A STUDY OF FACTORS AFFECTING THE COOLING LOAD FOR AIR CONDITIONING

by

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Signature of Chairman of Departmental
Committee on Graduate Students.......................... Signature redacted

Cambridge, Massachusetts
May 15, 1935

Professor George W. Swett
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

I herewith submit a thesis entitled "A STUDY OF FACTORS AFFECTING THE COOLING LOAD FOR AIR CONDITIONING," in partial fulfillment of the requirements for the degree of Master of Science.

Respectfully yours,

Signature redacted

Maurice E. Bates

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INTRODUCTION

Although air conditioning is a rather new industry, in the past few years such rapid progress has been made in the design and manufacture of the equipment and the public has been made so "air-conditioned minded" that there is opening up a very large market for air conditioning units.

While much time and effort has been spent in perfecting the equipment by means of which the air is properly conditioned, very little attention has been given to the structures in which the equipment is placed. Until quite recently, air conditioning systems seem to have been merely "installed" with little or no attempt made to fit the cooling capacity of the machine to the maximum cooling requirements which might occur in the building to be conditioned. The results that obtain from such guesswork must nearly always be wasteful, for if the equipment turns out to be inadequate to maintain required conditions of the air, more equipment must subsequently be added at a greater proportionate cost, and if the cooling capacity is above the maximum requirements there will likewise be a loss.

During the past few years there has been some investigational work done on the factors which affect the cooling load for air conditioning, but, as the reader will see, there remains to be done a great amount of research work before rational calculations can be substituted for the "rule of thumb" designing which still exists to a large extent. The investigations of this subject which have been carried on, to date, are largely independent and scattered. To the author's knowledge, they have never before been brought together.

The purpose of this work is to study the factors which affect the cooling load for air conditioning. These factors, as presented, are:

1. Analysis of Weather Data.
2. Heat Transmission.
3. Air Filtration.
4. Solar Radiation.
5. Effect of Solar Radiation on Heat Transmission.
6. Solar Radiation Transmitted Through Bare and Shaded Windows.
7. Heat Emitted Within Building.
8. Ventilation Requirements.
9. Atmospheric Humidity.
10. Migration of Moisture and Its Effect on Heat Conductivity.

While all of these items are discussed to some extent, emphasis has been placed upon two important factors about which the least is known at the present time; namely, the effect of solar radiation and the effect of moisture migration.

In the Appendix, quotations are given from the American Society of Heating and Ventilating Engineers 1935 Guide, and from the manuals of the Kelvinator, Frigidaire and Westinghouse Air Conditioning Companies, showing how the solar radiation load is calculated by these authorities. This is the only one of the cooling load factors which is so compared because all of the others are calculated according to more or less standardized and generally accepted methods.

So little is known of the effect of moisture migration that it is not mentioned by any of these authorities.

ANALYSIS OF WEATHER DATA

As a whole the United States has a temperate climate. The country extends over approximately 24 deg of latitude, and this fact, together with the presence of several mountain ranges and variations in altitude, results in a large variation in climatic conditions. In San Francisco, the mean dry bulb temperature for July is 57.3 deg F, in Phoenix 90.5 deg, in New York 73.5 deg. A similar variation is experienced in passing from the northern states southward. The mean dry bulb temperature for July in Chicago is 72.3 deg. The temperature rises more or less uniformly in passing southward, reaching a July mean of 81.3 deg in New Orleans. There is a like variation in wet bulb temperatures encountered throughout the country, with a minimum mean for July of 52.6 deg F in Lander, Wyoming, and a maximum mean of 77 deg at Galveston, Texas. These extremes in temperatures emphasize the fact that correct and economical design of air conditioning systems demands a comprehensive understanding and proper interpretation of temperature readings obtained by the Weather Bureau stations. Weather Bureau reports are frequently misleading as they report the maximum temperature for the day with the relative humidity which occurs during a different period and which usually is much higher than the relative humidity occurring at the maximum temperature.

Outdoor Conditions as Basis for Design.

The heating system is not based on the minimum outdoor temperature for the heating season, but on a point approximately 15 deg F above the lowest recorded, and similarly a cooling system should not be based on extreme temperatures, as these occur during a comparatively few days only. Neither is the mean summer temperature for the hottest month the correct basis, since in that case equipment would be inadequate during a considerable portion. The monthly mean temperature, however, does offer a satisfactory starting point for establishing the correct basis for the design. The wet bulb and dry bulb temperatures to be used for the design will be at some point between the mean and the maximum temperatures. The number of degrees to be added to the mean is determined by the mean. As the mean temperature approaches the maximum temperature the daily variation from the mean approaches zero. For example, if it is assumed that for all practical purposes the maximum wet bulb temperature recorded in the United States is 84 deg, then if any locality had a mean wet bulb temperature of 84 deg there would be no daily variation above or below the mean, and the correct basis for design would equal the mean wet bulb temperature.

The outside design temperatures for different cities in the United States are given in Table I. Knowing these conditions and the maintained conditions required, the heat transmission, sun effect and outside air load may be calculated in the recommended manner. These design temperatures are not

Table I

AVERAGE MAXIMUM DESIGN DRY-BULB TEMPERATURES, DESIGN WET-BULB TEMPERATURES, WIND VELOCITIES, AND WIND DIRECTIONS FOR JUNE, JULY, AUGUST, AND SEPTEMBER.

State	City	Average Maximum Design Dry-bulb	Design Wet-bulb	Summer Wind Velocity MPH	Prevailing Summer Wind Direction
Ala.	Birmingham	93	77	5.2	S
	Mobile	94	78	8.6	SW
Ariz.	Phoenix	110	77	6.0	W
Ark.	Little Rock	95	77	7.0	NE
Calif.	Los Angeles	88	70	6.0	SW
	San Francisco	85	68	11.0	SW
Colo.	Denver	90	64	6.8	S
Conn.	New Haven	88	74	7.3	S
D. C.	Washington	93	76	6.2	S
Fla.	Jacksonville	94	78	8.7	SW
	Tampa	94	79	7.0	E
Ga.	Atlanta	91	75	7.3	NW
	Savannah	95	79	7.8	SW
Idaho	Boise	95	65	5.8	NW
Ill.	Chicago	88	73	10.2	NE
	Peoria	91	75	8.2	S
Ind.	Indianapolis	90	73	9.0	SW
Iowa	Des Moines	92	74	6.6	SW
Ky.	Louisville	94	75	8.0	SW
La.	New Orleans	94	79	7.0	SW
Maine	Portland	85	71	7.3	S
Md.	Baltimore	93	76	6.9	SW
Mass.	Boston	88	73	9.2	SW
Mich.	Detroit	88	72	10.3	SW
Minn.	Minneapolis	84	72	8.4	SE
Miss.	Vicksburg	95	78	6.2	SW
Mo.	Kansas City	92	75	9.5	S
	St. Louis	93	76	9.4	SW
Mont.	Helena	87	63	7.3	SW
Nebr.	Lincoln	93	74	9.3	S
Nev.	Reno	93	64	7.4	W
N.J.	Trenton	93	75	10.0	SW
N.Y.	Albany	90	74	7.1	S
	Buffalo	83	72	12.2	SW
	New York	91	75	12.9	SW
N.M.	Santa Fe	87	63	6.5	SE
N.C.	Asheville	87	72	5.6	SE
	Wilmington	93	79	7.8	SW
N.D.	Bismarck	88	69	8.8	NW
Ohio	Cleveland	87	72	9.9	S
	Cincinnati	93	75	6.6	SW
Okla	Oklahoma City	96	76	10.1	S
Ore.	Portland	83	65	6.6	NW

Table I (Continued)

State	City	Average Maximum Design Dry-bulb	Design Wet-bulb	Summer Wind Velocity MPH	Prevailing Summer Wind Direction
Pa.	Philadelphia	93	76	9.7	SW
	Pittsburgh	91	73	9.0	NW
R.I.	Providence	85	73	10.0	NW
S.C.	Charleston	94	80	9.9	SW
	Greenville	93	76	6.8	NE
Tenn.	Chattanooga	94	76	6.5	SW
	Memphis	93	77	7.5	SW
Texas	Dallas	99	76	9.4	S
	Galveston	93	79	9.7	S
	San Antonio	100	78	7.4	SE
	Houston	93	79	7.7	S
	El Paso	98	69	6.9	E
Utah	Salt Lake City	95	67	8.2	SE
Vt.	Burlington	85	71	8.9	S
Va.	Norfolk	91	76	10.9	S
	Richmond	95	76	6.2	SW
Wash.	Seattle	83	61	7.9	S
	Spokane	89	63	6.5	SW
W.Va.	Parkersburg	90	74	5.3	SE
Wis.	Madison	89	73	8.1	SW
	Milwaukee	87	72	10.4	S
Wyo.	Cheyenne	85	62	9.2	S

maximum temperatures nor average temperatures, but they have been chosen after considerable study of the Weather Bureau records as the temperature that is not exceeded more than 5 to 8 per cent of the time during June, July, August and September for an average year. Therefore, the refrigeration load made up by the transmission, sun effect, and outside air is a maximum only 5 to 8 per cent of the season and ranges from zero to maximum 92 to 95 per cent of the time.

Variation of Climate Load.

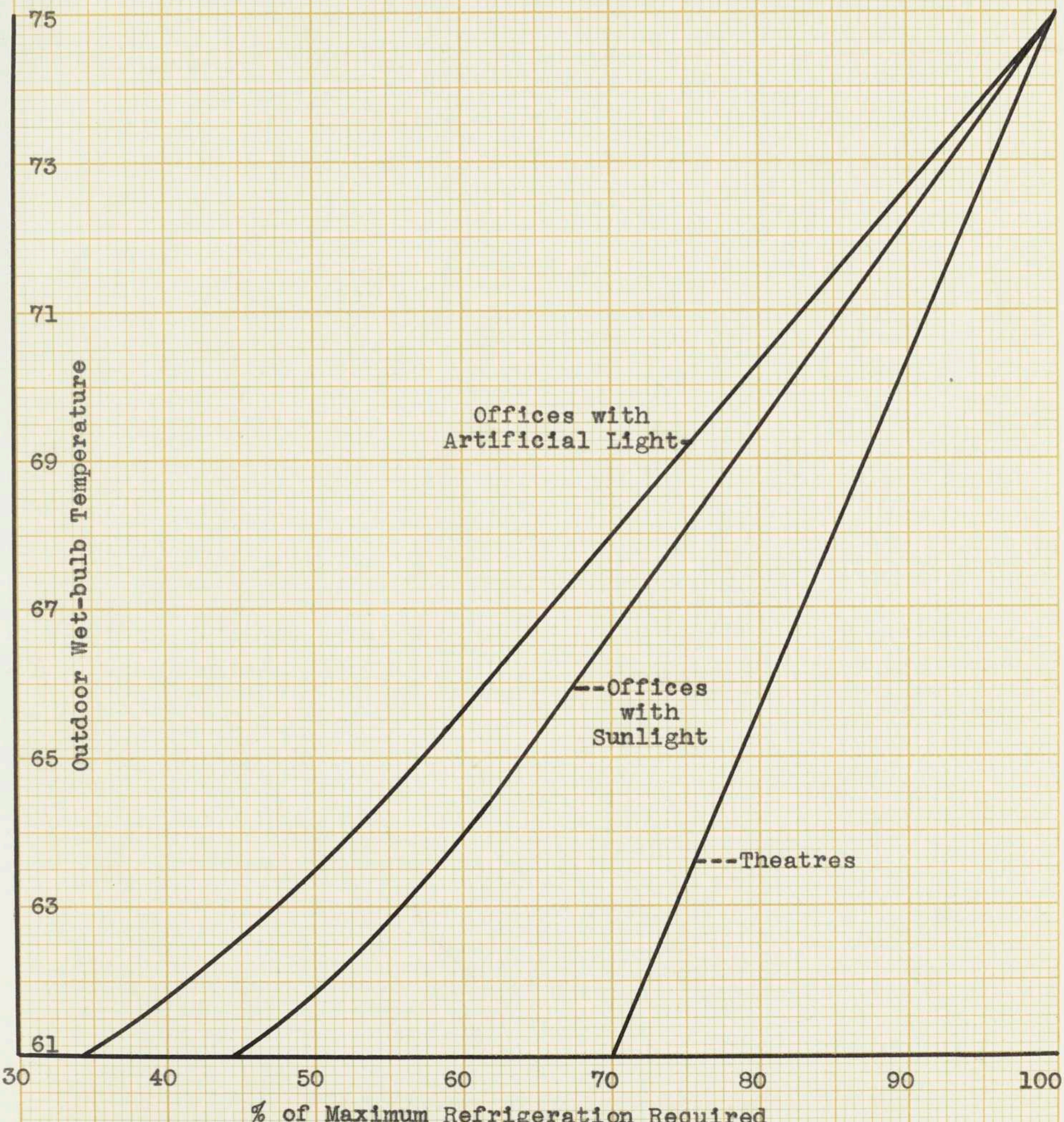
The total load on an air cooling plant may, to advantage, be divided into the internal load and the climate load. Such factors as heat from lights and heat and moisture from occupancy constitute the internal load, while the climate load varies with the sun intensity and outdoor wet and dry bulb temperatures. When the outdoor temperatures equal the corresponding indoor temperatures and the sun is not shining, the climate load approaches zero. On the other hand, the internal load is practically constant irrespective of the outdoor conditions.

Fig. 1, based on a maximum wet bulb temperature of 75 deg and a maximum dry bulb temperature of 95 deg, shows the effect of a drop in outdoor wet bulb temperature on the refrigerating capacity required to take care of the internal load for theaters and office buildings. These two types of spaces have been selected as illustrating the essential difference between internal and climate loads and their effect on operating costs. A theater load is largely an internal load, and the reduction in cooling effect required is much less than the office building where the internal load is relatively small. In theaters, the reduction in tonnage as the weather becomes cooler is not so much as might be expected, and even when the outdoor wet bulb temperature falls as low as 61 deg still 70 per cent of maximum capacity is required.

Rooms in an office building having a northern exposure require only 33 per cent of maximum capacity when the

Fig. 1

EFFECT OF OUTDOOR TEMPERATURE ON REFRIGERATING CAPACITY



outdoor wet bulb temperature falls to 61 deg. A room heavily insulated and without windows would require approximately 100 per cent of maximum capacity, regardless of the outdoor conditions, and the curve for such a construction would accordingly fall to the right of the theater curve. The maximum capacity required in this case would, of course, be less than for a more normal construction, but the percentage of maximum capacity required with a falling outdoor temperature would be greater.

HEAT TRANSMISSION

Whenever a difference in temperature exists between the two sides of any structural material, such as a wall or roof of a building, a transfer of heat takes place through that material. When the inside temperature is the higher, heat reaches or enters the inside surface of the wall by radiation and convection, because the air and objects within the building are always warmer than the inside surface of the wall when the inside air temperature t is greater than the outside air temperature t_o. This heat must then pass through the material of the wall from the inside to the outside surface by conduction, and is finally given off from the outside surface by radiation and convection, provided, of course, that equilibrium has been established and all four temperatures are constant. If the outdoor temperature is the higher, the reverse process takes place.

Calculations for Transmission Losses.

The generally accepted method of computing the heat transfer through a building structure is that found in the Guide of the American Society of Heating and Ventilating Engineers, and the following equations are taken from that book.

The calculations for heat transmission losses are made by multiplying the area A in square feet of wall, glass, roof, floor, or material through which the loss takes place, by the proper coefficient U for such construction or material and by the temperature difference between the inside air temperature t at the proper level (in many cases not the breathing-line) and the outside air temperature t_o. Therefore,

$$H_t -- AU(t-t_o)$$

where

H_t--Btu per hour transmitted through the material of the wall, glass, roof or floor.

A--area in square feet of wall, glass, roof, floor, or material, taken from building plans or actually measured. (Use the net inside or heated surface dimensions in all cases).

$t - t_o$--temperature difference between inside and outside air, in which t must always be taken at the proper level.

Areas where Transmission Losses Occur: Heat is transmitted into a building through all of those surfaces which separate cooled spaces from the outside air or from warmer spaces within the building. In general, five kinds of surfaces are involved: (1) outside walls; (2) outside glass; (3) inside walls or partitions next to warmer spaces; (4) ceilings of upper floors, either below a warm attic space or as the underside of a roof slab; and (5) floors of cooled rooms above a warm space.

The net outside wall surface is usually determined by reference to the scale plans and elevations of the building concerned. In some cases, of course, the actual building may have to be measured. The total area of all outside openings which are occupied by windows and doors is accurately measured and listed as glass. The glass area is then deducted from the total outside wall area for each room and the difference is the net wall area. The outside wall areas for any floor should be based on the vertical floor-to-floor heights and the horizontal distance from center to center of partitions separating different rooms. If there are no partitions, measure from inside face of one wall to inside face of next wall. The areas of walls, ceilings and floors next to warm or untreated spaces are found, of course, by taking the inside dimensions of such areas, measured on the cooled side.

Coefficients of Transmission.

The coefficients of transmission may be determined by means of the guarded hot box or the Nicholls Heat Meter, or they may be calculated from fundamental constants. Because of the unlimited number of combinations of building materials, it would be impractical to attempt to determine by test the heat transmission coefficients of every type of construction in use; consequently, in most cases it is advisable to calculate these coefficients. The American Society of Heating and

Ventilating Engineers has compiled the value of coefficients for many types of construction, and these values can be found in their Guide.

Symbols: The following symbols are used in heat transmission formulae:

U--Thermal transmittance or over-all coefficient of heat transmission and is the amount of heat expressed in Btu transmitted in one hour per square foot of the wall, floor, roof or ceiling for a difference in temperature of 1 deg F between the air on the inside and outside of the wall, floor, roof, or ceiling.

k--Thermal conductivity and is the amount of heat expressed in Btu transmitted in one hour through 1 sq ft of a homogeneous material 1 in. thick for a difference in temperature of 1 deg F between the two surfaces of the material. The conductivity of any material depends on the structure of the material and its density. Heavy or dense materials, the weight of which per cubic foot is high, usually transmit more heat than light or less dense materials, the weight of which per cubic foot is low.

C--Thermal conductance and is the amount of heat expressed in Btu transmitted in one hour through 1 sq ft of a non-homogeneous material for the thickness or type under consideration for a difference in temperature of 1 deg F between the two surfaces of the material. Conductance is usually used to designate the heat transmitted through such heterogeneous materials as plaster board and hollow clay tile.

f--Film or surface conductance and is the amount of heat expressed in Btu transmitted by radiation, conduction and convection from a surface to the air surrounding it, or vice versa, in one hour per square foot of the surface for a difference in temperature of 1 deg between the surface and the surrounding air. To differentiate between inside and outside wall (or floor, roof or ceiling) surfaces, f_i is used to designate the inside film or surface conductance and f_o the outside film or surface conductance.

a--Thermal conductance of an air space and is the amount of heat expressed in Btu transmitted by radiation, conduction and convection in one hour through an area of 1 sq ft of an air space for a temperature difference of 1 deg F. The conductance of an air space depends on the mean absolute temperature, the width, the position and the character of the materials enclosing it.

R--Resistance or resistivity which is the reciprocal of transmission, conductance, or conductivity, i.e.:

$\frac{1}{U}$ -- over-all or air-to-air resistance.

$\frac{1}{k}$ -- internal resistivity.

$\frac{1}{C}$ -- internal resistance.

$\frac{1}{f}$ -- film or surface resistance.

$\frac{1}{a}$ -- air-space resistance.

Fundamental Formulae: The formula of the over-all coefficient for a simple wall x inches thick is:

$$U = \frac{1}{\frac{1}{f_1} + \frac{1}{f_o} + \frac{x}{k}}$$

and for a compound wall of several materials having thicknesses in inches of x_1, x_2, x_3, etc., the coefficient is:

$$U = \frac{1}{\frac{1}{f_1} + \frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} \quad \text{etc.}}$$

In the case of air-space construction, an air-space coefficient for each air space must be inserted. Thus for a simple wall with one air space,

$$U = \frac{1}{\frac{1}{f_1} + \frac{1}{f_o} + \frac{1}{a} + \frac{x}{k}}$$

and for a simple wall of several air spaces having conductances of a_1, a_2, a_3, etc., the coefficient is:

$$U = \frac{1}{\frac{1}{f_1} + \frac{1}{f_o} + \frac{x}{k} + \frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3} \quad \text{etc.}}$$

With certain special forms of materials which have irregular air spaces (such as hollow tile) or are otherwise non-homogeneous, it is necessary to use the conductance (C) for the unit construction, in which case $\frac{x}{k}$ is replaced by $\frac{1}{C}$.

As in the case of the simple wall, f_i and f_o are always the inside and outside surface coefficients for the two materials in contact with air. If the air is still (no wind), then for the same material f_i and f_o are the same, and $f_i = f_o$; but, if the outside air is in motion, then f_o is always greater than f_i and will increase as the wind velocity increases. Values for f_i in still and moving air have been determined for various building materials at the University of Minnesota. The range of values for ordinary building materials is comparatively small and for practical purposes may be assumed constant for either still air or any given wind velocity, particularly in view of the fact that the surface resistances usually comprise only a small part of the total resistance of the construction, except in the case of thin, highly conductive walls.

In designing a heating plant it becomes necessary to allow for an extra heat loss on the windward side of the building, because the wind removes the warm, stagnant air film on the outer surface of the wall and increases the heat loss. It is not necessary to make any such allowance when figuring the maximum cooling load because the film of air absorbs heat from the hot surface of the wall and becomes much warmer than the outside air temperature. When the wind removes this film of hot air it reduces the heat flow into the building and decreases the cooling load.

While most building materials have surfaces which show similar characteristics as far as the transmission of heat is concerned, it is a well-known fact that certain surfaces such as aluminum bronze, gold bronze, aluminum foil, or in fact any metallic, highly polished surface presents a greater resistance to heat transmission than the surface of the average building material.

The greater heat resistance of such metallic surfaces is due primarily to their higher reflectivity and consequent lower emissivity of radiant heat. The use of multiple layers of metallic surfaces, combined with air spaces of low resistance, provides a definite insulating effect.

Adjacent Rooms.

If there is an unheated or uncooled room adjacent to the room for which the heat transmission is to be figured, some temperature for the partition which separates the two rooms must be assumed. Good practice is to take this temperature as the mean between that out of doors and that of the room which is under consideration. In computing the heat transmission through a floor or ceiling between a conditioned room and an untreated room, the temperature of the latter likewise may be assumed as the mean temperature. That is, if it is 90 deg F outside and 70 deg F inside the attic temperature is assumed to be 80 deg F.

The temperature in an attic space which has no windows, dormers, vertical walls or other openings to the outside may be calculated as follows:

$$t_b = \frac{tU_{ce} + nt_oU_r}{U_{ce} + nU_r}$$

where

t -- inside temperature near the ceiling under the attic.
t_b -- temperature in the attic.
t_o -- temperature outside.
U_{ce} -- coefficient of heat transmission of the ceiling.
U_r -- coefficient of heat transmission of the roof.
n -- ratio of the area of the roof to the area of the ceiling.

The same process applied to a room adjacent to a conditioned room would permit the temperature of that room to be calculated accurately, since the heat passing between the conditioned room and the adjacent room must equal the heat passing between the adjacent room and the outside. The application of this heat transfer can be arranged as follows:

$$t_a = \frac{H_1t + H_2t_o}{H_2 + H_1}$$

where

t -- temperature of the conditioned room.
t_a -- temperature of the adjacent unconditioned room.
t_o -- temperature outside.
H_1 -- heat loss or heat gain through walls, glass, ceiling and floor, in Btu for one degree difference in temperature from the conditioned room to the unconditioned room.
H_2 -- heat loss or heat gain through the walls, glass, ceiling or floor in Btu for one degree difference in temperature from the conditioned room to the outside.

The following table of temperatures for unconditioned adjacent rooms is taken from the Kelvinator Air Conditioning Manual:

*APPROXIMATE INDOOR TEMPERATURES FOR UNCONDITIONED SPACES

Outside Design Dry Bulb	Inside Dry Bulb	Outside Design Dry Bulb	Inside Dry Bulb
110	99	94	88
109	99	93	87
108	98	92	86
107	97	91	86
106	96	90	85
105	96	89	84
104	95	88	84
103	94	87	83
102	94	86	82
101	93	85	82
100	92	84	81
99	91	83	80
98	91	82	79
97	90	81	79
96	89	80	78
95	89	79	77

*This tabulation of temperatures assumes that there is no heat generation within the indoor space, and that there is no air-conditioning or forced circulation of outdoor air through this indoor space.

This tabulation does not apply to spaces which are on the top floor directly under sun-exposed roofs, or for spaces which have an exceptional amount of sun-exposed glass surface in the confining walls and ceilings.

AIR FILTRATION

Infiltration (or exfiltration) losses are those resulting from the displacement of cooled air in a building by warm outside air, the interchange taking place through various apertures in the building, such as cracks around doors, windows, fireplaces and chimneys. This leakage of air must be considered in cooling calculations.

Causes of Air Leakage.

A building is a shell in which the internal pressure in general is not in equilibrium with the external pressure. At some places, the latter is greater than the former, and inflow will occur in such regions through any openings in the wall whether large or small. At other places the reverse is true. The internal pressure automatically assumes a value to correspond to the requirement that outflow must equal inflow. The agencies that cause leakage are the natural forces of wind and temperature difference, and those produced by fans if any are used. A consideration of all factors involved in causing pressure difference at various places about a building would present an exceedingly complex problem.

In tall, single story buildings, the chimney effect caused by the inside-outside temperature difference becomes a factor of importance. Even in multi-story buildings it usually is not possible to isolate the several floors completely, and chimney effect is operative to a considerable degree, tending to force air out at the lower levels and in at the upper.

Since the full force of the wind usually is not the effective pressure differential, owing to back pressure built up within the building, the actual amount of infiltration is assumed to be 80 per cent of that determined in laboratory experiments.

Air Leakage Through Walls.

The A.S.H.V.E. Guide gives data on infiltration through brick and frame walls. The brick walls listed are walls which show poor workmanship and which are constructed of porous brick and lime mortar. For good workmanship, the leakage through hard brick walls with cement-lime mortar does not exceed one-third the values given. These tests indicate that plastering reduces the leakage by about 96 per cent; a heavy coat of cold water paint, 50 per cent; and 3 coats of oil paint carefully applied, 28 per cent. The infiltration through walls ranges from 6 to 25 per cent of that through windows and doors in a 10-story office building, with imperfect sealing of plaster at the baseboards of the rooms. With perfect sealing the range is from 0.5 to 2.7 per cent or a practically negligible quantity, which indicates the importance of good workmanship in proper sealing at the baseboard. It will be noted that the infiltration through properly plastered walls can be neglected.

Window Leakage.

The amount of infiltration in cubic feet per hour per foot of crack for various types of windows is given in the Guide. For window and sash leakage, the length of crack in double-hung windows is equal to the perimeter of sash plus length of meeting rail. For steel sash the length of crack is the aggregate perimeter of the movable or ventilating sections plus the linear feet of sash section in contact with steel work (at a different leakage rate) at mullions. The crack length for frame windows (when frame is not calked) is the perimeter of the frame. Steel sash frame properly grouted with cement mortar into brickwork or concrete is not to be counted as crack. A study of storm sash leads to the conclusion that they are of little value in reducing infiltration when applied to well fitted windows, but that a reduction of 50 per cent might be expected when storm sash are applied to poorly fitted or loose windows. Infiltration through door cracks may be assumed to be twice that of window cracks.

Wind Velocity to be Chosen.

Although all authorities do not agree upon the value of the wind velocity that should be chosen for any given locality, it is common engineering practice to use the average wind velocity during the three warmest months of the year. Average wind velocities for the months of June, July, August and September for various cities in the United States are given in Table I.

In considering both the transmission and infiltration losses, the more exact procedure would be to select the outside temperature and the wind velocity corresponding thereto, based on Weather Bureau records, which would result in the maximum cooling demand. Since the proportion of transmission and infiltration losses varies with the construction and is different for every building, the proper combination of temperature and wind velocity to be selected would be different for every type of building, even in the same locality. Furthermore, such a procedure would necessitate a laborious cut-and-try process in every case in order to determine the worst combination of conditions for the building under consideration. It would also be necessary to consider heat lag due to heat capacity in the case of heavy masonry walls, and other factors, to arrive at the most accurate solution of the problem. Although heat capacity should be considered wherever possible, it is seldom possible to accurately determine the worst combination of outside temperature and wind velocity for a given building and locality.

Crack Used for Computations.

In no case should the amount of crack used for computation be less than half of the total crack in the outside walls of the room. Thus, in a room with one exposed wall, take all the crack; with two exposed walls, take the wall having the most crack; and with three or four exposed walls, take the wall having the most crack; but in no case take less than half the total crack. For a building having no partitions, whatever wind enters through the cracks on the windward side must leave through the cracks on the leeward side. Therefore, take one-half the total crack for computing each side and end of the building.

The amount of air leakage is sometimes roughly estimated by assuming a certain number of air changes per hour for each room, the number of changes assumed being dependent upon the type, use and location of the room, as indicated in Table II.

Table II

AIR CHANGES TAKING PLACE UNDER AVERAGE CONDITIONS EXCLUSIVE OF AIR PROVIDED FOR VENTILATION

Kind of Room or Building	Number of Air Changes Taking Place Per Hour
Rooms, 1 side exposed	1
Rooms, 2 sides exposed	$1\frac{1}{2}$
Rooms, 3 sides exposed	2
Rooms, 4 sides exposed	2
Rooms with no windows or outside doors	$\frac{1}{2}$ to $\frac{3}{4}$
Entrance Halls	2 to 3
Reception Halls	2
Living Rooms	1 to 2
Dining Rooms	1 to 2
Bath Rooms	2
Drug Stores	2 to 3
Clothing Stores	1
Churches, Factories, Lofts, etc	$\frac{1}{2}$ to 3

SOLAR RADIATION

The effect of solar radiation on the amount of heat absorbed or lost by a building is ordinarily neglected in computing capacity required in a projected heating system. This is quite permissible in heating work since the absorption of radiant energy on sunshiny days means only a slightly reduced load on the heating system, while on cloudy days it is zero. The advent of cooling by refrigeration as an adjunct to summer air conditioning necessitates a closer analysis, for radiant solar energy, absorbed by the building, constitutes a much greater proportion of the summer cooling load than of the winter heating load. Moreover, heat absorbed from this source adds to the ordinary cooling requirements and increases the maximum capacity of the equipment required, whereas it does not affect the maximum capacity for which the heating system must be designed.

The total amount of radiant energy falling on any building during the day may be considerable, and much care should be used to reduce the fraction actually absorbed to the smallest possible value. The absorption varies greatly with the condition and material of the absorbing surface, rooms with a high ratio of wall and roof surface to cubic contents being at a particular disadvantage. The radiation through unshaded windows is a particularly serious item.

Factors Influencing the Intensity of Sun Radiation.

The energy passing a unit area perpendicular to the direction of the sun's rays, if measured at a point outside the earth's atmosphere and at a fixed distance from the sun, is very nearly constant, varying about plus or minus 1.5 per cent under the influence of solar storms and other solar conditions not accurately predictable. The amount passing unit area within the earth's atmosphere depends on a great many things and varies greatly, especially with atmospheric changes. However, since maximum values are of particular interest, consideration need be given only to clear, dry days.

Because of atmospheric absorption of energy before it reaches the surface of the earth, the energy intensity received is dependent on the amount of atmosphere traversed and, hence, on the altitude of the sun and the elevation of the observer. For example, the amount of atmosphere traversed with the sun at altitude 90 deg is just one-half that with altitude 30 deg.

Data on this point are shown in Table III for a few locations. It should be noted that a distinct difference is noticeable between a.m. and p.m. intensities for the same solar altitude, intensities being much lower during the later hours of the day. The formation of ozone in the upper atmosphere and the vaporization of moisture into the lower atmosphere, both of which decrease atmospheric transmission, offer an explanation of this difference. In industrial districts the dust and smoke content of the air in different directions from the point of observation may be an important factor. The distance of the sun at different periods of the year varies about 3.3 per cent and, hence, the energy intensity shows a corresponding variation of 6.7 per cent, other things being equal.

Since it is desired to know the amount of energy falling on a given surface and not on a surface perpendicular

Table III

SOLAR RADIATION OBSERVATIONS
(Taken from Monthly Weather Review, 1928)

I_0 in Btu. per hr. per sq. ft. averaged from intermittent readings.

Solar Altitude

Washington, D.C.	May	June	July	Aug.	Sept.
11.3 deg	...	...	113	135	...
14.3	139	111	135	150	142
19.3	173	186	161	175	166
30	221	223	195	201	192
90	292	277	265	274	248
30	219	...	...	...	301
19.3	175	...	...	...	...
14.3	119	...	...	...	...
11.3	...	...	...	...	...
Madison, Wis.					
11.3 deg	...	...	...	...	...
14.3	...	...	...	208	...
19.3	...	...	...	246	243
30	241	257	234	254	254
90	305	310	292	303	298
30	...	...	...	274	259
19.3	...	...	...	...	...
14.3	...	...	...	...	...
11.3	...	...	...	...	...
Lincoln, Neb.					
11.3 deg	...	...	...	155	...
14.3	175	199	166	173	186
19.3	190	225	199	203	221
30	237	259	241	243	259
90	301	307	294	288	314
30	254	269	243	243	254
19.3	...	232	199	217	214
14.3	...	204	168	190	184
11.3	...	...	...	166	166

to the direction of the sun's rays, the orientation of the plane involved becomes an important factor. The calculation of the angle of incidence of the sun's rays at any given point is quite involved, but tables have been constructed by G. A. Hendrickson and J. H. Walker by means of which the true radiation effect can be quickly figured.

Calculation of Radiation Intensity.

The intensity of solar energy passing a given plane may be expressed as

$$I = KI_o$$

where

- I--intensity, Btu per hr per sq ft of area in the absorbing plane.
- I_o--intensity, Btu per hr per sq ft of area in a plane perpendicular to the direction of the sun's rays.
- K--cosine of the angle between the direction of the sun's rays and a line perpendicular to the absorbing plane.

Values of I_o are best determined for each locality by pyrheliometric readings since, as previously noted, it varies greatly with local conditions. Measured outside the earth's atmosphere and at mean distance of the earth from the sun, I_o would be very nearly constant at 429 Btu per hr per sq ft. In general, then

$$I_o = 429a$$

where a, the coefficient of atmospheric transmission, varies between 0.6 and 0.9 for different stations within the borders of the United States with the sun in the meridian. Some data on I_o are given in Table III. Information on the variation of a is available in Bulletin 79 of the National Research Council, pages 37-44. The foregoing expression for I_o is an average value and applies for the earth at mean distance from the sun.

Tables V-VIII inclusive, give values of K for vertical planes (walls and windows) at 0 deg, 15 deg, 30 deg, 45 deg and 60 deg., North or South latitude and for each hour of the day that the sun shines. Table IX gives values of K for horizontal planes (flat roofs).

These five tables permit a fairly accurate determination of the amount of energy falling on a given plane when I_o is known. Unfortunately, it is not an easy matter, except in a few simple cases, to pass from this information to a determination of the amounts of this energy that are reflected, absorbed, reradiated, lost to the surroundings by conduction, and transmitted through the material of the plane on which they fall. Fortunately, however, the simplest case is the one of most importance in the determination of summer cooling loads, namely, the transmission of solar energy through window glass. In this case about 85 per cent to 93 per cent (depending on the thickness and cleanliness of the glass) of the heat striking the area is transmitted through ordinary clear glass.

It is of interest to note how the disposition of the exterior surface affects the variation in cooling loads. Rooms with a large eastern exposure will have a very pronounced daily maximum during the morning hours, whereas a large expanse of horizontal roof with skylights or a large western exposure give maxima at noon or in the afternoon, respectively. There is also a seasonal variation of these maxima. Buildings having a relatively large wall area as compared to the roof area will normally have their maximum daily maxima in late summer when the sun is low, while low flat buildings with a relatively large roof area will experience their greatest daily maxima in early summer (June in northern latitudes, December in southern) when the sun reaches its maximum altitudes.

The values of K given take no account of the diffuse radiant energy from a clear illuminated sky. This item is about 10 to 15 per cent as great as the maximum value of direct solar radiation (measured in a direction perpendicular to the sun's rays) for horizontal planes and about 5 or 6 per cent for vertical planes. If a portion of the sky is shaded from the surface considered, these percentages would be correspondingly reduced.

Explanation of the Tables.

The azimuth of a wall as used in Tables V-VIII, inclusive, is the angle in degrees between the exterior of the wall and a meridian plane, measured clockwise from the south. The definition is illustrated in Fig. 2.

The solar altitude of Table III is the angular distance of the sun above the horizon measured in a vertical plane.

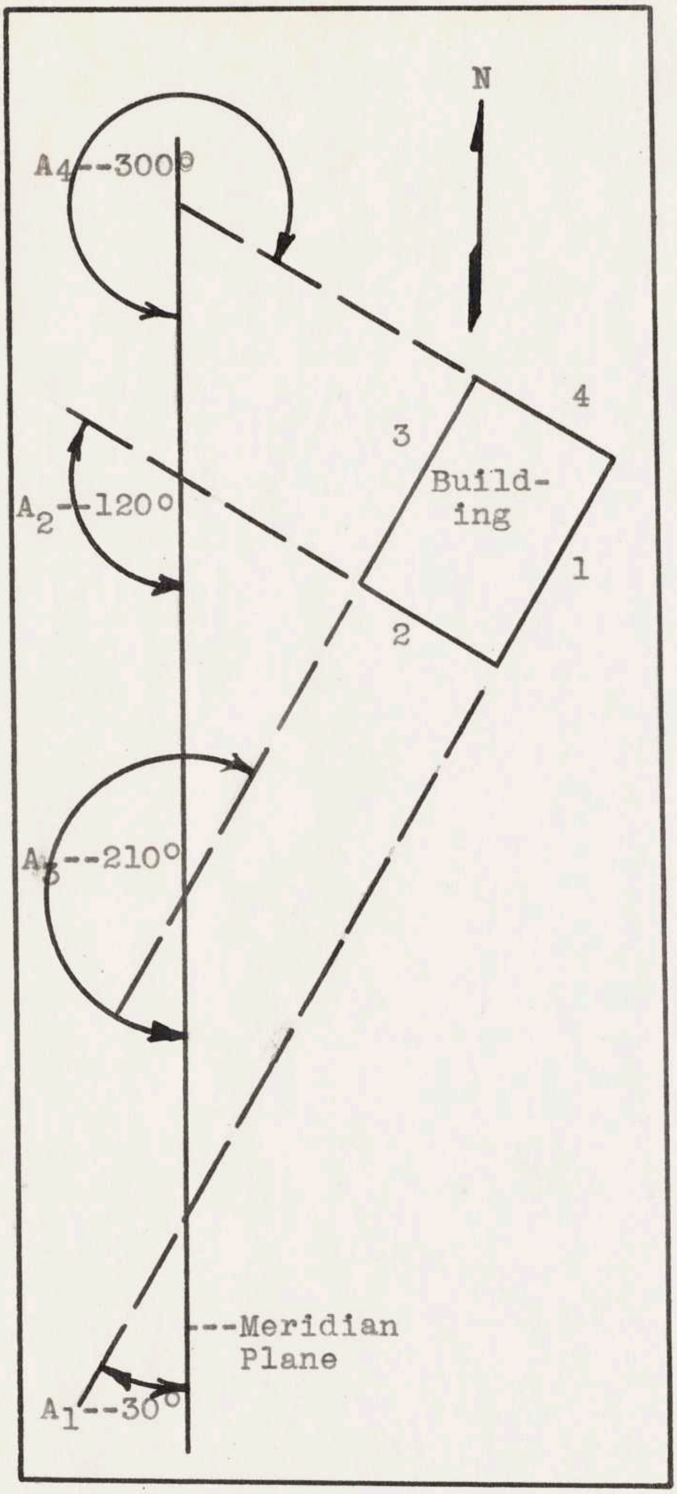


Fig. 2

Azimuths of different walls of building referred to in sample calculations. The azimuth A is always measured clockwise from the south into the exterior of the wall.

Table IV

LATITUDE AND LONGITUDE OF PRINCIPAL CITIES IN THE UNITED STATES

	Longitude		Latitude	
Atlanta..................	84°	20'	33°	45'
Baltimore................	76	40	39	15
Boston...................	71	5	42	25
Buffalo..................	78	50	42	50
Chicago..................	87	40	41	45
Cincinnati...............	84	30	39	10
Cleveland................	81	45	41	30
Dallas...................	96	45	32	45
Denver...................	105		39	45
Detroit..................	83	5	42	20
Indianapolis.............	86	10	39	45
Los Angeles..............	118	15	34	
Louisville...............	85	45	38	15
Memphis..................	90		35	10
Miami....................	80	15	25	45
Milwaukee................	88		43	
Minneapolis..............	93	15	45	
New Orleans..............	90		30	
New York.................	74		40	45
Philadelphia.............	75	5	40	
Pittsburgh...............	80		40	25
St. Louis................	90	10	38	40
San Francisco............	122	30	37	45
Seattle..................	122	20	47	40
Washington...............	77		38	50

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Day		7	8	3	2			10	11	5	3	

Table No. for Vertical Planes	No.Lat.			V	VI	VII	VI	V		
	So.Lat.	VII	VI	V				V	VI	VII
Section of Table IX for Horiz.Planes	No.Lat.	4	2	1	3	5	3	1	2	4
	So.Lat.	5	3	1	2	4	2	1	3	5

Fig. 3

Chronological determination of tables in which K values for different seasons of the year are found.

Table V

VALUES OF K FOR VERTICAL PLANES

Mar. 8 to Apr. 3 and Sept. 11 to Oct. 5
for either North or South latitudes

Azimuth scales for values of K in black.

Latitude	Local Time A.M.	P.M.	A.M. 0 / P.M. 180	15 / 165	30 / 150	45 / 135	60 / 120	75 / 105	90 / 90	105 / 75	120 / 60	135 / 45	150 / 30	165 / 15	180 / 0
Latitude 0°	6	6	1.000	0.966	0.866	0.707	0.500	0.259	0.000	0.259	0.500	0.707	0.866	0.966	1.000
	7	5	.966	.933	.837	.683	.483	.250	.000	.250	.483	.683	.837	.933	.966
	8	4	.866	.837	.750	.612	.433	.224	.000	.224	.433	.612	.750	.837	.866
	9	3	.707	.683	.612	.500	.354	.183	.000	.183	.354	.500	.612	.683	.707
	10	2	.500	.483	.433	.354	.250	.129	.000	.129	.250	.354	.433	.483	.500
	11	1	.259	.250	.224	.183	.129	.067	.000	.067	.129	.183	.224	.250	.259
	12		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Latitude 15°	6	6	1.000	0.966	0.866	0.707	0.500	0.259	0.000	0.259	0.500	0.707	0.866	0.966	1.000
	7	5	.966	.950	.870	.730	.541	.315	.065	.185	.425	.636	.803	.916	.966
	8	4	.866	.870	.815	.704	.545	.349	.129	.099	.321	.521	.685	.803	.866
	9	3	.707	.730	.704	.629	.512	.360	.183	.006	.195	.371	.521	.636	.707
	10	2	.500	.541	.545	.512	.444	.346	.224	.087	.056	.195	.321	.425	.500
	11	1	.259	.315	.349	.360	.346	.309	.250	.175	.087	.006	.099	.185	.259
	12		.000	.065	.129	.183	.224	.250	.259	.250	.224	.183	.129	.065	.000
Latitude 30°	6	6	1.000	0.966	0.866	0.707	0.500	0.259	0.000	0.259	0.500	0.707	0.866	0.966	1.000
	7	5	.966	.967	.901	.775	.595	.375	.129	.125	.371	.592	.772	.900	.966
	8	4	.866	.901	.875	.789	.650	.466	.250	.017	.217	.436	.625	.772	.866
	9	3	.707	.775	.789	.750	.660	.525	.354	.159	.047	.250	.436	.592	.707
	10	2	.500	.595	.650	.660	.625	.548	.433	.289	.125	.047	.217	.371	.500
	11	1	.259	.375	.466	.525	.548	.536	.483	.400	.289	.159	.017	.125	.259
	12		.000	.129	.250	.354	.433	.483	.500	.483	.433	.354	.250	.129	.000
Latitude 45°	6	6	1.000	0.966	0.866	0.707	0.500	0.259	0.000	0.259	0.500	0.707	0.866	0.966	1.000
	7	5	.966	.980	.928	.812	.642	.427	.183	.073	.325	.554	.745	.886	.966
	8	4	.866	.928	.927	.862	.739	.566	.354	.117	.127	.362	.573	.745	.866
	9	3	.707	.812	.862	.854	.787	.666	.500	.300	.080	.146	.362	.554	.707
	10	2	.500	.642	.739	.787	.780	.721	.612	.462	.280	.080	.127	.325	.500
	11	1	.259	.427	.566	.666	.721	.727	.683	.593	.462	.300	.117	.073	.259
	12		.000	.183	.354	.500	.612	.683	.707	.683	.612	.500	.354	.183	.000
Latitude 60°	6	6	1.000	0.966	0.866	0.707	0.500	0.259	0.000	0.259	0.500	0.707	0.866	0.966	1.000
	7	5	.966	.991	.949	.842	.677	.467	.224	.034	.289	.525	.724	.875	.966
	8	4	.866	.949	.967	.919	.808	.642	.433	.194	.058	.306	.534	.724	.866
	9	3	.707	.842	.919	.933	.884	.775	.612	.409	.177	.067	.306	.525	.707
	10	2	.500	.677	.808	.884	.900	.854	.750	.595	.400	.177	.058	.289	.500
	11	1	.259	.467	.642	.775	.854	.875	.837	.741	.595	.409	.194	.034	.259
	12		.000	.224	.433	.612	.750	.837	.866	.837	.750	.612	.433	.224	.000
		P.M.	360	345	330	315	300	285	270	255	240	225	210	195	180
	A.M.		180	195	210	225	240	255	270	285	300	315	330	345	360

Azimuth scales for values of K in red.

Table VI

VALUES OF K FOR VERTICAL PLANES

Apr. 3 to May 2 and Aug. 10 to Sept. 11 for locations in North latitudes. Feb. 7 to Mar. 8 and Oct. 5 to Nov. 3 for locations in South latitudes.

Local Time				Azimuth scales for values of K in black.												
	A.M.			0	15	30	45	60	75	90	105	120	135	150	165	180
		P.M.		180	165	150	135	120	105	90	75	60	45	30	15	0
Latitude 0°	5	7	*	0.951	0.874	0.737	0.550	0.325	0.078	0.174	0.414	0.626	0.795	0.911	0.964	0.951
	6	6		.985	.906	.766	.574	.342	.085	.174	.423	.643	.819	.940	.996	.985
	7	5		.951	.874	.737	.550	.325	.078	.174	.414	.626	.795	.911	.964	.951
	8	4		.853	.779	.652	.480	.276	.053	.174	.388	.577	.726	.825	.869	.853
	9	3		.696	.628	.516	.370	.198	.012	.174	.348	.499	.615	.690	.718	.696
	10	2		.492	.431	.340	.225	.096	.040	.174	.295	.397	.471	.513	.521	.492
	11	1		.255	.201	.154	.057	.023	.102	.174	.234	.278	.303	.308	.291	.255
	12			.000	.045	.087	.123	.150	.168	.174	.168	.150	.123	.087	.045	.000
Latitude 15°	5	7	*	0.951	0.858	0.707	0.507	0.273	0.020	0.231	0.472	0.678	0.838	0.941	0.979	0.951
	6	6		.985	.908	.769	.578	.347	.093	.168	.417	.638	.815	.937	.995	.985
	7	5		.951	.893	.773	.601	.388	.148	.104	.345	.564	.745	.875	.945	.951
	8	4		.853	.813	.718	.575	.392	.182	.040	.260	.461	.632	.759	.834	.853
	9	3		.696	.676	.609	.501	.359	.192	.012	.168	.337	.484	.597	.669	.696
	10	2		.492	.489	.453	.386	.292	.179	.053	.076	.200	.311	.400	.462	.492
	11	1		.255	.267	.260	.236	.195	.142	.078	.010	.059	.125	.181	.226	.255
	12			.000	.020	.044	.062	.075	.084	.087	.084	.075	.062	.044	.020	.000
Latitude 30°	5	7	*	0.951	0.847	0.685	0.476	0.235	0.022	0.278	0.515	0.716	0.869	0.963	0.991	0.951
	6	6		.985	.912	.778	.590	.362	.110	.150	.400	.623	.803	.928	.990	.985
	7	5		.951	.913	.812	.656	.456	.224	.023	.268	.496	.689	.835	.925	.951
	8	4		.853	.849	.787	.671	.509	.313	.096	.128	.343	.535	.691	.799	.853
	9	3		.696	.724	.702	.632	.519	.371	.198	.011	.177	.353	.504	.621	.696
	10	2		.492	.547	.564	.543	.485	.394	.276	.139	.007	.153	.288	.404	.492
	11	1		.255	.330	.383	.410	.409	.382	.325	.248	.154	.050	.058	.162	.255
	12			.000	.089	.171	.242	.296	.330	.342	.330	.296	.242	.171	.089	.000
Latitude 45°	5	7	*	0.951	0.840	0.672	0.458	0.213	0.047	0.303	0.539	0.738	0.887	0.975	0.997	0.951
	6	6		.985	.919	.791	.610	.386	.136	.123	.373	.599	.783	.914	.983	.985
	7	5		.951	.934	.853	.713	.525	.302	.057	.191	.426	.632	.795	.904	.951
	8	4		.853	.882	.851	.762	.622	.439	.225	.003	.231	.444	.626	.765	.853
	9	3		.696	.768	.788	.754	.668	.537	.370	.177	.028	.231	.418	.577	.696
	10	2		.492	.600	.667	.688	.662	.591	.480	.336	.170	.009	.186	.351	.492
	11	1		.255	.389	.496	.569	.604	.597	.550	.465	.349	.209	.054	.104	.255
	12			.000	.148	.287	.406	.497	.554	.574	.554	.497	.406	.287	.148	.000
Latitude 60°	4	8	*	0.853	0.691	0.482	0.240	0.018	0.275	0.513	0.717	0.871	0.966	0.995	0.957	0.853
	5	7		.951	.839	.670	.455	.209	.051	.308	.543	.742	.890	.978	.998	.951
	6	6		.985	.929	.809	.635	.417	.171	.087	.339	.568	.758	.896	.974	.985
	7	5		.951	.953	.891	.767	.592	.376	.134	.117	.360	.578	.757	.884	.951
	8	4		.853	.912	.908	.843	.721	.549	.340	.107	.132	.363	.569	.736	.853
	9	3		.696	.806	.861	.857	.795	.679	.516	.318	.099	.127	.345	.539	.696
	10	2		.492	.644	.752	.809	.811	.757	.652	.502	.318	.113	.101	.307	.492
	11	1		.255	.437	.589	.701	.766	.778	.737	.646	.511	.341	.148	.055	.255
	12			.000	.198	.383	.542	.663	.740	.766	.740	.663	.542	.383	.198	.000
		P.M.		360	345	330	315	300	285	270	255	240	225	210	195	180
	A.M.			180	195	210	225	240	255	270	285	300	315	330	345	360
Time				Azimuth scales for values of K in red.												

*Note: Sunset and sunrise in these intervals.

Table VII--VALUES OF K FOR VERTICAL PLANES

May 2 to Aug. 10 for locations in North latitudes.
Nov. 3 to Feb. 7 for locations in South latitudes.

Local Time			Azimuth scales for values of K in black.												
	A.M.	P.M.	0	15	30	45	60	75	90	105	120	135	150	165	180
			180	165	150	135	120	105	90	75	60	45	30	15	0
Latitude 0°	5	7 *	0.908	0.788	0.615	0.400	0.158	0.095	0.342	0.565	0.750	0.884	0.957	0.965	0.908
	6	6	.940	.819	.643	.423	.174	.087	.342	.574	.766	.906	.985	.996	.940
	7	5	.908	.788	.615	.400	.158	.095	.342	.565	.750	.884	.957	.965	.908
	8	4	.814	.698	.534	.334	.111	.120	.342	.541	.703	.817	.876	.875	.814
	9	3	.664	.553	.404	.228	.036	.158	.342	.502	.628	.712	.746	.730	.664
	10	2	.470	.365	.236	.090	.061	.209	.342	.452	.531	.574	.578	.542	.470
	11	1	.243	.146	.040	.070	.175	.267	.342	.393	.418	.414	.382	.323	.248
	12		.000	.089	.171	.242	.296	.330	.342	.330	.296	.242	.171	.089	.000
Latitude 15°	5	7 *	0.908	0.775	0.589	0.364	0.113	0.145	0.391	0.615	0.794	0.920	0.983	0.979	0.908
	6	6	.940	.822	.649	.431	.184	.076	.330	.562	.756	.898	.979	.993	.940
	7	5	.908	.808	.652	.453	.222	.023	.270	.493	.685	.831	.920	.946	.908
	8	4	.814	.732	.600	.428	.226	.009	.209	.412	.588	.723	.809	.840	.814
	9	3	.664	.601	.496	.358	.195	.019	.158	.325	.469	.582	.655	.683	.664
	10	2	.470	.423	.347	.248	.131	.006	.120	.237	.339	.417	.467	.485	.470
	11	1	.243	.210	.163	.104	.039	.029	.095	.155	.204	.239	.258	.260	.243
	12		.000	.025	.044	.062	.076	.084	.087	.084	.076	.062	.044	.025	.000
Latitude 30°	5	7 *	0.908	0.769	0.577	0.346	0.092	0.169	0.418	0.638	0.816	0.937	0.995	0.985	0.908
	6	6	.940	.831	.666	.455	.213	.043	.296	.529	.726	.874	.962	.984	.940
	7	5	.908	.832	.699	.518	.303	.066	.175	.404	.605	.765	.873	.922	.908
	8	4	.814	.770	.674	.532	.354	.151	.061	.270	.460	.619	.735	.802	.814
	9	3	.664	.651	.593	.495	.363	.207	.036	.137	.301	.444	.557	.632	.664
	10	2	.470	.482	.462	.410	.331	.229	.111	.015	.139	.254	.352	.425	.470
	11	1	.243	.276	.289	.283	.258	.217	.158	.089	.015	.061	.132	.194	.243
	12		.000	.045	.087	.123	.150	.168	.174	.168	.150	.123	.087	.045	.000
Latitude 45°	4	8 *	0.814	0.637	0.418	0.170	0.090	0.344	0.574	0.765	0.904	0.981	0.992	0.935	0.814
	5	7	.908	.770	.579	.349	.095	.165	.414	.635	.812	.934	.993	.984	.908
	6	6	.940	.845	.693	.493	.260	.010	.242	.477	.679	.835	.935	.970	.940
	7	5	.908	.859	.751	.592	.393	.167	.070	.302	.514	.691	.821	.895	.908
	8	4	.814	.809	.750	.639	.485	.298	.090	.123	.329	.512	.660	.763	.814
	9	3	.664	.701	.689	.631	.530	.392	.228	.048	.135	.309	.461	.583	.664
	10	2	.470	.540	.574	.568	.523	.444	.334	.201	.054	.096	.240	.368	.470
	11	1	.243	.338	.411	.455	.468	.449	.400	.323	.225	.111	.011	.131	.243
	12		.000	.109	.211	.299	.366	.408	.423	.408	.366	.299	.211	.109	.000
Latitude 60°	3	9 *	0.664	0.449	0.202	0.058	0.314	0.549	0.746	0.893	0.979	0.998	0.949	0.835	0.664
	4	8	.814	.636	.416	.167	.094	.348	.578	.769	.907	.984	.994	.936	.814
	5	7	.908	.778	.595	.372	.123	.134	.382	.604	.784	.912	.977	.975	.908
	6	6	.940	.863	.728	.544	.322	.078	.171	.408	.618	.785	.899	.952	.940
	7	5	.908	.887	.806	.670	.488	.273	.040	.197	.419	.614	.766	.866	.908
	8	4	.814	.847	.823	.742	.611	.438	.236	.017	.203	.409	.587	.725	.814
	9	3	.664	.746	.778	.756	.682	.563	.404	.219	.018	.184	.373	.537	.664
	10	2	.470	.592	.674	.710	.697	.637	.534	.394	.227	.045	.140	.316	.470
	11	1	.243	.394	.518	.607	.654	.657	.615	.531	.411	.263	.097	.076	.243
	12		.000	.166	.321	.455	.557	.621	.643	.621	.557	.455	.321	.166	.000
		P.M.	360	345	330	315	300	285	270	255	240	225	210	195	180
	A.M.		180	195	210	225	240	255	270	285	300	315	330	345	360
Time			Azimuth scales for values of K in red.												

*Note: Sunset and sunrise in these intervals.

Table VIII

VALUES OF K FOR VERTICAL PLANES

Feb. 7 to Mar. 8 and Oct. 5 to Nov. 3 for locations in North latitudes. Apr. 3 to May 2 and Aug. 10 to Sept. 11 for locations in South latitudes.

Local Time — Azimuth scales for values of K in black.

Latitude 15°	Local Time A.M.	Local Time P.M.													
	A.M.		0	15	30	45	60	75	90	105	120	135	150	165	180
		P.M.	180	165	150	135	120	105	90	75	60	45	30	15	0
	6	6 *	0.985	0.995	0.937	0.815	0.638	0.417	0.168	0.093	0.347	0.578	0.769	0.908	0.985
	7	5	.951	.979	.941	.838	.678	.472	.231	.020	.273	.507	.707	.858	.951
	8	4	.853	.900	.886	.812	.682	.506	.295	.064	.171	.394	.591	.747	.853
	9	3	.696	.763	.777	.738	.649	.516	.348	.156	.047	.246	.429	.583	.696
	10	2	.492	.576	.621	.623	.583	.503	.388	.248	.090	.074	.232	.375	.492
	11	1	.255	.353	.428	.473	.486	.466	.414	.334	.231	.112	.014	.139	.255
	12	12	.000	.107	.211	.299	.366	.408	.423	.408	.366	.299	.211	.107	.000
		P.M.	360	345	330	315	300	285	270	255	240	225	210	195	180
	A.M.		180	195	210	225	240	255	270	285	300	315	330	345	360

Time

Azimuth scales for values of K in red.

*Note: Sunrise and sunset in these intervals.

Table IX*

VALUES OF K FOR HORIZONTAL PLANES

Local Time A.M.	Local Time P.M.	Section	Latitude 0	5	10	15	20	25	30	35	40	45	50	55	60
6	6	Section 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	5		.259	.258	.255	.250	.243	.235	.224	.212	.198	.183	.166	.148	.129
8	4		.500	.498	.492	.483	.470	.453	.433	.410	.383	.354	.321	.287	.250
9	3		.707	.704	.696	.683	.664	.641	.612	.579	.542	.500	.455	.406	.354
10	2		.866	.863	.853	.837	.814	.785	.750	.709	.663	.612	.557	.497	.433
11	1		.966	.962	.951	.933	.908	.875	.837	.791	.740	.683	.621	.554	.483
12			1.000	.996	.985	.966	.940	.906	.866	.819	.766	.707	.643	.574	.500
12		Section 2 (Red)	0.985	0.966	0.940	0.907	0.866	0.819	0.766	0.707	0.643	0.574	0.500	0.423	0.342
1	11		.951	.932	.907	.874	.834	.789	.737	.680	.617	.550	.478	.403	.325
2	10		.853	.834	.810	.779	.742	.700	.652	.599	.542	.480	.415	.347	.276
3	9		.696	.673	.656	.628	.595	.558	.516	.471	.422	.371	.315	.257	.198
4	8		.492	.475	.455	.431	.403	.373	.340	.304	.266	.225	.183	.140	.096
5	7		.255	.239	.221	.201	.180	.158	.134	.109	.084	.057	.031	.004	.023
6	6	Section 3 (Black)	.000	.015	.030	.045	.059	.073	.087	.100	.112	.123	.133	.142	.150
7	5		.255	.269	.281	.291	.299	.304	.308	.308	.307	.303	.297	.288	.278
8	4		.492	.506	.515	.521	.522	.520	.513	.503	.489	.471	.450	.425	.397
9	3		.696	.709	.716	.718	.714	.705	.690	.670	.645	.615	.581	.542	.498
10	2		.853	.865	.870	.869	.861	.846	.825	.798	.765	.726	.681	.631	.577
11	1		.951	.963	.967	.964	.953	.935	.911	.879	.840	.795	.744	.688	.626
12			.985	.996	1.000	.996	.985	.966	.940	.906	.866	.819	.766	.707	.643
12		Section 4 (Red)	0.940	0.906	0.866	0.819	0.766	0.707	0.643	0.574	0.500	0.423	0.342	0.259	0.174
1	11		.908	.874	.834	.788	.736	.678	.615	.547	.475	.400	.321	.240	.158
2	10		.814	.781	.742	.698	.648	.593	.534	.470	.404	.334	.261	.187	.111
3	9		.664	.632	.595	.553	.507	.458	.404	.348	.289	.228	.165	.101	.036
4	8		.470	.438	.403	.365	.325	.281	.236	.189	.140	.090	.040	.011	.061
5	7		.243	.212	.180	.146	.112	.076	.040	.003	.034	.070	.106	.141	.175
6	6	Section 5 (Black)	.000	.030	.059	.089	.117	.145	.171	.196	.220	.242	.262	.280	.296
7	5		.243	.272	.299	.323	.346	.365	.382	.395	.406	.414	.418	.420	.418
8	4		.470	.498	.522	.542	.558	.570	.578	.581	.580	.574	.564	.550	.531
9	3		.664	.692	.714	.730	.741	.747	.746	.740	.729	.712	.689	.661	.628
10	2		.814	.840	.861	.875	.882	.882	.876	.863	.843	.817	.785	.747	.703
11	1		.908	.934	.953	.965	.970	.967	.957	.940	.915	.884	.845	.801	.750
12			.940	.966	.985	.996	1.000	.996	.985	.966	.940	.906	.866	.819	.766

*Key to sections of this table are given in Fig. 3.

Table IV and Fig. 3 may be used to help locate the correct table for use with different seasons of the year, and for different locations in the United States.

All tables are computed for apparent solar time and three solar positions, 0 deg, 10 deg, and 20 deg, from the equator. It is intended that when the sun is within 5 deg of one of these positions the value of K computed for that position be used. This is the significance of Fig. 3.

Local mean solar time may be substituted for apparent solar time. The difference is never more than 16 min. and is usually much less. To obtain local mean solar time from standard time:

$$t\text{--}t_s - \frac{L - L_m}{15}$$

where

t--local mean solar time, in hr.
t_s--standard time in hr.
L--longitude of location.
L_m--longitude of meridian on which standard time is based.

The standard time zones in the United States are:

Time Zone	Meridian West from Greenwich
Atlantic	60°
Eastern	75
Central	90
Mountain	105
Pacific	120

Sample Computation.

Suppose it is desired to know the solar energy falling on the walls and roof of a building situated as shown in Fig. 2, located at 30 deg north latitude and 82 deg 30 min longitude west from Greenwich, on July 25.

This defines the problem, and to solve it proceed as follows: First, get the details of the problem clear. What is desired is to find values of K for use in the formula $I{-}{-}KI_0$. To solve this problem entirely this formula must be applied to each of the four walls, and to the roof separately. As the value K changes with different hours of the day, it will be well to find it for all daylight hours. The most convenient way to do this is to set up a table and enter the values as they are found. This table, therefore, will contain five columns for the K's, one each for the southeast wall, southwest wall, northwest wall, northeast wall, and one for the roof. As the tables are based on solar (or local) time, while standard time for the time zone is the one usually carried on watches, there will be two columns for time, one for the standard time and one for the solar time.

With the table set up one can proceed with the solution. First, set down the daylight hours as standard time. With this case, the time will be eastern standard, since the location is between 75 deg and 90 deg west longitude. Apply the time equation for each hour and find the mean solar time. Enter in the mean solar (or local) time column.

With the times entered, the next step is to determine in which of the tables the values of K for the walls and the roof will be found. Fig. 3 gives the key to this. Use it as follows: Since July 25 is the day under consideration, look under the column marked July opposite North latitude and find numeral VII. This indicates that value of K for walls will be found in Table VII. In the same way, under July opposite North latitude find the figure 5. This indicates that values of K for the roof will be found in section 5 of Table IX. This locates the proper tables and one is now ready to solve as soon as the azimuths of the building walls are determined. This is best done by actually making a drawing like Fig. 2 being careful to measure the azimuth clockwise from the south into the exterior of the wall.

The use of Table VII can be illustrated by finding values of K for the southeast wall. Values for other walls are found in exactly the same way. The latitude being 30 deg in the example, enter Table VII at the section marked latitude 30 deg at the left. In the first column it is found that sunrise occurs between 5 a.m. and 6 a.m., and sunset between 6 p.m. and 7 p.m. local time. The figures in the table are then at hourly intervals from 6 a.m. to 6 p.m. The azimuth of the southeast wall is 30 deg (from Fig. 2).

The construction of Tables V to VIII is rather complicated and should be explained. It will be noted that all figures from 0 deg to 180 deg appear twice in the scale of azimuth values across the top of the tables, the same being true of values from 180 deg to 360 deg at the bottom. When the azimuth scale at the top is being used, only values of K in black type are to be considered. If when reading into a particular square in the table and using the azimuth scale at the top there is no black type in that position, this indicates that K for that case is 0. Exactly the same is true when using the scale at the bottom and reading up. Here only red figures are used, and if there are no red figures, K is 0.

Since there are two azimuth scales at both top and bottom, arrow heads are used at the left to show the azimuth scale to be used. Thus, in all cases, for morning hours the upper azimuth scale at the top or the lower scale at the bottom of the table is the one to be used. The tables are so arranged solely to save space. Doubling the azimuth scales need not be confusing if care is taken to distinguish between the types.

For the example being considered with an azimuth of 30 deg, the figures will be found on the upper azimuth scale at the top for morning hours, and the lower scale at the top for afternoon hours. At 6 a.m. the value of K will thus be found to be 0.666; at 7 a.m. it will be 0.699. Enter these figures in the table and continue to noon, when K is 0.087. Now passing to the afternoon, the reading at 1 p.m. one must read under 30 deg in the lower column on the top scale and find .132, but this is in red type. This means that the value of K is zero, and it is so entered in the table. The same is true for all afternoon hours for the southeast wall.

The northwest wall has an azimuth of 210 deg and must be read on the bottom azimuth scales. Proceeding in the same way as for the southeast wall, find the columns for 210 deg on the bottom scales. At 6 a.m. find the figure 0.666 in black type. Bearing in mind that when using azimuth scales at the bottom, black type indicates a K value of zero, it is found that there are no values of K above zero during any of the morning hours for the northwest wall. In the afternoon, however, one finds that at 1 p.m. there is a value of .132 in red type. Enter this in the table, and continue for other afternoon hours.

These cases illustrate the use of Tables V to VIII. For the roof, use Table IX as follows: It has already been noted that for this example section 5 of Table IX is to be used. Beside section 5 find the word "Black". This means that section 5 includes all black type in the lower third of the table.

In this case, for latitude 30 deg, read under the 30 deg column and begin at 6 a.m. This gives .171, and since this is in black, include it in the table. It will be noted that values in black will be found till 6 p.m. At 7 p.m., however, one finds a red figure. This means that at 7 p.m., K equals zero for the roof.

When the values have all been found and entered in the table, it will appear as follows for this example:

Time Eastern Standard	Apparent Mean Solar	K_1 S.E. Wall	K_2 S.W. Wall	K_3 N.W. Wall	K_4 N.E. Wall	K_r Roof
6:30 a.m.	6:00 a.m.	0.666			0.726	0.171
7:30	7:00	0.699			0.605	0.382
8:30	8:00	0.674			0.460	0.578
9:30	9:00	0.593			0.301	0.746
10:30	10:00	0.462			0.139	0.876
11:30	11:00	0.289	0.015			0.957
12:30 p.m.	12:00 m.	0.087	0.150			0.985
1:30	1:00		0.258	0.132		0.957
2:30	2:00		0.331	0.352		0.876
3:30	3:00		0.363	0.557		0.746
4:30	4:00		0.354	0.735		0.578
5:30	5:00		0.303	0.873		0.382
6:30	6:00		0.213	0.962		0.171

The values of I_o are to be found by local observation. If I_o--220 Btu per hr per sq ft at 10:30 a.m. on July 25, then the energy falling on the southeast wall is:

$$\begin{aligned} I_1 &\text{--} K_1 I_o \\ &\text{--} 0.462 \text{ x } 220 \\ &\text{--} 101.6 \text{ Btu per hr per sq ft} \end{aligned}$$

on the northeast wall is:

$$\begin{aligned} I_4 &\text{--} K_4 I_o \\ &\text{--} 0.132 \text{ x } 220 \\ &\text{--} 29.0 \text{ Btu per hr per sq ft} \end{aligned}$$

on the roof is:

$$\begin{aligned} I_r &\text{--} K_r I_o \\ &\text{--} 0.876 \text{ x } 220 \\ &\text{--} 192.7 \text{ Btu per hr per sq ft} \end{aligned}$$

The southwest and northwest walls are shaded.

AFFECT OF SOLAR RADIATION ON HEAT TRANSMISSION

Although solar radiation is an important factor in the mechanism of heat flow into and out of buildings, in practical heat transmission problems it is usual to neglect the sun effect entirely, to employ coefficients determined under steady state conditions, and to consider the average inside and outside temperatures constant throughout the day. With this practice, factors are used to take care of wind, sun effect or its absence, or other unusual conditions in order to insure the selection of a heating plant sufficiently large to handle the load on the coldest day, or an air-conditioning system of sufficient capacity for the warmest weather.

The calculation of heat transmitted through walls and roof does not take into consideration the heat capacity of the structure and the consequent time lag in the transmission of heat. In the thick walls used in modern office buildings the time lag may amount to 10 hours or more. Thus in many cases the wall transmission cannot be added directly to the cooling load from other sources because the peak of the wall transmission load may not coincide with the peak of the total cooling load and may even occur after the cooling system has been shut down for the day. In other cases, however, the heat wave due to solar radiation may reach the interior at about the same time that the interior cooling load comes on.

Factors Affecting Periodic Heat Flow.

The flow of heat into an air-conditioned space through a roof or wall on a hot summer day, because of the higher outside air temperature and the solar radiation on the outer surface, is very complex. It may be illustrated in Fig. 4, where XY is the roof or wall structure. The impingement

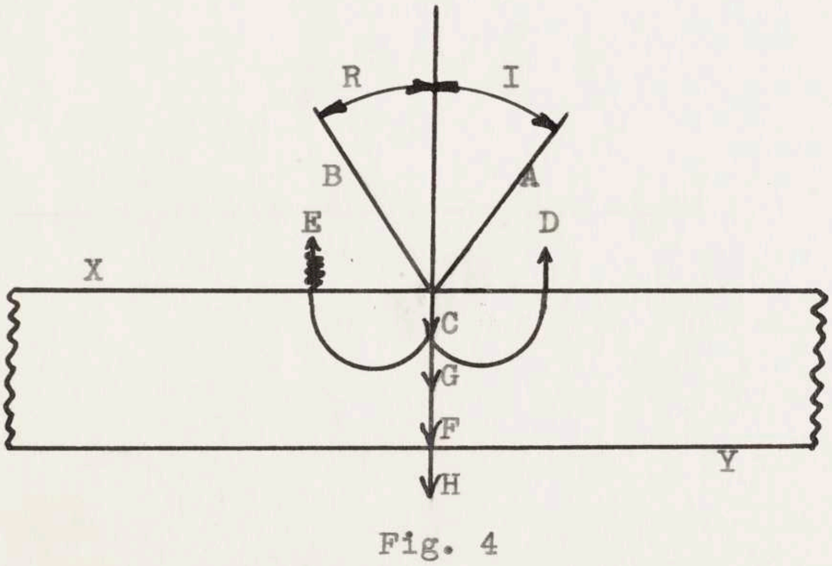


Fig. 4

Factors affecting heat flow through a structure.

of solar radiation against the outside surface is represented by A. The intensity of impingement on the surface, X, not normal to the sun's rays, decreases with the angle of incidence, I, which is a function of time; a part of the energy, B, is not absorbed, but is reflected away. The magnitude ofB is a function of the character of the surface, X, and of the angle of reflection, R, which varies with the time of day. The remaining energy, C, is absorbed as heat by the surface, X, raises its temperature enough to cause the radiation, D, back through the air, and the convection loss, E, by direct contact with the air. Also, as the temperature of the surface, X, is raised by the absorption of radiant energy, heat flows in the direction, F. As the temperature of the surface, X, rises to a maximum at noon and then recedes, a wave of heat advances towards F. Because heat is required to raise the temperature of each increment of the distance, X to Y, the rate of heat flow past any point between X and Y diminishes as the wave penetrates through the structure, and when the wave reaches the surface, Y, it has a much lowered amplitude, dependent upon the conductivity, density, specific heat and thickness of the material in the wall, the film resistance of its lower surface, and the temperature of the air below. The crest of the wave reaching the surface, Y, will be delayed a certain time after the crest at the surface, X.

Conductivity, density and specific heat are factors which combine to damp out the wave amplitude. In a theoretical consideration of heat transfer they are combined into a single constant called the diffusivity. This combined constant takes into account the resistance to heat flow and the heat capacity of the structure.

The heat reaching the lower surface tends to build up its temperature, and a small amount of heat, G, returns in a reflected wave upward towards X. The magnitude of this reflected wave also depends upon the physical properties of the structure. Only H, the heat entering the air-conditioned space below, is of interest to the air-conditioning engineer.

An ideal solution of the problem of heat flow as affected by solar radiation would give the value of H for all hours of the day as a function of the intensity of solar radiation perpendicular to the direction of the sun's rays, of the atmospheric conditions, and of the physical characteristics of the structure. Such a solution involves the following factors: the intensity of solar radiation, A, perpendicular to the direction of the rays; the angle of incidence, I, of impingement against the surface; the reflected energy, B, depending upon the angle of reflection, R; the radiated heat, D, depending upon the convection from the surface, X; the difference in temperature of the surface, X, and the outside air; the temperature difference between the surfaces, X and Y; the conductivity, the density, specific heat and thickness of the structure; the film resistance for the surfaces, X and Y; and the controlled temperature of the air below. This makes thirteen factors upon which H depends, the first five of which are harmonic functions of time.

Unfortunately, the calculations for the transmission of heat from solar radiation through building walls are too complicated to be of much practical value to the heating and ventilating engineer. Approximate results may be obtained by adding the number of degrees given in Table X to the outside design dry-bulb temperature in calculating the heat transmission through a wall or roof which may be exposed to the sun for any appreciable length of time. Table X was obtained from a study of the data in A.S.H.V.E. research papers on solar radiation. Black and aluminum painted surfaces represent the extremes which are likely to occur. For other types of surfaces, values intermediate between those given in the table can be used. The data in Table XI were likewise obtained from A.S.H.V.E. research papers, and while they result principally from study of experimental slabs, they give an idea of the time lag to be expected in various structures. The incompleteness of this table indicates the need for much more experimental work.

Table X

ALLOWANCE FOR SOLAR RADIATION ON ROOFS AND WALLS

Approximate Number of Degrees to Add to Dry-Bulb Temperature for Different Types of Surfaces.

Type of Surface	Black	Red Brick or Tile	Aluminum Paint
Roof, horizontal	45	30	15
East or west wall	30	20	10
South wall	15	10	5

Table XI

TIME LAG IN TRANSMISSION OF SOLAR RADIATION THROUGH WALLS AND ROOFS

Type and Thickness of Wall or Roof	Time Lag, Hours
2-in. pine	$1\frac{1}{2}$
6-in. concrete	3
4-in. gypsum	$2\frac{1}{2}$
3-in. concrete and 1-in. cork	2
2-in. iron and cork (equivalent to 3/4-in. concrete and 2.15-in. cork)	$2\frac{1}{2}$
4-in. iron and cork (equivalent to 5 1/2-in. concrete and 1.94-in. cork)	$7\frac{1}{4}$
8-in. iron and cork (equivalent to 16-in. concrete and 1.53-in. cork)	19
22-in. brick and tile wall	10

SOLAR RADIATION TRANSMITTED THROUGH BARE AND SHADED WINDOWS

Studies made at the Research Laboratory of the American Society of Heating and Ventilating Engineers have indicated that solar radiation through windows is a large portion of the cooling load in summer air conditioning. A study, made by Walker, Sanford, and Wells in cooperation with the Society, of the sources of heat comprising the summer cooling load in air conditioning a modern office building has shown solar radiation through windows to be the predominating factor. Consideration of these results by the Committee on Research led to their authorization of an investigation concerning heat gain through windows from solar radiation under different weather conditions, and as affected by several types and applications of window shading appurtenances.

Shades.

Shades tested were of the ordinary commercial spring roll type made of a filled cotton cloth of medium weight. Their original finish was a buff color, but for some tests they were painted on the side facing the sun with metallic aluminum in lacquer. In their standard application they overlapped the window frame by approximately 1 in. all around and hung quite snugly to it. For a few tests, wooden cleats were nailed around the shade to hold it so tightly to the frame that there was a minimum transfer of convected air; while for one inside test, the shade was hung with an air gap of approximately 1 1/2 in. between its periphery and the frame of the window to give free circulation of convected air. For another inside test, the shade was half drawn.

Blinds.

Commercial Venetian blinds with two different finishes were tested. Some were stained a dark green; and others were finished by sputtering molten aluminum metal over the wooden slats to affix a solid metallic aluminum coating which both reflected and diffused solar energy falling on it. The slats of all Venetian blinds tested were 2 3/8 in. wide, 1/8 in. thick, spaced 1 3/4 in. apart. A Venetian blind was considered to have a standard adjustment when it hung close to the frame of the window, fully extended, with its slats set at an angle of 45 deg. so they excluded the sun's rays. For one test the slats were closed tightly, and for another they were wide open in a horizontal position. Venetian blinds intended for use on the outside were designed with features which enabled them to be hung away from the window, as an awning without sides, at any adjustable angle up to about 30 deg. Several tests were made with such a blind hung as an awning at the maximum angle, but one test was made with the angle adjusted during the day to admit a maximum amount of light without any direct sunshine getting through the sides.

Awnings.

The awnings used in the study were of a commercial type having sides and an 8 in. decorative fringe, made of medium weight striped canvas supported on a steel framework. In their standard application they projected 44 in. from the building and left the tops of the windows at angles of 40 deg. The tops and sides of the awnings were tightly fastened to the walls of the house. For most tests, the awnings were used just as purchased (standard finish), but for one test an awning was given a heavy coat of metallic aluminum in lacquer on its outside surface.

Complete shading was accomplished by four large canvas shields placed in front of the window to shade the opening from solar radiation. The nearest canvas was held about 7 in. from the glass and 5 in. from the wall, and the other three shields were placed successively farther away and were separated by three 4 in. air spaces. This arrangement allowed free air circulation between the canvas and the window and between the different layers of canvas which eliminated both direct radiation from the sun and reradiation from the canvas nearest the glass. Hence, the only heat transfer through the window should have been that due to conduction from the stratum of shaded air nearest the window.

Results of Investigation.

Twenty-five successful tests were made on different window arrangements, with results as listed in Table XII. The percentage figures in this table were obtained by dividing the total amount of heat actually entering through the shaded window by the total amount of heat calculated to enter through a bare window (solar radiation plus glass transmission based on observed outside glass temperature). For bare windows on which the sun shines, the transmission of heat from outside air to glass is small as the glass temperature is raised by the solar radiation absorbed. Therefore, in calculating the total heat gain through windows on the sunny sides of buildings, it is sufficiently accurate to figure the total cooling load due to the window as the solar radiation times the proper percentage from Table XII, and to neglect the heat transmission through the glass caused by the difference between the temperatures of the inside and outside air.

Interception of Solar Radiation by Glass.

A related study was made of the comparative percentages of solar radiation intercepted, either by absorption or reflection, by different kinds and thicknesses of glass held at various angles of incidence with the sun's rays. Table

Table XII

AVERAGE VALUES FOR WINDOW CONDITIONS

Appurtenance					
Type	Finish	Location	Adjust-ment	No. of tests	Percent transmission by appurtenance
	Complete Shading			5	5
Ven Bl.	Al.	Outside	Closed	1	8
"	Al+Green	"	St'd.	9	15
Shade	Al.	"	Cleated	2	16
Ven Bl.	"	"	Adjusted	1	21
Awning	"	"	St'd.	1	22
Ven Bl.	"	"	Wide Open	1	26
Awning	St'd.	"	St'd.	4	28
Ven Bl.	Al+Green	"	As Awning	3	29
Shade	Buff	"	St'd.	2	30
"	Al+Buff	Inside	Cleated	3	36
"	"	"	St'd.	5	45
"	Buff	"	With Gap	1	53
Ven Bl.	Al.	"	St'd.	3	58
Shade	Buff	"	½ Drawn	1	68
	Bare Window			11	97

Abbreviations:

With Gap--1½ in. between periphery of shade and frame.
St'd--Standard.
Plain canvas awning.
Shade typically applied.
Venetian blind--hanging down--slats at 45 deg.
Al.--Aluminum.
Ven. Bl.--Venetian blind.
As Awn.--Venetian blind adjusted away from window, as awning without sides
Adjusted--Venetian blind used as awning but moved periodically to keep sun off window.
Wide open--Venetian blind--slats horizontal.
Closed--Venetian blind--slats vertical.

XIII gives the percentage of energy intercepted for the different conditions studied. No account was taken in this analysis of the refraction of the rays as they passed through the glass. It will be noted that the relation between the radiation intercepted and the thickness of the glass traversed is approximately the same whether the thickness results from placing several pieces of glass normal to the rays, or from changing the angle of incidence of a single piece. This indicates that the increased interception occasioned by changing the angle of incidence results from increased absorption within the glass because of its greater thickness rather than from the reflection, and that reflection is not an important factor in heat transfer through a window by solar radiation. This assumption was used in the analysis of the data. It should be pointed out, however, that the decreased transmission occasioned by the piling up of several pieces of glass normal to the sun's rays may have resulted from partial reflections at the several surfaces, rather than from increased thickness.

It will be noted that Table XII gives the amount of heat delivered through the window as 97 per cent of the solar radiation, which is greater than is indicated by the figures for absorption in Table XIII. The explanation is that much of the radiation absorbed by the glass is delivered to the room.

Table XIII

SOLAR RADIATION INTERCEPTED BY GLASS OF VARIOUS TYPES, THICKNESSES, AND AT VARIOUS ANGLES

Type of Glass	Thickness Pieces	Thickness Each Piece In.	Angle of Incidence Deg.	Radiation Intercepted, Per Cent
Plate: Yellow tinge	1	0.255	0	14.8
Plate: Green tinge	1	0.240	0	16.6
Plate: Clear	1	0.270	0	12.8
Window: Single strength; A-quality	1	0.071	0	10.7
Photographic	1	0.070	0	9.0
Window: Double strength; A-quality	1	0.127	0	11.2
Window; Double strength; A-quality	2	0.127	0	27.8
Window: Double strength; A-quality	3	0.127	0	38.4
Window: Double strength; A-quality	4	0.127	0	45.7
Window: Double strength; A-quality	1	0.127	0	10.8
Window: Double strength; A-quality	1	0.127	15	11.9
Window: Double strength; A-quality	1	0.127	30	12.7
Window: Double strength; A-quality	1	0.127	45	14.9
Window: Double strength; A-quality	1	0.127	60	26.0
Window: Double strength; A-quality	1	0.127	75	41.6
Window: Double strength; A-quality	1	0.127	82.5	53.7

HEAT EMITTED WITHIN BUILDING

All sources of heat must, of course, be considered in calculating the maximum cooling load for any enclosure. In a theater or auditorium the heat from the occupants may comprise nearly the total cooling load. In large stores electric lights may greatly increase the cooling load, especially if the lights are in use while the sun is shining the brightest. In a large factory where there are many electric motors and machines, so much heat may be given off that cooling is necessary the year around.

In other structures the transmission or solar radiation load may predominate. Every air conditioning installation requires an individual solution of the internal heat sources which may occur at any given time. In some cases no allowance need be made for an internal load, especially if it is small or if it does not occur when other loads have their peaks. In other cases several heat sources may occur simultaneously, and hence greatly influence the cooling capacity required.

Table XIV shows the heat which is given off by some devices. These sources are only a few out of many possible ones. Heat given off by human beings, both at rest and while doing various kinds of work, will be found in the Guide of the American Society of Heating and Ventilating Engineers.

Table XIV

HEAT GAIN DUE TO VARIOUS DEVICES, BTU PER HOUR

Lights and electric appliances...........	3,415	per KW
Motors, 1/10 hp............................	255	
Motors, 1 hp...............................	2,546	
Restaurant coffee urns, 10-gal capacity..	16,000	
Dish warmers per 10 sq ft of shelf.......	6,000	
Restaurant range--4 burners and oven.....	100,000	
Residence gas range		
Giant burner........................	12,000	
Medium burner.......................	9,000	
Oven................................	1,000	per cu ft
Pilot...............................	250	of space
Electric range		
Small burner, 100 to 1350 watts.....	3,415	to 4,600
Large burner, 1700 to 2200 watts....	5,800	to 7,500
Oven, 2000 to 3000 watts............	6,830	to 10,245
Appliance connection, 660 watts.....	2,250	
Warming compartment, 300 watts......	1,025	

VENTILATION REQUIREMENTS

In order to maintain satisfactory air conditions inside an enclosure it is usually necessary in the summer to dehumidify and cool both the fresh air that is introduced from outside and also the air which is recirculated. The desired air conditions are set forth in the A.S.H.V.E. Ventilation Standards which follow. It is the intent of the Committee in presenting these standards to confine itself to a statement of those requirements which, based on present day knowledge, will provide adequate ventilation for spaces intended for human occupancy. The following standards apply to all spaces occupied by human beings in all buildings for which ventilation regulations are to be established.

Section I--Air Temperature and Humidity

The temperature and humidity of the air in such occupied spaces, and in which the only source of contamination is the occupant, shall be maintained at all times during occupancy at an Effective Temperature, as hereinafter stated.

The relative humidity shall be not less than 30 per cent, nor more than 60 per cent in any case. The Effective Temperature shall range between 64 deg and 69 deg when heating or humidification is required, and between 69 deg and 73 deg when cooling or dehumidification is required.

These Effective Temperatures shall be maintained at a level of 36 in. above the floor.

Section II--Air Quality

The air in such occupied spaces shall at all times be free from toxic, unhealthful or disagreeable gases and fumes and shall be relatively free from odors and dust.

In every space coming within the provisions of these requirements and in which the quality of the air is below the standards prescribed by good medical and engineering practices, due to toxic substances, bacteria, dust, excessive temperature, excessive humidity, objectionable odors, or other similar causes, means for ventilating shall be provided so that the quality of the air shall be raised to these standards.

Section III--Air Motion

The air in such occupied spaces shall at all times be in constant motion sufficient to maintain a reasonable uniformity of temperature and humidity, but not such as to cause objectionable drafts in any occupied portion of such spaces.

The air motion in such occupied spaces, and in which the only source of contamination is the occupant, shall have a velocity of not more than 50 feet per minute, measured at a height of 36 in. above the floor.

Section IV--Air Distribution

The air in all rooms and enclosed spaces shall, under the provisions of these requirements, be distributed with reasonable uniformity, and the variation in the carbon dioxide content of the air shall be taken as a measure of such distribution.

The air in a space ventilated in accordance with these requirements, and in which the only source of contamination is the occupant, shall be distributed and circulated so that the variation in the concentration of carbon dioxide, when measured at a height of 36 in. above the floor, shall not exceed one part in 10,000.

Section V--Air Quantity

The quantity of air used to ventilate the given space during occupancy shall always be sufficient to maintain the standards of air temperature, air quality, air motion and air distribution as herein required. Not less than 10 cubic feet per minute per occupant of the total air circulated to meet these requirements shall be taken from an outdoor source.

Factors Influencing Applications.

Air Quality: In occupied spaces in which the vitiation is entirely of human origin, the chemical composition of the air, the dust, and bacteria content may be dismissed from consideration so that the problem consists in maintaining a suitable temperature with a moderate humidity, and in keeping the atmosphere free from objectionable odors. Such unpleasant odors, human or otherwise, can be easily detected by persons entering the room from clean, odorless air.

Air Motion: The air in occupied spaces must be in constant gentle motion sufficient to maintain a satisfactory uniformity of temperature and humidity, but not such as to cause objectionable drafts in any occupied portion of such spaces. Stagnant air, no matter how pure, is depressing, and it fails to produce the pleasant and stimulating effect of cool air in gentle motion.

Studies by Baetjer on the influence of air motion on comfort indicate that in ordinary air conditioning work the velocity of air currents should never be allowed to fall below 5 fpm, nor should it be allowed to exceed 50 fpm, except when the temperature of the air current striking the face is higher than the temperature of the room. The lower limit of

5 fpm may be taken as the minimum during the heating season, and the upper limit of 50 fpm as the maximum during the cooling season.

Air Distribution: As a rule satisfactory distribution is secured when the air movement or turbulence as measured by the Kata thermometer is uniform in all parts of the occupied space and when simultaneous readings of temperature at any two points on the same level within the occupied space do not differ by more than 3 deg. Measurements of CO_2 are acceptable in lieu of temperature and air motion variations, but the usual method of determining CO_2 in air is much more laborious than the determination of temperature and air movement. When CO_2 is used as an index of distribution, the variation in the concentration of the gas at a height of 36 in. above the floor should not exceed one part in 10,000 parts of air.

Air Quantity: The quantity of air to be circulated through an occupied space, whether by natural or mechanical means, or whether the air is conditioned or not, must in all cases be sufficient to maintain the required standards of air temperature, quality, motion and distribution. The factors which determine air quantity include the type and nature of the building, locality, climate, height of rooms, floor area, window area, extent of occupancy, and last but not least, the method of distribution.

Actually there are two air quantities to be considered, namely, (1) total air required and (2) outside air required.

The difference between these two quantities represents the amount to be recirculated, or

Total air--outside air + recirculated air

Sometimes the ratio of the outside air to the total air can be decreased if the air introduced is conditioned, but in the light of present information, a minimum of 10 cfm of outdoor air per person should be provided. If the air is not conditioned as in a ventilating system, the vitiated air is usually exhausted to the atmosphere, in which case all of the air introduced is outside air.

Temperature Rise: The total quantity of air introduced is governed largely by the allowable temperature rise when cooling is required and the allowable temperature drop when heating is required. As a rule, the introduction and distribution of warm air into an occupied space does not present as many difficulties as does the introduction of cold air. The former is determined from the amount of heat to be given up to the space, and the latter is determined from the amount of heat to be removed from the space, using a temperature rise that will produced uniform distribution without the production of disagreeable drafts.

Two of the most important factors on which the temperature rise depends are (1) the method of distribution and (2) the most economical temperature rise for the conditions involved. Some systems of distribution produce drafts with but a few degrees temperature rise, while other systems operate successfully with a temperature rise as high as 35 deg. The total air quantity introduced in any particular case is inversely proportional to the temperature rise, and depends largely upon the judgment and ingenuity of the engineer in designing the most suitable system for the particular conditions. Small quantities of air reduce the size of equipment, ducts, space, and initial cost, but require lower air temperatures. In any specific case, the cost of refrigeration must be balanced against the extra cost in increased size of equipment and running expense.

Outside Air: In order to provide uniform temperature conditions, it is necessary to maintain a pressure of about 0.1 in. of water in the room or space to be ventilated or conditioned. This usually requires the introduction of a certain amount of outside air which depends on the particular conditions involved, and may vary over a considerable range.

In rooms in which the only source of contamination is the occupant, the minimum quantity of outside or new air to be circulated appears to be that necessary to remove objectionable body odors. The concentration of body odors in turn depends largely upon the temperature of the air; the higher the temperature, the greater the amount of perspiration (sensible or insensible) given off from the skin, and the greater the concentration of odors.

Under proper temperature conditions, body odors may be reduced to a concentration that is not objectionable by as little as 10 cfm of outside air per person. This is the minimum amount specified in the Ventilation Standards adopted in 1932 by the Society. The ventilation laws of many states require the introduction of 30 cfm of outside air per occupant, but the present tendency is to supply a smaller amount of conditioned air.

The total quantity of air required to maintain the standards of temperature, distribution, and air motion is usually at least twice as great as that required to keep down body odors, owing largely to difficulties encountered with distribution systems.

Recirculation.

The saving in operating costs due to recirculation of the air, while very considerable, must not be obtained at the expense of air quality. The percentage of recirculated air may be varied to suit the seasonal changes so as to conserve heat in winter and refrigeration in summer, but at no time during occupancy should there be taken from out of doors less than 10 cfm for each occupant. As a general rule, recirculation impairs the quality of the air by excessive humidity (if not conditioned), excessive odors, or both, and it tends to deprive the air of its ionic content, but the influence of this factor on comfort and health is at present a matter of speculation.

Toilets and similar rooms and all kitchens in buildings using recirculation should be separately, mechanically ventilated, with the exhaust in excess of the supply, in order to prevent objectionable odors from diffusing into other parts of the building. This air removal may in many cases be sufficient to insure an adequate replacement of outside air to the general recirculating system.

ATMOSPHERIC HUMIDITY

Fresh Air.

After the inside wet and dry bulb temperatures have been decided upon as the ones that are to be maintained in a given air conditioned enclosure, and the outdoor design wet and dry bulb temperatures selected from Table I, the cooling load necessary to dehumidify the fresh air may be calculated. The quantity of outside air to be dehumidified will naturally depend upon the ventilation requirements. To the volume of air drawn in from the outside by fans should also be added the air that has been calculated to enter the building through cracks, crevices, doors and other places where infiltration might occur.

The heat gain resulting from the outside air introduced may be calculated from the following formula:

$$H_1 -- Qd_o(\theta_o - \theta)$$

where

H_1--heat to be removed from outside air entering the building, Btu per hour.

Q--total volume of outside air entering the building, cubic feet per hour.

d_o--density of outside air, pounds per cubic foot, at the temperature t_o.

θ_o--heat content of mixture of outside dry air (at temperature t_o) and water vapor, Btu per pound of dry air.

θ--heat content of mixture of inside dry air (at temperature t) and water vapor, Btu per pound of dry air.

The total heat content of a mixture of dry air and water vapor is calculated by referring the wet bulb temperature to a psychrometric chart.

Moisture Liberated Within Building.

In some air conditioning installations the moisture liberated within the enclosure may constitute a large part of the cooling load. In theatres, auditoriums and similar buildings where large crowds gather, each occupant not only gives up a considerable amount of sensible heat but also from 700 to 1200 grains of moisture per hour. Tables and curves may be found in the A.S.H.V.E. Guide which show the sensible and latent heat given off by the human body under various conditions of temperature and activity.

There may be several other sources of moisture within a conditioned space. In industrial applications a large amount of moisture may be given off by the materials in process, or by escaping steam. Each case must be studied individually. In some instances a source of latent heat will not affect the maximum design cooling load because it does not occur when other heat sources are at a maximum. In other cases large sources of latent heat will occur at the same time that the sensible heat load is at its greatest, and hence will materially affect the design of the system. The maximum combination of all sources of moisture determines the dew point to which the conditioned air must be chilled in order to reduce the relative humidity.

MIGRATION OF MOISTURE AND ITS EFFECT ON HEAT CONDUCTIVITY

It is a strange fact that, in spite of the development of all branches of technique, there are still cases where one part of a certain branch is well investigated and developed while another remains neglected. An example of this is the absorption of moisture by building materials, and the accumulation of moisture inside these materials. It is well known that moisture greatly influences certain properties of building materials, among these being heat conductivity, which has particular interest for heating and air conditioning engineers.

Accumulation of moisture inside walls, roofs, and similar building parts, not only assists the absorption of moisture but also causes other troubles. Thus, accumulated water or water vapor, when in direct and continuous contact with certain materials composing the walls, may ruin them chemically and may cause the appearance of fungus growths. Moreover, if a low enough temperature exists at the point of accumulation, the water changes into ice, thus ruining the materials mechanically. In addition, the accumulation of moisture, when it comes from inside the building, means an escape of moisture and a decrease of relative humidity which, in some cases, must be maintained at a high level.

Types of Moisture Penetration.

Some of the factors which cause moisture accumulation are known and have been well investigated, while the influence of others is but little known even among specialists. One of these little-known factors is the humidity of air. It is desirable to distinguish between two different processes of moisture penetration: first, penetration into a substance, and second, penetration through a substance. The first process results in the absorption of moisture by substances. The second one assists the absorption and, under certain circumstances, may result in accumulation of moisture. Also, there are two distinct cases of absorption of moisture by building materials:

1. When the material is exposed to water vapor, and

2. When the material is covered by a liquid film or submerged in water.

Materials behave differently in each case. To know all about moisture absorption it is necessary to learn the absorbing capacity of a material in both cases, because both cases can exist in practice. As an example, suppose one takes two building materials much used as heat insulators. Table XV shows how greatly their absorbing properties differ when they are exposed to air containing various percentages of water vapor. The moisture absorbed is given in percent.

Table XV

Material	Relative humidity of air 0%	25%	50%	75%	100%
A	0	2.4	3.1	8.2	20
B	0	0.1	0.1	0.1	0.1

From the table one sees that, when in contact with vapor, material A absorbs considerable amounts of moisture and that, when compared with material B, its non-absorbent character is far from excellent. On the other hand, the absorption of material B is surprisingly small and constant throughout the whole range.

Fig. 5 shows graphically the values of moisture content in material A at different relative humidities of air. At 60% to 70% relative humidity the moisture content is about 7%, while at 85% to 90% relative humidity it is around 15%.

In spite of the very small absorbing capacity of material B, walls insulated with it occasionally have shown areas where the inter-spaces are filled with ice. The same phenomenon has been observed in other granular and fibrous materials used as heat insulators. Before attempting to explain this little known phenomenon, let it be noted what the above-mentioned amount of moisture content means and how much the conductivity of materials is influenced by moisture content.

Influence of Moisture on Conductivity.

It is well known that moisture added to an insulating building material increases its coefficient of heat conductivity.

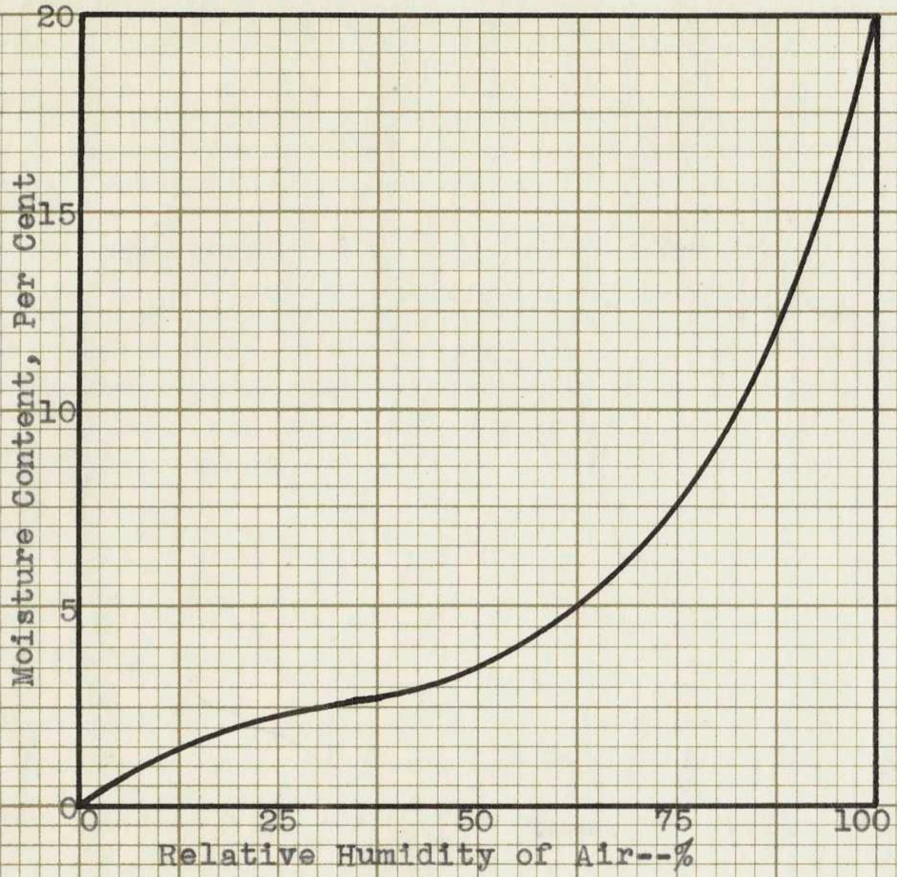


Fig. 5. Values of moisture content in material A at different relative humidities of air.

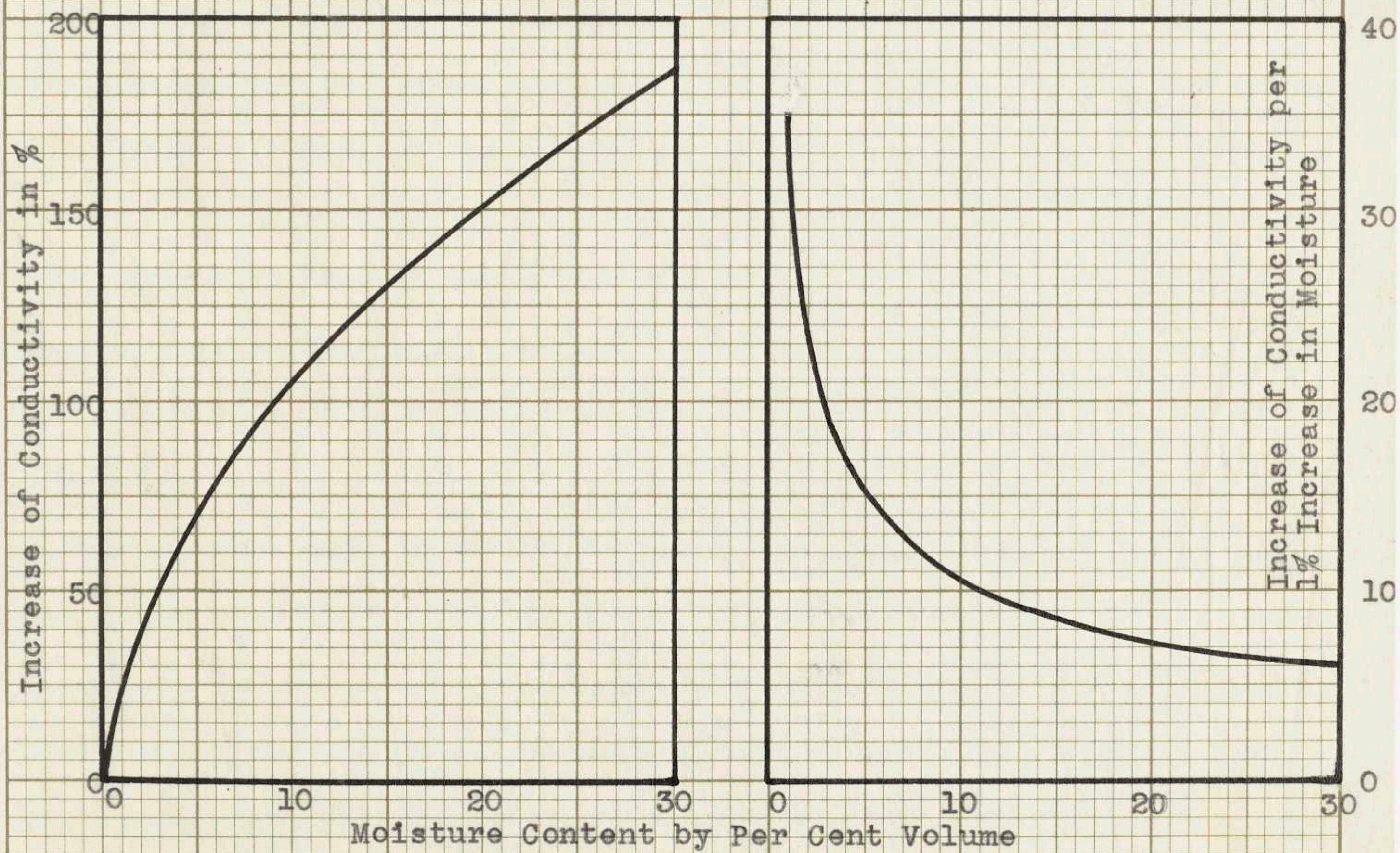


Fig. 6. The important effect of moisture on conductivity.

The explanation is that the moisture is a relatively good conductor of heat as compared with the substance itself. Fig. 6 is from studies made by I. S. Cammerer and shows the relation between conductivity and moisture content. Doctor Cammerer is of the opinion that this diagram represents the relation between the moisture content and the heat conductivity for all porous materials. It is questionable, however, whether the same amount of moisture added can produce the same effect on the conductivity of all porous materials. It would rather be expected that in the case of adding say 10% of moisture both to a substance with a coefficient of conductivity of 0.3 and to a substance with a coefficient of conductivity of 0.6 (if both are dry), that the added moisture will change the conductivity of the first material to a greater extent than that of the second one. This means that the better non-conductor of heat the material is, the more dangerous is the influence of the moisture added.

From Fig. 6 it will be seen that even a small amount of moisture changes the conductivity considerably. In the case of material A, previously mentioned, Fig. 5 shows that, when in contact with air of 85% to 90% relative humidity, it will have a moisture content of 15%. This would mean that the increase in the coefficient of conductivity would be about 135% over its value when the material is dry. Thus, if the conductivity dry is 1.0, the coefficient for 15% moisture would be 2.35. Doctor Cammerer mentions cases where the moisture content in building materials has reached a value of 30%, which means an increase in conductivity of about 200%.

The important effect of even small amounts of moisture is evident from examining the right-hand curve of Fig. 6. It can be seen that the increase of conductivity for each per cent of added moisture is large at the beginning. The first per cent of moisture added increases the conductivity about 30%, while the first 21% of moisture added increases the conductivity only 7% per 1% volume of moisture. Cases are known where 10% of moisture was found in the insulating material A. Other data given in the same article by Doctor Cammerer show that impregnation with a water-proofing substance does not give any guarantee of full prevention of moisture absorption, since in some cases the moisture content in the treated material was found to reach 3% to 3.5%. Even such a small moisture content means an increase of conductivity of about 60%.

From the above the following conclusions can be drawn:

1. Moisture influences the heat conductivity of different materials to a very great extent, and cases are known where the moisture content reaches an extremely high value.

2. Even if the moisture content is small, the change in conductivity is so considerable that all calculations of heat transmission may become wrong.

3. In cases where high humidity prevails, it is of importance that means be found to prevent moisture penetration through walls, roofs, and other parts of buildings, and for controlling the moisture content in building materials.

Process of Moisture Migration.

The penetration of a gas through any material occurs because of the difference between the partial pressures of this gas on the two sides of the material. The amount of penetrated gas expressed in volume units is assumed to be in direct proportion to the difference between the partial pressures. To illustrate how large this difference can be, the approximate values of water vapor pressure at different air conditions are given in Table XVI.

Table XVI

Conditions	Winter (1)	Intermediate (2)	Summer (3)
Dry bulb temp., Deg. F.	-15	30	80
Relative humidity, %	80	85	60
Vapor Pressure, mm. Hg.	0.3	3	15

In this table conditions in column (1) are typical of outside winter conditions; in column (2) appear inside conditions as they should be maintained in some cold storage rooms; in column (3) are outside summer conditions. This table does not represent average conditions and the figures are given only to illustrate the fact that the partial pressures of water vapor inside and outside may differ considerably. In this case, for winter conditions, the difference in partial pressures is 2.7 mm., and for summer conditions is 12 mm.

Partial pressures of the air, inside and outside, depend on the total or barometric pressure. Let it be assumed that the total pressure inside and outside are the same. This assumption is not correct in general because in many cases the total pressure inside must be higher than outside in order to provide proper air distribution, and for other reasons. Sometimes, if air is exhausted from a room, the total pressure inside is smaller than outside. However, the total pressures can be assumed to be equal in order to illustrate a particular case.

It is evident that at the winter conditions, water vapor will move from the inside toward the outside, while the air--its partial pressure being greater outside--will move in the opposite direction, i.e., from outside into inside (See Fig. 7a). In summer the partial pressure of water vapor

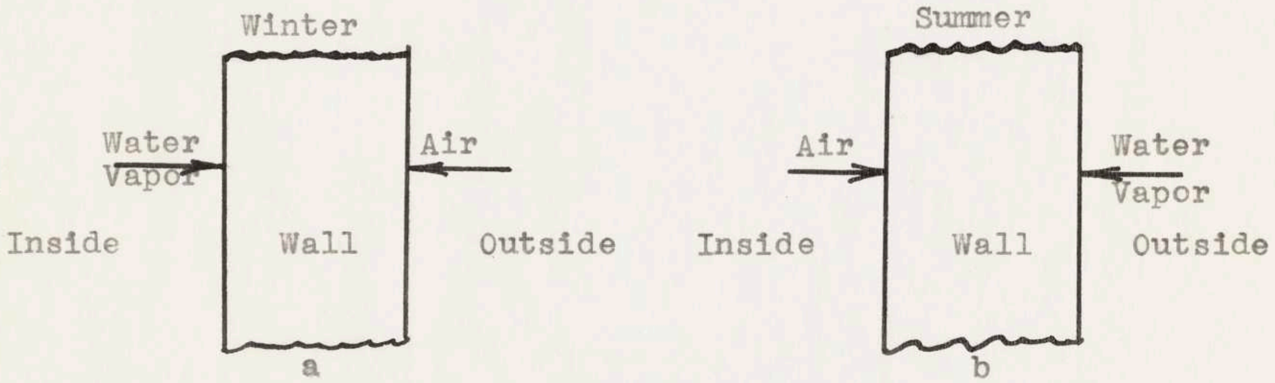


Fig. 7

outside is greater, and the partial pressure of air is smaller, than inside. Therefore, the direction of motion for both will be as indicated in Fig. 7b.

Referring to Fig. 7a, it is clear that with winter conditions the temperature of the water vapor while moving through the wall will drop, and may reach a dew point temperature at some point inside the wall. If so, the vapor will begin to condense at this area. If the temperature is low enough the condensed water will freeze. As the greatest drop of temperature inside a compound wall occurs within the insulating material, there is a possibility that the dew point temperature will be reached inside the insulating material. Here is a simple explanation of the phenomenon of the presence of ice inside the walls, or in the insulating material itself.

Suppose now that the accumulation of condensed water vapor occurs in the insulating material or very close to it. This gives an example of an insulating material absorbing moisture in the liquid state. This would not be dangerous to some materials but would be distinctly dangerous to others, for instance, a material having capillarity.

To go further and see what can be done to prevent moisture accumulation in the walls, suppose there is a simple wall like the one shown in Fig. 8. For such a wall the amount

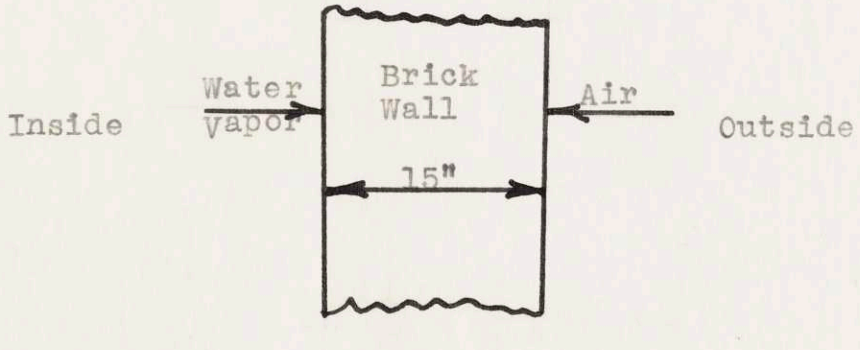


Fig. 8

of penetrated gas (air or water vapor) is relatively small. It may be computed by using the following formula:

$$L = \frac{r}{e}$$

where L is the volume of penetrated gas in liters, r is the coefficient of penetration in liters per hour per square meter per millimeter of water per meter thickness, and e is the thickness of the material in meters. C. Lang gives (for brick) a value of r=3. For this case the thickness of the wall is equal to 15 in. or 0.38 meter, and

$$L = \frac{3}{0.38} = 8 \text{ liters} = 0.28 \text{ cu. ft.}$$

Taking into account the very small density of water vapor, the amount of penetrated vapor is thus seen to be quite small for such a wall.

Another important factor helps to prevent any considerable amount of moisture from accumulating inside the wall shown in Fig. 8. Air entering the wall from the outside will become warmer, and when reaching the point of condensation of water vapor it will try to re-evaporate the condensed water and to bring it back into the room. For these two reasons the danger of accumulation of any considerable amount of moisture in a simple wall is not too great.

Consider, however, a compound wall like the one shown in Fig. 9, which consists of a material (c) of relatively small thickness and high coefficient of penetration, and of a material

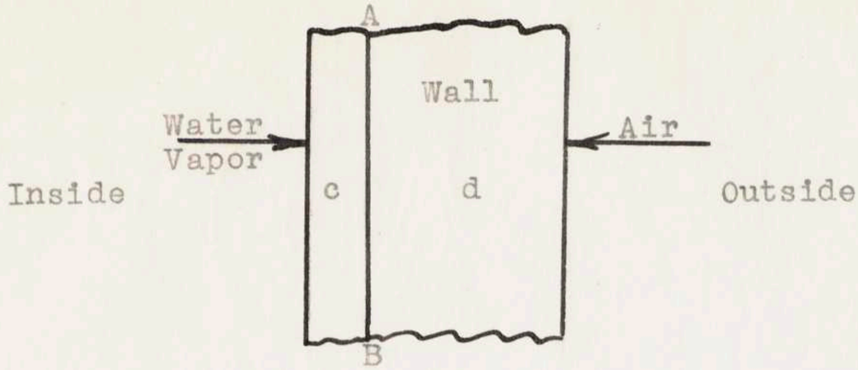


Fig. 9

(d) which is relatively thick with a low coefficient of penetration. The water vapor will go through material c easily. When meeting the material d along the line AB, the penetrated water vapor will begin to accumulate at this line because of the much higher resistance to penetration of material d. When the dew point temperature at line AB is reached, the vapor will begin to condense so that more and more water vapor will be attracted from the inside toward line AB and the amount of condensed water will become larger and larger. On the other hand, there is no great chance for moisture to be carried away by the incoming air because the material d will resist the penetration of the air from the outside just as it resists the penetration of vapor from the inside. Thus, in a case of a compound wall, the moisture accumulation can be considerable.

Means of Combating Moisture Accumulation.

Based on these considerations, the way to prevent or at least to oppose, the accumulation of moisture in the wall built up of the two materials c and d is simple enough.

It is only necessary to change the location to that shown in Fig. 10. In this case a considerably smaller amount of

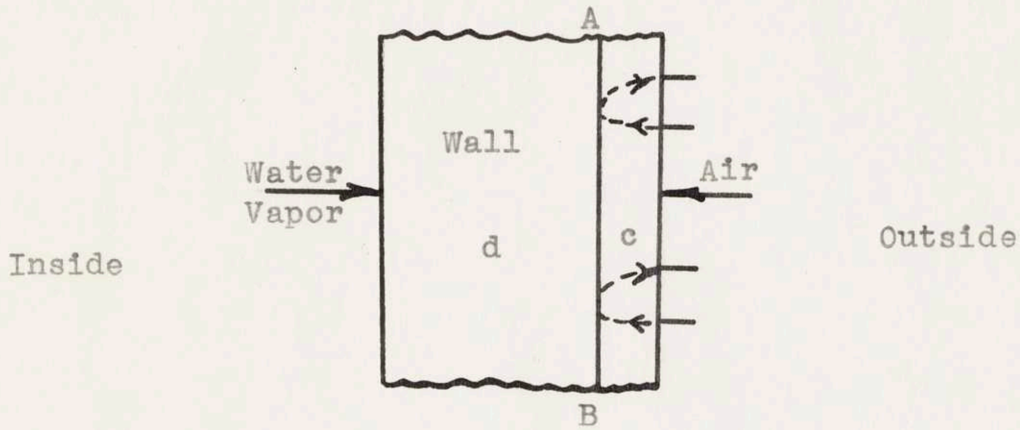


Fig. 10

accumulated moisture should be expected because: (1) material d will permit the penetration of only a small amount of water vapor because of its thickness and low coefficient of penetration, and (2) the air from outside will be given a much better chance to reach the line AB. Upon reaching this line the entering air, becoming warmer, will tend to evaporate the moisture, if any, accumulated along line AB, and may escape again to the outside due to local circulations as shown in Fig. 10.

For such a case, and considering winter conditions, the conclusion is that where moisture accumulation within the wall is caused by humidity of air, the materials composing the wall should be located in such a way that their coefficient of penetration decreases from the inside toward the outside of the wall.

Without analyzing a similar case for summer conditions, it is clear that an opposite arrangement of materials will be desirable. This reversal does not mean, however, that nothing can be done. In some cases only winter or else summer conditions need be dealt with. In other cases one condition or the other prevails to such an extent that it is only necessary to take care of the worse.

Even where winter and summer conditions are equally important, and it is necessary to take care of both, some steps can be undertaken to diminish the undesirable effect of moisture accumulation. According to Matschinsky, the following ways can be recommended for such a case:

1. Moisture-proof material on both sides of walls, roofs, etc. In this case the inside materials should be very dry and there must be an opening at the top of the wall for free circulation of air. This method is rather expensive.

2. The moisture-proof material can be located in the middle of the wall. This diminishes the temperature difference for both parts of the wall and, consequently, the danger of moisture penetration. A continuous moisture accumulation will be prevented by the fact that the moisture accumulated on one side of the moisture-proof material will be given a chance to be carried away.

3. No use of moisture-proof material at all, but providing conditions of possible free circulation of air through the wall. This circulation will take care of evaporating the accumulated moisture.

These suggestions should be carefully checked. Perhaps better remedies can be found for this case as well as for other cases, and all will require a great amount of investigational work.

The preceding analysis was made with certain assumptions which are not always justified in actual cases. For example, a sufficient overpressure inside the room can change the direction of air motion and a new analysis of the whole process would be necessary. Besides that, when solving the problem of how to build up the wall or roof, it is not practical to consider the location of materials from a point of view of their coefficient of penetration only. Other important considerations of a purely structural nature also must be taken into account. Under certain circumstances they may be contrary to the considerations given herein. It is not easy to solve this problem, but if properly handled and analyzed it can be so solved as to take care of all requirements and to reconcile all opposing factors.

Probably even with sufficient investigation it will be found that there is no general solution to the problem of preventing moisture accumulation. Each particular case seems to be individual, all conditions must be carefully studied and all processes properly analyzed. The most important factors to study are:

1. Inside and outside conditions, especially the prevailing temperatures and humidities.

2. The coefficients of penetration of gas through all materials, which comprise the walls, roofs and other parts of buildings.

3. Temperature distribution inside the walls, etc., in order to know, at least approximately, where a dew point for prevailing conditions can be reached.

Need of Revised Coefficient Tables.

On account of the fact that moisture so greatly influences heat conductivity, this factor should be taken care of always. For example, to state that a value of the conductivity for some material is equal to 0.3 is not enough; it also must be made clear at what moisture content this value is found. In most tables for the coefficients of conductivity of building materials there is no indication as to the moisture content. Often, when the coefficients are given for insulating materials, the best value is stated. As anyone knows, this means making the sample as dry as possible. But it is also known that in many practical cases dry conditions can not be maintained and that, therefore, the values given should not be used unless a correction for the expected moisture content is introduced.

In most cases of heat loss calculation, no such corrections are made, although some writers have advocated making them. The designer usually has to be satisfied with the results he gets when using the values of heat conductivity as they are given in tables. These are the values found under laboratory conditions. That these values can be quite different from the actual values met in practice is proved partially by the fact that the actual heat losses often differ considerably from the computed values.

Thus it can be seen that there are two problems about which data should be secured:

1. Final establishing of the relation between the moisture content and the heat conductivity of building materials, and compiling new coefficient tables showing this relation.

2. Finding out ways for controlling, or at least determining (if possible, even predetermining), the moisture content, as well as preventing the accumulation and penetration of moisture inside walls.

CONCLUSIONS

The proper selection of equipment for a successful air conditioning installation is dependent on an accurate load or Btu estimate. The success of any estimate, in turn, is dependent to a large degree upon the judgment used by the estimator in evaluating the various factors affecting such an estimate.

The amount of heat and moisture from the various sources is continually varying from hour to hour and from day to day. It is safe to say that these factors are never present in the same identical proportion on any two occasions.

Sometimes the maximum intensity of heat and moisture resulting from several factors occur simultaneously, when a pyramiding of maxima will exist. An equal pyramid of all the factors may not occur sufficiently often to warrant the expenditure for an air conditioning installation which will have sufficient capacity to cope with this maximum. Therefore, the engineer must use experience and judgment to evaluate the maximum conditions which may occur frequently enough to justify the initial investment and also the cost of operation and maintenance of the system he recommends.

It is obvious that if the Btu estimate is based on illogical assumptions, there will be a pyramiding of errors and the resultant selection of equipment will be worth little more than a pure guess. In making the estimate, it is usually wisest and safest to calculate each factor at its probable average maximum and then later to review the estimate to find the combination of maxima which will occur simultaneously and which should be used as the basis for the selection of the equipment.

As is stated earlier in this thesis, the only factor which differs materially in its method of calculation by various authorities is that of solar radiation. In the Appendix there are given four ways of estimating this source of heat. That used by the A.S.H.V.E. includes the results of the most recent investigations of the subject, and is a compromise between the highly involved and mathematically complicated findings of research workers and the "rule of thumb" estimating used by practical air conditioning engineers. In the author's judgement the A.S.H.V.E. method of calculating the sun load is sufficiently accurate for most air conditioning installations except those having a very large glass exposure. In such a case a more accurate study, such as that shown on page 42, should be made of the sun load. For most installations there is no need to go to such refinement because it is impossible to figure other cooling load factors so closely.

An analysis of the methods used by the three air conditioning companies shows that that of the Kelvinator company is based on the most rational assumptions and includes some of the findings of recent investigations. The method used by the Westinghouse company is considered to be the least desirable to follow, since it appears to be not far removed from a pure guess.

The reader has by this time, no doubt, come to the conclusion that while there may be need for additional information on all the factors affecting the cooling load, there is an urgent need for further knowledge of the effect of solar radiation, especially as it influences heat transmission. It is of small use to the engineer to know exactly how much radiant energy falls on a given wall, if he cannot determine how much of this energy finally gets into the room and how great the time lag is.

There is also a great need for more information on the migration of moisture through structures and its effect on heat transmission. Until more is known about this phenomenon, correct results of heat gain calculation in any actual case cannot be expected. Lacking a solution of this problem, the whole work done on the determination of laboratory values of coefficients of heat conductivity has no considerable practical value. One cannot help wondering why all the exactness of determing coefficients with results reported to third and fourth decimal places if one per cent of moisture added can change the conductivity and, consequently, the amount of heat conducted 20 per cent or more.

APPENDIX

Including:

Methods of calculating the solar radiation load used by the following:

The American Society of Heating and Ventilating Engineers

The Kelvinator Air Conditioning Company

The Frigidaire Air Conditioning Company

The Westinghouse Air Conditioning Company

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To illustrate how the solar radiation heat load is taken care of in actual air conditioning practice, the following extracts are taken from the American Society of Heating and Ventilating Engineers Guide for 1935, and from the manuals of the Kelvinator, Frigidaire and Westinghouse air conditioning companies.

A.S.H.V.E. GUIDE, 1935

"Fig. 11 shows the total amount of solar energy

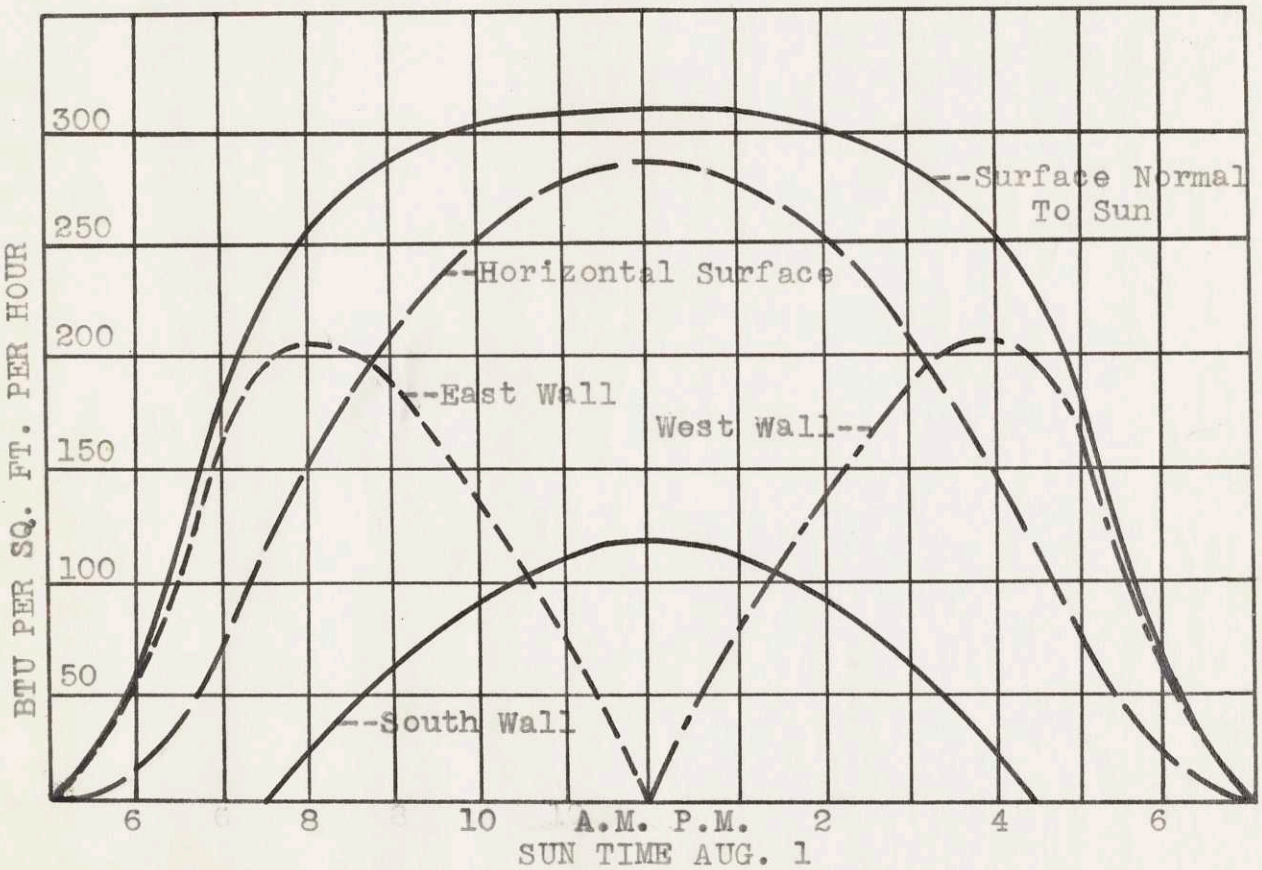

Fig. 11 (From A.S.H.V.E. Guide)

Curves Giving Solar Intensity Normal to Sun, on Horizontal Surface and on Walls for August 1.

in Btu per square foot per hour received during the day by a surface normal to the rays of the sun, by a horizontal surface, and by east, west, and south walls. The curves are drawn from A.S.H.V.E. Laboratory data obtained by pyrheliometer, are based on sun time, and are for a perfectly clear day on August 1 at a north latitude of 40 deg. Data from these curves may be used with little error for most United States latitudes and for all of the hotter months of the year.

"Unfortunately, the calculations for the transmission of heat from solar radiation through building walls are too complicated to be of much practical value to the heating and ventilating engineer. Approximate results may be obtained by adding the number of degrees given in Table XVII to the outside design dry-bulb temperature in calculating the heat

Table XVII (From 1935 Guide)

ALLOWANCE FOR SOLAR RADIATION ON ROOFS AND WALLS

Approximate Number of Degrees to Add to Dry-Bulb Temperature for Different Types of Surfaces.

Type of Surface	Black	Red Brick or Tile	Al. Paint
Roof, horizontal..........	45	30	15
East or west wall.........	30	20	10
South wall................	15	10	5

transmission through a wall or roof which may be exposed to the sun for an appreciable length of time. Table XVII was obtained from a study of the data in A.S.H.V.E. research papers on solar radiation. Black and aluminum painted surfaces represent the extremes which are likely to occur. For other types of surfaces, values intermediate between those given in the table can be used.

"The calculation of heat transmitted through walls and roof does not take into consideration the heat capacity of the structure and the consequent time lag in the transmission of heat. In the thick walls used in modern office buildings the time lag may amount to 10 hours or more. Thus in many cases the wall transmission cannot be added directly to the cooling load from other sources because the peak of the wall transmission load may not coincide with the peak of the total cooling load and may even occur after the cooling system has been shut down for the day. The data in Table XVIII were taken from A.S.H.V.E. research papers, and while they result principally from a study of experimental slabs, they give an idea of the time lag to be expected in various structures.

Table XVIII (From 1935 Guide)

TIME LAG IN TRANSMISSION OF SOLAR RADIATION THROUGH WALLS AND ROOFS

Type and Thickness of Wall or Roof	Time Lag, Hours
2-in. pine	$1\frac{1}{2}$
6-in. concrete	3
4-in. gypsum	$2\frac{1}{2}$
3-in. concrete and 1-in. cork	2
2-in. iron and cork (equivalent to 3/4-in. concrete and 2.15-in. cork)	$2\frac{1}{2}$
4-in. iron and cork (equivalent to 5 1/2-in. concrete and 1.94-in. cork)	$7\frac{1}{4}$
8-in. iron and cork (equivalent to 16-in. concrete and 1.53-in. cork)	19
22-in. brick and tile wall	10

"For bare windows on which the sun shines, the transmission of heat from outside air to glass is small as the glass temperature is raised by the solar radiation absorbed. Therefore, in calculating the total heat gain through windows on the sunny sides of buildings, it is sufficiently accurate to figure the total cooling load due to the window as the solar radiation times the proper percentage from Table XIX, and to neglect the heat transmission through the glass caused by the difference between the temperatures of the inside and outside air. Another reason for neglecting this glass transmission load is that the curves in Fig. 11 were based on the maximum intensity of solar radiation observed at the A.S.H.V.E. Laboratory during a three-year study, so results based on these curves will be amply high."

Table XIX (From 1935 Guide)

SOLAR RADIATION TRANSMITTED THROUGH BARE AND SHADED WINDOWS

	Per Cent Delivered to Room
Bare window glass..................................	97
Canvas awning......................................	28
Inside shade, fully drawn..........................	45
Inside shade, one-half drawn.......................	68
Inside Venetian blind, fully covering window.....	58
Outside Venetian blind, fully covering window....	22

KELVINATOR METHOD

"The capacity of a surface to absorb the radiant heat of the sun is dependent on various factors, among which are the color, construction and smoothness of the surface. The amount of heat absorbed is also dependent upon the angle between the surface and the sun's rays. The resultant surface temperature of horizontal surfaces, such as roofs, is much greater than that of vertical surfaces, such as walls. Similarly, the roof temperatures of southern buildings are greater than those of northern buildings. For most practical purposes, the surface temperature of roofs can be expressed as 50 deg above that of the outside design temperature of the locality. The wall temperature can be evaluated at 15 deg above the outside design temperature. Due to the fact that some of the radiant heat penetrates through the glass of the window, and in order to simplify the calculations, the surface temperature of glass is assumed at 25 deg above the outside design temperature.

"The actual determination of the transmission coefficient for solar heat is very difficult and complicated. However, for the practical purpose of air conditioning estimates it is reasonably accurate to add 10 per cent to the regular transmission coefficient.

"An area factor as tabulated in Table XX is a percentage multiplier used to compensate for the protection effect of shades, awnings, Venetian blinds and recessed windows. This

Table XX (From Kelvinator Manual)

HEAT GAIN--SUN EFFECT

Sensible Heat of Sun--Area x Area Factor x Sun Transmission Constant x Temperature Difference

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AREA FACTOR: (To compensate for protecting effect of awnings, shades, blinds, etc.)

Windows:-	
Unshaded	100%
White shades, inside of glass	60%
Venetian blinds, inside of glass	80%
White shades and Venetian blinds, inside of glass	50%
Drapes and curtains, inside of glass	90%
Recessed windows, with shades	40%
Awnings outside of window	20%
Ventilating shutters, outside of window	10%
Tree Shade, protecting window from direct sun.	25%-50%
Show Windows:- (Enclosed by glass or thin wood partition)	
Shaded by awnings or marquee	10%
Sunlit-Deep window (Depth equal to or greater than heighth)	30%
Sunlit-Shallow	100%
Skylight:-	
Unshaded	100%
White shades, inside of glass	60%
Exterior Walls:-	
Net area of sun-exposed surface	100%
Roofs and Skylights:- (100% of horizontally projected area)	100%

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factor is never less than 50 per cent for windows provided with shades, as even with the shades drawn to cover the entire window the solar radiation will raise the temperature between the glass and the shade and result in considerable transmission of heat into the conditioned room. Similarly, awnings may cut off some of the direct rays of the sun, but the temperature underneath the awnings will be much higher than the normal outside temperature. In addition to this, the awnings will not cut off the solar radiation which is reflected by sidewalks, pavements, and other surfaces directly beneath the window. The Venetian blinds reduce the glare of the direct sun, but due to the method of their installation, an area factor less than 80 per cent should not be used. When the glass of the window is recessed about 20 inches or more from the face of the sun-exposed wall an area factor less than 20 per cent should not be used. There are many factors which should be considered, however, before large reductions in the area of the window would be permissible in calculating sun effect.

"It is generally considered that the walls of the east, south and west sides of a room may each be exposed to the direct rays of the sun. The estimator should determine which of these surfaces is the maximum and use such surface in the estimate. The direct sunlight on the east wall reaches a maximum at mid-morning, the direct sunlight gain on the south wall reaches a maximum at high noon, while the direct sunlight gain on the west wall reaches a maximum later in the afternoon, between four and five o'clock. Where there are several rooms on a floor being conditioned, it is necessary to estimate sun effect on each room separately, as each room will have to carry its sun effect load when that sun effect occurs; also when a large space requiring two or more units is conditioned, each unit should be designed to have sufficient capacity to take care of the sun effect of its own location."

FRIGIDAIRE METHOD

"When the ceiling is also the roof, add 40 deg to temperature difference. When the ceiling is directly under roof, but separated by a six-inch air space, add 15 deg to temperature difference. Skylights should be estimated on the basis of transmitting 160 Btus per hour per sq. ft. in the north, or 180 Btus per hour per sq. ft. in the south; if shaded, use 100 Btus per hour per sq. ft. in the north and 120 in the south.

"If the walls are located adjacent to an unusual source of heat, increase temperature difference by amount this source is above normal surroundings. For glass windows and doors use the ordinary transmission coefficient, unless exposed to direct sunlight; in this case use the following:

Sun Exposure	Heat Leakage in Btus Per Sq. Ft. per Hour
East	160
West	160
South	75

"If outside awnings are over windows and doors, use the ordinary transmission coefficient with twice the normal temperature difference to allow for the increase in temperature under the awning. It is recommended that awnings be used wherever possible so that it is not necessary to consider the high sun radiation factors for the glass surfaces.

"In making calculations for solar radiation, it should be kept in mind that the sunlight does not strike the east, south and west windows all at the same time. Therefore, when determining the heat load use the radiation factor for glass windows and doors for that sun exposure direction (either east, west or south) having the largest glass area. The heat load for the remaining glass areas should be calculated using the normal temperature difference.

"If awnings are over glass windows and doors it is necessary to consider the double temperature difference only for the glass windows and doors for that sun exposure direction having the largest glass area. Of course, the normal temperature difference should be used for the remaining glass areas.

"Inside shades of light colored and impervious material are of assistance in cutting down the effect of solar radiation. Very little data is available regarding the benefits to be obtained therefrom, and we recommend not more than a 50 per cent reduction in solar radiation be expected with good shades."

WESTINGHOUSE METHOD

"To calculate the solar radiation load through windows and skylights, multiply the glass area by 60 and 100 respectively where there is protection with white shades, Venetian blinds, etc. Where there is no such protection, use factors of 180 and 300 respectively. When the glass is not exposed to the sun, calculate the radiation load by using the accepted transfer coefficients.

"To estimate the heat gain through roofs and walls which may be exposed to the sun, increase the normal temperature difference by 30 deg and 10 deg, respectively, and use the ordinary transfer coefficients."

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