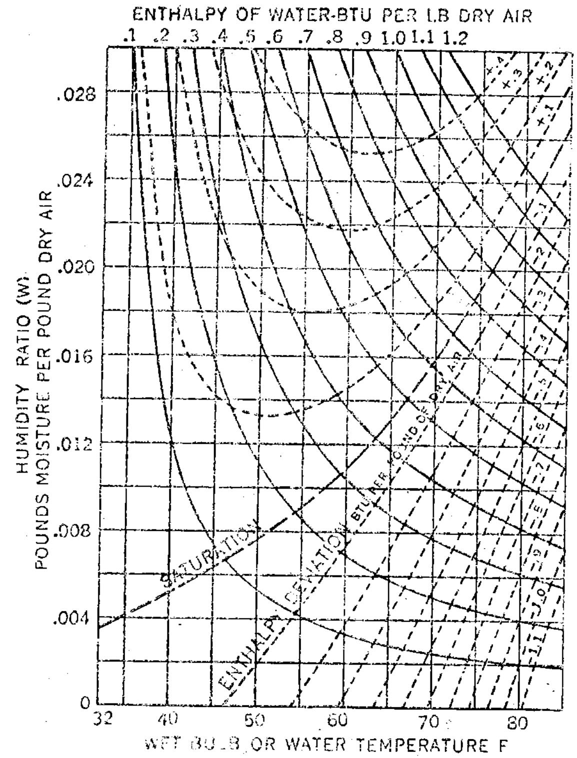

Fig. A6.6 Nomograph for Example A6.2

Sensible Heat Ratio and Its Relation to the Psychrometric Chart

The term Sensible Heat Ratio (SHR) is the ratio of sensible to total heat, where total heat is the sum of sensible and latent heat. This ratio is also referred to as the Sensible Heat Factor. The pure sensible heat process of Fig. A6.4 has SHR = 1.0 because the total heat is the sensible heat. The cooling and dehumidification process of Fig. A6.5 has SHR less than 1.0 because both sensible and latent cooling are involved. A pure latent heating (or cooling) process has SHR = 0.

$$\mathrm{SHR} = \frac{\mathrm{SH}}{\mathrm{SH} + \mathrm{LH}} = \frac{\mathrm{SH}}{\mathrm{TH}} \qquad \text{(A6.13)}$$

where

SHR = sensible heat ratio,
SH = sensible heat,
LH = latent heat,
and TH = total heat.

When the load being considered is that of a room, Eq. (A6.13) is modified by the addition of an R (for room) before each symbol. Room Sensible Heat Ratio (RSHR) is given by

$$\mathrm{RSHR} = \frac{\mathrm{RSH}}{\mathrm{RSH} + \mathrm{RLH}} = \frac{\mathrm{RSH}}{\mathrm{RTH}} \qquad \text{(A6.14)}$$

A Grand Sensible Heat Ratio (GSHR) is defined as the ratio of total sensible heat (TSH) to the grand total heat load (GTH) that a conditioning apparatus must handle. The total sensible heat and the total latent heat (TLH) in this case include the respective components of outdoor air heat loads

$$\mathrm{GSHR} = \frac{\mathrm{TSH}}{\mathrm{TSH} + \mathrm{TLH}} = \frac{\mathrm{TSH}}{\mathrm{GTH}} \qquad \text{(A6.15)}$$

The concept of the Grand Sensible Heat Ratio (GSHR) is similar to that of the room sensible heat ratio (RSHR) except that the RSHR relates conditions of the room supply air to those of the room design; whereas, the GSHR relates conditions of the conditioning apparatus supply air to those of the air from the apparatus. The condition of the air entering the apparatus

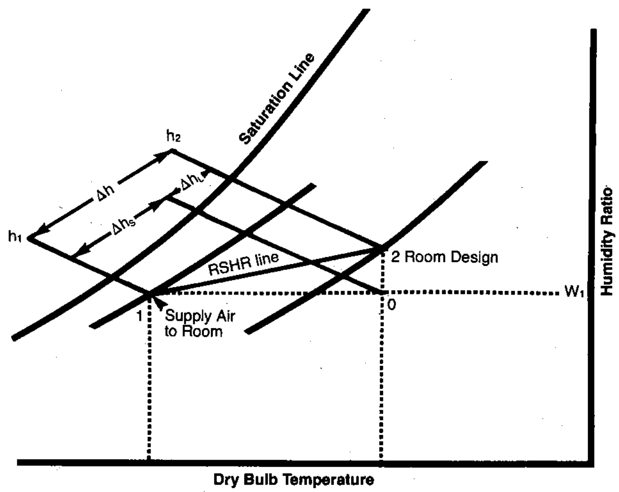

Fig. A6.7 RSHR Line and Associated Heat Components

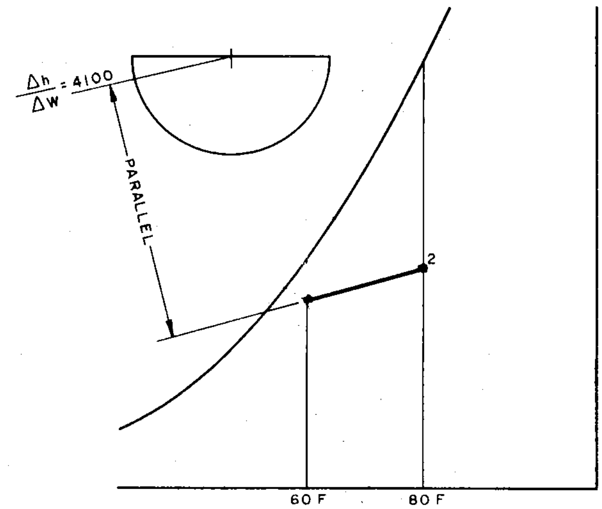

Fig. A6.8 Schematic Solution for Example A6.3

(mixture condition of outdoor and return room air) and the condition of the air leaving the apparatus may be plotted on the psychrometric chart and connected by a straight line. This line represents the psychrometric process of the air as it passes through the conditioning apparatus, and it is referred to as the grand sensible heat ratio line (GSHR line).

Consider the heating and humidification process of Fig. A6.7 which represents the change in condition of air in a room due to various sensible and latent load sources. Room design condition is point (2) and supply air to the room is point (1). The supply air to the conditioned space must be able to satisfy both the room sensible and room latent loads. As the supplied air picks up the two types of heat load, it follows some path from (1) to (2). A straight line from (1) to (2), called the room sensible heat ratio line (RSHR line), represents the effective psychrometric process. The slope of this RSHR line relates to the ratio of sensible to latent loads in the room, as in the triangular construction shown.

Dotted line (1-0) represents the sensible heating process and line (0-2) represents the latent heating process of the air. Per pound of dry air, the room sensible heat is $\Delta h_s = \text{RSH}/m_a$, the room latent heat is $\Delta h_L = \text{RLH}/m_a$, and the total room heat is $\Delta h = \text{RTH}/m_a$. The supply air mass, m_a, is usually the discharge from an air conditioning apparatus, so it cannot be independently set without considering the operating characteristics of the conditioner.

The direction of the RSHR line can be drawn on the psychrometric chart without knowing the condition of the supply air as long as there is knowledge of the room load components and of room design conditions. Room design condition (2) is first located on the chart. From a combination of the steady-state energy conservation equation and the conservation of water mass,

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{\Delta h}{\Delta W} = \frac{\Delta h_s + h_L}{W_2 - W_1} = \frac{m_a \Delta h_s + m_a \Delta h_L}{m_a (W_2 - W_1)} = \frac{q_s + q_L}{m_{W\,tot}} \qquad \text{(A6.16)}$$

where

q_s is total sensible heat gain between (1) and (2),
q_L is total latent heat gain between (1) and (2),
and $m_{W\,tot}$ is total gain in water vapor mass between (1) and (2).

According to Eq. (A6.16), a general rule exists for establishing a *condition* line:

On the ASHRAE psychrometric chart and for a given state (2) of withdrawn air, all possible states (conditions) for the supply air (1) must lie on a straight line (condition line) drawn through the statepoint of the withdrawn air (2) and which has a direction specified by the numerical value of $(q_s + q_L)/(m_{W\,tot}) = (\Delta h)/(\Delta W)$.

Three alternate procedures could be followed to locate the condition line, if the quantities q_s, q_L and $m_{W\,tot}$ are known. One would be to calculate the value of the ratio $(\Delta h)/(\Delta W)$, followed by assuming a ΔW to get a corresponding Δh, and then constructing the line. The second procedure would be to use the $(\Delta h)/(\Delta W)$ protractor on the ASHRAE chart (Fig. A6.1). The use of the protractor is shown on Fig. A6.8. This figure uses $\Delta h/\Delta W = 4100$, which is consistent with Example A6.3. A summary of the procedure is as follows:

1. Establish a reference line of direction $\Delta h/\Delta W$ on the protractor.
2. Parallel to this reference line, draw a straight line on the psychrometric chart through condition (2).
3. Supply air condition must lie on this line somewhere between the saturation line and condition (2).
4. Exact location of point (1) will depend upon the air supply quantity, or vice versa.

A third (and approximately correct) procedure in locating the condition line is to use the sensible total heat ratio scale of the protractor $\Delta H_s/\Delta H_t = \text{RSHR}$ instead of the $\Delta h/\Delta W$ scale, but using the above four steps. The use of the RSHR scale is illustrated in Example 6.1.

Example A6.3 RSHR and Δh/ΔW; Supply Air Condition Partially Known

Moist air is withdrawn from a room at 80 F dry bulb temperature and 66 F wet bulb temperature. The sensible rate of heat gain for the space is 30,000 Btu/hr. A rate of moisture gain of 10 lb/hr occurs from the space occupants. This moisture is assumed as saturated water vapor at 90 F. Moist air is introduced into the room at a dry bulb temperature of 60 F. Find the room sensible heat ratio (RSHR) and $\Delta h/\Delta W$.

Fig. A6.8 shows the schematic solution. The supply air must be able to satisfy both the room sensible and room latent heat loads. Point (2), the room design condition, is located at the intersection of 80 F db and 66 F wb. From the 1977 ASHRAE Handbook of Fundamentals, the enthalpy of saturated water vapor at 90 F is 1100.44 Btu/lb.

From Eq. (A6.16)

$$\frac{\Delta h}{\Delta W} = \frac{q_s + q_L}{m_{W\ tot}} = \frac{30{,}000 + 10(1100.44)}{10} = 4100 \text{ Btu/lb water}$$

With the $\Delta h/\Delta W$ protractor, a reference line of direction $\Delta h/\Delta W = 4100$ is established. Parallel to this reference line, a straight line is drawn on the chart through Point (2). Point (1) is established where this line crosses the supply dry bulb temperature of 60 F.

The alternate (and approximately correct) procedure is to establish the RSHR line by calculating

$$\text{RSHR} = \frac{\text{RSH}}{\text{RTH}} = \frac{\Delta H_s}{\Delta H_T}$$

$$\text{RSHR} = \frac{30{,}000}{30{,}000 + 10(1100.44)} = 0.732$$

This ratio should be coincident with $\Delta h/\Delta W = 4100$ on the protractor, but it is harder to estimate.

Adiabatic Mixing Process

It is quite common in air conditioning systems to mix two or more air streams. In particular, the supply air to a room or zone conditioning apparatus is usually a mixture of outside and return room air. If this mixing is assumed to occur under adiabatic conditions, (no heating or cooling) the final mixed condition lies on the straight line connecting the conditions of the outside air and room design air on the psychrometric chart.

Fig. A6.9(a) and Fig. A6.9(b), respectively, show the schematic of the mixing and of the psychrometric chart procedure for obtaining the final mixed condition. On this figure the numbers 1, 2, and 3 stand for room, outside, and mixed conditions, respectively. The fundamental equations which apply are the conservation of energy, the conservation of air mass, and the conservation of water:

$$m_1h_1 + m_2h_2 = m_3h_3 \qquad \text{Energy} \qquad (A6.17)$$

$$m_1 + m_2 = m_3 \qquad \text{Air Mass} \qquad (A6.18)$$

$$m_1W_1 + m_2W_2 = m_3W_3 \qquad \text{Water Vapor Mass} \qquad (A6.19)$$

By elimination of m_3 and comparison to Fig. A6.9(b),

$$\frac{m_1}{m_2} = \frac{h_2 - h_3}{h_3 - h_1} = \frac{W_2 - W_3}{W_3 - W_1} = \frac{\text{Line } \overline{32}}{\text{Line } \overline{13}} \qquad (A6.20)$$

Eq. (A6.20) shows that the mixture condition 3 may be graphically located for given conditions 1 and 2 and known ratio, m_1/m_2, of room return to outside air. Eq. (A6.20) includes Eq. (A6.12) given earlier.

Example A6.4 Adiabatic Mixing

Room air at 78 F dry bulb temperature, 50% rh at a rate of 500 scfm is mixed with outside air having 80 F dry bulb temperature, 80% rh and a rate of 100 scfm. Barometric pressure is 14.696 psia. Determine the mixture condition

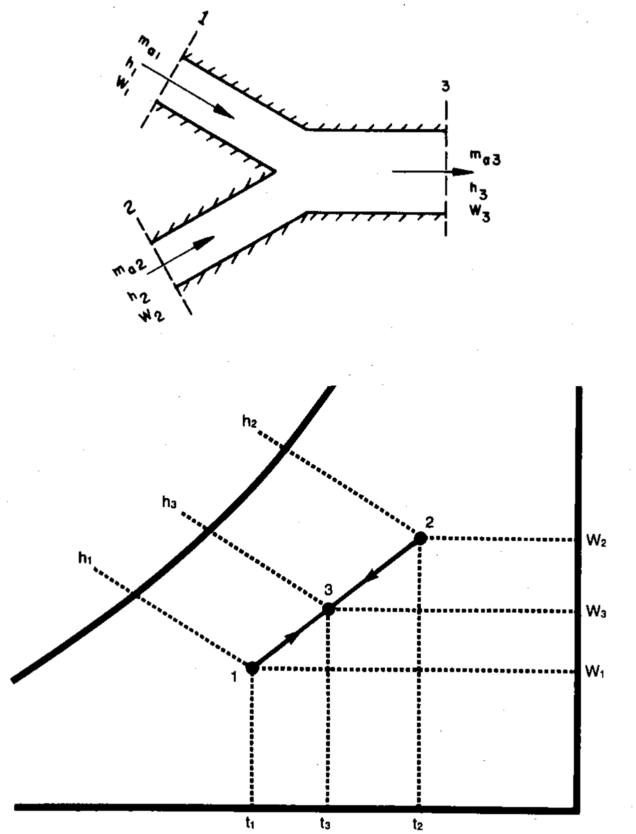

Fig. A6.9 Schematic of Adiabatic Mixing

a) using only psychrometric formulas except for initial room and outside properties, and
b) using the psychrometric chart, Fig. A6.1, based on scfm ratios

a) Standard specific volume of dry air is 13.33 ft³/lbm. This is the value assumed in defining standard volume flow rate, scfm

$$m_1/m_2 = \text{scfm}_1/\text{scfm}_2 = 500/100 = 5.0$$

From the psychrometric chart, Fig. A6.1,

$h_2 = 38.6$ Btu/lb d.a.; $h_1 = 30.0$ Btu/lb d.a.

$W_2 = 0.0177$ lb/lb d.a.; $W_1 = 0.011$ lb/lb d.a.

Using Eq. (A6.20),

$$5.0 = \frac{3.86 - h_3}{h_3 - 30.0} = \frac{0.0177 - W_3}{W_3 - 0.011}.$$

Solution yields $h_3 = 31.45$ Btu/lb d.a. and $W_3 = 0.0121$ lb/lb d.a. This establishes the mixture condition 3, which could be located on the chart as shown in Fig. A6.9.

b) Using the graphical relation in Eq. (A6.20),

$$5.0 = \frac{\text{Line } \overline{32}}{\text{Line } \overline{13}}$$

or since Line $\overline{12}$ = Line $\overline{32}$ + Line $\overline{13}$

Line $\overline{32}$ = 5/6 (Line $\overline{12}$)

The mixture condition 3 may then be inserted 5/6 of the way from condition 2 toward condition 1. The values of h_2 and W_2 will essentially agree with those calculated above.

Note that the scfm of the room (100 scfm) is 0.1667 = 1/6 of the total (100 + 500 scfm) and likewise the scfm of the outside air (500 scfm) is 0.833 = 5/6 of the total.

The mixture conditions are

$$\text{db } t_3 = 78.3; \; h_3 = 31.2; \; W_3 = 0.0112$$

Using the mixture enthalpy as a basis for comparison, the percent error based on calculated h_3 is:

$$\frac{31.45 - 31.2}{31.45} \times 100 = 0.66\%$$

Two thirds of one percent is indeed small. In any problem in the normal range, the graphical construction is recommended due to its simplicity.

Example A6.4a Calculation of Mixture Condition Using Enthalpies

Room air at 78 F db and 50% rh is mixed with outside air at 95 F db and 75 F wb in a mixture consisting of 30% room air.

Determine the mixture conditions
a) using psychrometric formulae
b) graphically on the psychrometric chart, using enthalpies instead of scfm.

a) $m_1/m_2 = 0.3/0.7 = (h_2 - h_3)/(h_3 - h_1)$

From the psychrometric chart:

$$h_1 = 30.0 \text{ Btu/lb d.a.}; \; h_2 = 38.5 \text{ Btu/lb d.a.}$$

$$h_3 = 35.95 \text{ from calculation}$$

Again, from the psychrometric chart:

$$\text{db } t_3 = 89.9 \text{ F}; \; \text{wb } t_3 = 72.1; \; W_3 = 0.0129 \text{ lb/lb d.a.}$$

b) This approximation corresponds to the b) solution of Example A6.4, using enthalpies instead of scfm. It is to be used in the absence of scfm, and only in the normal range of HVAC applications.

The smaller fraction of air, in this case 0.3 (corresponding to room air), is the fraction of the line segment traversed to arrive at the mixture point after beginning at the point corresponding to the higher percentage (outside air). After the room and outside conditions are plotted on the chart, beginning at the outside design point, move 3/10 of the distance toward the room point, or starting at the room point move 7/10 the distance toward the outside point.

A6.3-3 REQUIRED AIR QUANTITY FOR SENSIBLE AND LATENT LOADS

The required air quantity, $SCFM_s$, to handle the room sensible load may be calculated from Eq. (A6.2)

$$SCFM_s = RSH/(1.10)\,(t_R - t_s)$$

where

$SCFM_s$ = supply air to the room, standard cfm
RSH = room sensible heat, Btu/hr
t_R = room design temperature, F db
t_s = air supply temperature to the room, F db

The required air quantity, $SCFM_{app}$ through the conditioner to satisfy the total sensible air conditioning load (including supplementary loads) is also calculated from Eq. (A6.2)

$$SCFM_{app} = TSH/(1.10)(t_M - t_L)$$

where

$SCFM_{app}$ = air through the conditioner, standard cfm
TSH = total sensible heat, Btu/hr
t_M = temperature of the mixture of return and outside air entering the conditioner, F db
t_L = air temperature leaving the conditioner, F db

When no mass flow loss or heat gains are considered between discharge from the conditioner (at t_L) and supply to the room (at t_s), $SCFM_{app} = SCFM_s$ and $t_L = t_s$ as represented by the point where the GSHR and RSHR lines cross.

When heat gain is considered between discharge from the conditioner (at t_L) and supply to the room (at t_s), the two temperatures, t_L and t_s, are unequal, even though mass flow loss may be negligible. This heat gain may be intentional reheat as in Example 6.7, from fan operation as in Example 6.5a, or from supply duct heat gain as in Example 6.4.

When flow loss occurs between apparatus discharge and room supply, the best available values for $SCFM_s$ and $SCFM_{app}$ should be used.

The outdoor air intake, $SCFM_{oa}$, relates to outdoor sensible heat load, OSH by Eq. (A6.2)

$$SCFM_{oa} = OSH/(1.10)\,(t_0 - t_R)$$

where

$SCFM_{oa}$ = specified outdoor intake to air distribution system, standard cfm
OSH = outdoor sensible heat load, Btu/hr
t_0 = outdoor design temperature, F db
t_r = room design temperature, F db

The sensible heat loads each have a companion latent heat load expressed in the form of Eq. (A6.5), so that

$$SCFM_s = RLH/(4840)(W_R - W_S)$$

$$SCFM_{app} = TLH/(4840)(W_M - W_L)$$

$$SCFM_{oa} = OLH/(4840)(W_o - W_R)$$

where

W = humidity ratio, lb/lb d.a.
and RLH = room latent heat load, for example.

A6.3-4 SPRAY PROCESSES AND SATURATION EFFICIENCY

Spray processes are those in which the air is passed through a chamber having a continuous spray of water inside. Sprays are used for cooling and dehumidifying (process 1, Fig. A6.10), sensible cooling (process 2), cooling and humidifying (process 3), and heating and humidifying (process 5). Process 4 shows the simplest case: adiabatic cooling. Assuming a cooler as in Fig. A6.11, in which the spray water is captured and recirculated, adiabatic cooling takes place when the spray water is neither heated nor cooled. Adiabatic cooling nearly follows the wet bulb temperature line on the psychromatic chart. In order to obtain a process lying to the right of the adiabatic cooling line, (less cooling and more humidifying) heat must be added to the spray water. Similarly, to obtain a process to the left of the adiabatic line, the spray water must be cooled. The adiabatic line is the evaporative cooling line (OH) of Fig. A6.3.

In Fig. A6.10 all processes are shown as continued to the saturation line. In practice this condition is seldom achieved For this reason, the concept of saturation efficiency, η_{sat} is u

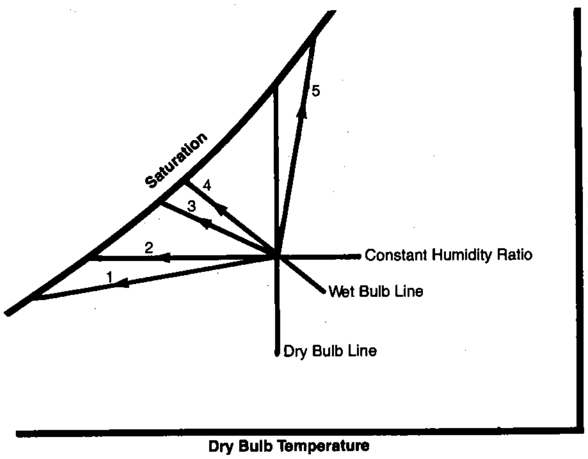

Fig A6.10 Spray Processes

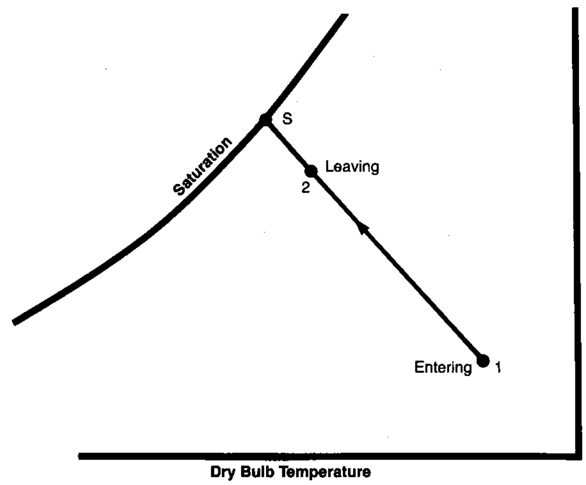

Fig A6.12 Saturation Efficiency, η_{sat}; Eq. (A6.22)

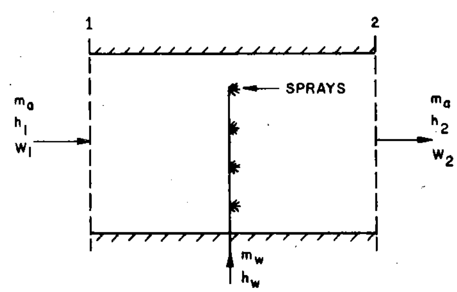

Fig. A6.11 Typical Spray Chamber

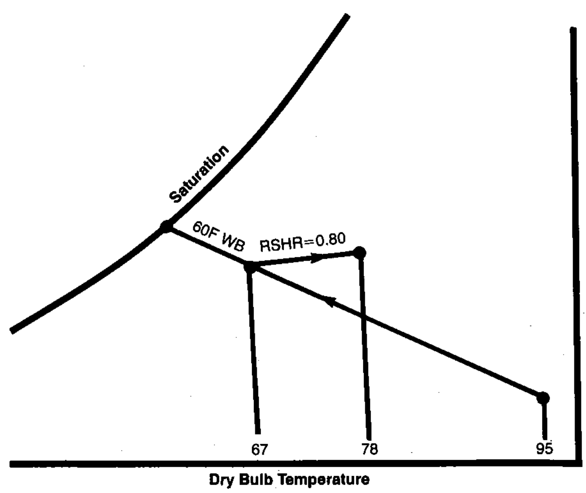

Fig. A6.13 Schematic Solution for Example A6.5

For adiabatic cooling:

$$\eta_{sat} = \frac{T_{1_{DB}} - T_{2_{DB}}}{T_{1_{DB}} - T_{1_{WB}}} \times 100; \text{ (Adiabatic)} \qquad (A6.21)$$

In the more general spray case, referring to Fig. A6.12,

$$\eta_{sat} = \frac{T_{in_{DB}} - T_{out_{DB}}}{T_{in_{DB}} - T_{sat}} \times 100; \text{ (General)} \qquad (A6.22)$$

Thus, the length of the GSHR line from inlet to outlet conditions is equal to η_{sat} percentage of the entire line extended from inlet condition to the saturation curve.

EXAMPLE A6.5 Adiabatic Cooling

100% outside air at 95 F db and 60 F wb enters a recirculating water system. It passes adiabatically through the system, discharging to a room at a saturation efficiency of 80%. Room design condition is 78 F db. Room sensible heat load is 200,000 Btu/hr and room latent heat load is 50,000 Btu/hr. Calculate the condition entering the room, room design rh, and the scfm of supply air.

The psychrometric chart, Fig. A6.13, shows the process lines which are determined as follows:

1. Using Eq. (A6.21), calculate the dry bulb temperature at room supply, t_2 db = 67 F db.
2. Calculate RSHR = RSH/RTH = 200,000/(200,000 + 50,000) = 0.8
3. Beginning at outside air condition, draw a line upward along the 60 F wet bulb line — adiabatic cooling — until it intersects 67 F db. This is the room supply condition: 60 F wb, 67 F db.
4. Transfer a line parallel to the $\Delta H_S/\Delta H_T = 0.8$ line of the protractor and starting from room supply.
5. Locate room design where this RSHR line intersects the room design of 78 F db. Thus room design rh = 49%.

The SCFM of supply air is

$$\text{scfm} = 200{,}000/(1.10)(78 - 67) = 16{,}530$$

The scfm of supply air could have been calculated from the room latent heat load and humidity ratios read from the psychrometric chart, but with a loss in precision. Because the RSHR line was not very steep, temperature change was read with greater precision than the humidity ratio change. In cases where the RSHR line is steep, the latent heat equation would be preferred.

A6.4 EFFECTIVE SURFACE TEMPERATURE (t_{es}), APPARATUS DEWPOINT (adp), AND BYPASS FACTOR (BF)

Effective Surface Temperature (t_{es})

The surface temperature of any air conditioning apparatus varies over the surface as the air contacts it. The Effective Surface Temperature (t_{es}) is defined as the assumed uniform surface temperature which would produce the same leaving air conditions as the non-uniform surface temperature that actually occurs on the apparatus in operation. The effective surface temperature serves as a common reference point for numerically equating heat flow from the supply air to the heat flow to the apparatus. It is used in calculating air quantity and in making the proper economical choice of cooling coils.

Apparatus Dewpoint (adp):

For cooling with dehumidification, the effective surface temperature (t_{es}) is at the point where the effective conditioning process line (GSHR Line) intersects the saturation line on the psychrometric chart (See Fig. A6.14, for example). In such cases, t_{es} is considered to be the dewpoint of the surface of the apparatus (adp). It is only for cooling with dehumidification that t_{es} is required to lie on the saturation line, hence, the term adp is reserved for cooling-dehumidification processes.

Bypass Factor (BF):

Bypass Factor (BF) is defined as the fraction of air which is assumed to pass through the conditioner completely unchanged. Decreasing (or increasing) the apparatus heat transfer surface increases (or decreases) the bypass factor. Decreasing (or increasing) the air velocity decreases (or increases) the bypass factor, but this effect is less significant than the effect due to heat transfer surface.

There is a psychrometric relation between bypass factor, adp, GSHR and RSHR, as will be demonstrated. A bypass factor of zero means that all air leaving the apparatus is at adp conditions.

The complement of bypass factor, that is (1-BF), is usually used in discussion of spray washer equipment and when converted to a percentage is called the Saturation Efficiency, η_{sat}. (See Section A6.3-4)

Selection of a proper bypass factor for a particular application involves an economic balance of first cost and operating cost of equipment.

Consider an interpretation of BF in terms of the apparatus operating line (the GSHR line) on the psychrometric chart. Where the GSHR line intersects the saturation line has been defined as the apparatus dewpoint (adp), and this adp is identical to the leaving condition of the apparatus if the bypass factor is zero. It follows that the entering and leaving air conditions at the conditioning apparatus and the apparatus dewpoint are related psychrometrically to the bypass factor. Although it is recognized that bypass factor is not a true straight line function, it can be evaluated quite accurately from the following equations:

$$BF = \frac{t_L - t_{adp}}{t_M - t_{adp}} = \frac{h_L - h_{adp}}{h_M - h_{adp}} = \frac{W_L - W_{adp}}{W_M - W_{adp}} \quad (A6.23)$$

where *L*, *M* and *adp* refer to leaving the apparatus, mixture entering the apparatus, and apparatus dewpoint, respectively.

The quantity (1-*BF*), which represents that portion of air considered leaving the apparatus at the adp, is given by

$$\frac{\eta_{sat}}{100} = 1 - BF = \frac{t_M - t_L}{t_M - t_{adp}} = \frac{h_M - h_L}{h_M - h_{adp}} = \frac{W_M - W_L}{W_M - W_{adp}} \quad (A6.24)$$

Note that the temperature form of Eq. (A6.24) agrees with Eq. (A6.22).

Fig. A6.14 may be used to illustrate the relationship between the bypass factor and the GSHR line. Considering the line from the adp through point *L* to point *M* to have unit length, the portion of the line from adp to *L* has length BF and the portion of the line from *L* to *M* has length (1-*BF*).

A ratio of BF to its complement (1-BF) may be written by use of Eq. (A6.23) and (A6.24)

$$\frac{BF}{1 - BF} = \frac{t_L - t_{adp}}{t_M - t_L} = \frac{h_L - h_{adp}}{h_M - h_L} = \frac{W_L - W_{adp}}{W_M - W_L} \quad (A6.25)$$

Referring to Fig. A6.14, consider the room condition, *R*, and outdoor condition, 0, to be fixed. Also consider the direction of the RSHR line to remain fixed. If the proportions of outside and return air are changed, the position of the mixture point, *M*, will change and so will the direction of the GSHR line. As a consequence, condition *L*, the apparatus dewpoint, bypass factor, and required air quantity will also change.

A6.5 EFFECTIVE SENSIBLE HEAT RATIO AND REQUIRED AIR QUANTITY

To relate bypass factor and apparatus dewpoint to the load calculation, the Effective Sensible Heat Ratio term (ESHR) was developed. Its purpose is to simplify the calculation of air quantity and apparatus selection when heat gains and mass loss between discharge from the conditioner and supply to the room are negligible.

The Effective Sensible Heat Ratio is the ratio of effective room sensible heat to the sum of effective room sensible and latent heats. Effective room sensible heat is composed of room sensible heat (as used in RSHR) plus that portion of the outdoor air sensible load which is considered as being bypassed, unchanged, through the conditioning apparatus. The effective room latent heat is composed of the room latent heat (as used in RSHR) plus that portion of the outdoor air latent heat load which is considered as being passed, unchanged, through the conditioning apparatus. This ratio is expressed in the following formula:

$$ESHR = \frac{ERSH}{ERSH + ERLH} = \frac{ERSH}{ERTH}$$

$$= \frac{RSH + BF(OSH)}{[RSH + BF(OSH)] + [RLH + BF(OLH)]} \quad (A6.26)$$

where

OSH = outside sensible heat load, Btu/hr
OLH = outside latent heat load, Btu/hr

The bypassed outdoor air loads that are included in the calculation of ESHR are, in effect, loads imposed on the conditioned space in exactly the same manner as the infiltration load. The infiltration load comes through the doors and windows; the bypassed air load is supplied to the space through the air distribution system.

Required Air Quantity:

By analogy to the equations of Section A6.3-3, the required

air quantity, $SCFM_s$, to handle the room load may be calculated from

$$(1 - BF)(SCFM_s) = ERSH/(1.10)(t_R - t_{adp}) \quad (A6.27)$$

where

$(1 - BF)(SCFM_s)$ = *effective* supply air to the room, cfm based on *effective* supply temperature, t_{adp}

$SCFM_s$ = supply air to the room, cfm (standard)

$$SCFM_s = ERSH/(1.10)(t_R - t_{adp})(1 - BF) \quad (A6.27a)$$

Drawing a straight line between the adp and room design conditions (adp − R), Fig. A6.14 represents the ESHR ratio. The interrelationship of RSHR, GSHR, adp and ESHR is graphically illustrated in Fig. A6.14. Heat gains or mass losses between conditioner discharge and room supply are neglected.

Tables have been prepared to simplify the method of determining adp from ESHR so that it is not necessary to plot ESHR on a psychrometric chart.

In a normal, well designed, tight system the difference in supply air temperature to the zone and the air temperature leaving the apparatus; that is, $t_S - t_L$, is usually not more than a few degrees. When it is necessary to include this temperature difference and/or mass loss between apparatus and zone in the analysis, the use of an effective room sensible heat ratio (ESHR) is no longer possible.

The GSHR line sometimes intersects the saturation curve in nearly a tangent fashion. In fact, there may be applications where the calculated ESHR and GSHR lines do not intersect the saturation line when plotted on the psychrometric chart. This occurs when the latent zone load is high with respect to total loads; that is, low ESHR. In such applications, an approximate adp is selected and the air is reheated to the RSHR line or it may be possible, at times, to remove or reduce the need for reheat by changing the room design condition. (Example 6.8)

If the supply air quantity is not fixed, the best approach to determining the adp is to assume a maximum allowable temperature difference between the supply air and the zone after the ventilation requirement is first determined. Then, calculate the supply air conditions to the zone based on the requirement that the common point (L) on the GSHR line and (S) on the RSHR line must properly handle the sensible and latent zone loads.

There are four major criteria which should be examined in the establishing of supply air requirements to the zone. These are:

1. Air movement in the zone.
2. Maximum temperature difference between the supply air and room design.
3. The selected adp should provide an economical refrigeration machine selection.
4. The ventilation requirement may sometimes result in a 100% outdoor air application.

Ventilation or code requirements may be such that the required outdoor air may be equal to, or greater than, the air quantity required to handle the zone load. A general approach to determining the required amount of dehumidified air when all outdoor air is required is as follows:

1. Based on the given ventilation requirement of all outdoor air, calculate the outdoor air load, the ESHR based on a reasonable BF, and the adp in that order. (This assumes that the ESHR line intersects the saturation line.)
2. Calculate the dehumidified air quantity required.
   a. If the dehumidified air quantity is *equal* to the outdoor air requirements, the solution is evident.
   b. If the dehumidified air quantity is *less than* the outdoor air requirements, a coil with a larger bypass factor should be investigated provided the difference in air quantities is small. When a large difference is indicated, however, reheat is the required solution. This situation may occur when the application requires large exhaust air quantities; for example, a hospital operating room where much ventilation is an absolute necessity.
   c. If the dehumidification air quantity is *greater than* the outdoor air requirements, substitute $SCFM_{sa}$ for $SCFM_{oa}$ in the outdoor air load calculations of Step 1.
3. When Step 2c, is encountered and the substitution of new $SCFM_{oa}$ is made, repeat Steps 1 and 2. The new dehumidified air quantity calculated should check reasonably close to the $SCFM_{oa}$.

EXAMPLE A6.6 Air Quantity Using ESHR, adp and BF

Zone sensible load = 80,000 Btu/hr
Zone latent load = 20,000 Btu/hr
Room design = 75 F dry bulb, 50% rh
Outdoor design = 95 F dry bulb, 50% rh

In addition to the above, let ventilation be specified at 1,000 scfm of outdoor air. No losses are assumed between apparatus and zone.

Find:
1. Outdoor air load, Btu/hr
2. Grand total heat, Btu/hr
3. Effective sensible heat ratio, ESHR
4. Apparatus dewpoint temperature, adp
5. Bypass factor, BF
6. Dehumidified air quantity. (cfm of dry air)
7. Entering and leaving conditions at the apparatus

Fig. A6.14 shows the psychrometric chart solution.

1. The outdoor air sensible heat load due to ventilation,

$$OSH = 1.10\,(cfm_{oa})\,(t_o - t_R)$$

$$OSH = 1{,}000\,(1.10)\,(95 - 75) = 22{,}000 \text{ Btu/hr}$$

The outdoor air latent load due to the ventilation;

$$OLH = cfm_{oa}\,(4840)\,(W_0 - W_R)$$

$$OLH = 1{,}000\,(4840)\,(0.0178 - 0.0092) = 41{,}625 \text{ Btu/hr}$$

$$OTH = OSH + OLH = 22{,}000 + 41{,}625 = 63{,}625 \text{ Btu/hr}$$

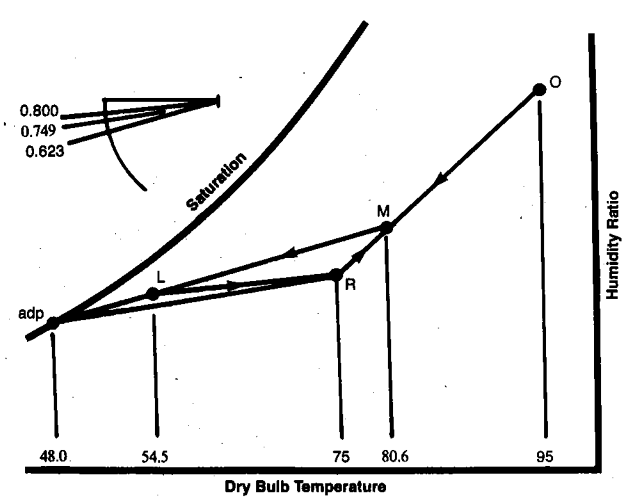

Fig. A6.13 Schematic Solution for Example A6.5

2. TSH = RSH + OSH = 80,000 + 22,000 = 102,000 Btu/hr

   TLH = RLH + OLH = 20,000 + 41,625 = 61,625 Btu/hr

   GTH = TSH +TLH = 102,000 + 61,625 = 163,625 Btu/hr

3, 4 and 5. The effective sensible heat ratio (ESHR) cannot be established independently of the BF and adp.

$$GSHR = TSH/GTH = 102,000/63,625 = 0.623$$

$$RSHR = RSH/RTH = 80,000/100,000 = 0.800$$

$$ERSH = 80,000 + BF(22,000)$$

$$ERLH = 20,000 + BF(41,625)$$

$$ERTH = ERSH + ERLH$$

$$ESHR = \frac{80,000 + 22,000\ BF}{100,000 + 63,625\ BF}$$

There is a high latent load because of the high humidity ratio of the outdoor ventilation air.

Assume BF = 0.20

$$ESHR = \frac{84,400}{112,725} = 0.749$$

Construction of the ESHR line on Fig. A6.14 (based on the protractor line having $\Delta H_S/\Delta H_T = 0.749$) gives the same value of adp

ESHR = 0.749; adp = 48.0 F, for assumed BF = 0.20

6. SCFMs = 84,400/(1.10) (75 − 48.0) (0.8) = 3,550

There are now two choices of approach to determine the entering and leaving conditions — either by complete dependence on the chart, or by the preferred use of calculations.

Depending strictly on the chart, Fig. A6.14, draw in the mixing line (O-R) and draw the GSHR line starting up from the adp at the slope given by the protractor for a GSHR value of 0.623. Where the GSHR line and mixing line cross establishes the mixture condition (M). Drawing the RSHR line at the slope required by RSHR = 0.800 determines the condition (L) leaving the apparatus where the RSHR line intersects the GSHR line.

Using the calculation approach, the adiabatic mixing rule of Eq. (A6.10a) gives

$$m_{aR}/m_{a0} = \frac{95 - t_M}{t_M - 75} = SCFM_R/SCFM_0$$

$$t_M = \frac{m_{a0}(95) + m_{aR}(75)}{m_{a0} + m_{aR}}$$

Assuming that the apparatus selected for 3,550 cfm, 48.0 F adp, and GTH = 163,625 Btu/hr has a bypass factor equal, or nearly equal, to the selected BF = 0.20, and that it is not necessary to physically bypass around the apparatus,

$$t_M = \frac{1,000\ (95) + 2,550\ (75)}{3,550} = 80.6\ F$$

The mass ratios were replaced by standard cfm ratios. Using Eq. (A6.23) with BF = 0.20 and adp = 48.0F.

$$t_L = t_{adp} + BF\ (t_M - t_{adp})$$

$$t_L = 48.0 + 0.20\ (80.6 - 48.0) = 54.5\ F$$

Completely established now are the GSHR line, RSHR line, condition (*L*) leaving the apparatus and entering the zone, the adp, and the mixing condition (*M*) entering the conditioning apparatus.

Temperatures of several points are shown on Fig. A6.14.

A summary of approximate enthalpy values is:

Point	adp	*L*	*R*	*M*	*O*
h, Btu/lb	19.3	22.0	28.2	32.0	42.4

Example A6.6 has been treated methodically in proceeding through the various steps. However, supplementary loads such as fan and duct heat gain and duct leakage losses were ignored. In actual practice, these heat gains and losses must be taken into account in estimating the cooling load. The solution found in the example used the ESHR concept. This solution could now be used as a basis for a solution which includes the other gains and losses.

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*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-623-997/1553

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Washington, D.C. 20410

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April 1980
HUD-PDR-533