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MID-SOUTH SOLAR TOTAL ENERGY;
INSTITUTIONAL ANALYSIS

FINAL REPORT

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R. E. Powe
C. T. Carley
R. E. Forbes
L. R. Johnson
A. K. Stiffler
B. K. Hodge
C. W. Bouchillon

MN ONLY

MASTER

Mississippi Energy Research Center
Engineering and Industrial Research Station
Mississippi State University
Mississippi State, Mississippi 39762

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SUMMARY OF RESULTS

A variety of individual components likely to be employed in total energy systems have been considered in detail. Also, algorithms have been developed for the approximate prediction of building heating and cooling loads based on gross parameters such as floor area, type of wall construction, etc. A brief summary of results in each of these areas is given in the following paragraphs, and more detailed descriptions are given in the Appendices.

Correlation of Historical Energy Consumption Data

A comprehensive survey was undertaken to determine the current usage of energy by the university. Electricity and fuel were considered separately. Single electrical meter serves the entire campus, and for the last several years electrical consumption has been recorded every half hour. In contrast, several types of fuel are used and these are metered at numerous points across the campus. Natural gas is the primary fuel, but the university does not have a guaranteed supply, so in very cold periods the supply is reduced. The difference is made up through use of fuel oil.

Least squares techniques were employed to develop correlation equations predicting both the electrical and fuel usage. These equations project consumption rates for the next several years. Details are given in Appendix A.

Algorithm Development for Heating and Cooling Load Calculations

In order that the results of this study might be extended to

other institutions in a convenient manner, an effort was undertaken to develop a simplified procedure for estimating building heating and cooling loads. This procedure is based on gross floor area, wall area, glass to wall area ratio, heating and cooling degree days, etc. Details are given in Appendix B, and results were found to be in good agreement with actual consumption data.

Solar Assisted Space Heating System

This system was designed to meet the heating requirements of 28 buildings located near the center of the Mississippi State University campus. This particular group of buildings was chosen because they are connected by an existing steam tunnel system which could be easily employed to convey heated water. The heating system developed uses flat plate collectors to produce low grade thermal energy and a heat pump to extract energy from this source and provide heating to the buildings. This system is described more completely in Appendix C.

Space Cooling System Design

The objective of this system is to use thermal energy available at around 200°F to provide cooling requirements for the 28 buildings located near the center of the campus. This heat could be provided by solar collectors, or it could be waste energy from some other process. In this particular design absorption refrigeration systems were employed to supply chilled water to the central distribution system. The design is described in Appendix D.

Solar Electric System

A solar driven system for supplying electrical energy is

described in Appendix E. This system uses concentrating collectors to provide 465°F liquid to the boiler of an organic Rankine cycle, which drives a turbine coupled to a generator with a 500 kw electrical output. A likely working fluid for the organic Rankine cycle system would be toluene.

Flat Plate Solar Collector System

Appendix F concentrates on the assessment of flat plate collectors likely to be employed with any of the energy systems described previously. Specific commercially available collectors are used as examples, and a collection field to provide domestic hot water and space heating for the Mississippi State University campus is sized.

Central Solar Receiver

Efforts regarding this concept are currently in their infancy. In Appendix G a possible concept for such a system is outlined, and some of the operating parameters are given.

Geothermal Energy System

In the vicinity of Mississippi State University there exists the possibility of exploiting some very low grade geothermal energy sources. At about the 500 foot depth, groundwater is reported to be a temperature of around 60°F, while at a depth of 1 to 2 thousand feet, groundwater is reported to be at a temperature of over 100°F. There thus exists the potential of using one of these sources to improve the effectiveness of operation of a conventional heat pump system. Preliminary calculations concerning such systems are shown in Appendix H.

System Considerations and Evaluation

This section defines several alternative energy systems which will meet the energy demands of the institution and carries out an analysis of these systems with regard to component efficiency, size, and cost. Attention is focused on seasonal monthly demands and the availability of solar energy during equivalent periods.

APPENDIX A
Correlation of Historical Energy
Consumption Data

A comprehensive survey was undertaken to determine the current usage of energy by the university. The survey was divided into two parts: electricity, and natural gas and fuel oil.

Electricity

All electricity used by the central campus of the university comes from the Starkville Electric and Water Department, Starkville, Mississippi; there is a single meter which is read monthly by the Electric Department, usually about the twenty-first or twenty-second of the month. For the last several years, the university has had a recorder connected to the meter which will print the electrical usage each half hour. Data from the recorder are maintained by the university Physical Plant Department; bills sent to the university from Starkville Electric Department are received by the Physical Plant Department where the electrical consumption, cost, and meter reading data are recorded. The bill is then sent to the Accounting Department for payment. Thus, the Physical Plant Department has available all data concerning electrical consumption by the university.

Monthly Consumption

The data on monthly consumption, from the monthly bills, were copied from July 1969 through December 1977, one hundred and two months. Since each bill was for a part of the billing month and for a part of the previous month, the consumption was prorated to the two months based on the days of each month included on the bill. For example, if the meter was read on the twenty-third of the month, and the bill covered 32 days from the previous date read, then $9/32$ of the consumption was allocated to the previous month and $23/32$ was allocated to the billing month. After allocation, the results were divided by the number of days in each month to obtain the Monthly Average

Daily Usage (MADU). These results are plotted against Month in Figure 1.

Figure 1 exhibits a strong cyclical component and a long range increasing trend in energy consumption. The cyclical component reflects the monthly temperature and the long range trend is believed to be caused by the physical growth of the university. Data concerning these two factors were obtained from publications of the U.S. Weather Bureau (a weather station is located on the university campus) and from internal reports prepared by the university Physical Plant Department. Data for these two factors are plotted in Figures 2 and 3.

A step-wise regression analysis was run on the data, with MADU as the dependent variable and, monthly temperature, monthly temperature squared, size of the university (area in square feet of all university buildings), and one variable for each month of the year for a total of 15 independent variables. After reviewing the results, a second analysis was run using only three independent variables: monthly temperature squared (TEMP2), size of the university (SQFTBL), and a single variable for the months of September, October, and November (SON). The results of this analysis gave a multiple correlation coefficient of 0.91. Summary results are given below. Figure 4 plots the values from the regression analysis (Δ) and actual demand (*).

Variable	Coefficient	Standard Error	Student t
TEMP2	11.186	.59850	18.67
SQFTBL	.04172	.00396	10.54
SON	9386.9	2292.1	4.09
Constant	-71784.87		

$$\text{MADU} = -71784.87 + 11.186\text{TEMP2} + .01472\text{SQFTBL} + 9386.9\text{SON}$$

The 1990's

Using the scheduled physical additions to the university for the next three years, and thereafter, the historical growth of the university (100,000

ft. square per year), the monthly electricity consumption by the university from 1990 through 1999 was predicted. The temperature used for each month was the average temperature for the month, calculated from the data collected from the publications of the U.S. Weather Bureau. The results are given in Table 1.

Daily Consumption of Electricity

The consumption of electricity each thirty minute period during the day was obtained from data provided by the Physical Plant Department. One week in February and one week in July were selected for analysis. The weeks selected were typical work weeks in that neither include school holidays.

For each week selected, the energy consumption in each half hour was averaged for the five work days, and for the two weekend days. Figures 5, 6, 7, and 8 show the average consumption for the weeks selected. The shape of the curves for the week day averages are not unexpected; the electrical usage climbs sharply at 8 a.m., dips during the noon hour, and falls again at 5 p.m. The weekend curves show only a slight rise in the morning and no dip during the noon hour.

Natural Gas and Fuel Oil

The natural gas used by the university is purchased from the Mississippi Valley Gas Company; the fuel oil has been purchased from several vendors over the years. The university does not have a guaranteed supply of natural gas and in very cold periods, the supply is reduced. The university makes up the difference with fuel oil.

Unlike electricity, there are numerous gas lines to the university, each being metered separately. The Mississippi Valley Gas Company reads these meters on different days during the month. Several years ago, the bills for gas consumption were sent to different organizations of the university, who recorded data from bills, then sent them to Accounting for payment. In

several of these instances, the data of interest to these organizations was only the dollar amount, thus information on gas consumption was unavailable. More recently, all bills are sent to the Physical Plant Department who recorded all data from the bill. Occasionally, the recorded values are obviously incorrect. Usually this was due to the "gas-man" misreading the meter, and is followed by one or more months of adjustment by the gas company. Missing data, incorrect data, and general lack of availability were problems in collecting and analyzing gas data.

All bills for fuel oil are sent to the university Physical Plant Department. Most of the fuel oil is used by the university steam plant, but some is used at other locations; there are no records to indicate where the fuel oil was used, therefore all of it was assumed to have been used at the steam plant. In analyzing these data, the fuel oil was converted into equivalent natural gas then added to the natural gas quantity used by the steam plant. The conversion is as follows:

1 CCF of natural gas = 100,000 BTU

1 gallon of fuel oil = 138,800 BTU

1 gallon of fuel oil = 1.388 CCF of natural gas

Steam Plant

The buildings in the central portion of the campus are all steam heated in the winter; thus the steam plant is the largest user of natural gas and fuel oil. Data on natural gas consumption by the steam plant were available from July 1969 through December 1977. These data were analyzed following the same procedure as was used for electricity. The gas consumption was first apportioned to the month using the date the meter was read. The monthly quantity was then divided by the days in the month to obtain the Monthly Average Daily Usage (MADU). The results of these calculations were plotted against Month, and are shown in Figure 9.

Other Gas Users

Data has been collected from other sources using gas; however, results are not sufficiently complete at this time to present results.

ELECTRICITY FOR SEPTEMBER 1969 - DECEMBER 1977

Figure 1

SEPTEMBER 1969 - DECEMBER 1977

THE CURVE COMPOSED OF THE SYMBOL (*) REPRESENTS AVERAGE MONTHLY TEMPERATURE FOR SEPT 1969 - DECEMBER 1977

Figure 2

THE GROWTH OF MSU IN FT. SQUARED 1970-1977

THE CURVE COMPOSED OF THE SYMBOL (+) REPRESENTS THE GROWTH OF MSU IN FT. SQUARED 1970-1977

Figure 3

ELECTRICITY FOR SEPTEMBER 1969 - DECEMBER 1977

THE CURVE COMPOSED OF THE SYMBOL (●) REPRESENTS MONTHLY AVE. DAILY USAGE FOR SEPTEMBER 1969 - DECEMBER 1977
 THE CURVE COMPOSED OF THE SYMBOL (▲) REPRESENTS MONTHLY AVE. DAILY USAGE CALCULATED BY REGRESSION EQUATION

Figure 4

Table 1

ELECTRICITY USAGE FOR 1990 - 1999

MONTH	MON. AVE. DAILY USAGE	MONTHLY USAGE			
1. -V/10	147324.63	5437063.44			
2.	101978.70	5375405.12			
3.	211184.54	6546720.62			
4.	221221.93	6636658.00			
5.	232258.54	7203114.56			
6.	230260.61	7080718.31			
7.	230058.25	7433705.69			
8.	230104.08	7344044.44			
9.	230519.65	6915549.37			
10.	212252.03	6595340.75			
11.	101250.58	5901657.50			
12.	101474.27	5935702.25			
13. -W/91	101524.63	5937263.44	7A.	250000.61	7706710.37
14.	102176.70	5433005.12	79.	265158.25	8219005.62
15.	211554.74	6670920.62	A0.	263304.98	8165244.50
16.	224221.33	6702658.00	H1.	265719.65	7671569.44
17.	235558.54	7333314.56	A2.	237092.93	7371568.81
18.	238100.61	7160718.31	A3.	223584.50	6767557.56
19.	244158.25	7505905.69	H4.	216674.27	6715502.31
20.	242394.98	7514244.44	A5. -1/1/97	216724.63	6715502.31
21.	234714.65	7041589.37	H6.	221374.70	6105505.10
22.	214052.03	6725540.75	H7.	240554.54	7408120.62
23.	202552.58	6077657.50	A8.	250621.94	7516558.66
24.	106674.27	6065902.25	A9.	261758.54	8114514.62
25. -1/1/94	105524.63	6007463.44	A0.	264000.61	7922718.37
26.	200278.70	5613605.12	01.	260258.25	830105.62
27.	210584.54	6807120.62	02.	267504.98	8295404.50
28.	220221.93	6886658.00	03.	250010.65	7797509.44
29.	240078.54	7203114.56	04.	242152.93	7505760.81
30.	243000.61	7202718.31	05.	227738.50	6832557.56
31.	240358.25	7299405.69	06.	220074.27	6047102.31
32.	242604.98	7644444.44	07. -1/1/98	220024.63	6845003.44
33.	230010.65	7167503.37	08.	220578.70	6311205.10
34.	221152.93	6635740.75	09.	244754.54	7383120.62
35.	205744.58	6233657.50	100.	250621.94	7800558.66
36.	102074.27	6105902.25	101.	260004.54	8244714.56
37. -1/1/93	100024.63	6107663.44	102.	260200.61	8444710.37
38.	204578.70	5725205.12	103.	273358.25	8480305.62
39.	223264.54	693720.62	104.	271704.98	8425006.50
40.	233821.93	7114268.00	105.	264110.65	7121509.44
41.	244058.54	7523716.50	106.	246552.03	7050001.81
42.	247290.61	7419718.31	107.	231004.50	6900007.56
43.	252358.25	7724444.44	108.	275074.27	9105720.31
44.	254700.98	7774004.44	109. -1/1/97	225124.63	6770363.44
45.	243110.65	7203589.37	110.	220278.70	6433005.10
46.	225352.93	6985940.75	111.	230504.44	7427551.56
47.	210094.58	6329057.50	112.	240635.84	7484475.06
48.	204074.27	6326302.25	113.	260772.44	8485005.56
49. -1/1/94	204124.63	6327863.44	114.	272400.61	8174718.37
50.	204718.70	5955405.12	115.	277758.25	8615505.62
51.	227064.54	7355520.62	116.	275004.98	8555844.50
52.	230021.93	7144058.00	117.	268319.65	8445007.44
53.	240210.61	7723514.56	118.	250552.93	7767100.81
54.	241400.61	7544718.31	119.	236198.50	7081007.56
55.	255758.25	7955505.69	120.	220274.27	9262775
56.	254004.98	7904444.44			7107502.31
57.	247310.65	7419509.37			
58.	220552.03	7115100.75			
59.	210184.58	605557.50			
60.	200274.27	6465502.25			
61. -1/1/93	200324.63	6455563.44			
62.	212078.70	5963405.12			
63.	232154.54	7157720.62			
64.	242221.93	7266658.00			
65.	253358.54	7404114.56			
66.	257600.61	7670718.31			
67.	260058.25	8060705.69			
68.	260104.08	8035644.44			
69.	251510.65	7535589.37			
70.	233752.93	7240340.75			
71.	210584.58	6581657.50			
72. -1/1/96	212474.27	6587702.25			
73.	212524.63	6587263.44			
74.	217178.70	6081005.10			
75.	236354.54	7327820.62			
76.	242421.94	7392658.06			
77.	257558.54	7984314.62

Figure 5

Figure 6

Figure 7

Figure 8

GAS + FUEL OIL DATA FOR STEAM PLANT JUL '69 - DEC '77

THE CURVE COMPOSED OF THE SYMBOL (*) REPRESENTS GAS + FUEL OIL DATA FOR STEAM PLANT JUL '69 - DEC '77

Figure 9

APPENDIX B

Algorithm Development for Heating and Cooling Load Calculations

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LIST OF SYMBOLS

Symbols Used in Computer Programs

AF = area of floor, in sq. ft.
 AG* = area of glass, in sq. ft.
 AR = area of roof, in sq. ft.
 AW* = area of wall, in sq. ft.
 AP = area of partition, in sq. ft.
 COFF = number of coffee maker.
 DOMO = number of days operation in a month
 ETD = $95.0F^{\circ} - TAMAX$
 FF+ = per cent decrease or increase of floor area
 FAPL+ = per cent decrease or increase of appliances
 FAC = a coefficient to light equation
 FG* = per cent decrease or increase of glass area
 FLIG+ = percent decrease or increase in light usage
 FPAR+ = per cent decrease or increase of partition area
 FR+ = per cent decrease or increase of roof area
 FVEN = percent decrease or increase air, in CFM
 FW* = per cent decrease or increase of wall area
 K = number of days in a month
 QCR = heat gain or loss from roof, in BTU/month
 QCF = heat gain or loss from floor, in BTU/month
 Q = cfm
 QG* = heat gain or loss from glass, in BTU/month
 QAPT = total heat gain or loss from appliances, in BTU/month
 QLG = total heat gain or loss from lights, in BTU/month
 QLH = total latent heat gain or loss from people, in BTU/month
 QINF = total heat gain from infiltration, in BTU/month
 QPT = total heat gain or loss from partition, in BTU/month
 QSH = total sensible heat gain from people; in BTU/month
 QTCL = total cooling or heating load, in BTU/month
 QTHP = total heat gain from people, in BTU/month
 QTG = total heat gain or loss from glass, in BTU/month
 QTW = total heat gain or loss from wall, in BTU/month
 QVEN = total heat gain or loss from ventilation BTU/month
 QW* = heat gain or loss from walls, in BTU/month
 SC* = direct solar and diffuse sky radiation + convection and radiation, in BTU/day
 TAMAX = maximum monthly average daily usage, in degree F°
 TAMIN = minimum monthly average daily usage, in degree F°
 TDP = partition temperature difference, in degree F°
 TDF = floor temperature difference
 TER = roof equivalent temperature, in degree F°/day
 TE* = walls temperature equivalent, in degree F°/day
 TMAX = maximum daily temperature, in degree F°
 TMIN = minimum daily temperature, in degree F°
 T = hours operation per day

UF = transmission coefficient of floor, in BTU/(hr-sq. ft.-F°)
UG * + = transmission coefficient of glass, in BTU/(hr-sq. ft.-F°)
UR = transmission coefficient of roof, in BTU/(hr-sq. ft.-F°)
UP = transmission coefficient of partition, in BTU/(hr-sq. ft.-F°)

* = one or two digits on the right hand side shows the geographical direction

+ = use percentage positive for expansion and negative otherwise.

INTRODUCTION

The U. S. Department of Energy has contracted with the Energy Research Center at Mississippi State University to develop conceptual designs for alternative energy sources on an institutional scale.

A subprogram of this effort was to evaluate the energy load distribution of the Mississippi State University campus. Specifically, the purpose was to develop an accurate algorithm for predicting heating and cooling loads for typical buildings on the campus. Buildings considered have historical consumption data available from the Physical Plant Department.

Topics covered in this report include basics of heat gain calculations, conduction heat transfer, cooling load calculation procedures, computer model for cooling load calculations, heating load calculation procedures, degree - day method, and computer model for heating load calculations.

CHAPTER II

COOLING LOAD

Basics of Heat Gain Calculation

A heat gain calculation is required to obtain the size of cooling equipment needed for a structure (office, residence, factory, college, ...). As the name indicates, it measures the heat gained by structure during summer or cooling season. The method of heat gain calculation, listed in this chapter, is very similar to the method that is listed in Trane Air-Conditioning Manual and ASHRAE's Handbook of Fundamentals.

Terms and Definitions

Heat Transfer - Heat always go from a material or region to an adjacent one of the lower temperature.

BTUH (British Thermal Units Per Hour) - The term is used to express the amount of heat, loss or gain, of a structure or material. It is also, generally, used in rating the capacity of cooling or heating equipment.

R - Value - The R-Value of material is a term to indicate the material's resistance to heat flow. The larger the R (resistance) of material, the less heat transfer.

U - Value - The U-Value of material is a term that is equal to reciprocal of R-Value. The smaller the U-value the less heat transfer. U is called coefficient of transmission.

Sensible Heat Gain - The actual calculated heat gain in BTUH of a structure.

Latent Heat Gain - The latent heat gain is the amount of heat gain introduced by the air moisture and this moisture should be removed by the cooling equipment. The latent heat gain usually is calculated as 30% of the total sensible heat gain.

Infiltration - The flow of the heat with air into or out of a building as through cracks, in and around doors, windows, etc.

Ventilation - The amount of air requires per occupant.

Duct Heat Gain or Duct Heat Loss - The amount of heat transfer in or out of duct when the outside air temperature is different from the air temperature flowing through the duct.

Design Temperature - The temperature that is assumed in designing a cooling system and in calculating heat gain. Inside design temperature is the temperature that is to be maintained inside a structure, as the outside design temperature is the assumed highest average temperature of the outside air in a given temperature.

Design Temperature Difference - This is the difference temperature between the outside design and inside one that is used to determine the heat gain of a structure.

Temperature Equivalent - The temperature that is, usually, greater than the Design Temperature Difference. The recommended values are listed in Table 2-37¹ through Table 2-44¹ for different part of structure and month of year.

Conduction Heat Transfer

Heat Transfer Equation - The theory of conduction heat transfer first was mathematically developed by the French mathematician J. B. Fourier. Fourier's equation for unidirectional heat flow, based on experimental

evidence, is

$$\frac{dQ}{d\theta} = -KA \frac{dt}{dx} \quad (2-1)$$

where $dQ/d\theta$ = heat transfer per unit of time;

K = a proportional factor called thermal conductivity;

A = area of the section through which heat is flowing;

dt = temperature difference causing the heat flow;

dx = length of path through the material, in the direction of heat flow.

In the terms dQ , $d\theta$, dt , and dx are differential notation. Those indicate infinitesimal changes in these quantities.

For steady heat flow, which is a common case, the heat transferred is constant, $dQ/d\theta = q$ in BTU per unit of time (usually BTU per hour), and thus

$$q = -KA \frac{dt}{dx} \quad (2-2)$$

Typical values of K for general substances and for buildings materials appear in Table 2-2¹.

Conduction through a plain wall leads to the following Fourier's equation:

$$q = K \frac{A}{x} (t_1 - t_2) = K \frac{A \Delta t}{x} \quad (2-3)$$

where q = heat transfer per unit of time (usually Hour), in BTU;

K = thermal conductivity, in BTU ft (or inches) per hr sq ft degree F;

A = area of wall, in square feet;

x = thickness of the wall, in feet or inches;

Δt = the temperature difference on both sides of the walls, in F.

Figure 1. Sketch of Composite Wall.

Conduction through a composite wall, shown in Figure 2-1, can be applied if using equation 2-3 in connection with so-called resistance concept. Writing equation 2-3 in the most general form and rearranging the terms results

$$q = K \frac{A}{x} (t_1 - t_2) = \frac{t_1 - t_2}{x/KA} = \frac{t_1 - t_2}{R} \quad (2-4)$$

where $R = x/KA$ is called the thermal resistance.

The heat transfer through each section of composite wall, under steady state condition, is the same

$$q = q_a = q_b = q_c$$

and

$$q = \frac{t_1 - t_2}{R_a} = \frac{t_2 - t_3}{R_b} = \frac{t_3 - t_4}{R_c} = \frac{t_1 - t_4}{R_t} \quad (2-5)$$

And in the general form,

$$q = \frac{t_1 - t_n}{R_t} = \frac{t_1 - t_n}{\frac{x_a}{K_a A_a} + \frac{x_b}{K_b A_b} + \frac{x_c}{K_c A_c} + \dots + \frac{x_n}{K_n A_n}} \quad (2-6)$$

Considering film f_o and f_i on both sides of material, then equation 2-5 reduces to, in units of BTU per hr sq ft,

$$q = \frac{t_i - t_o}{\frac{1}{f_i(1)} + \frac{x_a}{K_a(1)} + \frac{x_b}{K_b(1)} + \frac{x_c}{K_c(1)} + \dots + \frac{1}{f_o(1)}} \quad (2-7)$$

The values of the film - or surface - conductance coefficient f increase with the increasing surface roughness and they are increasing with the wind and air velocity over the surface. The values of f also increase with rising temperature difference. Houghten and McDermott, using their own and Rowley's data, obtained that the following equations represent the values of f for buildings materials, when V is expressed in miles per hour:

$$f = 1.4 + 0.28V \text{ for very smooth surface}$$

$$f = 1.6 + 0.30 V \text{ for smooth surface}$$

$$f = 2.0 + 0.40 V \text{ for cast concrete and smooth brick}$$

$$f = 2.1 + 0.50 V \text{ for rough stucco surfaces}$$

(2-8)

The film coefficient for inside still-air conditions on non-reflective surface has taken a single value, $f_i = 1.65$ BTU per hr sq ft deg F, while for outside surface, for a wind velocity of 15 mph, has taken $f_o = 6.02$.

It is sometimes to impracticable to determine the heat-flow conditions through the various subsections of a heat-transfer barrier, but an over-all heat transfer coefficient, U , can be found, either experimentally or from tabulations for surface buildup in a similar manner. So for composite wall equation 2-7 becomes

$$\begin{aligned} q &= AU(t_i - t_o) = AU\Delta t + \frac{RTU}{HR} \\ &= AU\Delta T \end{aligned} \quad (2-9)$$

where U is the over-all coefficient of heat transfer expressed in BTU per hr sq ft F° .

For a composite wall, the general expression is as follows:

$$R = \sum_{i=1}^{\infty} R_i, \quad i = 1, 2, 3, \dots \quad (2-10)$$

or

$$R = \frac{1}{f_1} + \frac{X_1}{K_1} + \frac{1}{A_1} + \frac{X_2}{K_2} + \frac{1}{A_2} + \dots + \frac{1}{f_o} = \frac{1}{V} \quad (2-11)$$

where a = thermal conductance of an air space, in units of BTU per hr sq ft deg F .

R = resistance to heat flow.

$= \frac{1}{V}$ = over-all resistance, in hr sq ft deg F° per BTU.

$= 1/f$ = film resistance.

$= 1/a$ = air-space resistance.

The coefficient of transmission (V) can be written from equation 2-10 and equation 2-11 as follows,

$$V = \frac{1}{\sum R_i} = \frac{1}{R} \quad (2-12)$$

Procedure of Cooling Load Calculation

The first step to calculate the heat gain of a structure is the measuring of all the structure components. The total heat gain would be the sum of gains of each different component of the structure.

Heat Gain Through Exterior Walls

Values of the over-all coefficient U are given in Tables 2-4¹ to 2-7¹.

Just the net area of an outside wall is used to calculate the heat gain. The areas of all doors and windows must be subtracted from the

total area of walls, this gives the net area. Applying equation (2-9) to get

$$q = AU\Delta T; A=\text{Area in SQ FT}$$

or

$$q = AU(ETD) \text{ BTU/HR} \quad (2-13)$$

where ETD is called "Equivalent Temperature Difference." This equivalent temperature difference is used when the size of cooling system is desired to obtain. The values of ETD are listed in Table 2-37¹ through Table 2-44¹ for different type of structure and different month of year.

Heat Gain From Glass

For many structures the solar heat gain on the windows, roof, and walls is an important part of the total load. The angle of the sun's rays at any hour of any day are known for any surface of structure. But the correct amount of radiant heat passing through material is not known. There is enough information to estimate solar heat gains close enough for all practical purposes.

Table 2-23 through 2-44 contain all basic factors for estimating the effect of solar heat through single pane glass windows and through glass blocks.

The solar heat gain for single common window glass at 40 degrees north latitude is given in Tables 2-23 through Table 2-30. (These tables can also be used for south latitude by reading up from the bottom). These tables are for 95°F outdoor air and 78°F inside temperature. They cover month of March through September.

Applying equation 2-9 to determine the heat gain from glasses in unit of BTU per hour

$$q = AU\Delta D, A = \text{Area in SQ. FT} \quad (2-13)$$

where value of U is given in Table 2-2. Table 2-2 is for glass and glass blocks only.

If shading devices are used to reduce the solar load on glass surfaces, the bottom expression is recommended. Several shading equipments are described in Table 2-31¹. The equation for common window glass:

$$q = (\text{area}) \left[\begin{matrix} \text{direct} & \text{shade} & \text{convection} & \text{type} \\ \text{(radiation)} & \text{(factor)} & \text{(radiation)} & \text{(factor)} \end{matrix} \right] \quad (2-14)$$

where Table 2-24 gives direct radiation;

Table 2-31 gives shade factor;

Table 2-28 gives convection radiation;

Table 2-32A gives Type factor

Here is a three steps summary of how to use all the glass tables.

- Step 1. Obtain a value of direct radiation from Table 2-23 through 2-26, multiply this value by shade factor from Table 3-31 thru 3-31C.
- Step 2. Select a value of convection and radiation from Tables 2-27 through 2-30, multiply this value by type factor from Table 2-32A.
- Step 3. Add Step 1 and Step 2.

Heat Gain from Ceiling and Roofs

The temperature of the warm room above the conditioned room will be 5 to 7 degrees cooler than the outside air temperature. A ten degree difference is used in calculating the heat flow through the ceiling when a 17 degree difference is used for exterior walls.

The U value should be selected for the entire floor and ceiling construction. The value of U is given in Table 2-12 and Table 13.

Many buildings have totally enclosed attics under flat roofs. This is true for hotel, office and apartments. By a totally enclosed attic

we mean an attic with no openings in its outside wall. Applying equation 2-13

$$q = AU(ETD) \text{ BTU/HR}$$

where $V = \frac{1}{\sum R_i}$

Heat Gain from Floor

The temperature of an unconditioned room is 5.0 to 7.0 degrees lower than the outdoor temperature. Therefore a 10-degree difference may be used for floors when a 17-degree difference is used for exterior walls. Assume there is more than a 17-degree difference for the outside walls. Then the temperature difference for the floors should be 5 degrees less than for the outside walls.

Applying equation 2-13 to determine heat gain from the floor as follows,

$$q = AUA\Delta T \text{ BTU/HR}$$

where A = Area of floor, SQ FT

ΔT = temperature difference

U = Transmission Coefficient from Table 3-10 and Table 3-11.

Heat Gain from Ventilation

In most air conditioned spaces dilution by outdoor air is used to control odors. The following explains the method in detail.

Outdoor air for ventilation is cooled and dehumidified before being delivered to the conditioned room. This is done normally by mixing the same percentage of the return air with the outdoor air right before cooling coil. The mixture then passes through cooling coils and is supplied to the rooms by fan.

Table 2-22 gives the amount of outdoor air generally used for different applications.

The heat gain by ventilation usually comes from two parts, sensible and latent heat.

Sensible heat,

$$\begin{aligned}
 q_s &= MCp\Delta T \\
 &= UACp\Delta T, UA = Q \text{ in unit cfm} \\
 &= CpQ\Delta T \text{ BTU per min.} \\
 &= 60 * Cp * Q * (t_o - t_i) \\
 \text{or} \quad &= 60 * .24 * .075 * Q * (t_o - t_i) \\
 q_s &= 1.08Q(t_o - t_i) \text{ BTU/HR} \quad (2-15)
 \end{aligned}$$

where Q = CFM/person;

t_o = outdoor temperature, in degree F° ;

t_i = indoor temperature, in degree F° .

NOTE: For extreme accuracy, the temperature of mean height of the room should be used.

Latent heat,

$$q_L = .7Q(HR_o - HR_i) \text{ BTU/HR}$$

where HR_o = the outside humidity ratio in unit of grains/lb;

HR_i = the inside humidity ratio in unit of grains/lb.

For $95F^\circ$ db outside and $78F^\circ$ db inside temperature the value for $HR_o = 105$ gr/lb and $HR_i = 71.5$ gr/lb.

Infiltration

Ambient air generally leaks into a building from cracks around sash, windows, and doors.

There are two methods that can be used to determine infiltration: the crack method, and the air change method.

Crack Method:

Air infiltration through a few types of windows for two different wind velocities is given in Table 3-21. These data are the results of laboratory test and many field measurements. The 7.5 mph wind velocity generally is used for winter and 15.0 mph for summer. The application is very simple, just measure the crack length and multiply that by the proper leakage rate from table to obtain the total CFM leakage. Leakage take place usually around the windows and doors.

Air Change Method:

The air change in one room volume per hour or more is called "Air change Method". The air change method normally is considered a way to determine the amount of heat gain or heat loss.

When infiltration takes place it adds sensible and latent heat load to the room. The sensible heat gain or loss is given by the following equation:

$$q_s = 1.08 Q(t_o - t_i) \text{ Btuh}$$

where

q_s = Sensible heat, Btuh

Q = Air flow rate, given in Table 2-20.

t_o = Ambient air temperature, F°

t_i = Room air temperature, F°

The latent heat gain or loss is given by the following equation:

$$q_l = 0.7 Q(HR_o - HR_i) \text{ Btuh}$$

where

q_l = Latent heat, Btuh

Q = Air flow rate, CFM

HR_o = Humidity ratio of ambient air, grains/lb

HR_i = Humidity ratio of room air, grains/lb

Body Heat

Heat losses from the human body differs from one another. They also differs with the type of his activity. The body always releases latent and sensible heat; and both must be considered in designing air conditioning systems. The values of latent and sensible heat are listed in Table 2-14 for several types of physical activity.

Electric Motors and Equipment

Electric motors give off sensible heat while running. The electric motors are considered as air handling equipment and those are used mostly in dual systems.

Electric motors are not 100 percent efficient, so they generate some heat.

Light is another source of electric equipment that generates sensible heat. This heat can be calculated by the following equation:

$$q = \text{watts} \times 3.4 \times [\text{allowance factor}]$$

where

q = sensible heat gain, Btuh

watts = Total wattage of all incandescent fixtures in room

3.4 = Heat equivalent of electric energy, Btuh per watt

Table 2-16 and Table 2-17 give heat gain from electric motors and electric appliances.

Gas-Burning Equipment

The heat released by gas-fired appliances is given in Table 2-18. Some of the equipments are not listed in Table 2-18, so the manufacturer's

data can be used to determine heat gain. The following information, if data is not available, can be used to estimate heat gain.

1. Natural gas releases about 1,000 Btu per cu. ft.
2. LP gas releases about 2,000 Btu per cu. ft.
3. A 2 in. natural gas burner uses about 10 cu. ft. of gas per hour; a 4 in. burner uses about 15.0 cu. ft. per hr.
4. Total heat from a gas appliance may be assumed to be half latent and half sensible heat.

Heat Flow Through Partitions

Heat transfer through interior walls classified as partition heat loss or gain. Rooms located adjacent to unheated or uncooled spaces are usually heated or cooled during the winter and summer time. In this case, the heat transfer through partitions should be considered.

The heat loss or gain through partitions are treated exactly the same way as outside walls. U value for different types of material of partitions are listed in Tables 2-8 and 2-9.

Unconditioned rooms adjacent to conditioned rooms are generally 5.0 to 7.0 degrees less than the ambient air temperature. If, for example, a 17.0 degree design temperature difference is chosen for outside walls, a 10.0 degree difference may be chosen for partitions. If there is more than a 17.0 degree temperature difference for outside walls, use 5.0 degrees less than the temperature difference for outside walls.

The partition heat loss or gain is calculated by the following equation:

$$q = AU\Delta T \text{ BTU/hr}$$

Design Temperature Difference

The heat transfer through walls, windows, roof, etc., depends on the temperature difference across them. So the temperature difference

across the walls, windows, roof, etc. should be determined. The indoor temperature usually is taken 78.0 degrees F° dry-bulb and the outdoor 85.0 or 95.0 degrees F° dry-bulb in the United States.

During the cooling season when there are radiation and solar heat gains, the actual temperature difference (total equivalent temperature difference) is greater than outdoor minus indoor temperature for walls and roofs. So, the total equivalent temperatures are given in Table 2-37 through Table 2-44 for roofs and walls. The tables are based on 95.0 degrees F° dry-bulb outdoor and 78.0 degrees F° dry-bulb indoor temperature. For outdoor temperature other than 95.0 degrees F° dry-bulb the total equivalent temperature can be calculated as following equation.

$$T_{ec} = T_{et} + (95 - T_{go})$$

where

T_{ec} = total equivalent temperature difference calculated, F°

T_{et} = total equivalent temperature difference given in Tables, F°

95 = 95.0 outdoor temperature based on Tables, F°

T_{go} = outdoor temperature for a given design, F°

For our design, the daily maximum and daily minimum temperature has been collected from Weather Bureau data for Mississippi State from June 1977 through November 1979. The monthly average daily usage is calculated for maximum, minimum, and average temperature. These are tabulated in Table 2-48.

The monthly average daily usage of maximum temperature vs. months of fiscal year of 1977-1978 is shown on Figure 2. The area under this temperature and line 78F° is the cooling region.

The outside design temperatures and latitudes for various cities in the United States is given in Table 2-45.

Fig. 2

Monthly Maximum Temperature vs. Time

Computer Model of Cooling Load Calculation

The historical data such as temperature and electrical usage were collected for fiscal year of 1977 through 1978 for Mississippi State University. The electrical consumption records were available for each month of year in the Physical Plant Department.

The area of walls, glasses, roofs and floors were computed for twenty nine buildings of M.S.U. These buildings were chosen because their electricity, natural gas, and fuel oil usages were available.

The average transmission coefficient, U , for walls, glasses, roofs, and floors have been calculated and these values have been used in computer program.

The Direct Solar and Diffuse Sky Radiation and Heat Gain by Convection and Radiation for common window glass has been defined from Tabel 2-23 through Table 2-30.

The Total Equivalent Temperature differences have been determined for walls and roofs. These equivalent temperature differences are listed in Table 2-37 through Table 2-44 for period of cooling season from 8:00 a.m. to 12:00 p.m.

The results of the cooling load calculation are shown on the computer print out. QTCL and COP are indicating the total monthly cooling load, BTU, and coefficient of performance. QTCL is directly proportional and COP is inversely proportional to the outdoor temperature. COP vs. months of cooling period is shown in Figure 3.

The computer program, in the following page, can be used to compute cooling load for a large building at any location and at any given input data. If partial operation is desired, just give the percentages of the desired values to the factor*. These factors have multiplied by each equation of heat gain in the program.

* Factors are listed in symbols section on page vii.

FISCAL YEAR 1977-1978

Fig. 3

Coefficient Of Performance vs. Time

31	DOMO= 31.0	COP= .970	QTCL=	.62955629+10	TAMAX= 93.7	DD=15.68
31	DOMO= 21.0	COP= .737	QTCL=	.58646015+10	TAMAX= 91.8	DD=13.77
30	DOMO= 30.0	COP= .682	QTCL=	.75081295+10	TAMAX= 86.0	DD= 7.97
31	DOMO= 31.0	NO COOLING IS REQUIRED				
30	DOMO= 30.0	NO COOLING IS REQUIRED				
31	DOMO= 31.0	NO COOLING IS REQUIRED				
31	DOMO= 31.0	NO COOLING IS REQUIRED				
28	DOMO= 28.0	NO COOLING IS REQUIRED				
31	DOMO= 31.0	NO COOLING IS REQUIRED				
30	DOMO= 30.0	COP=1.790	QTCL=	.47964392+10	TAMAX= 78.3	DD= .30
31	DOMO= 18.0	COP=1.898	QTCL=	.38218503+10	TAMAX= 80.9	DD= 2.90
30	DOMO= 30.0	COP= .772	QTCL=	.58021508+10	TAMAX= 89.4	DD=11.37

TAMAX FROM JULY 1977 THROUGH JUNE 1978

93.68 91.77 85.97 73.39 65.67 54.16 42.03 46.75 60.06 78.30 80.90 89.37


```

101* TENSE=TESE-ETO
102* TENSE=TESA-ETO
103* C** HEAT GAIN FROM ROOF:
104* C
105* QCR=AR*UR*TER*(1.+FR)*DOMO
106* C
107* C** HEAT GAIN FROM WALLS:
108* C
109* QWN=AWN*UWN*TEWN*(1.+FWN)*DOMO
110* QWE=AWW*UWW*TEWW*(1.+FWW)*DOMO
111* QWE=AWW*UWW*TEWE*(1.+FWE)*DOMO
112* QWS=AWS*UWS*TEWS*(1.+FWS)*DOMO
113* QWNE=AWN*UWN*TEWNE*(1.+FWE)*DOMO
114* QWNE=AWNE*UWNE*TEWNE*(1.+FWE)*DOMO
115* QWSE=AWSE*UWSE*TEWSE*(1.+FWE)*DOMO
116* QWSW=AWS*UWS*TEWSW*(1.+FWSW)*DOMO
117* QW(N)=QWN+QWE+QWS+QWNE+QWSE+QWSW+QWSE
118* C
119* C** HEAT GAIN FROM GLASSES:
120* C
121* QGN=AGN*SCN*(1.+FGN)
122* QGE=AGE*SCE*(1.+FGE)
123* QGW=AGW*SCW*(1.+FGW)
124* QGS=AGS*SCS*(1.+FGS)
125* QGNW=AGNW*SCNW*(1.+FGNW)
126* QGNE=AGNE*SCNE*(1.+FGNE)
127* QGSE=AGSE*SCSE*(1.+FGSE)
128* QGSW=AGSW*SCSW*(1.+FGSW)
129* QG(N)=QGN+QGE+QGW+QGS+QGNW+QGNE+QGSW+QGSE
130* C
131* C** HEAT GAIN FROM FLOOR
132* C
133* QF=AF*UF*T*DOMO*TDF*(1.+FF)
134* C
135* C** VENTILATION: (15 CFM/PERSON)(PERSONS)(1.08)(TDM(N))
136* C
137* C SENSIBLE
138* C
139* QVENS=1.08*PERSON*15.0*T*DOMO*DD(N)*(1.+FVEN)
140* C
141* C LATENT
142* C
143* QVENL=0.70*PERSON*15.0*T*DOMO*(105.0-71.5)*(1.+FVEN)
144* QVEN=QVENS+QVENL
145* C
146* C** HEAT GAIN FROM PARTITIONS:
147* C
148* QPT=AP*UP*T*DOMO*(1.+FPAR)*TDP
149* C
150* C** HEAT GAIN FROM PEOPLE:
151* C
152* C LATENT
153* C
154* QLH=PERSON*ULH*24.0*DOMO*(1.+FPER)
155* C
156* C SENSIBLE
157* C
158* QSH=PERSON*ULH*24.0*DOMO*(1.+FPER)
159* QTHP=QLH+QSH
160* C
161* C** HEAT GAIN FROM LIGHTS:
162* C
163* QLG=LIGHT*3.40*FAC*T*DOMO*(1.+FLIG)
164* C
165* C** HEAT GAIN FROM APPLIANSES:
166* C
167* QAP1=COFF*2250.0*1*DOMO*(1.+FAPL)
168* C
169* C
170* C
171* QAP1=COFF*2250.0*24.0*DOMO SONS)(1.08)(TDM(N)) TMEAN(50)
172* C
173* C
174* C** INFILTRATION: SUMMER CONDITION(7 1/2 MPH WIND )
175* C
176* C
177* QINFL=9*T*DOMO*(105.0-71.5)*(0.7)
178* QINF5=9*T*DOMO*DD(N)*1.08
179* QINF1=QINF5+QINFL
180* C

```

```

101* QTCCL(N)=QCR+QTL(N)+QTG(N)+SF+QVEN+QPT+QTHP+QLG+QAP1+QINFT
102* EQ=EQAM*5X*H*EFF
103* COP(N)=QTCCL(N)/HEU
104* WRITE(6,32)(N,QCQO,COP(N),QTCCL(N),TAMAX(N),DD(N))
105* 32 FORMAT(//,14,5X,'DOMO=',F5.1,5X,'COP=',F5.3,5X,'QTCCL=',E20.8,5X,
106* 1 'TAMAX=',F5.1,5X,'DD=',F5.2)
107* GO TO 1
108*
109* 10 WRITE(5,12)A,QCQO
110* 12 FORMAT(//,14,5X,'DOMO=',F5.1,5X,' NO COOLING IS REQUIRED')
111* 1 CONTINUE
112* 10 WRITE(6,101)(TAMAX(N),N=1,12)
113* 101 FORMAT(//,12F5.2,///)
114* 12 F5.2,///)
115* CALL PLOTS2(B,QTCCL,N,0)
116* CALL PLOTS2(B,TAMAX,N,0)
117* STOP
118* END

```

NO OF COMPILATIONS:

NO DIAGNOSTICS.

SL73R1 05/11/79 01:43:31

LIMITS	001000	016270	6841	18ANK	WORDS	DECIMAL
	040000	051417	4080	5ANK	WORDS	DECIMAL
ADDRESS	018236					

SEGMENT	NAME	001000	016270	040000	051417			
OR-EB	(1)	001000	001242	(2)	040000	040001	16	APR 75
				(0)	040002	040015	27	JAN 72
				(0)	040016	040017	18	FEB 72
	(1)	001243	004243	(0)	040170	042055	27	APR 72
IR-TEB	(1)	004244	004371	(0)	042056	042114	11	MAR 75
				(2)	BLANK\$COMMON			
ISS/ES-0220	(1)	004372	015234	(2)	042370	046167	02	NOV 78
	(3)	015235	015235	(4)	046170	046241	20	FEB 78
COMMON(COMMONBLOCK)	(1)	015236	016270	(0)	046242	051417	11	MAY 79
				(2)	BLANK\$COMMON			

BS. LEVEL 7341
 ERRORS : NONE

CHAPTER III

HEATING LOAD

To design a heating system, an estimate should be made of the maximum heat loss of the space to be heated, based on a selected indoor air temperature during periods of heating season. The heat losses may be divided into two main groups, namely: (1) the transmission losses through the walls, floor, glass, or other surfaces; and (2) heat required to warm outdoor air which leaks in through doors, windows, or open windows, or heat required to warm ventilation air.

Procedure of Heating Load Calculation

The procedure of heating load calculation is almost the same as cooling load calculation which is listed in Chapter II. To refresh the memory, we repeat the general procedure for calculating heat losses for a structure as following:

1. Determine net area of walls, glasses, roof, and floor. Such measurements are made from blue-print or from actual building.
2. Compute, or select from Tables, total transmission coefficient for walls, glasses, floor, and roof for the structure.
3. Find the volume of infiltration in Unit of CFM for the building plus the wind velocity for the same location.
4. Estimate the number of occupants and their duty.
5. Determine the ventilation air that must be supplied to building to make comfort.
6. Select the design outdoor weather conditions: temperature, climate and wind speed.
7. Select a method for heating load calculation. In this project method of Degree-Days has been used because it has been suggested by most air conditioning books.

Method of Degree-Days

An extensive series of tests, conducted by the American Gas Association, showed that the fuel wage in residences and public buildings varies directly as the difference between 65F° dry bulb and outdoor temperature. These tests indicated that when outdoor air is 65F° dry-bulb no heat is required and the fuel usage is zero; also, the fuel consumption will be double if ambient temperature of 55F° dry-bulb changes to 45F° dry-bulb.

The difference between the average ambient air temperature and 65F dry-bulb is very important as an index of heating requirements and gives the basis for the degree-day for the nominal winter heating load. A degree-day occurs for every degree the average ambient temperature is below 65F° during a 24-hours period. The heat losses can be calculated by the following equation:

$$q = AU(65.0 - T_{ave.}) \quad (3-1)$$

where

q = Heat loss, Btuh

A = Area, sq. ft.

U = Total transmission coefficient Btu/hr-sq. ft-F°

$$T_{av} = (T_{max} + T_{min})/2.0$$

T_{max} = maximum outdoor temperature, in degree F°

T_{min} = Minimum outdoor temperature, in degree F°

Computer Model of Heating Load Calculation

The historical data such as temperature and total energy consumption were collected for twenty-nine buildings of Mississippi State University for the heating season for fiscal year of 1977 through 1978. The tempera-

ture record was available at the Mitchel Memorial Library and the total energy, natural gas + fuel oil, record was in Physical Plant Department.

The conversion of natural gas and fuel oil to Btu is as following,

1 CCF of natural gas = 100,000 BTU

1 gallon of fuel oil = 138,000 BTU.

The total useful energy consumption was considered as 40% of the total energy supplied to the Steam Plant by MSU during the heating season of fiscal year of 1977 through 1978.

The heating load for the twenty-nine buildings has been computed as shown on computer printout. The monthly computed load and total useful energy consumption have been graphed vs. the months of fiscal year of 1977 through 1978 and these are shown on figure 4.

This computer program can be used to compute heating load for any structure with the method of degree-day. This method explained before.

Fig. 4

31	DOMO= 31.0	NO HEATING IS REQUIRED				
31	DOMO= 20.0	NO HEATING IS REQUIRED				
30	DOMO= 30.0	NO HEATING IS REQUIRED				
31	DOOM= 31.0	TMEAN= 61.5	DD= 3.5	TDM= 2580.0	QTCL=	.29735660+10
30	DOOM= 26.0	TMEAN= 55.8	DD= 9.2	TDM= 5730.4	QTCL=	.64871381+10
31	DOOM= 21.0	TMEAN= 44.0	DD= 21.0	TDM= 10559.6	QTCL=	.11880214+11
31	DOOM= 26.0	TMEAN= 33.9	DD= 31.1	TDM= 19424.5	QTCL=	.21819108+11
28	DOOM= 28.0	TMEAN= 35.8	DD= 29.2	TDM= 19644.0	QTCL=	.22070332+11
31	DOOM= 26.5	TMEAN= 49.7	DD= 15.3	TDM= 9724.6	QTCL=	.10960478+11
30	DOMO= 30.0	NO HEATING IS REQUIRED				
31	DOMO= 19.0	NO HEATING IS REQUIRED				
30	DOMO= 28.5	NO HEATING IS REQUIRED				

MONTHLY AVERAGE DAILY USAGE TEMPERATURE

FOR MSU FROM JULY 1977 THROUGH JUNE 1978

82.90 81.47 76.48 61.53 55.82 44.05 33.87 35.77 49.71 65.60 70.42 78.98


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31*      UGSE=0.0
32*      UGSA=0.0
33*      UGSE=0.0
34*      UGSE=0.0
35*      UGSE=0.0
36*      UGSE=0.0
37*      UGN=.41
38*      UWE=.41
39*      UWS=.41
40*      UWS=.41
41*      LIGHT=0.0
42*      ULN=100.0
43*      USN=210.0
44*      PERSON=0.86*0
45*      UP=.36
46*      UR=.23
47*
48*      C
49*      C
50*      C
51*      F= GLASS SHADING COEFFICIENT
52*      F=0.25
53*      UGS=1.06*F
54*      UG=1.06*F
55*      USE=1.06*F
56*      UGN=1.06*F
57*      UP=0.0
58*      C
59*      T= NUMBER OF HOURS IN A DAY
60*      T=24.0
61*      C
62*      COFF=50.0
63*      AP=0.0
64*      C
65*      C
66*      TDP=4.0
67*      C
68*      FAC=1.20
69*      WRITE(6,99)
70*      99 FORMAT('1')
71*      DO 1 N=1,12
72*      100*      G(N)=N
73*      READ(5,9) K,DOMO
74*      9 READ(5,3) (TMIN(I),TMAX(I),I=1,K)
75*      9 FORMAT(18F4.1,/,18F4.1,/,18F4.1,/,18F4.1)
76*      9 FORMAT(14,F10.1)
77*      SUM1(1)=0.0
78*      SUM2(1)=0.0
79*      DO 301 I=1,K
80*      SUM1(I+1)=SUM1(I)+TMIN(I)
81*      SUM2(I+1)=SUM2(I)+TMAX(I)
82*      301 CONTINUE
83*      TMIN(N)=SUM1(K+1)/FLOAT(K)
84*      TMAX(N)=SUM2(K+1)/FLOAT(K)
85*      TMEAN(N)=(TMIN(N)+TMAX(N))/2.0
86*      10 IF (TMEAN(N)-65.0) 10,20,20
87*      TUM(N)=TMEAN(N)-65.0-TMEAN(N)
88*      TUM(N)=TUM(N)*I*DOMO
89*      C
90*      C** HEAT LOSS FROM ROOF:
91*      C
92*      QCR=AR*UR*TUM(N)
93*      C
94*      C** HEAT LOSS FROM WALLS:
95*      C
96*      QWN=AWN*UWN*TUM(N)
97*      QNW=AWW*UWW*TUM(N)
98*      QWE=AWE*UWE*TUM(N)
99*      QWS=AWS*UWS*TUM(N)
100*      QWNW=AWN*UWN*UWN*TUM(N)
101*      QWNE=AWNE*UWNE*TUM(N)
102*      QWSW=AWS*UWS*UWS*TUM(N)
103*      QWSE=AWSE*UWSE*TUM(N)
104*      QWT(N)=QWN+QWE+QWW+QWS+QWNW+QWNE+QWSW+QWSE
105*      C
106*      C** HEAT LOSS FROM GLASSES:
107*      C
108*      QGN=AGN*UGN*TUM(N)
109*      QGE=AGE*UGE*TUM(N)
110*      QGW=AGW*UGW*TUM(N)
111*      QGS=AGS*UGS*TUM(N)

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111*      QGN=AGNA*JGNA*TDM(N)
112*      QGNE=AGNE*JGNE*TDM(N)
113*      QGS=AGSE*JGSE*TDM(N)
114*      QGSE=AGSE*JGSE*TDM(N)
115*      QIG(N)=QGN+QGE+QGW+QGS+QGNA+QGNE+QGSN+QGSE
116*
117*      C** HEAT LOSS FROM FLOORS:
118*      C
119*      QF=AF*UF*TDM(N)
120*
121*      C** VENTILATION: (15 CFM/PERSON)(PERSONS)(1.08)(TDM(N))
122*      QVENS=15.0*PERSON*1.08*TDM(N)
123*      QVENL=15.0*PERSON*(105.0-71.5)*DOMO*T*(.7)
124*      QVEN=QVENS+QVENL
125*
126*      C** HEAT LOSS FROM PARTITIONS:
127*      C
128*      QPT=AP*UP*TDM(N)
129*
130*      C** HEAT GAIN FROM PEOPLE:
131*      C      LATENT
132*      C      QLH=PERSON*ULH*24.0*DOMO
133*      C
134*      C      SENSIBLE
135*      C      QSH=PERSON*ULH*24.0*DOMO
136*      C      QTHP=QLH+QSH
137*
138*      C** HEAT GAIN FROM LIGHTS:
139*      C
140*      QLG=LIGHT*3.40*FAC*24.0*DOMO
141*
142*      C** HEAT GAIN FROM APPLIANSES:
143*      C
144*      QAP1=COFF*2250.0*24.0*DOMO
145*
146*      C
147*      C
148*      C
149*      C
150*      C
151*      C
152*      C
153*      C** INFILTRATION: WINTER CONDITION(7 1/2 MPH WIND )
154*      C      QINFS=Q*T*DOMO*DD(N)*1.08
155*      C
156*      C      QINFL=Q*T*DOMO*(105.0-71.5)*(.7)
157*      C      QINFT=QINFS+QINFL
158*      C
159*      C
160*      QITCL(N)=QCR+QTW(N)+GTG(N)+QF+QVEN+QPT-QTHP-QLG-QAP1+QINFT
161*      WRITE(6,32)K,DOMO,TMEAN(N),DD(N),TDM(N),QITCL(N)
162*      32 FORMAT(//,14,5X,'DOMO=',F5.1,5X,'TMEAN=',F7.1,5X,'DD=',F6.1,
163*      $ 5X,'TDM=',F8.1,5X,'QITCL=',E20.8)
164*      GO TO 1
165*      20 WRITE(6,12)K,DOMO
166*      12 FORMAT(//,14,5X,'DOMO=',F5.1,5X,' NO HEATING IS REQUIRED')
167*      CONTINUE
168*      1 WRITE(6,101)(TMEAN(N),N=1,12)
169*      101 FORMAT(//,5X,'MONTHLY AVERAGE DAILY USAGE TEMPERATURE
170*      $ FOR MSU FROM JULY 1977 THROUGH JUNE 1978',//,12F8.2)
171*      CALL PLOTS2(B,QITCL,N,0)
172*      CALL PLOTS2(B,TMEAN,N,0)
173*      STOP
174*      END
175*

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NO OF COMPILOATION: NO DIAGNOSTICS.

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CONCLUSION

In this project there are two computer programs. One is for cooling load and the other is for a heating load. The programs were developed to compute cooling and heating loads for Mississippi State University (MSU) and its possible use in other institutions. The results of cooling and heating load computations are compared with the total monthly energy consumption data. This is available in Physical Plant Department located in MSU campus. The results of the cooling and heating load computations are almost matching with the available energy data. The results could be better if hourly temperature and hourly energy consumption data were available only for cooling and heating load.

REFERENCES

1. Trane Air Conditioning Manual, McGill Graphic Arts, Inc., 1965, pp. 48-51 and pp. 360-394.
2. Environmental Engineering, Harper and Row, Inc., 1970, pp. 204-205.
3. ASHRAE Guide and Data Book, 1965.

TABLE 2-1
Design Temperature Differences

ITEM NO.	ITEM	TEMPERATURE DIFFERENCE* F
1	WALLS, EXTERIOR	17
2	GLASS IN EXTERIOR WALLS	17
3	GLASS IN PARTITIONS	10
4	STORE SHOW WINDOWS HAVING A LARGE LIGHTING LOAD	30
5	PARTITIONS	10
6	PARTITIONS, OR GLASS IN PARTITIONS, ADJACENT TO LAUNDRIES, KITCHENS, OR BOILER ROOMS	25
7	FLOORS ABOVE UNCONDITIONED ROOMS	10
8	FLOORS ON GROUND	0
9	FLOORS ABOVE BASEMENTS	0
10	FLOORS ABOVE ROOMS OR BASEMENTS USED AS LAUNDRIES, KITCHENS, OR BOILER ROOMS	35
11	FLOORS ABOVE VENTED SPACES	17
12	FLOORS ABOVE UNVENTED SPACES	0
13	CEILINGS WITH UNCONDITIONED ROOMS ABOVE	10
14	CEILINGS WITH ROOMS ABOVE USED AS LAUNDRIES, KITCHENS, ETC.	20
15	CEILING WITH ROOF DIRECTLY ABOVE (NO ATTIC)	17
16	CEILING WITH TOTALLY ENCLOSED ATTIC ABOVE	17
17	CEILING WITH CROSS-VENTILATED ATTIC ABOVE	17

*These temperature differences are based on the assumption that the air conditioning system is being designed to maintain an inside temperature 17 F lower than the outdoor temperature. For air conditioning systems designed to maintain a greater temperature difference than 17 F between the inside and outside, add to the values in the above table, the difference between the assumed design temperature difference and 17 F.

TABLE 2-2
Over-all Heat Transfer Coefficients
for Glass and Glass Blocks

DESCRIPTION	OUTDOOR EXPOSURE
SINGLE-GLASS WINDOWS	1.06
DOUBLE-GLASS WINDOWS	0.63
TRIPLE-GLASS WINDOWS	0.34
GLASS BLOCK	0.56
GLASS BLOCK	0.48

TABLE 2-3

Heat Transfer Coefficients of Building Materials*

MATERIAL	DESCRIPTION	CONDUCTIVITY K#	CONDUCTANCE C +
BUILDING BOARDS	ASBESTOS-CEMENT BOARD.....	4.0	
	GYPSUM OR PLASTER BOARD...1/2 IN.....		2.25
	PLYWOOD.....	0.80	
	PLYWOOD...3/4 IN.....		1.07
	SHEATHING (IMPREGNATED OR COATED).....	0.38	
	SHEATHING (IMPREGNATED OR COATED) 25/32 IN. WOOD FIBER—HARDBOARD TYPE.....	1.40	0.49
INSULATING MATERIALS	BLANKET AND BATT: MINERAL WOOL FIBERS (ROCK, SLAG, OR GLASS).....	0.27	
	WOOD FIBER.....	0.25	
	BOARDS AND SLABS: CELLULAR GLASS.....	0.39	
	CORKBOARD.....	0.27	
	GLASS FIBER.....	0.25	
	INSULATING ROOF DECK...2 IN.....		0.18
MASONRY MATERIALS	LOOSE FILL: MINERAL WOOL (GLASS, SLAG, OR ROCK).....	0.27	
	VERMICULITE (EXPANDED).....	0.46	
	CONCRETE: CEMENT MORTAR.....	5.0	
	LIGHTWEIGHT AGGREGATES, EXPANDED SHALE, CLAY, SLATE, SLAGS; CINDER; PUMICE; PERLITE; VERMICULITE.....	1.7	
	SAND AND GRAVEL OR STONE AGGREGATE.....	12.0	
	STUCCO.....	5.0	
	BRICK, TILE, BLOCK, AND STONE: BRICK, COMMON.....	5.0	
	BRICK, FACE.....	9.0	
	TILE, HOLLOW CLAY, 1 CELL DEEP, 4 IN.....		0.90
	TILE, HOLLOW CLAY, 2 CELLS, 8 IN.....		0.54
	BLOCK, CONCRETE, 3 OVAL CORE: SAND & GRAVEL AGGREGATE...4 IN.....		1.40
	SAND & GRAVEL AGGREGATE...8 IN.....		0.90
	CINDER AGGREGATE...4 IN.....		0.90
	CINDER AGGREGATE...8 IN.....		0.58
	STONE, LIME OR SAND.....	12.50	
PLASTERING MATERIALS	CEMENT PLASTER, SAND AGGREGATE.....	5.0	
	GYPSUM PLASTER: LIGHTWEIGHT AGGREGATE...1/2 IN.....		0.12
	LT. WT. AGG. ON METAL LATH...3/4 IN.....		2.13
	PERLITE AGGREGATE.....	1.5	
	SAND AGGREGATE.....	5.6	
	SAND AGGREGATE ON METAL LATH 3/4 IN..... VERMICULITE AGGREGATE.....	1.7	7.70
ROOFING	ASPHALT ROLL ROOFING.....		6.50
	BUILT-UP ROOFING...3/8 IN.....		3.00
SIDING MATERIALS	ASBESTOS-CEMENT, 1/4 IN. LAPPED.....		4.76
	ASPHALT INSULATING (1/2 IN. BOARD).....		0.69
	WOOD, BEVEL, 1/2 X 6, LAPPED.....		1.23
WOODS	MAPLE, OAK, AND SIMILAR HARDWOODS.....	1.10	
	FIR, PINE, AND SIMILAR SOFTWOODS.....	0.80	
	FIR, PINE & SIM. SOFTWOODS 25/32 IN.....		1.02

*Extracted with permission from ASHRAE Guide and Data Book, 1965.

#Conductivity given in Btu in. per hr sq ft F

+Conductance given in Btu per hr sq ft F

TABLE 2-4

Coefficients of Transmission (U) of Frame Walls

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

EXTERIOR ¹			INTERIOR FINISH		TYPE OF SHEATHING ³						NUMBER		
					NONE. BUILD- ING PAPER	GYP- SUM BOARD 1/2 IN.	PLY- WOOD 5/16 IN.	WOOD 25/32 IN. AND BUILD- ING PAPER	INSULATION BOARD SHEATHING				
									1/2 IN.	25/32 IN.			
RESISTANCE ↓					0.06	0.45	0.39	1.04	1.32	2.06			
MATERIAL	R	AV. R	MATERIAL	R	U	U	U	U	U	U			
					A	B	C	D	E	F			
WOOD SIDING DROP-(1 IN. X 8 IN.) BEVEL (1/2 IN. X 8 IN.) WOOD SHINGLES 7 1/2 IN. EXPOSURE WOOD PANELS (3/4 IN.)	0.79 0.81	0.85 ²	NONE.....	-	0.57	0.47	0.48	0.36	0.33	0.27	1		
			GYP. SUM. BD. (3/8 IN.).....	0.32	0.33	0.29	0.30	0.25	0.23	0.20	2		
			GYP. LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.30	0.27	0.27	0.23	0.22	0.19	3		
			GYP. LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.32	0.28	0.29	0.24	0.23	0.19	4		
	0.87 0.94		METAL LATH AND 3/4 IN. PLAS. (LT. WT. AGG.).....	0.47	0.31	0.28	0.28	0.24	0.22	0.19	5		
			METAL LATH AND 3/4 IN. PLAS. (SAND AGG.).....	0.13	0.35	0.31	0.31	0.26	0.24	0.21	6		
			INSUL. BD. (1/2 IN.).....	1.43	0.24	0.22	0.22	0.19	0.18	0.16	7		
			INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	1.52	0.24	0.22	0.22	0.19	0.18	0.16	8		
			PLYWOOD (1/4 IN.).....	0.31	0.33	0.29	0.30	0.25	0.23	0.20	9		
			WOOD PANELS (3/4 IN.).....	0.94	0.27	0.25	0.25	0.22	0.20	0.18	10		
			WOOD LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.32	0.28	0.29	0.24	0.23	0.19	11		
FACE-BRICK VENEER ⁴ PLYWOOD (3/8 IN.)	0.44 0.47		0.45 ²	NONE.....	-	0.73	0.56	0.58	0.42	0.38	0.30	12	
				GYP. SUM. BD. (3/8 IN.).....	0.32	0.37	0.33	0.33	0.27	0.25	0.21	13	
				GYP. LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.33	0.30	0.30	0.25	0.24	0.20	14	
				GYP. LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.36	0.32	0.32	0.27	0.25	0.21	15	
	0.45 ²			METAL LATH AND 3/4 IN. PLAS. (LT. WT. AGG.).....	0.47	0.35	0.31	0.32	0.26	0.25	0.21	16	
				METAL LATH AND 3/4 IN. PLAS. (SAND AGG.).....	0.13	0.40	0.35	0.36	0.29	0.27	0.22	17	
				INSUL. BD. (1/2 IN.).....	1.43	0.26	0.24	0.24	0.21	0.20	0.17	18	
				INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	1.52	0.26	0.23	0.24	0.21	0.19	0.17	19	
				PLYWOOD (1/4 IN.).....	0.31	0.38	0.33	0.33	0.27	0.26	0.21	20	
				WOOD PANELS (3/4 IN.).....	0.94	0.30	0.27	0.28	0.23	0.22	0.19	21	
				WOOD LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.36	0.32	0.32	0.27	0.25	0.21	22	

¹Note that although several types of exterior finish may be grouped because they have approximately the same thermal resistance value, it is not implied that all types may be suitable for application over all types of sheathing listed.

²Average resistance of items listed. This average was used in computation of U values shown.

³Building paper is not included except where noted.

⁴Small air space between building paper and brick veneer neglected.

⁵Where stucco is applied over insulating board or gypsum sheathing, building paper is generally required, but the change in U value is negligible.

Extracted with permission from 1965 ASHRAE Guide and Data Book.

TABLE 2-4 (CONTINUED)

Coefficients of Transmission (U) of Frame Walls

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

EXTERIOR ¹			INTERIOR FINISH		TYPE OF SHEATHING ³						NUMBER
					NONE, BUILD- ING PAPER	GYP- SUM BOARD 1/2 IN.	PLY- WOOD 5/16 IN.	WOOD 25/32 IN AND BUILD- ING PAPER	INSULATION BOARD SHEATHING		
									1/2 IN.	25/32 IN.	
RESISTANCE ↓→					0.06	0.45	0.39	1.04	1.32	2.06	
MATERIAL	R	AV. R	MATERIAL	R	U	U	U	U	U	U	
					A	B	C	D	E	F	
WOOD SHINGLES OVER INSUL.: BACKER BD. (5/16 IN.) ASPHALT INSUL. SIDING	1.40 1.45	1.42 ²	NONE.....	—	0.43	0.37	0.38	0.30	0.28	0.23	23
			GYP-SUM BD. (3/8 IN.).....	0.32	0.28	0.25	0.25	0.22	0.20	0.18	24
			GYP-SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.25	0.23	0.23	0.20	0.19	0.17	25
			GYP-SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.27	0.24	0.25	0.21	0.20	0.18	26
			METAL LATH AND 3/4 IN. PLAS. (LT. WT. AGG.).....	0.47	0.27	0.24	0.24	0.21	0.20	0.17	27
			METAL LATH AND 3/4 IN. PLAS. (SAND AGG.).....	0.13	0.29	0.26	0.27	0.23	0.21	0.18	28
			INSUL. BD. (1/2 IN.).....	1.43	0.21	0.20	0.20	0.18	0.17	0.15	29
			INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	1.52	0.21	0.19	0.19	0.17	0.16	0.15	30
			PLYWOOD (1/4 IN.).....	0.31	0.28	0.25	0.25	0.22	0.20	0.18	31
			WOOD PANELS (3/4 IN.).....	0.94	0.24	0.22	0.22	0.19	0.18	0.16	32
			WOOD LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.27	0.24	0.25	0.21	0.20	0.18	33
ASBESTOS-CEMENT SIDING STUCCO ⁴ 1 IN. ASPHALT ROLL SIDING	0.21 0.20 0.15	0.19 ²	NONE.....	—	0.91	0.67	0.70	0.48	0.42	0.32	34
			GYP-SUM BD. (3/8 IN.).....	0.32	0.42	0.38	0.37	0.30	0.27	0.23	35
			GYP-SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.37	0.32	0.33	0.27	0.25	0.21	36
			GYP-SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.40	0.35	0.36	0.29	0.27	0.22	37
			METAL LATH AND 3/4 IN. PLAS. (LT. WT. AGG.).....	0.47	0.39	0.34	0.35	0.28	0.26	0.22	38
			METAL LATH AND 3/4 IN. PLAS. (SAND AGG.).....	0.13	0.45	0.39	0.40	0.31	0.29	0.24	39
			INSUL. BD. (1/2 IN.).....	1.43	0.29	0.26	0.26	0.22	0.21	0.18	40
			INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	1.52	0.28	0.25	0.26	0.22	0.21	0.18	41
			PLYWOOD (1/4 IN.).....	0.31	0.42	0.36	0.37	0.30	0.27	0.23	42
			WOOD PANELS (3/4 IN.).....	0.94	0.33	0.29	0.30	0.25	0.23	0.20	43
			WOOD LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.40	0.35	0.36	0.29	0.27	0.22	44

¹Note that although several types of exterior finish may be grouped because they have approximately the same thermal resistance value, it is not implied that all types may be suitable for application over all types of sheathing listed.

²Average resistance of items listed. This average was used in computation of U values shown.

³Building paper is not included except where noted.

⁴Small air space between building paper and brick veneer neglected.

⁵Where stucco is applied over insulating board or gypsum sheathing, building paper is generally required, but the change in U value is negligible.

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TABLE 2-5

Coefficients of Transmission (U) of Solid Masonry Walls

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

EXTERIOR CONSTRUCTION ³		RESISTANCE	NONE	INTERIOR FINISH										NO.
				PLAS. 5/8 IN. ON WALL		METAL LATH AND 3/4 IN. PLAS. ON FURRING		GYPSUM LATH (3/8 IN.) AND 1/2 IN. PLAS. ON FURRING			INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. ON FURRING		WOOD AND 1/2 IN. PLAS.	
				(SAND AGG.)	(LT. WT. AGG.)	(SAND AGG.)	(LT. WT. AGG.)	NO PLAS.	(SAND AGG.)	(LT. WT. AGG.)	NO PLAS.	(SAND AGG.)	(SAND AGG.)	
				0.11	0.39	0.13	0.47	0.32	0.41	0.64	1.43	1.52	0.40	
MATERIAL	R	U	U	U	U	U	U	U	U	U	U	U		
		A	B	C	D	E	F	G	H	I	J	K		
BRICK (FACE AND COMMON) ⁴														
(6 IN.)	0.61	0.68	0.64	0.54	0.39	0.34	0.36	0.35	0.33	0.26	0.25	0.35	1	
(8 IN.)	1.24	0.48	0.45	0.41	0.31	0.28	0.30	0.29	0.27	0.22	0.22	0.29	2	
(12 IN.)	2.04	0.35	0.33	0.30	0.25	0.23	0.24	0.23	0.22	0.19	0.19	0.23	3	
(16 IN.)	2.84	0.27	0.26	0.25	0.21	0.19	0.20	0.20	0.19	0.16	0.16	0.20	4	
BRICK (COMMON ONLY)														
(8 IN.)	1.60	0.41	0.39	0.35	0.28	0.26	0.27	0.26	0.25	0.21	0.20	0.26	5	
(12 IN.)	2.40	0.31	0.30	0.27	0.23	0.21	0.22	0.22	0.21	0.18	0.17	0.22	6	
(16 IN.)	3.20	0.25	0.24	0.23	0.19	0.18	0.19	0.18	0.18	0.16	0.15	0.18	7	
STONE (LIME AND SAND)														
(8 IN.)	0.64	0.67	0.63	0.53	0.39	0.34	0.36	0.35	0.32	0.26	0.25	0.35	8	
(12 IN.)	0.96	0.55	0.52	0.45	0.34	0.31	0.32	0.31	0.29	0.24	0.23	0.31	9	
(16 IN.)	1.28	0.47	0.45	0.40	0.31	0.28	0.29	0.28	0.27	0.22	0.22	0.29	10	
(24 IN.)	1.92	0.36	0.35	0.32	0.26	0.24	0.25	0.24	0.23	0.19	0.19	0.24	11	
HOLLOW CLAY TILE														
(8 IN.)	1.85	0.36	0.36	0.32	0.26	0.24	0.25	0.25	0.23	0.20	0.19	0.25	12	
(10 IN.)	2.22	0.33	0.31	0.29	0.24	0.22	0.23	0.22	0.21	0.18	0.18	0.23	13	
(12 IN.)	2.50	0.30	0.29	0.27	0.22	0.21	0.22	0.21	0.20	0.17	0.17	0.21	14	
POURED CONCRETE														
30 LB. PER CU FT														
(4 IN.)	4.44	0.19	0.19	0.18	0.16	0.15	0.15	0.15	0.14	0.13	0.13	0.15	15	
(6 IN.)	6.66	0.13	0.13	0.13	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.11	16	
(8 IN.)	8.88	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.09	17	
(10 IN.)	11.10	0.08	0.08	0.08	0.08	0.07	0.08	0.08	0.07	0.07	0.07	0.08	18	
60 LB. PER CU FT														
(6 IN.)	2.40	0.31	0.30	0.27	0.23	0.21	0.22	0.22	0.21	0.18	0.17	0.22	19	
(8 IN.)	3.20	0.25	0.24	0.23	0.19	0.18	0.19	0.18	0.18	0.16	0.15	0.18	20	
(10 IN.)	4.00	0.21	0.20	0.19	0.17	0.16	0.16	0.16	0.15	0.14	0.14	0.16	21	
(12 IN.)	4.80	0.18	0.17	0.17	0.15	0.14	0.14	0.14	0.14	0.12	0.12	0.14	22	
140 LB. PER CU FT														
(8 IN.)	0.48	0.75	0.69	0.58	0.41	0.36	0.38	0.37	0.34	0.27	0.26	0.37	23	
(8 IN.)	0.64	0.67	0.63	0.53	0.39	0.34	0.36	0.35	0.32	0.26	0.25	0.35	24	
(10 IN.)	0.80	0.61	0.57	0.49	0.36	0.32	0.34	0.33	0.31	0.25	0.24	0.33	25	
(12 IN.)	0.96	0.55	0.52	0.45	0.34	0.31	0.32	0.31	0.29	0.24	0.23	0.31	26	
CONCRETE BLOCK														
(GRAVEL AGG.) (8 IN.)	1.11	0.52	0.48	0.43	0.33	0.29	0.31	0.30	0.28	0.23	0.22	0.30	27	
(12 IN.)	1.28	0.47	0.45	0.40	0.31	0.28	0.29	0.28	0.27	0.22	0.22	0.29	28	
(CINDER AGG.) (8 IN.)	1.72	0.39	0.37	0.34	0.27	0.25	0.26	0.25	0.24	0.20	0.20	0.25	29	
(12 IN.)	1.89	0.36	0.35	0.32	0.26	0.24	0.25	0.24	0.23	0.19	0.19	0.24	30	
(LT. WT. AGG.) (8 IN.)	2.00	0.35	0.34	0.31	0.26	0.23	0.24	0.24	0.22	0.19	0.19	0.24	31	
(12 IN.)	2.27	0.32	0.31	0.28	0.24	0.22	0.23	0.22	0.21	0.18	0.18	0.22	32	

³If stucco or structural glass is applied to the exterior, the additional resistance value of 0.10 would have a negligible effect on the U value.

⁴Brick, 6 in. (5½ in. actual) is assumed to have no backing. Walls 8, 12 and 16 in. have 4 in. of face brick and balance of common brick.

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TABLE 2-6

Coefficients of Transmission (U) of Masonry Walls

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

EXTERIOR FACING			BACKING		RESISTANCE ↓	NONE	INTERIOR FINISH										R U B B L E I N C H	
							PLAS. 5/8 IN. ON WALL		METAL LATH AND 3/4 IN. PLAS. ON FURRING		GYPSUM LATH (3/8 IN.) AND 1/2 IN. PLAS. ON FURRING		INSUL. BD. LATH (1/2 IN.) 1/2 IN. PLAS. ON FURRING		WOOD AND LATH 1/2 IN. PLAS.			
(SAND AGG.)	(LT. WT. AGG.)	(SAND AGG.)	(LT. WT. AGG.)	NO PLAS.	(SAND AGG.)	(LT. WT. AGG.)	NO PLAS.	(SAND AGG.)	(SAND AGG.)									
0.11	0.39	0.13	0.47	0.32	0.41	0.64	1.43	1.52	0.40									
MATERIAL	R	AV. R	MATERIAL	R	U	U	U	U	U	U	U	U	U	U	U			
					A	B	C	D	E	F	G	H	I	J	K			
FACE BRICK 4 IN. STONE 4 IN. PRECAST CONCRETE (SAND AGG.) 4 IN. 6 IN.	0.44	.39	CONCRETE BLOCK (CINDER AGG.)															
			(4 IN.)	1.11	0.41	0.39	0.35	0.28	0.28	0.27	0.26	0.25	0.21	0.20	0.26	1		
			(8 IN.)	1.72	0.33	0.32	0.29	0.24	0.22	0.23	0.23	0.21	0.18	0.18	0.23	2		
			(12 IN.)	1.89	0.31	0.30	0.28	0.23	0.21	0.22	0.22	0.21	0.18	0.17	0.22	3		
			(LT. WT. AGG.)															
			(4 IN.)	1.50	0.35	0.34	0.31	0.25	0.23	0.24	0.24	0.22	0.19	0.19	0.24	4		
	0.32		(8 IN.)	2.00	0.30	0.29	0.27	0.23	0.21	0.22	0.21	0.20	0.17	0.17	0.21	5		
			(12 IN.)	2.27	0.28	0.27	0.25	0.21	0.20	0.20	0.20	0.19	0.17	0.18	0.20	6		
			(SAND AGG.)															
	0.32		(4 IN.)	0.71	0.49	0.46	0.41	0.32	0.29	0.30	0.29	0.27	0.22	0.22	0.29	7		
			(8 IN.)	1.11	0.41	0.39	0.35	0.28	0.26	0.27	0.26	0.25	0.21	0.20	0.26	8		
			(12 IN.)	1.28	0.38	0.37	0.33	0.27	0.25	0.26	0.25	0.24	0.20	0.20	0.25	9		
	0.48		HOLLOW CLAY TILE															
			(4 IN.)	1.11	0.41	0.39	0.35	0.28	0.26	0.27	0.26	0.25	0.21	0.20	0.26	10		
			(8 IN.)	1.85	0.31	0.30	0.28	0.23	0.22	0.22	0.22	0.21	0.18	0.18	0.22	11		
COMMON BRICK 4 IN. PRECAST CONCRETE (SAND AGG.) 8 IN.	0.80		.72	(12 IN.)	2.50	0.26	0.25	0.24	0.20	0.19	0.19	0.19	0.18	0.16	0.16	0.19	12	
				CONCRETE (SAND AGG.)														
				(4 IN.)	0.32	0.60	0.56	0.49	0.36	0.32	0.34	0.33	0.31	0.25	0.24	0.33	13	
				(8 IN.)	0.48	0.55	0.52	0.45	0.34	0.31	0.32	0.31	0.29	0.24	0.23	0.31	14	
				(8 IN.)	0.64	0.51	0.48	0.42	0.32	0.29	0.31	0.30	0.28	0.23	0.22	0.30	15	
				CONCRETE BLOCK (CINDER AGG.)														
	0.64			(4 IN.)	1.11	0.30	0.28	0.32	0.28	0.24	0.25	0.24	0.23	0.19	0.19	0.24	16	
				(8 IN.)	1.72	0.29	0.29	0.26	0.22	0.21	0.21	0.21	0.20	0.17	0.17	0.21	17	
				(12 IN.)	1.89	0.28	0.27	0.25	0.21	0.20	0.21	0.20	0.19	0.17	0.17	0.20	18	
	0.64			(LT. WT. AGG.)														
				(4 IN.)	1.50	0.32	0.30	0.28	0.23	0.22	0.22	0.22	0.21	0.18	0.18	0.22	19	
				(8 IN.)	2.00	0.27	0.26	0.25	0.21	0.20	0.20	0.20	0.19	0.16	0.16	0.20	20	
	0.64			(12 IN.)	2.27	0.25	0.25	0.23	0.20	0.19	0.19	0.19	0.18	0.16	0.16	0.19	21	
				(SAND AGG.)														
				(4 IN.)	0.71	0.42	0.40	0.36	0.29	0.28	0.27	0.27	0.25	0.21	0.21	0.27	22	
COMMON BRICK 4 IN. PRECAST CONCRETE (SAND AGG.) 8 IN.	0.80	.72		(8 IN.)	1.11	0.36	0.35	0.32	0.26	0.24	0.25	0.24	0.23	0.19	0.19	0.24	23	
				(12 IN.)	1.28	0.34	0.33	0.30	0.25	0.23	0.24	0.23	0.22	0.19	0.18	0.23	24	
				HOLLOW CLAY TILE														
				(4 IN.)	1.11	0.36	0.35	0.32	0.26	0.24	0.25	0.24	0.23	0.19	0.19	0.24	25	
				(8 IN.)	1.85	0.28	0.28	0.26	0.22	0.20	0.21	0.20	0.19	0.17	0.17	0.20	26	
				(12 IN.)	2.50	0.24	0.23	0.22	0.19	0.18	0.18	0.18	0.17	0.15	0.15	0.18	27	
	0.64			CONCRETE (SAND AGG.)														
				(4 IN.)	0.32	0.50	0.48	0.42	0.32	0.29	0.30	0.30	0.28	0.23	0.22	0.30	28	
				(8 IN.)	0.48	0.47	0.44	0.39	0.31	0.28	0.29	0.28	0.27	0.22	0.22	0.28	29	
	0.64			(8 IN.)	0.64	0.43	0.41	0.37	0.29	0.27	0.28	0.27	0.26	0.21	0.21	0.27	30	

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TABLE 2-7

Coefficients of Transmission (U) of Masonry Cavity Walls

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

EXTERIOR CONSTRUCTION			INNER SECTION		NONE	INTERIOR FINISH										NUMBER
						PLAS. 5/8 IN. ON WALL		METAL LATH AND 3/4 IN. PLAS. ON FURRING		GYPSUM LATH (3/8 IN.) AND 1/2 IN. PLAS. ON FURRING			INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. ON FURRING		WOOD LATH AND 1/2 IN. PLAS.	
						(SAND AGG.) 0.11	(LT. WT. AGG.) 0.39	(SAND AGG.) 0.13	(LT. WT. AGG.) 0.47	NO PLAS. 0.32	(SAND AGG.) 0.41	(LT. WT. AGG.) 0.64	NO PLAS. 1.43	(SAND AGG.) 1.52	(SAND AGG.) 0.40	
MATERIAL	R	AV. R	MATERIAL	R	U	U	U	U	U	U	U	U	U	U	U	
					A	B	C	D	E	F	G	H	I	J	K	
FACE BRICK (4 IN.)		0.44	CONCRETE BLOCK (4 IN.)													
			(GRAVEL AGG.)... 0.71	0.34	0.32	0.30	0.25	0.23	0.23	0.23	0.22	0.19	0.18	0.23	1	
			(CINDER AGG.)... 1.11	0.30	0.29	0.27	0.22	0.21	0.21	0.21	0.20	0.17	0.17	0.21	2	
			(LT. WT. AGG.)... 1.50	0.27	0.26	0.24	0.21	0.19	0.20	0.19	0.19	0.16	0.16	0.19	3	
			COMMON BRICK (4 IN.)	0.80	0.33	0.32	0.29	0.24	0.22	0.23	0.23	0.21	0.18	0.18	0.23	4
			CLAY TILE (4 IN.)	1.11	0.30	0.29	0.27	0.22	0.21	0.21	0.21	0.20	0.17	0.17	0.21	5
COMMON BRICK (4 IN.) CONCRETE BLOCK (GRAVEL AGG.) (4 IN.)	0.80 0.76 0.71		CONCRETE BLOCK (4 IN.)													
			(GRAVEL AGG.)... 0.71	0.30	0.29	0.27	0.23	0.21	0.22	0.21	0.20	0.18	0.17	0.21	6	
			(CINDER AGG.)... 1.11	0.27	0.26	0.25	0.21	0.19	0.20	0.20	0.19	0.16	0.16	0.20	7	
			(LT. WT. AGG.)... 1.50	0.25	0.24	0.22	0.19	0.18	0.19	0.18	0.18	0.15	0.15	0.18	8	
			COMMON BRICK (4 IN.)	0.80	0.30	0.29	0.27	0.22	0.21	0.21	0.21	0.20	0.17	0.17	0.21	9
			CLAY TILE (4 IN.)	1.11	0.27	0.26	0.25	0.21	0.19	0.20	0.20	0.19	0.16	0.16	0.20	10
CONCRETE BLOCK (CINDER AGG.) (4 IN.)	1.11		CONCRETE BLOCK (4 IN.)													
			(GRAVEL AGG.)... 0.71	0.27	0.27	0.25	0.21	0.20	0.20	0.20	0.19	0.17	0.16	0.20	11	
			(CINDER AGG.)... 1.11	0.25	0.24	0.23	0.19	0.18	0.19	0.18	0.18	0.16	0.15	0.18	12	
			(LT. WT. AGG.)... 1.50	0.23	0.22	0.21	0.18	0.17	0.17	0.17	0.17	0.15	0.14	0.17	13	
			COMMON BRICK (4 IN.)	0.80	0.27	0.26	0.24	0.21	0.19	0.20	0.20	0.19	0.16	0.16	0.20	14
			CLAY TILE (4 IN.)	1.11	0.25	0.24	0.23	0.19	0.18	0.19	0.18	0.18	0.16	0.15	0.18	15

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TABLE 2-8

Coefficients of Transmission (U) of Frame Partitions or Interior Walls

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides

TYPE OF INTERIOR FINISH		SINGLE PARTITION (FINISH ON ONLY ONE SIDE OF STUDS)	DOUBLE PARTITION (FINISH ON BOTH SIDES OF STUDS)	NUMBER
MATERIAL	R	U	U	
		A	B	
GYPSUM BD. (3/8 IN.).....	0.32	0.60	0.34	1
GYPSUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.50	0.28	2
GYPSUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.58	0.32	3
METAL LATH AND 3/4 IN. PLAS. (LT. WT. AGG.).....	0.47	0.55	0.31	4
METAL LATH AND 3/4 IN. PLAS. (SAND AGG.).....	0.13	0.67	0.39	5
INSUL. BD. (1/2 IN.).....	1.43	0.36	0.19	6
INSUL. BD. LATH (1/2 IN.) AND 1/2 PLAS. (SAND AGG.).....	1.52	0.35	0.19	7
PLYWOOD: (1/4 IN.).....	0.31	0.60	0.34	8
(3/8 IN.).....	0.47	0.55	0.31	9
(1/2 IN.).....	0.63	0.50	0.28	10
WOOD PANELS (3/4 IN.).....	0.94	0.43	0.24	11
WOOD-LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.57	0.32	12
SHEET-METAL PANELS ADHERED TO WOOD (FRAMING).....	U	0.74	0.43	13
GLASS AND GLASS BLOCKS.....	SEE TABLE 3-2			

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TABLE 2-9

Coefficients of Transmission (U) of Masonry Partitions

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides

TYPE OF PARTITION		SURFACE FINISH					NUMBER
		NONE	PLAS. (LT. WT. AGG.) 5/8 IN.		PLAS. (SAND AGG.) 5/8 IN.		
			ONE SIDE 0.39	TWO SIDES 0.78	ONE SIDE 0.11	TWO SIDES 0.22	
RESISTANCE							
MATERIAL	R	U	U	U	U	U	
		A	B	C	D	E	
HOLLOW CONCRETE BLOCK (CINDER AGG.)							
(3 IN.).....	0.86	0.45	0.38	0.33	0.43	0.41	1
(4 IN.).....	1.11	0.40	0.35	0.31	0.39	0.37	2
(8 IN.).....	1.72	0.32	0.29	0.26	0.31	0.30	3
(12 IN.).....	1.89	0.31	0.27	0.25	0.30	0.29	4
(LT. WT. AGG.)							
(3 IN.).....	1.27	0.38	0.33	0.30	0.36	0.35	5
(4 IN.).....	1.50	0.35	0.31	0.27	0.34	0.32	6
(8 IN.).....	2.00	0.30	0.27	0.24	0.29	0.28	7
(12 IN.).....	2.27	0.28	0.25	0.23	0.27	0.26	8
(GRAVEL AGG.)							
(8 IN.).....	1.11	0.40	0.35	0.31	0.39	0.37	9
(12 IN.).....	1.28	0.38	0.33	0.29	0.36	0.35	10
HOLLOW CLAY TILE							
(3 IN.).....	0.80	0.46	0.39	0.34	0.44	0.42	11
(4 IN.).....	1.11	0.40	0.35	0.31	0.39	0.37	12
(6 IN.).....	1.52	0.35	0.31	0.27	0.33	0.32	13
(8 IN.).....	1.85	0.31	0.28	0.25	0.30	0.29	14
HOLLOW GYPSUM TILE							
(3 IN.).....	1.35	0.37	0.32	0.29	0.35	0.34	15
(4 IN.).....	1.67	0.33	0.29	0.26	0.32	0.31	16
SOLID PLASTER WALLS							
GYPSUM LATH (1/2 IN.) AND PLAS.							
3/4 IN. EACH SIDE							
(LT. WT. AGG.).....	1.39	0.36	-	-	-	-	17
(SAND AGG.).....	0.71	0.48	-	-	-	-	18
1 IN. EACH SIDE							
(LT. WT. AGG.).....	1.73	0.32	-	-	-	-	19
(SAND AGG.).....	0.81	0.46	-	-	-	-	20
METAL LATH AND PLAS. ¹							
2 IN. TOTAL THICKNESS							
(LT. WT. AGG.).....	1.28	0.38	-	-	-	-	21
(SAND AGG.).....	0.36	0.58	-	-	-	-	22
2 1/2 IN. TOTAL THICKNESS							
(LT. WT. AGG.).....	1.60	0.34	-	-	-	-	23
(SAND AGG.).....	0.45	0.55	-	-	-	-	24
GLASS AND GLASS BLOCKS.....		SEE TABLE 3-2					

¹Metal Core and Supports disregarded. Plaster troweled smooth both sides.
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TABLE 2-10

Coefficients of Transmission (U) of Frame Construction Ceilings and Floors

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference between the air on the two sides) and are based on still air (no wind) conditions on both sides

DIRECTION OF HEAT		HEAT FLOW UPWARD (WINTER CONDITIONS)						HEAT FLOW DOWNWARD (SUMMER CONDITIONS)						
		TYPE OF FLOOR												
		WOOD SUBFLOOR (25/32 IN.), FELT, AND—						WOOD SUBFLOOR (25/32 IN.), FELT, AND—						
		NONE	WOOD SUBFLOOR (25/32 IN.)	CEMENT (1 1/2 IN.) AND CERAMIC TILE (1/2 IN.)	HARDWOOD FLOOR (3/4 IN.)	PLYWOOD (5/8 IN.) AND FLOOR TILE OR LINOLEUM (1/8 IN.)	INSUL. BD. (3/8 IN.) AND HARD BD. (1/4 IN.) AND FLOOR TILE OR LINOLEUM (1/8 IN.)	NONE	WOOD SUBFLOOR (25/32 IN.)	CEMENT (1 1/2 IN.) AND CERAMIC TILE (1/2 IN.)	HARDWOOD FLOOR (3/4 IN.)	PLYWOOD (5/8 IN.) AND FLOOR TILE OR LINOLEUM (1/8 IN.)	INSUL. BD. (3/8 IN.) AND HARD BD. (1/4 IN.) AND FLOOR TILE OR LINOLEUM (1/8 IN.)	NUMBER
TYPE OF CEILING		—	0.98	1.38	1.72	1.87	2.26	—	0.98	1.38	1.72	1.87	2.26	
RESISTANCE ↓		—	0.98	1.38	1.72	1.87	2.26	—	0.98	1.38	1.72	1.87	2.26	
MATERIAL	R	U	U	U	U	U	U	U	U	U	U	U	U	
		A	B	C	D	E	F	G	H	I	J	K	L	
NONE.....	—	—	0.45	0.38	0.34	0.32	0.29	—	0.35	0.31	0.28	0.26	0.24	1
GYP SUM BD. (3/8 IN.).....	0.32	0.65	0.30	0.27	0.24	0.23	0.22	0.46	0.24	0.22	0.21	0.20	0.19	2
GYP SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (LT. WT. AGG.).....	0.64	0.54	0.27	0.24	0.23	0.22	0.20	0.40	0.22	0.21	0.19	0.18	0.17	3
GYP SUM LATH (3/8 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	0.41	0.61	0.29	0.26	0.24	0.23	0.21	0.44	0.24	0.22	0.20	0.20	0.18	4
METAL LATH AND 3/8 IN. PLAS. (LT. WT. AGG.).....	0.47	0.59	0.28	0.26	0.23	0.23	0.21	0.43	0.23	0.21	0.20	0.19	0.18	5
METAL LATH AND 3/8 IN. PLAS. (SAND AGG.).....	0.13	0.74	0.31	0.28	0.26	0.25	0.22	0.51	0.25	0.23	0.21	0.21	0.19	6
INSUL. BD. (1/2 IN.).....	1.43	0.38	0.22	0.20	0.19	0.19	0.17	0.31	0.19	0.18	0.17	0.16	0.15	7
INSUL. BD. LATH (1/2 IN.) AND 1/2 IN. PLAS. (SAND AGG.).....	1.52	0.36	0.22	0.20	0.19	0.18	0.17	0.30	0.19	0.17	0.17	0.16	0.15	8
ACOUSTICAL TILE (1/2 IN.) ON GYP SUM BD. (3/8 IN.).....	1.51 ²	0.37	0.22	0.20	0.19	0.18	0.17	0.30	0.19	0.17	0.17	0.16	0.15	9
(1/2 IN.) ON FURRING.....	1.19	0.41	0.24	0.22	0.20	0.19	0.18	0.33	0.20	0.19	0.17	0.17	0.16	10
(3/4 IN.) ON GYP SUM BD. (3/8 IN.).....	2.10 ²	0.30	0.19	0.18	0.17	0.17	0.15	0.25	0.17	0.16	0.15	0.15	0.14	11
(3/4 IN.) ON FURRING.....	1.78	0.33	0.21	0.19	0.18	0.17	0.16	0.28	0.18	0.17	0.16	0.15	0.15	12
WOOD LATH AND 1/2 IN. PLAS. (SAND AGG.).....	0.40	0.62	0.29	0.26	0.24	0.23	0.21	0.45	0.24	0.22	0.20	0.20	0.18	13

¹Includes asphalt, rubber, and plastic tile (1/2 in.), ceramic tile, or terrazzo (1 in.).

²Includes thermal resistance of 3/8 in. gypsum wall board.

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TABLE 2-11

**Coefficients of Transmission (U) of Concrete Floor-Ceiling Constructions
(Summer Conditions, Downward Flow)**

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides

TYPE OF DECK			TYPE OF FINISH FLOOR	RESISTANCE	↓	TYPE OF CEILING																NUMBER
						CEILING APPLIED DIRECTLY TO SLAB					SUSPENDED CEILING											
											GYPSUM BD. (3/8 IN.) AND PLAS.					METAL LATH AND PLAS.		ACOUSTICAL TILE				
PLAS.		ACOUSTICAL TILE-GLUED		NO PLAS.	(LT. WT. AGG.) 1/2 IN.	(SAND AGG.) 1/2 IN.	(LT. WT. AGG.) 3/4 IN.	(SAND AGG.) 3/4 IN.	ON FURRING OR CHANNELS		ON GYPSUM BD. (3/8 IN.)											
									1/2 IN.	3/4 IN.	1/2 IN.	3/4 IN.										
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U					
O	P	Q	R	S	T	U	U	V	W	X	Y	Z	Z'	Z''								
CONCRETE ⁴ (SAND AGG.) (4 IN.) 0.32 (6 IN.) 0.48	0.40	NONE	-----	0.45	0.43	0.44	0.29	0.25	0.28	0.26	0.27	0.27	0.30	0.23	0.20	0.21	0.19	1				
		FLOOR TILE ⁵ OR LINOLEUM (1/8 IN.)	0.05	0.44	0.42	0.43	0.29	0.25	0.28	0.26	0.27	0.27	0.29	0.22	0.20	0.21	0.19	2				
		WOOD BLOCK (13/16 IN.) ON SLAB	0.74	0.34	0.33	0.33	0.24	0.21	0.23	0.22	0.23	0.23	0.24	0.19	0.17	0.18	0.17	3				
		FLOOR ON SLEEPERS PLYWOOD SUBFLOOR (3/8 IN.), FELT AND FLOOR TILE ⁵ OR LINOLEUM (1/8 IN.)	0.89	0.23	0.23	0.23	0.18	0.17	0.19	0.18	0.19	0.18	0.20	0.16	0.15	0.15	0.14	4				
		WOOD SUBFLOOR (25/32 IN.), FELT AND HARDWOOD (3/4 IN.)	1.72	0.20	0.19	0.20	0.16	0.15	0.16	0.15	0.16	0.16	0.17	0.14	0.13	0.14	0.13	5				
CONCRETE ⁴ (SAND AGG.) (8 IN.) 0.64 (10 IN.) 0.80	0.72	NONE	-----	0.39	0.38	0.39	0.27	0.23	0.26	0.24	0.25	0.25	0.27	0.21	0.19	0.20	0.18	6				
		FLOOR TILE ⁵ OR LINOLEUM (1/8 IN.)	0.05	0.38	0.37	0.38	0.26	0.23	0.26	0.24	0.25	0.25	0.27	0.21	0.19	0.20	0.18	7				
		WOOD BLOCK (13/16 IN.) ON SLAB	0.74	0.30	0.30	0.30	0.22	0.20	0.22	0.20	0.21	0.21	0.23	0.18	0.16	0.17	0.16	8				
		FLOOR ON SLEEPERS PLYWOOD SUBFLOOR (3/8 IN.), FELT AND FLOOR TILE ⁵ OR LINOLEUM (1/8 IN.)	0.89	0.22	0.21	0.22	0.17	0.16	0.18	0.17	0.18	0.17	0.18	0.15	0.14	0.15	0.14	9				
		WOOD SUBFLOOR (25/32 IN.), FELT AND HARDWOOD (3/4 IN.)	1.72	0.19	0.18	0.18	0.15	0.14	0.16	0.15	0.15	0.15	0.16	0.14	0.13	0.13	0.12	10				

⁴ Concrete is assumed to have a thermal conductivity k of 12.0.

⁵ Includes asphalt, rubber, and plastic tile (1/8 in.), ceramic tile on terrazzo (1 in.).

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TABLE 2-12

Coefficients of Transmission (U) of Flat Masonry Roofs with Built-up Roofing with and without Suspended Ceiling (Summer Conditions, Downward Flow)

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 7.5 mph

TYPE OF DECK	TYPE OF FORM	RESISTANCE	TYPE OF CEILING																NUMBER
			ROOF INSULATION—NO CEILING								SUSPENDED CEILING								
			C VALUE OF ROOF INSULATION								GYPSUM BD. (3/8 IN.) AND PLAS.		METAL LATH AND PLAS.		ACOUSTICAL TILE				
			NONE	0.72	0.36	0.24	0.19	0.15	0.12	NO PLAS.	LT. WT. AGG. (1/2 IN.)	SAND AGG. (1/2 IN.)	LT. WT. AGG. (3/4 IN.)	SAND AGG. (3/4 IN.)	ON FURRING OR CHANNELS		ON GYPSUM BD. (3/8 IN.)		
															1/2 IN.	3/4 IN.	1/2 IN.	3/4 IN.	
			1	1.39	2.78	4.17	5.26	6.67	8.33	0.32	0.64	0.41	0.47	0.13	1.19	1.78	1.51	2.10	
MATERIAL	R	MATERIAL	R	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	
				A'	B'	C'	D'	E'	F'	G'	H'	I'	J'	K'	L'	M'	N'	O'	P'
CONCRETE SLAB ⁴ (GRAVEL AGG.) (4 IN.)...0.32 (6 IN.) 0.48 (8 IN.)...0.64 LT. WT. AGG. ⁵ (2 IN.)...2.22 (3 IN.)...3.33 (4 IN.)...4.44	TEMPORARY.....	—	0.55	0.31	0.22	0.17	0.14	0.12	0.10	0.32	0.29	0.31	0.30	0.34	0.25	0.22	0.23	0.20	1
	TEMPORARY.....	—	0.51	0.30	0.21	0.16	0.14	0.12	0.10	0.30	0.28	0.30	0.29	0.32	0.24	0.21	0.22	0.20	2
	TEMPORARY.....	—	0.47	0.28	0.20	0.16	0.14	0.11	0.10	0.29	0.27	0.28	0.28	0.31	0.23	0.20	0.22	0.19	3
	CORRUGATED METAL ³	0	0.27	0.20	0.15	0.13	0.11	0.10	0.08	0.20	0.19	0.20	0.19	0.21	0.17	0.15	0.16	0.15	4
	INSUL. BD. (1 IN.).....	2.78	0.15	0.13	0.11	0.09	0.09	0.08	0.07	0.13	0.12	0.13	0.13	0.13	0.12	0.11	0.11	0.10	5
	INSUL. BD. (1 1/2 IN.).....	4.17	0.13	0.11	0.09	0.08	0.08	0.07	0.06	0.11	0.11	0.11	0.11	0.11	0.10	0.09	0.10	0.09	6
	GLASS FIB. BD. (1 IN.).....	4.00	0.13	0.11	0.10	0.08	0.08	0.07	0.06	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.09	7
	CORRUGATED METAL ³	0	0.21	0.16	0.13	0.11	0.10	0.09	0.08	0.16	0.16	0.16	0.16	0.17	0.14	0.13	0.14	0.13	8
	INSUL. BD. (1 IN.).....	2.78	0.13	0.11	0.10	0.08	0.08	0.07	0.06	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.09	9
	INSUL. BD. (1 1/2 IN.).....	4.17	0.11	0.10	0.08	0.08	0.07	0.06	0.06	0.10	0.09	0.10	0.10	0.10	0.09	0.09	0.09	0.08	10
	GLASS FIB. BD. (1 IN.).....	4.00	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.08	11
	CORRUGATED METAL ³	0	0.17	0.14	0.11	0.10	0.09	0.08	0.07	0.14	0.13	0.14	0.14	0.14	0.12	0.12	0.12	0.11	12
	INSUL. BD. (1 IN.).....	2.78	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	13
	INSUL. BD. (1 1/2 IN.).....	4.17	0.10	0.09	0.08	0.07	0.07	0.06	0.05	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	14
	GLASS FIB. BD. (1 IN.).....	4.00	0.10	0.09	0.08	0.07	0.07	0.06	0.05	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	15
GYPSUM SLAB ⁷ (2 IN.)...1.20 (3 IN.)...1.80 (4 IN.)...2.40	GYPSUM BD. (1/2 IN.).....	0.45	0.32	0.22	0.17	0.14	0.12	0.10	0.09	0.22	0.21	0.22	0.22	0.23	0.19	0.17	0.18	0.16	16
	INSUL. BD. (1 IN.).....	2.78	0.18	0.15	0.12	0.10	0.09	0.08	0.07	0.15	0.14	0.15	0.14	0.15	0.13	0.12	0.13	0.12	17
	INSUL. BD. (1 1/2 IN.).....	4.17	0.15	0.12	0.10	0.09	0.08	0.07	0.07	0.12	0.12	0.12	0.12	0.13	0.11	0.10	0.11	0.10	18
	ASBESTOS-CEMENT BD. ⁶ (1/4 IN.).....	0.06	0.34	0.23	0.18	0.14	0.12	0.10	0.09	0.25	0.23	0.24	0.24	0.26	0.20	0.18	0.19	0.17	19
	GLASS FIB. BD. (1 IN.).....	4.00	0.15	0.12	0.11	0.09	0.08	0.07	0.07	0.13	0.12	0.12	0.12	0.13	0.11	0.11	0.11	0.10	20
	GYPSUM BD. (1/2 IN.).....	0.45	0.27	0.19	0.15	0.13	0.11	0.10	0.08	0.20	0.19	0.19	0.19	0.21	0.17	0.15	0.16	0.15	21
	INSUL. BD. (1 IN.).....	2.78	0.16	0.13	0.11	0.10	0.09	0.08	0.07	0.14	0.13	0.13	0.13	0.14	0.12	0.11	0.12	0.11	22
	INSUL. BD. (1 1/2 IN.).....	4.17	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.11	0.11	0.11	0.11	0.12	0.10	0.11	0.10	0.10	23
	ASBESTOS-CEMENT BD. (1/4 IN.).....	0.06	0.30	0.21	0.16	0.13	0.12	0.10	0.09	0.21	0.20	0.21	0.21	0.22	0.18	0.16	0.17	0.16	24
	GLASS FIB. BD. (1 IN.).....	4.00	0.14	0.12	0.10	0.09	0.08	0.07	0.06	0.12	0.11	0.12	0.11	0.12	0.11	0.10	0.10	0.10	25
	GYPSUM BD. (1/2 IN.).....	0.45	0.23	0.17	0.14	0.12	0.10	0.09	0.08	0.18	0.17	0.17	0.17	0.18	0.15	0.14	0.15	0.13	26
	INSUL. BD. (1 IN.).....	2.78	0.15	0.12	0.11	0.09	0.08	0.07	0.07	0.13	0.12	0.12	0.12	0.13	0.11	0.11	0.11	0.10	27
	INSUL. BD. (1 1/2 IN.).....	4.17	0.12	0.11	0.09	0.08	0.08	0.07	0.06	0.11	0.10	0.11	0.11	0.11	0.10	0.09	0.10	0.09	28
	ASBESTOS-CEMENT BD. ³ 1/4 IN.).....	0.06	0.25	0.19	0.15	0.12	0.11	0.09	0.08	0.19	0.18	0.19	0.19	0.20	0.16	0.15	0.16	0.14	29
	GLASS FIB. BD. (1 IN.).....	4.00	0.13	0.11	0.09	0.08	0.08	0.07	0.06	0.11	0.11	0.11	0.11	0.11	0.10	0.09	0.10	0.09	30

³U values would also apply if slab were poured on metal lath, paper-backed wire, fabric, or asbestos-cement board (1/4 in.)

⁴Concrete assumed to have a thermal conductivity k of 12.0 and a density of 140 lb per cu ft.

⁵Concrete assumed to have a thermal conductivity k of 0.90 and a density of 30 lb per cu ft.

⁶Gypsum slab 2 1/4 in. thick since this is recommended practice.

⁷Gypsum fiber concrete with 12 1/2 percent wood chips (thermal conductivity k = 1.66).

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TABLE 2-13

Coefficients of Transmission (U) of Wood or Metal Construction Flat Roofs and Ceilings (Summer Conditions, Downward Flow)

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based upon an outside wind velocity of 7.5 mph

TYPE OF DECK (BUILT-UP ROOF IN ALL CASES)		INSULATION ADDED ON TOP OF DECK ¹		TYPE OF CEILING												NUMBER
				GYPSUM BD. (3/8 IN.) AND PLAS.				METAL LATH AND PLAS.		INSUL. BD. (1/2 IN.) PLAIN (1.43) OR 1/2 IN. PLAS. SAND AGG. 1.52 1.47	ACOUSTICAL TILE					
		NONE	NONE	LT. WT. AGG. 1/2 IN.	SAND AGG. 1/2 IN.	LT. WT. AGG. 3/4 IN.	SAND AGG. 3/4 IN.	ON FURRING			ON GYPSUM DB. (1/2 IN.)					
								CON- DUCT- ANCE INSUL.	RE- SIST- ANCE	0.32	0.64	0.41	0.47	0.13	1/2 IN. 1.19		3/4 IN. 1.78	1/2 IN. 1.51	3/4 IN. 2.10
RESISTANCE		R	C	R	U	U	U	U	U	U	U	U	U	U	U	
MATERIAL		R	C	R	A'	B'	C'	D'	E'	F'	G'	H'	I'	J'	K'	
WOOD ² 1 IN.	0.98	NONE	-----	0.40	0.26	0.24	0.26	0.25	0.28	0.20	0.22	0.19	0.20	0.18	0.18	1
		0.72	1.39	0.26	0.19	0.18	0.19	0.19	0.20	0.16	0.17	0.15	0.16	0.14	0.14	2
		0.36	2.78	0.19	0.15	0.15	0.15	0.15	0.16	0.13	0.14	0.13	0.13	0.12	0.12	3
		0.24	4.17	0.15	0.13	0.12	0.12	0.12	0.13	0.11	0.11	0.11	0.11	0.10	0.10	4
		0.19	5.26	0.13	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	5
		0.15	6.67	0.11	0.10	0.09	0.10	0.09	0.10	0.09	0.09	0.09	0.08	0.08	0.08	6
		0.12	8.33	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	7
WOOD ² 2 IN.	2.03	NONE	-----	0.28	0.21	0.19	0.20	0.20	0.22	0.17	0.18	0.16	0.17	0.15	0.15	8
		0.72	1.39	0.20	0.16	0.15	0.16	0.16	0.17	0.14	0.14	0.13	0.14	0.13	0.13	9
		0.36	2.78	0.16	0.13	0.13	0.13	0.13	0.13	0.11	0.12	0.11	0.11	0.11	0.11	10
		0.24	4.17	0.13	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	11
		0.19	5.26	0.11	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	12
		0.15	6.67	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	13
		0.12	8.33	0.08	0.08	0.07	0.07	0.07	0.08	0.08	0.07	0.07	0.07	0.07	0.07	14
WOOD ² 3 IN.	3.23	NONE	-----	0.21	0.17	0.16	0.16	0.16	0.17	0.14	0.15	0.13	0.14	0.13	0.13	15
		0.72	1.39	0.16	0.13	0.13	0.13	0.13	0.14	0.12	0.12	0.11	0.12	0.11	0.11	16
		0.36	2.78	0.13	0.11	0.11	0.11	0.11	0.12	0.10	0.10	0.10	0.10	0.09	0.09	17
		0.24	4.17	0.11	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	18
		0.19	5.26	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	19
		0.15	6.67	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	20
		0.12	8.33	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	21
PREFORMED SLABS-WOOD FIBER AND CEMENT BINDER	3.60 5.40	NONE	-----	0.20	0.16	0.15	0.15	0.15	0.16	0.13	0.14	0.15	0.13	0.12	0.12	22
		NONE	-----	0.14	0.12	0.12	0.12	0.12	0.13	0.11	0.11	0.12	0.11	0.10	0.10	23
FLAT METAL ROOF DECK	0	NONE	-----	0.67	0.38	0.32	0.34	0.34	0.38	0.25	0.27	0.23	0.25	0.22	0.22	24
		0.72	1.39	0.35	0.24	0.22	0.23	0.23	0.25	0.19	0.20	0.18	0.19	0.17	0.17	25
		0.36	2.78	0.23	0.18	0.17	0.18	0.17	0.19	0.15	0.16	0.14	0.15	0.14	0.14	26
		0.24	4.17	0.18	0.14	0.14	0.14	0.14	0.15	0.12	0.13	0.12	0.12	0.11	0.11	27
		0.19	5.26	0.15	0.12	0.12	0.12	0.12	0.13	0.11	0.11	0.11	0.11	0.10	0.10	28
		0.15	6.67	0.12	0.11	0.10	0.10	0.10	0.11	0.09	0.10	0.09	0.09	0.09	0.09	29
		0.12	8.33	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	30

² Wood deck 1, 2, and 3 in. is assumed to be 25/32, 1%, and 2%, in. thick, respectively. The thermal conductivity k is assumed to be 0.80.

⁴ If a vapor barrier is used beneath roof insulation it will have a negligible effect on the U value.

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TABLE 2-14

Heat Gain from Occupants of Conditioned Spaces¹

DEGREE OF ACTIVITY	TYPICAL APPLICATION	TOTAL HEAT ADULTS, MALE BTU/HR	TOTAL HEAT ADJUSTED ² BTU/HR	SENSIBLE HEAT BTU/HR	LATENT HEAT BTU/HR
SEATED AT REST	THEATER-MATINEE	390	330	200	130
SEATED, VERY LIGHT WORK	THEATER-EVENING	390	350	215	135
MODERATELY ACTIVE OFFICE WORK	OFFICES, HOTELS, APARTMENTS	450	400	215	185
	OFFICES, HOTELS, APARTMENTS	475	450	220	230
STANDING, LIGHT WORK; OR WALKING SLOWLY	RETAIL AND DEPARTMENT STORES	550	450	220	230
WALKING; SEATED	DRUG STORE	550	500	220	280
STANDING; WALKING SLOWLY	BANK	490	550	240	310
SEDENTARY WORK	RESTAURANT ³	800	750	240	510
LIGHT BENCH WORK	FACTORY	900	850	270	580
MODERATE DANCING	DANCE HALL				
WALKING 3 MPH;	FACTORY	1000	1000	330	670
MODERATELY HEAVY WORK	BOWLING ALLEY	1500	1450	510	940
BOWLING ⁴	FACTORY	1500	1450	510	940
HEAVY WORK					

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NOTES:

¹ Tabulated values are based on 78 F for dry-bulb temperature.

² Adjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85 per cent of that for an adult male, and that the gain from a child is 75 per cent of that for an adult male.

³ Adjusted total heat value for sedentary work, restaurant, includes 60 Btu/h for food per individual (30 Btu sensible and 30 Btu latent).

⁴ For bowling figure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing (550 Btu/h).

TABLE 2-15

Over-all Heat Transfer Coefficient for Ductwork

DESCRIPTION OF DUCTWORK	U
SHEET METAL, NOT INSULATED	1.18
1/2 IN. THICK INSULATION BOARD WITH OR WITHOUT SHEET METAL	0.38
1 IN. DITTO	0.22
1 1/2 IN. DITTO	0.15
2 IN. DITTO	0.12

TABLE 2-16

Heat Gain From Electric Motors

NAMEPLATE RATING, HP	APPROXIMATE EFFICIENCY	HEAT GAIN, BTUH PER HP FOR CONTINUOUS RUNNING #
UP TO 1/4*	60	4200
1/2 TO 1	70	3600
1 1/2 TO 5	80	3200
7 1/2 TO 20	85	3000
OVER 20	88	2900

* Including 1/4 hp

Two things are assumed when the last column is used:

(1) the motor and its load are in either the room or the air stream,

(2) the load is equal (or almost equal) to the nameplate rating.

In general, these assumptions are true—especially for motors of 20 hp or less.

TABLE 2-17
Heat Gain From Electric Appliances

APPLIANCE	CAPACITY	MFG'RS INPUT RATING		PROBABLE MAX. HOURLY INPUT BTUH	RECOMMENDED RATE OF HEAT GAIN BTUH			
		WATTS	BTUH		WITHOUT HOOD			WITH HOOD ALL SENSIBLE
					SENSIBLE	LATENT	TOTAL	
COFFEE BREWER	1 BURNER	625	2130	1000	770	230	1000	340
COFFEE URN	3 GAL	2000	6800	3400	2550	850	3400	1000
COFFEE URN	5 GAL	3000	10200	5100	3850	1250	5100	1600
FOOD WARMER, PER SQ. FT. OF TOP SURFACE		240	820	400	320	80	400	130
FRY KETTLE	14 LB.	5500	18750	9400	2800	6600	9400	3000
FRY KETTLE	21 LB.	8000	27300	13700	4100	9600	13700	4300
GRIDDLE FRYING, PER SQ. FT. OF TOP		2700	9200	4600	3000	1600	4600	1500
TOASTER 360 SLICES PER HOUR	2 SLICES WIDE	2200	7500	3700	1960	1740	3700	1200
TOASTER, POP-UP	4 SLICE	2540	8350	4200	2230	1970	4200	1300
WAFFLE IRON	2 GRIDS	1650	5620	2800	1680	1120	2800	900

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TABLE 2-18
Heat Gain From Gas Appliances

APPLIANCE	CAPACITY	MFG'RS INPUT RATING PROBABLE			RECOMMENDED RATE OF HEAT GAIN			
			BTUH	MAX. HOURLY INPUT BTUH	BTUH			WITH HOOD ALL SENSIBLE
					WITHOUT HOOD			
					SENSIBLE	LATENT	TOTAL	
COFFEE BREWER	PER BURNER		5500	2500	1750	750	2500	500
COFFEE URN	3 GAL		10000	5000	3500	1500	5000	1000
COFFEE URN	5 GAL		15000	7500	5250	2250	7500	1500
FOOD WARMER, PER SQ. FT. OF TOP			1400	700	560	140	700	140
FRY KETTLE	15 LB.		30000	15000	7500	7500	15000	3000
FRY KETTLE	32 LB.		65000	32500	EXHAUST HOOD REQUIRED			6500
GRIDDLE, PER SQ. FT. OF TOP			15000	7500	4900	2600	7500	1500
SHORT ORDER STOVE, PER BURNER			10000	5000	3200	1800	5000	1000
TOASTER, 360 SLICES PER HOUR, CONTINUOUS	2 SLICES WIDE		12000	6000	3600	2400	6000	1200

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TABLE 2-19
Heat Loss From Pipes
(Btuh per Lineal Foot)

HOT WATER, 180 F*				STEAM, 5 PSIG*		
PIPE SIZE, IN.	BARE	CORRUGATED & LAMINATED ASBESTOS, 4 PLY, 1 IN. (K=0.60)	GLASS FIBER, 1 IN. (K=0.27)	BARE	CORRUGATED & LAMINATED ASBESTOS, 4 PLY, 1 IN. (K=0.60)	GLASS FIBER 1 IN. (K=0.27)
1/2	56	20	9	93	33	15
3/4	68	25	12	113	38	18
1	84	29	13	139	43	20
1 1/4	104	33	15	172	51	23
1 1/2	117	37	17	195	55	25
2	144	42	19	239	66	30
2 1/2	172	49	22	285	75	34
3	206	57	26	342	86	39
4	260	69	32	431	108	49

* Room Air Temperature, 78 F

TABLE 2-20
(Air Change Method)

WINDOWS IN ROOM	AIR CHANGES PER HOUR
NO WINDOWS OR OUTSIDE DOORS	3/4
WINDOWS OR DOORS IN 1 WALL	1
WINDOWS OR DOORS IN 2 WALLS	1 1/2
WINDOWS OR DOORS IN 3 OR 4 WALLS	2
STORES	2

TABLE 2-22
Outdoor Air Requirements¹

APPLICATION	SMOKING	CFM PER PERSON ²		CFM PER SQ. FT. OF FLOOR
		REC- COM- MEND- ED	MINI- MUM ³	MINI- MUM ³
APARTMENT				
AVERAGE.....	SOME.....	20	10	.....
DELUXE.....	SOME.....	20	10	.....
BANKING SPACE.....	OCCASIONAL ...	10	7 1/2	.....
BARBER SHOPS.....	CONSIDERABLE	15	10	.....
BEAUTY PARLORS.....	OCCASIONAL ...	10	7 1/2	.....
BROKERS' BOARD ROOMS	VERY HEAVY ...	50 ⁴	20	.....
COCKTAIL BARS.....		40	25	.....
CORRIDORS (SUPPLY OR EXHAUST).....				0.25
DEPARTMENT STORES.....	NONE.....	7 1/2	5	0.05
DIRECTORS' ROOMS.....	EXTREME.....	50	30	.....
DRUG STORES ⁵	CONSIDERABLE	10	7 1/2	.....
FACTORIES ⁶	NONE.....	10	7 1/2	0.10
FIVE AND TEN CENT STORES.....	NONE.....	7 1/2	5	.....
FUNERAL PARLORS.....	NONE.....	10	7 1/2	.....
GARAGES ⁴				1.0
HOSPITALS				
OPERATING ROOMS ^{4,7}	NONE.....			2.0
PRIVATE ROOMS.....	NONE.....	30	25	0.33
WARDS.....	NONE.....	20	10	.....
HOTEL ROOMS.....	HEAVY.....	30	25	0.33
KITCHENS				
RESTAURANT.....				4.2
RESIDENCE.....				2.0
LABORATORIES ⁵	SOME.....	20	15	.....
MEETING ROOMS.....	VERY HEAVY ...	50	30	1.25
OFFICES				
GENERAL.....	SOME.....	15	10	.....
PRIVATE.....	NONE.....	25	15	0.25
PRIVATE.....	CONSIDERABLE	30	25	0.25
RESTAURANTS				
CAFETERIA ⁵	CONSIDERABLE	12	10	.....
DINING ROOM ⁵	CONSIDERABLE	15	12	.....
SCHOOLROOMS ⁴	NONE.....			.....
SHOP, RETAIL.....	NONE.....	10	7 1/2	.....
THEATER ⁴	NONE.....	7 1/2	5	.....
THEATER.....	SOME.....	15	10	.....
TOILETS ⁴ (EXHAUST).....				2.0

TABLE 2-21
Infiltration Through Windows
(cfh per ft)^a

TYPE OF WINDOW	DESCRIPTION OF WINDOW	WIND VELOCITY, MPH	
		7 1/2	15
DOUBLE-HUNG WOOD SASH (UNLOCKED)	TOTAL FOR AVERAGE WINDOW, NONWEATHER-STRIPPED, 1/16 IN. CRACK AND 3/64 IN. CLEARANCE	14	39
	DITTO, WEATHERSTRIPPED	8	24
	TOTAL FOR POORLY FITTED WINDOW, NONWEATHER-STRIPPED, 3/32 IN. CRACK AND 3/32 IN. CLEARANCE	48	111
	DITTO, WEATHERSTRIPPED	13	34
DOUBLE-HUNG METAL SASH	NONWEATHERSTRIPPED, LOCKED.....	33	70
	NONWEATHERSTRIPPED, UNLOCKED.....	34	74
	WEATHERSTRIPPED, UNLOCKED.....	13	32
ROLLED	INDUSTRIAL PIVOTED, 1/16 IN. CRACK.....	80	176
SECTION	ARCHITECTURAL PROJECTED, 3/64 IN. CRACK	36	88
STEEL	RESIDENTIAL CASEMENT, 1/32 IN. CRACK.....	23	52
SASH	HEAVY CASEMENT SECTION, PROJECTED, 1/32 IN. CRACK.....	16	38

^a Cubic feet of air per hour per lineal foot of crack.

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¹ Taken from present-day practice.

² This is contaminant-free air.

³ When minimum is used, take the larger of the two.

⁴ See local codes which may govern.

⁵ May be governed by exhaust.

⁶ May be governed by special sources of contamination or local codes.

⁷ All outside air recommended to overcome explosion hazard of anesthetics.

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TABLE 2-23

**Direct Solar and Diffuse Sky Radiation for Single Common Window Glass
for March 22 and September 22***
(Btu per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
MARCH 22 & SEPT. 22 NORTH LATITUDE	6 AM	0	0	0	0	0	0	0	0	0	SEPT. 22 & MARCH 22 SOUTH LATITUDE
	7 AM	5.5	36.1	112.9	98.0	14.2	5.9	5.1	4.8	22.1	
	8 AM	8.3	66.3	160.9	150.3	50.0	10.6	9.4	8.6	69.7	
	9 AM	9.9	34.5	152.7	170.5	87.4	13.9	12.5	11.0	114.8	
	10 AM	10.7	16.2	113.2	166.3	120.7	17.0	14.5	12.6	151.3	
	11 AM	11.0	17.0	57.8	143.8	140.2	51.0	15.6	13.3	172.6	
	12 NOON	11.1	16.9	22.6	103.7	148.2	103.7	22.6	16.9	179.4	
	1 PM	11.0	13.3	15.6	51.0	140.2	143.8	57.8	17.0	172.6	
	2 PM	10.7	12.6	14.5	17.0	120.7	166.3	113.2	16.2	151.3	
	3 PM	9.9	11.0	12.5	13.9	87.4	170.5	152.7	34.5	114.8	
	4 PM	8.3	8.6	9.4	10.6	50.0	150.9	160.9	66.3	69.7	
	5 PM	5.5	4.8	5.1	5.9	14.2	96.0	113.9	66.1	22.1	
	6 PM	0	0	0	0	0	0	0	0	0	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
		DIRECTION FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-23 is for 40 degrees North latitude. It may be used for 40 degrees South latitude on March 22 and September 22 by reading up from the bottom.

TABLE 2-24

**Direct Solar and Diffuse Sky Radiation for Single Common Window Glass
for April 20 and August 24***
(Btu per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
APRIL 20 & AUG. 24 NORTH LATITUDE	6 AM	8.5	62.5	77.8	45.8	4.0	3.6	3.0	2.9	9.4	OCT. 23 & FEB. 20 SOUTH LATITUDE
	7 AM	7.5	107.1	159.3	113.6	12.1	9.0	7.9	7.3	51.0	
	8 AM	9.5	91.5	175.3	145.7	30.4	13.0	11.6	10.4	102.0	
	9 AM	10.6	54.8	158.4	155.6	58.5	15.8	14.4	12.4	148.0	
	10 AM	11.2	19.1	113.8	146.0	86.5	17.5	16.0	13.7	183.0	
	11 AM	11.5	16.4	57.1	119.3	108.1	32.2	16.8	14.2	205.0	
	12 NOON	11.6	16.1	20.6	77.9	114.2	77.9	20.6	16.1	214.0	
	1 PM	11.5	14.2	16.8	32.2	108.1	119.3	57.1	16.4	205.0	
	2 PM	11.2	13.7	16.0	17.5	86.5	146.0	113.8	19.1	183.0	
	3 PM	10.6	12.4	14.4	15.8	58.5	155.6	158.4	54.8	148.0	
	4 PM	9.5	10.4	11.6	13.0	30.4	145.7	175.3	91.5	102.0	
	5 PM	7.5	7.3	7.9	9.0	12.1	113.6	159.3	107.1	51.0	
	6 PM	8.5	2.9	3.0	3.6	4.0	45.8	77.8	62.5	9.4	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
		DIRECTIONS FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-24 is for 40 degrees North latitude. It may be used for 40 degrees South latitude on February 20 and October 23 by reading up from the bottom.

TABLE 2-25

**Direct Solar and Diffuse Sky Radiation for Single Common Window Glass
for May 21 and July 23***
(Btu per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
MAY 21 & JULY 23 NORTH LATITUDE	6 AM	26.3	109.2	125.0	60.6	7.2	6.4	5.5	5.2	24.6	NOV. 21 & JAN. 21 SOUTH LATITUDE
	7 AM	15.2	130.7	170.7	103.4	12.4	11.0	9.7	8.8	74.0	
	8 AM	10.1	110.5	176.5	129.4	17.8	14.4	13.0	11.4	122.4	
	9 AM	11.0	73.8	153.9	133.7	33.9	16.9	15.5	13.3	169.2	
	10 AM	11.4	32.4	114.2	121.6	54.3	18.2	16.7	14.2	202.3	
	11 AM	11.6	15.3	52.3	94.1	73.5	21.7	17.4	14.5	224.4	
	12 NOON	11.6	14.5	17.4	52.1	78.9	52.1	17.4	14.5	232.0	
	1 PM	11.6	14.5	17.4	21.7	73.5	94.1	52.3	15.3	224.4	
	2 PM	11.4	14.2	16.7	18.2	54.3	121.6	114.2	32.4	202.3	
	3 PM	11.0	13.3	15.5	16.9	33.9	133.7	153.9	73.8	169.2	
	4 PM	10.1	11.4	13.0	14.4	17.8	129.4	176.5	110.5	122.4	
	5 PM	15.2	8.8	9.7	11.0	12.4	103.4	170.7	130.7	74.0	
	6 PM	26.3	5.2	5.5	6.4	7.2	60.6	125.0	109.2	24.6	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
		DIRECTIONS FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-25 is for 40 degrees North latitude. It may be used for 40 degrees South latitude on January 21 and November 21 by reading up from the bottom.

703.5 1749.6

TABLE 2-26

Direct Solar and Diffuse Sky Radiation for Single Common Window Glass for June 21*

(Btu/h per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
JUNE 21 NORTH LATITUDE	6 AM	33.2	120.4	132.9	61.2	8.2	7.2	6.4	5.9	32.3	DEC. 22 SOUTH LATITUDE
	7 AM	21.0	139.6	173.1	98.2	13.2	11.7	10.4	9.4	83.3	
	8 AM	12.2	123.4	175.4	120.3	16.5	14.9	13.5	11.8	130.9	
	9 AM	11.1	80.4	152.6	123.8	27.7	17.2	15.7	14.3	176.0	
	10 AM	11.5	35.0	107.4	109.7	44.3	19.4	17.0	14.3	210.8	
	11 AM	11.6	14.8	50.8	61.7	58.7	38.9	17.7	14.6	230.4	
	12 NOON	11.6	14.5	17.7	38.9	61.8	48.9	17.7	14.5	237.2	
	1 PM	11.6	14.6	17.7	38.9	58.7	61.7	50.8	14.8	230.4	
	2 PM	11.5	14.3	17.0	18.4	44.3	109.7	107.4	35.0	210.8	
	3 PM	11.1	14.3	15.7	17.2	27.7	123.8	152.6	80.4	176.0	
	4 PM	12.2	11.8	13.5	14.9	16.6	120.0	175.4	123.4	130.9	
	5 PM	21.0	9.4	10.4	11.7	13.2	98.2	173.1	139.6	83.3	
	6 PM	33.2	5.9	6.4	7.2	8.2	61.2	132.9	120.4	32.3	
			S	SE	E	NE	N	NW	W	SW		HORIZ
		DIRECTIONS FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-26 is for 40 degrees North latitude. It may be used for 40 degrees South latitude on December 22 by reading up from the bottom.

TABLE 2-27

Heat Gain by Convection and Radiation from Single Common Window Glass for March 22 and September 22*

(Btu/h per sq ft of masonry opening)

TIME OF YEAR	SUN TIME.	DIRECTION FOR NORTH LATITUDE (READ DOWN)										
		N	NE	E	SE	S	SW	W	NW	HORIZ		
MARCH 22 & SEPT. 22 NORTH LATITUDE	6 AM	-4.4	-4.4	-4.4	-4.4	-4.4	-4.4	-4.4	-4.4	-4.4	SEPT. 22 & MARCH 22 SOUTH LATITUDE	
	7 AM	-3.3	-2.0	-1.0	-2.4	-3.3	-3.3	-3.3	-3.3	-2.8		
	8 AM	-1.1	0.2	2.1	1.9	-0.1	-1.1	-1.1	-1.1	0.6		
	9 AM	2.2	2.9	5.2	5.6	4.0	2.2	2.2	2.2	4.9		
	10 AM	5.5	5.5	7.8	8.6	7.9	5.5	5.5	5.5	9.0		
	11 AM	9.9	9.9	11.1	12.8	12.7	10.9	9.9	9.9	13.9		
	12 NOON	13.2	13.2	13.2	15.2	16.2	15.2	13.2	13.2	17.4		
	1 PM	16.5	16.5	16.5	17.5	19.3	19.3	17.6	16.5	20.5		
	2 PM	17.6	17.6	17.6	17.6	20.0	20.9	19.9	17.6	21.1		
	3 PM	18.7	18.7	18.7	18.7	19.6	22.1	21.8	19.4	21.4		
	4 PM	17.6	17.6	17.6	17.6	18.6	19.6	20.8	18.9	18.8		
	5 PM	16.5	16.5	16.5	16.5	16.5	18.4	18.8	17.8	17.0		
	6 PM	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3		
		S	SE	E	NE	N	NW	W	SW	HORIZ		
DIRECTION FOR SOUTH LATITUDE (READ UP)											TIME OF YEAR	

*Table 2-27 is for 30 to 50 degrees North latitude. It can be used for March 22 and September 22 in the South latitude by reading up from the bottom. Room temperature is 78 F.

TABLE 2-28

Heat Gain by Convection and Radiation from Single Common Window Glass for April 20 and August 24*

(Btu/h per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTION FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
APRIL 20 & AUG. 24 NORTH LATITUDE	6 AM	-4.4	-3.2	-2.8	-3.5	-4.4	-4.4	-4.4	-4.4	-4.3	OCT. 23 & FEB. 20 SOUTH LATITUDE
	7 AM	-3.3	-1.1	-0.1	-1.1	-3.3	-3.3	-3.3	-3.3	-2.3	
	8 AM	-1.1	0.7	2.4	1.8	-0.5	-1.1	-1.1	-1.1	1.0	
	9 AM	2.2	3.3	5.4	5.3	3.4	2.2	2.2	2.2	5.4	
	10 AM	5.5	5.5	7.8	8.4	7.2	5.5	5.5	5.5	9.5	
	11 AM	9.9	9.9	11.0	12.3	12.1	10.5	9.9	9.9	14.4	
	12 NOON	13.2	13.2	13.2	14.8	15.5	14.8	13.2	13.2	17.9	
	1 PM	16.5	16.5	16.5	17.1	18.7	18.9	17.5	16.5	21.0	
	2 PM	17.6	17.6	17.6	17.5	19.3	20.5	19.9	17.6	21.6	
	3 PM	18.7	18.7	18.7	18.7	19.9	21.8	21.9	19.8	21.9	
	4 PM	17.6	17.6	17.6	17.6	18.2	20.5	21.1	19.4	19.2	
	5 PM	16.5	16.5	16.5	16.5	16.5	18.8	19.7	18.6	17.5	
	6 PM	14.3	14.3	14.3	14.3	14.3	15.2	15.9	15.5	14.4	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
DIRECTION FOR SOUTH LATITUDE (READ UP)											TIME OF YEAR

*Table 2-28 is for 30 to 50 degrees North latitude. It can be used for February 20 and October 23 in the South latitude by reading up from the bottom. Room temperature is 78 F.

TABLE 2-29
Heat Gain by Convection and Radiation from Single Common Window Glass
for May 21 and July 23*
(Btuh per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTION FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
MAY 21 & JULY 23 NORTH LATITUDE	6 AM	-3.9	-2.2	-1.9	-3.2	-4.4	-4.4	-4.4	-4.4	-4.1	NOV. 21 & JAN. 21 SOUTH LATITUDE
	7 AM	-3.3	-0.7	0.1	-1.2	-3.3	-3.3	-3.3	-3.3	-1.9	
	8 AM	-1.1	1.1	2.4	1.5	-1.1	-1.1	-1.1	-1.1	1.3	
	9 AM	2.2	3.7	5.3	4.9	2.9	2.2	2.2	2.2	5.7	
	10 AM	5.5	6.1	7.8	7.9	6.6	5.5	5.5	5.5	9.7	
	11 AM	9.9	9.9	10.9	11.8	11.4	9.9	9.9	9.9	14.6	
	12 NOON	13.2	13.2	13.2	14.2	14.8	14.2	13.2	13.2	18.1	
	1 PM	16.5	16.5	16.5	17.1	18.0	18.4	17.5	16.5	21.2	
	2 PM	17.6	17.6	17.6	17.6	18.7	20.0	19.9	18.2	21.8	
	3 PM	18.7	18.7	18.7	18.7	19.4	21.4	21.8	20.2	22.1	
	4 PM	17.6	17.6	17.6	17.6	17.6	20.2	21.1	19.8	19.5	
	5 PM	16.5	16.5	16.5	16.5	16.5	18.6	19.9	19.1	17.9	
	6 PM	14.3	14.3	14.3	14.3	14.3	15.4	16.8	16.5	14.6	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
		DIRECTION FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-29 is for 30 to 50 North latitude. It can be used for Jan. 21 and Nov. 21 in the South latitude by reading up from the bottom. Room temperature is 78 F.

TABLE 2-30
Heat Gain by Convection and Radiation from Single Common Window Glass
for June 21*
(Btuh per sq ft of masonry opening)

TIME OF YEAR	SUN TIME	DIRECTION FOR NORTH LATITUDE (READ DOWN)									
		N	NE	E	SE	S	SW	W	NW	HORIZ	
JUNE 21 NORTH LATITUDE	6 AM	-3.7	-2.0	-1.8	-3.2	-4.4	-4.4	-4.4	-4.4	-4.0	DEC. 22 SOUTH LATITUDE
	7 AM	0.9	-0.5	0.2	-1.3	-3.3	-3.3	-3.3	-3.3	-1.8	
	8 AM	-1.1	1.4	2.4	1.3	-1.1	-1.1	-1.1	-1.1	1.5	
	9 AM	2.2	3.8	5.2	4.7	2.8	2.2	2.2	2.2	5.7	
	10 AM	5.5	6.2	7.7	7.7	6.4	5.5	5.5	5.5	9.8	
	11 AM	9.9	9.9	10.9	11.5	11.1	10.7	9.9	9.9	14.7	
	12 NOON	13.2	13.2	13.2	14.2	14.5	14.2	13.2	13.2	19.1	
	1 PM	16.5	16.5	16.5	17.3	17.7	18.1	17.5	16.5	21.3	
	2 PM	17.6	17.6	17.6	17.6	18.5	19.8	19.8	18.3	21.9	
	3 PM	18.7	18.7	18.7	18.7	19.2	21.2	21.7	20.3	22.2	
	4 PM	17.6	17.6	17.6	17.6	17.6	20.0	21.1	20.1	19.7	
	5 PM	16.9	16.5	16.5	16.5	16.5	17.5	20.0	19.3	18.0	
	6 PM	15.0	14.3	14.3	14.3	14.3	15.5	16.9	16.7	14.7	
		S	SE	E	NE	N	NW	W	SW	HORIZ	
		DIRECTION FOR SOUTH LATITUDE (READ UP)									TIME OF YEAR

*Table 2-30 is for 30 to 50 North latitude. It can be used for Dec. 22 in the South latitude by reading up from the bottom. Room temperature is 78 F.

TABLE 2-31

Shading Coefficients—Single Glass and Insulating Glass¹—No shading

SINGLE GLASS					INSULATING GLASS					
TYPE OF GLASS	NOMINAL THICKNESS ²	SOLAR TRANS. ³	GLASS IN SUN	GLASS IN SHADE	TYPE OF GLASS	NOMINAL THICKNESS ^{2,4}	SOLAR TRANS. OUTER PANE	SOLAR TRANS. INNER PANE	GLASS IN SUN	GLASS IN SHADE
REGULAR SHEET	3/32, 1/8	0.86	1.00	1.00	REGULAR SHEET OUT.	3/32, 1/8	0.86	0.86	0.90	0.84
REGULAR PLATE	1/4	0.80	0.95	0.95	REGULAR SHEET IN					
	3/8	0.75	0.91	0.91						
	1/2	0.71	0.88	0.88	REGULAR PLATE OUT.	1/4	0.80	0.80	0.83	0.77
HEAT-ABS ⁴ SHEET	7/32	0.51	0.71	0.73	REGULAR PLATE IN					
HEAT-ABS ⁴ PLATE	1/4	0.45	0.57	0.74						
	3/8	0.34	0.57	0.54	HEAT-ABS ⁴ PLATE OUT.	1/4	0.46	0.80	0.56	0.53
GREY ⁵ SHEET	1/8	0.59	0.78	0.78	REGULAR PLATE IN					
	3/16	0.74	0.90	0.90						
	7/32	0.43	0.55	0.55	GREY ⁵ PLATE OUT.	1/4	0.45	0.80	0.56	0.53
	7/32	0.71	0.83	0.83	REGULAR PLATE IN					
	1/4	0.67	0.86	0.86						
GREY ⁵ PLATE	13/64	0.52	0.72	0.72	GREY PLATE ⁵ WITH SUN CONTROL FILM OUT.	1/4	0.23	0.80	0.42	0.44
	1/4	0.47	0.70	0.70						
	3/8	0.33	0.56	0.56	REGULAR PLATE IN					
	1/2	0.24	0.50	0.50						

¹ Refers to factory-fabricated units with 3/16, 1/4, or 1/2 in. air space or to prime windows plus storm windows.² Refer to manufacturer's literature for values.³ Thickness of each pane of glass, not thickness of assembled unit.⁴ Heat absorbing sheet does not meet radiant transmittance requirements of Federal Specification DD-G-451a. Heat absorbing plate meets these requirements.⁵ Glare-reducing glasses other than grey in color will have approximately equal shading coefficients for equal solar transmittances. Consult manufacturer's data for specific product values.

Note: For awnings or overhanging canopies which completely shade the glass area use a shade factor of 0.20 for all types of glass.

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TABLE 2-31A

Shading Coefficients—Single Glass with Indoor Shading (Also see Table 2-31 B)

TYPE OF GLASS	NOMINAL THICKNESS ¹	SOLAR TRANS. ¹	TYPE OF SHADING							
			VENETIAN BLINDS				ROLLER SHADE, OPAQUE			
			MEDIUM		LIGHT		DARK		WHITE	
			GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE
REGULAR SHEET	3/32 TO 1/4	0.87-0.80	0.64	0.66	0.55	0.60	0.59	0.61	0.25	0.22
REGULAR PLATE	1/4 TO 1/2	0.80-0.71								
REGULAR PATTERN	1/8 TO 9/32	0.87-0.79								
HEAT-ABSORBING PATTERN	1/8	---								
GREY SHEET	3/16, 7/32	0.74, 0.71	0.57	0.58	0.53	0.52	0.45	0.42	0.30	0.30
HEAT-ABSORBING SHEET	7/32	0.51								
HEAT-ABSORBING PLATE	1/4	0.46								
HEAT-ABSORBING PATTERN	3/16, 1/4	---								
GREY SHEET	1/8, 7/32	0.59, 0.45	0.54	0.53	0.52	0.52	0.40	0.36	0.28	0.26
GREY PLATE	13/64, 1/4	0.52, 0.45								
HEAT-ABSORBING SHEET, PLATE OR PATTERN	---	0.44-0.30								
HEAT-ABSORBING PLATE	3/8	0.34								
GREY PLATE	3/8	0.33	0.51	0.51	0.50	0.50	0.36	0.32	0.28	0.25
HEAT-ABSORBING SHEET, PLATE OR PATTERN	---	0.29-0.15								
GREY PLATE	1/2	0.24								

¹ Refer to manufacturer's literature for values.

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TABLE 2-31B

Shading Coefficients—Single Glass with Indoor Shading (Also see Table 2-31A)

TYPE OF GLASS (FOR NOMINAL THICKNESS ¹ AND SOLAR TRANS. ¹ SEE TABLE 2-31A)	TYPE OF SHADING-DRAPERIES (DESIGNATIONS INDICATE CLASS: I = OPEN WEAVE, LIGHT COLORED)																	
	D = DARK COLORED YARN						M = MEDIUM COLORED YARN						L = LIGHT COLORED YARN					
	OPEN WEAVE		SEMI- OPEN		CLOSED WEAVE		OPEN WEAVE		SEMI- OPEN		CLOSED WEAVE		OPEN WEAVE		SEMI- OPEN		CLOSED WEAVE	
	I _D		II _D		III _D		I _M		II _M		III _M		I _L		II _L		III _L	
	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE	GLASS IN SUN	GLASS IN SHADE
REGULAR SHEET REGULAR PLATE REGULAR PATTERN HEAT-ABS PATTERN GREY SHEET	0.76	0.69	0.69	0.62	0.66	0.60	0.69	0.62	0.63	0.58	0.57	0.51	0.67	0.60	0.55	0.49	0.47	0.42
HEAT-ABS SHEET HEAT-ABS PLATE HEAT-ABS PATTERN GREY SHEET GREY PLATE	0.58	0.52	0.54	0.49	0.52	0.47	0.54	0.49	0.50	0.45	0.47	0.42	0.53	0.48	0.45	0.40	0.41	0.36
HEAT-ABS SHEET, PLATE OR PATTERN HEAT-ABS PLATE GREY PLATE	0.49	0.44	0.45	0.41	0.44	0.40	0.46	0.41	0.43	0.39	0.40	0.36	0.45	0.40	0.39	0.36	0.36	0.32
HEAT-ABS SHEET, PLATE OR PATTERN GREY PLATE	0.37	0.33	0.36	0.33	0.35	0.32	0.35	0.32	0.34	0.31	0.33	0.30	0.35	0.31	0.33	0.30	0.31	0.28

¹ Refer to manufacturer's literature for values.

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TABLE 2-31C

Shading Coefficients for Hollow Glass Block Wall Panels

TYPE OF GLASS BLOCK ¹	DESCRIPTION OF GLASS BLOCK	SHADING COEFFICIENT ²	
		PANELS ³ IN THE SUN	PANELS ⁴ IN THE SHADE (N, NW, W, SW)
TYPE I	GLASS COLORLESS OR AQUA SMOOTH FACE A, D: SMOOTH B, C: SMOOTH OR WIDE RIBS, OR FLUTES HORIZONTAL OR VERTICAL, OR SHALLOW CONFIGURATION. E: NONE	0.65	0.40
TYPE IA	SAME AS TYPE I EXCEPT A: CERAMIC ENAMEL ON EXTERIOR FACE.	0.27	0.20
TYPE II I	SAME AS TYPE I EXCEPT E: GLASS FIBER SCREEN.	0.44	0.34
TYPE III	GLASS COLORLESS OR AQUA A, D: NARROW VERTICAL RIBS OR FLUTES. B, C: HORIZONTAL LIGHT-DIFFUSING PRISMS, OR HORIZONTAL LIGHT-DIRECTING PRISMS. E: GLASS FIBER SCREEN.	0.33	0.27
TYPE IIIA	SAME AS TYPE III EXCEPT E: GLASS FIBER SCREEN WITH GREEN CERAMIC SPRAY COATING, OR GLASS FIBER SCREEN AND GRAY GLASS, OR GLASS FIBER SCREEN WITH LIGHT-SELECTING PRISMS.	0.25	0.18

¹All values are for 7 $\frac{3}{4}$ x 7 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. block, set in light-colored mortar. For 11 $\frac{3}{4}$ x 11 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. block increase coefficients by 15 per cent, and for 5 $\frac{3}{4}$ x 5 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. blocks reduce coefficients by 15 percent.

²Shading coefficients are to be applied to Heat Gain Factors for one hour earlier than the time for which the load calculation is made to allow for heat storage in the panel.

³Shading coefficients are for peak load condition, but provide a close approximation for other conditions.

⁴For NE, E, and SE panels in the shade add 50 percent to the values listed for panels in the shade.

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TABLE 2-32

U Values for Various Fenestration (For 7 $\frac{1}{2}$ mph Wind) Btu/h per (Square Foot) (Fahrenheit Degree)

TYPE OF GLASS	U VALUE	
	NO SHADING	SHADING
ANY SINGLE GLASS	1.06	0.81
INSULATING GLASS-3/16 IN. AIR SPACE	0.64	0.54
1/4 IN. AIR SPACE	0.61	0.52
1/2 IN. AIR SPACE	0.56	0.48
PRIME WINDOW PLUS STORM WINDOW -AIR SPACE 1 IN. OR MORE	0.54 ²	0.47 ²
DOUBLE GLAZING WITH BETWEEN-GLASS SHADING	NO SUPPLEMENTARY SHADING	
LOUVERED SUN SCREEN-IN CONTACT WITH GLASS	0.95	
-SEPARATED BY AIR SPACE	0.63	
VENETIAN BLINDS	0.44	
GLASS BLOCK PANELS ³		
TYPES I AND II	0.56	
TYPES II, III, AND IIIA	0.48	

¹Values apply to tightly closed Venetian blinds, draperies, and roller shades.

²Values apply to storm sash with a tight air space. Air leakage present in virtually all storm windows will, in effect, increase this value.

³Values listed for 7 $\frac{3}{4}$ x 7 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. block. For 11 $\frac{3}{4}$ x 11 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. block, reduce the listed value by 0.04, and for 5 $\frac{3}{4}$ x 5 $\frac{3}{4}$ x 3 $\frac{3}{4}$ in. block, increase the listed value by 0.04.

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TABLE 2-32A

Multiplying Factors for Various Types of Glass

TYPE OF GLASS	NORMAL INCIDENCE TRANSMITTANCE ¹	MULTIPLYING FACTORS FOR		
		SECTION 1	SECTION 2	SECTION 3
² SINGLE COMMON WINDOW GLASS ($\frac{1}{4}$ " THICK)	0.87	1.00	1.00	0.00
SINGLE REGULAR PLATE GLASS ($\frac{1}{4}$ " THICK)	0.77	0.87	1.00	0.25
SINGLE HEAT ABSORBING PLATE GLASS	0.53	0.48 (0.58 IN SHADE)	1.00	1.00
DOUBLE COMMON WINDOW GLASS	0.76	0.85	0.60	0.10
DOUBLE REGULAR PLATE GLASS	0.60	0.66 (0.76 IN SHADE)	0.60	0.55
HEAT ABSORBING PLATE (OUTDOORS) REGULAR PLATE GLASS (INDOORS)	0.35	0.37 (0.47 IN SHADE)	0.60	0.75

¹Standard Glass

²Part of Description only

TABLE 2-33

Transmission Through Standard Glass Blocks for March 22 and September 22*
(Btu/h per sq ft)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)								
		N	NE	E	SE	S	SW	W	NW	
NORTH LATITUDE MAR. 22 AND SEPT. 22	6 AM	-2	-2	-2	-2	-2	-2	-2	-2	SOUTH LATITUDE MAR. 22 AND SEPT. 22
	7 AM	2	45	53	77	8	2	2	2	
	8 AM	6	45	106	129	39	6	6	6	
	9 AM	10	34	140	157	78	11	11	11	
	10 AM	14	18	111	162	111	16	14	14	
	11 AM	17	18	63	104	135	46	18	17	
	12 NOON	19	20	27	108	145	91	20	19	
	1 PM	21	22	23	65	144	136	51	22	
	2 PM	22	23	23	31	128	165	102	24	
	3 PM	21	21	22	22	101	170	141	35	
	4 PM	19	19	19	19	65	155	155	63	
	5 PM	15	16	16	16	29	106	124	69	
	6 PM	10	10	10	10	11	26	29	21	
		S	SE	E	NE	N	NW	W	SW	
		DIRECTION FOR SOUTH LATITUDE (READ UP)								TIME OF YEAR

TABLE 2-34

Transmission Through Standard Glass Blocks for April 20 and August 24*
(Btu/h per sq ft)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)								
		N	NE	E	SE	S	SW	W	NW	
NORTH LATITUDE APRIL 20 AND AUG. 24	6 AM	3	44	53	31	0	0	0	1	SOUTH LATITUDE FEB. 20 AND OCT. 23
	7 AM	6	87	129	89	5	5	5	5	
	8 AM	7	87	156	128	21	8	7	7	
	9 AM	12	57	148	104	49	12	12	12	
	10 AM	15	26	114	141	77	16	16	15	
	11 AM	18	19	63	121	101	30	19	18	
	12 NOON	21	22	29	34	111	69	22	22	
	1 PM	22	23	24	45	110	113	51	23	
	2 PM	23	24	24	27	94	142	104	27	
	3 PM	22	22	23	33	70	154	146	54	
	4 PM	20	20	21	21	41	148	167	90	
	5 PM	18	18	18	15	21	119	155	104	
	6 PM	15	13	12	13	13	62	95	74	
		S	SE	E	NE	N	NW	W	SW	
		DIRECTION FOR SOUTH LATITUDE (READ UP)								TIME OF YEAR

TABLE 2-35

Transmission Through Standard Glass Blocks for May 21 and July 23*
(Btu/h per sq ft)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)								
		N	NE	E	SE	S	SW	W	NW	
NORTH LATITUDE MAY 21 AND JULY 23	6 AM	17	76	96	39	2	2	2	2	SOUTH LATITUDE NOV. 21 AND JAN. 21
	7 AM	14	114	144	81	6	6	6	6	
	8 AM	11	106	159	111	12	10	10	10	
	9 AM	13	75	145	122	27	14	13	13	
	10 AM	16	37	111	116	49	17	17	16	
	11 AM	19	23	63	54	68	22	20	20	
	12 NOON	21	22	28	62	77	39	22	22	
	1 PM	23	24	24	32	76	35	49	24	
	2 PM	24	25	25	26	64	117	100	35	
	3 PM	23	24	24	24	44	131	144	71	
	4 PM	22	22	23	23	28	128	168	108	
	5 PM	23	19	19	20	20	105	165	126	
	6 PM	31	15	15	15	15	69	128	110	
		S	SE	E	NE	N	NW	W	SW	
		DIRECTION FOR SOUTH LATITUDE (READ UP)								TIME OF YEAR

*Includes direct and diffuse solar radiation, also convection and absorbed radiation. For 40 degrees latitude. Based on air temperatures of 95 F and 78 F. Both inside and outside faces of blocks are smooth. No aluminum foil or glass fiber screen at parting line. Data includes heat transfer through mortar as blocks fill masonry opening.

TABLE 2-36

Transmission Through Standard Glass Blocks for June 21*
(Btu/h per sq ft)

TIME OF YEAR	SUN TIME	DIRECTIONS FOR NORTH LATITUDE (READ DOWN)								SOUTH LATITUDE DEC. 22
		N	NE	E	SE	S	SW	W	NW	
NORTH LATITUDE JUNE 21	6 AM	24	96	92	38	3	3	3	3	
	7 AM	20	122	147	78	7	7	7	7	
	8 AM	12	112	157	103	11	10	10	10	
	9 AM	13	81	143	111	22	14	13	13	
	10 AM	16	43	107	104	37	17	17	17	
	11 AM	19	23	60	84	55	21	20	20	
	12 NOON	21	22	28	53	62	45	22	22	
	1 PM	23	24	24	31	61	77	48	24	
	2 PM	24	25	25	29	50	103	97	46	
	3 PM	23	24	24	24	37	119	140	88	
	4 PM	22	23	23	23	26	119	165	126	
	5 PM	28	20	20	21	21	101	167	144	
	6 PM	39	16	16	16	16	67	134	128	
		S	SE	E	NE	N	NW	W	SW	
		DIRECTION FOR SOUTH LATITUDE (READ UP)								TIME OF YEAR

*Includes direct and diffuse solar radiation, also convection and absorbed radiation. For 40 degrees latitude. Based on air temperatures of 95 F and 78 F. Both inside and outside faces of blocks are smooth. No aluminum foil or glass fiber screen at parting line. Data includes heat transfer through mortar as blocks fill masonry opening.

TABLE 2-37

**Total Equivalent Temperature Differentials for Roofs for
March 22 and September 22#**

DESCRIPTION OF ROOF CONSTRUCTION*	SUN TIME							
	A.M.				P.M.			
	8	10	12	2	4	6	8	10
LIGHT CONSTRUCTION ROOFS-EXPOSED TO SUN								
1" WOOD**OR 1" WOOD + 1" OR 2" INSULATION	11.4	33.8	48.2	55.9	46.2	25.7	11.7	5.7
MEDIUM CONSTRUCTION ROOFS-EXPOSED TO SUN								
2" CONCRETE OR 2" CONCRETE + 1" OR 2" INSULATION OR 2" WOOD	6.4	26.8	42.5	51.9	45.8	30.8	15.3	8.0
2" GYPSUM OR 2" GYPSUM + 1" INSULATION 1" WOOD OR 2" WOOD OR 2" CONCRETE OR 2" GYPSUM } + 4" ROCK WOOL IN FURRED CEILING	1.3	18.4	35.8	46.9	49.2	39.1	20.4	13.3
4" CONCRETE OR 4" CONCRETE WITH 2" INSULATION	1.3	18.4	34.2	45.2	47.5	37.5	22.0	13.0
HEAVY CONSTRUCTION ROOFS-EXPOSED TO SUN								
6" CONCRETE 6" CONCRETE + 2" INSULATION	5.0 6.7	6.7 6.7	22.1 18.8	34.5 31.1	41.8 38.5	40.5 40.5	30.4 32.1	18.4 20.0
ROOFS COVERED WITH WATER-EXPOSED TO SUN								
LIGHT CONSTRUCTION ROOF WITH 1" WATER HEAVY CONSTRUCTION ROOF WITH 1" WATER ANY ROOF WITH 6" WATER	1.3 0 0	5.3 0 1.7	16.4 -1.3 2.3	22.4 11.0 8.3	19.3 15.0 12.3	15.7 17.0 12.3	11.7 15.3 10.3	4.0 11.7 6.5
ROOFS WITH ROOF SPRAYS-EXPOSED TO SUN								
LIGHT CONSTRUCTION HEAVY CONSTRUCTION	1.3 0	5.3 0	13.0 3.7	19.9 9.3	17.7 13.3	15.7 15.3	11.7 13.7	4.0 11.7
ROOFS IN SHADE								
LIGHT CONSTRUCTION MEDIUM CONSTRUCTION HEAVY CONSTRUCTION	-2.0 -2.0 0	2.0 0 0	8.0 4.0 2.0	14.0 10.0 6.0	16.0 14.0 10.0	14.0 14.0 12.0	10.0 12.0 12.0	4.0 8.0 10.0

*Includes 3/4" felt roofing with or without slag. May also be used for shingle roof

**Nominal thickness of wood

#Table 2-37 is for 40 degrees North latitude. It may also be used for 40 degrees South latitude for March 22 and September 22.

TABLE 2-38

**Total Equivalent Temperature Differentials for Roofs for
April 20 and August 24#**

DESCRIPTION OF ROOF CONSTRUCTION*	SUN TIME							
	A.M.			P.M.				
	8	10	12	2	4	6	8	10
LIGHT CONSTRUCTION ROOFS-EXPOSED TO SUN								
1" WOOD**OR 1" WOOD + 1" OR 2" INSULATION	14.0	40.0	56.0	64.0	52.0	21.0	12.0	6.0
MEDIUM CONSTRUCTION ROOFS-EXPOSED TO SUN								
2" CONCRETE OR 2" CONCRETE + 1" OR 2" INSULATION OR 2" WOOD	8.0	32.0	50.0	60.0	52.0	34.0	16.0	8.0
2" GYPSUM OR 2" GYPSUM + 1" INSULATION 1" WOOD OR 2" WOOD OR 2" CONCRETE OR } + 4" ROCK WOOL 2" GYPSUM } IN FURRED CEILING	2.0	22.0	42.0	54.0	56.0	44.0	22.0	12.0
4" CONCRETE OR 4" CONCRETE WITH 2" INSULATION	2.0	22.0	40.0	52.0	54.0	42.0	24.0	14.0
HEAVY CONSTRUCTION ROOFS-EXPOSED TO SUN								
8" CONCRETE	6.0	8.0	26.0	40.0	48.0	46.0	34.0	20.0
6" CONCRETE + 2" INSULATION	8.0	8.0	22.0	36.0	44.0	46.0	36.0	22.0
ROOFS COVERED WITH WATER-EXPOSED TO SUN								
LIGHT CONSTRUCTION ROOF WITH 1" WATER	2.0	6.0	18.0	24.0	20.0	16.0	12.0	4.0
HEAVY CONSTRUCTION ROOF WITH 1" WATER	0	0	-2.0	12.0	16.0	18.0	16.0	12.0
ANY ROOF WITH 6" WATER	0	2.0	2.0	8.0	12.0	12.0	10.0	6.0
ROOFS WITH ROOF SPRAYS-EXPOSED TO SUN								
LIGHT CONSTRUCTION	2.0	6.0	14.0	20.0	18.0	16.0	12.0	4.0
HEAVY CONSTRUCTION	0	0	4.0	10.0	14.0	16.0	14.0	12.0
ROOFS IN SHADE								
LIGHT CONSTRUCTION	-2.0	2.0	8.0	14.0	16.0	14.0	10.0	4.0
MEDIUM CONSTRUCTION	-2.0	0	4.0	10.0	14.0	14.0	12.0	8.0
HEAVY CONSTRUCTION	0	0	2.0	6.0	10.0	12.0	12.0	10.0

*Includes 3/8" felt roofing with or without slag. May also be used for shingle roof.

**Nominal thickness of wood.

#Table 2-38 is for 40 degrees North latitude. It may also be used for 40 degrees South latitude for February 20 and October 23.

TABLE 2-39
**Total Equivalent Temperature Differentials for Roofs for
 May 21 and July 23#**

DESCRIPTION OF ROOF CONSTRUCTION*	SUN TIME								
	A.M.			P.M.					
	8	10	12	2	4	6	8	10	12
LIGHT CONSTRUCTION ROOFS-EXPOSED TO SUN									
1" WOOD**OR 1" WOOD + 1" OR 2" INSULATION	15.3	43.1	60.0	68.1	55.0	29.2	12.2	6.2	2.0
MEDIUM CONSTRUCTION ROOFS-EXPOSED TO SUN									
2" CONCRETE OR 2" CONCRETE + 1" OR 2" INSULATION OR 2" WOOD	8.8	34.6	53.8	64.1	55.7	35.7	16.3	8.0	4.0
2" GYPSUM OR 2" GYPSUM + 1" INSULATION 1" WOOD OR 2" WOOD OR 2" CONCRETE OR 2" GYPSUM	2.3	23.8	45.1	57.6	58.5	46.5	22.8	12.3	8.3
4" CONCRETE OR 4" CONCRETE WITH 2" INSULATION	2.3	23.8	43.0	55.5	57.3	44.3	25.0	14.5	8.3
HEAVY CONSTRUCTION ROOFS-EXPOSED TO SUN									
6" CONCRETE 6" CONCRETE + 2" INSULATION	6.5 8.7	8.7 8.7	28.0 23.7	42.8 38.5	51.1 46.8	48.8 48.8	35.8 38.0	20.8 23.0	14.7 16.8
ROOFS COVERED WITH WATER-EXPOSED TO SUN									
LIGHT CONSTRUCTION ROOF WITH 1" WATER HEAVY CONSTRUCTION ROOF WITH 1" WATER ANY ROOF WITH 6" WATER	2.3 0 0	6.3 0 2.2	18.8 -2.3 2.2	24.8 12.5 7.8	20.3 16.5 11.8	16.2 18.5 11.8	12.2 16.3 9.8	4.0 12.2 5.8	2.0 8.2 1.8
ROOFS WITH ROOF SPRAYS-EXPOSED TO SUN									
LIGHT CONSTRUCTION HEAVY CONSTRUCTION	2.3 0	6.3 0	14.5 4.2	20.5 10.3	18.2 14.3	16.2 16.3	12.2 14.2	4.0 12.2	2.0 8.2
ROOFS IN SHADE									
LIGHT CONSTRUCTION MEDIUM CONSTRUCTION HEAVY CONSTRUCTION	-2.0 -2.0 0	2.0 0 0	8.0 4.0 2.0	14.0 10.0 6.0	16.0 14.0 12.0	14.0 14.0 12.0	10.0 12.0 12.0	4.0 8.0 10.0	2.0 4.0 6.0

*Includes 3/8" felt roofing with or without slag. May also be used for shingle roof.

**Nominal thickness of wood.

#Table 2-39 is for 40 degrees North latitude. It may also be used for 40 degrees South latitude for January 21 and November 21.

TABLE 2-40

Total Equivalent Temperature Differentials for Roofs for June 21#

DESCRIPTION OF ROOF CONSTRUCTION*	SUN TIME									
	A.M.			P.M.						
	8	10	12	2	4	6	8	10	12	
LIGHT CONSTRUCTION - ROOFS EXPOSED TO SUN										
1" WOOD**OR 1" WOOD + 1" OR 2" INSULATION	15.7	44.1	61.1	69.3	55.8	29.5	12.2	6.2	2.0	
MEDIUM CONSTRUCTION - ROOFS EXPOSED TO SUN										
2" CONCRETE OR 2" CONCRETE + 1" OR 2" INSULATION OR 2" WOOD	9.1	35.4	54.1	65.3	55.1	36.1	16.4	8.0	4.0	
2" GYPSUM OR 2" GYPSUM + 1" INSULATION 1" WOOD OR 2" WOOD OR 2" CONCRETE OR 2" GYPSUM } + 4" ROCK WOOL IN FURRED CEILING	2.4	24.3	46.1	58.7	60.5	47.2	23.1	12.4	8.4	
4" CONCRETE OR 4" CONCRETE WITH 2" INSULATION	2.4	24.3	43.8	56.5	58.3	45.0	23.3	14.6	8.4	
HEAVY CONSTRUCTION - ROOFS EXPOSED TO SUN										
6" CONCRETE	6.5	30.2	50.6	63.6	52.1	49.6	36.3	21.1	12.6	
6" CONCRETE + 2" INSULATION	8.0	5.8	24.1	39.2	47.6	49.6	39.6	23.3	17.1	
ROOFS COVERED WITH WATER EXPOSED TO SUN										
LIGHT CONSTRUCTION ROOF WITH 1" WATER	2.4	6.4	10.1	25.1	20.4	16.2	12.2	4.0	2.0	
HEAVY CONSTRUCTION ROOF WITH 1" WATER	0	0	-2.4	12.6	16.6	18.6	16.4	12.2	8.2	
ANY ROOF WITH 6" WATER	0	2.2	2.2	7.9	11.8	11.8	9.8	5.8	1.8	
ROOFS WITH ROOF SPRING EXPOSED TO SUN										
LIGHT CONSTRUCTION	2.4	6.4	14.6	20.6	18.2	16.2	12.2	4.0	2.0	
HEAVY CONSTRUCTION	0	0	4.2	10.4	14.4	16.4	14.2	12.2	8.2	
ROOFS IN SHADE										
LIGHT CONSTRUCTION	-2.0	0.0	8.0	14.0	16.0	14.0	10.0	4.0	2.0	
MEDIUM CONSTRUCTION	-2.0	0	4.0	10.0	14.0	14.0	12.0	8.0	4.0	
HEAVY CONSTRUCTION	0	0	2.0	6.0	10.0	12.0	12.0	10.0	6.0	

*Includes 3/8" felt roofing with or without slag. May also be used for shingle roof.

**Nominal thickness of wood.

#Table 2-40 is for 40 degrees North latitude. It may also be used for 40 degrees South latitude for December 22.

TABLE 2-41
Total Equivalent Temperature Differentials for Walls for
March 22 and September 22*

NORTH LATITUDE		SUN TIME																SOUTH LATITUDE			
		A.M.								P.M.											
		8		10		12		2		4		6		8		10				12	
		EXTERIOR COLOR D = DARK L = LIGHT																			
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L		
FRAME																					
(SHADE)		NE	11	5	13	7	11	9	13	12	10	16	15	15	11	11	7	8	3	3	SE
		E	29	14	35	18	22	17	14	14	16	16	13	16	12	12	8	8	4	4	E
		SE	20	11	38	23	37	24	50	20	19	16	17	17	13	13	9	8	5	3	NE
		S	-2	-2	11	4	40	21	50	31	39	27	22	18	14	14	10	10	6	6	N
		SW	-2	-2	3	0	9	8	32	27	49	34	52	34	30	25	0	6	5	5	NW
		W	-2	-2	2	2	8	8	21	14	40	29	47	34	23	23	10	10	4	4	W
		NW	-2	-2	1	0	7	6	13	12	21	19	28	21	23	18	7	6	3	3	SW
		N	-2	-2	0	0	6	6	12	12	16	16	14	14	10	10	6	6	2	2	S (SHADE)
4" BRICK OR STONE VENEER + FRAME																					
(SHADE)		NE	-1	-2	13	7	12	7	10	8	13	12	15	15	14	14	11	11	7	6	SE
		E	3	2	29	15	30	18	15	15	14	14	16	16	14	14	12	10	8	8	E
		SE	6	1	23	15	38	21	33	21	22	17	17	17	14	14	13	10	9	9	NE
		S	-2	-2	0	0	25	13	42	27	42	27	29	22	14	14	10	10	6	6	N
		SW	3	1	3	0	5	5	16	11	40	27	45	32	22	29	13	10	9	9	NW
		W	2	0	2	2	6	4	12	10	27	19	40	29	41	29	17	15	8	8	W
		NW	-2	-2	0	0	3	3	9	8	13	13	23	19	25	20	12	11	7	7	SW
		N	-2	-2	0	0	2	2	8	8	12	12	14	14	14	14	10	10	6	6	S (SHADE)
8" HOLLOW TILE OR 8" CINDER BLOCK																					
(SHADE)		NE	1	1	1	1	11	6	10	7	10	3	13	12	14	13	13	12	9	9	SE
		E	5	4	13	5	24	13	26	15	21	13	14	12	16	14	16	12	12	10	E
		SE	5	3	5	3	23	13	27	17	26	18	17	15	17	15	15	12	11	8	NE
		S	4	4	4	4	8	4	25	13	42	23	42	23	31	20	16	12	12	8	N
		SW	5	3	5	3	5	3	10	7	16	13	32	22	38	25	32	22	11	6	NW
		W	5	4	5	4	5	4	7	6	12	10	19	16	30	23	32	23	19	15	W
		NW	1	1	1	1	2	1	4	3	9	8	13	12	18	16	22	18	10	9	SW
		N	0	0	0	0	0	0	2	2	8	8	12	12	12	12	12	12	6	6	S (SHADE)
8" BRICK OR 12" HOLLOW TILE OR 12" CINDER BLOCK																					
(SHADE)		NE	3	3	3	3	7	3	10	6	10	7	10	8	11	10	11	11	10	9	SE
		E	9	7	9	7	13	9	18	11	19	11	15	10	15	12	15	12	13	12	E
		SE	12	7	10	7	10	7	20	15	24	17	21	16	15	13	15	13	16	13	NE
		S	10	6	10	6	10	6	10	6	10	12	27	16	25	18	18	14	16	12	N
		SW	12	7	10	7	10	7	12	7	14	9	16	11	25	15	30	20	26	18	NW
		W	9	6	7	6	7	7	9	7	11	8	15	10	21	17	25	17	24	17	W
		NW	3	3	3	3	3	3	4	3	6	5	9	8	11	10	14	13	14	12	SW
		N	2	2	2	2	2	2	2	2	4	4	6	6	10	10	10	10	8	8	S (SHADE)
12" BRICK																					
(SHADE)		NE	8	7	7	6	7	5	7	5	8	5	9	6	9	6	9	7	10	8	SE
		E	13	10	13	9	13	9	11	8	13	9	15	11	15	11	15	10	15	10	E
		SE	14	9	14	9	14	9	14	9	14	9	17	12	19	14	19	14	16	11	N
		S	14	10	15	12	12	8	12	8	12	6	15	8	19	12	21	14	19	12	NE
		SW	14	9	14	9	14	9	14	9	14	9	16	12	14	12	16	11	18	13	NW
		W	13	10	13	9	13	9	11	8	11	8	11	8	11	8	13	10	17	12	W
		NW	8	7	7	6	7	5	7	5	7	5	7	5	7	5	9	7	10	8	SW
		N	6	6	4	4	4	4	4	4	4	4	4	4	4	4	6	6	8	8	S (SHADE)
8" CONCRETE OR STONE OR 8" CONCRETE BLOCK																					
(SHADE)		NE	5	4	4	3	4	3	5	4	5	7	12	10	14	12	12	10	9	8	SE
		E	7	6	15	9	24	13	24	13	19	11	13	12	15	12	13	12	11	10	E
		SE	10	5	10	7	22	15	24	17	24	10	13	10	15	13	16	13	14	11	N
		S	6	4	6	4	10	4	23	12	20	21	31	19	21	18	16	12	14	10	NE
		SW	10	5	7	5	10	5	12	7	13	14	28	21	30	20	28	21	14	11	NW
		W	7	6	7	6	7	6	5	8	13	10	21	15	23	19	29	19	15	11	W
		NW	4	3	4	3	4	3	5	5	7	7	11	10	18	13	18	13	8	7	SW
		N	2	2	2	2	2	2	2	2	4	4	8	8	10	10	8	8	6	6	S (SHADE)
12" CONCRETE OR STONE																					
(SHADE)		NE	9	4	5	3	5	3	6	6	10	7	14	8	10	8	12	11	10	9	SE
		E	11	7	9	7	11	7	18	11	19	13	17	11	13	12	15	12	15	12	E
		SE	12	7	12	7	10	7	20	12	22	14	21	14	10	13	15	13	16	13	N
		S	13	10	10	8	10	8	10	6	19	12	23	17	27	19	21	14	16	12	NE
		SW	12	7	12	7	10	7	10	7	12	7	14	11	23	18	23	18	23	16	NW
		W	11	7	9	7	9	7	11	7	11	8	13	10	17	12	23	15	23	15	W
		NW	5	4	5	3	5	3	6	4	6	8	9	7	10	9	15	12	15	12	SW
		N	2	2	2	2	2	2	2	2	4	4	6	6	8	8	10	10	8	8	S (SHADE)

*Table 2-41 is for March 22 and September 22 both N and S latitude.

TABLE 2-42

Total Equivalent Temperature Differentials for
Walls for April 20 and August 24*

NORTH LATITUDE		SUN TIME																SOUTH LATITUDE			
		A.M.								P.M.											
		8		10		12		2		4		6		8		10				12	
		SUNSHINE HOURS PER DAY																			
		D		L		D		L		D		L		D		L		D		L	
		L = LIGHT																			
		FRAME																			
(SHADE)	NE	19	9	21	11	14	11	14	12	16	15	16	12	12	8	6	4	4	SE		
	E	32	16	33	20	34	18	14	14	19	16	15	16	12	12	8	8	4	4	E	
	SE	19	10	33	21	34	22	24	19	18	18	16	16	12	12	8	8	4	4	NE	
	S	-2	-2	9	3	32	15	41	28	33	25	20	17	13	13	9	9	5	5	N	
	SW	-2	-2	2	0	9	8	31	23	28	18	17	15	10	10	8	6	4	4	NW	
	W	-2	-2	2	0	9	8	22	14	12	10	10	10	10	10	10	10	10	4	4	W
(SHADE)	NW	-2	-2	2	0	8	6	14	12	24	21	27	24	31	23	8	6	4	4	SW	
	N	-2	-2	0	0	8	6	12	12	18	16	14	14	10	10	6	6	2	2	S (SHADE)	
	4" BRICK OR STONE OR 6" CONCRETE BLOCK																				
	NE	0	-2	21	11	16	10	11	8	13	12	10	16	14	14	12	12	8	6	SE	
	E	4	2	32	16	33	19	16	13	14	14	10	16	14	14	12	10	8	8	E	
	SE	5	0	26	14	28	21	31	20	21	17	16	16	14	14	12	10	8	8	NE	
(SHADE)	S	-2	-2	9	3	19	11	24	22	25	24	23	20	14	14	10	10	6	6	N	
	SW	3	0	2	0	4	4	11	10	16	15	12	10	10	10	12	10	8	8	NW	
	W	2	0	2	0	6	4	12	10	28	20	16	16	14	14	18	16	9	8	W	
	NW	-2	-2	0	0	4	4	10	8	14	14	20	22	22	24	19	12	8	8	SW	
	N	-2	-2	0	0	2	2	8	8	12	12	14	14	14	14	10	10	6	6	S (SHADE)	
	8" HOLLOW TILE OR 8" CINDER BLOCK																				
(SHADE)	NE	2	2	2	2	16	10	15	10	11	8	12	13	15	14	14	12	10	10	SE	
	E	6	4	14	6	26	14	23	16	22	14	14	12	16	14	16	12	12	10	E	
	SE	5	2	5	2	21	12	25	16	24	17	17	14	17	14	14	12	10	8	NE	
	S	3	3	3	3	6	3	19	11	24	20	35	21	26	18	15	12	11	8	N	
	SW	5	2	5	2	3	2	9	7	15	13	31	21	35	24	31	21	10	8	NW	
	W	6	4	6	4	6	4	8	6	12	10	20	16	32	24	34	24	20	16	W	
(SHADE)	NW	2	2	2	2	3	2	5	4	10	8	14	12	22	19	28	22	11	10	SW	
	N	0	0	0	0	0	0	2	2	6	6	12	12	12	12	12	12	8	8	S (SHADE)	
	8" BRICK OR 12" HOLLOW TILE OR 14" CINDER BLOCK																				
	NE	4	4	4	4	10	4	15	9	14	9	11	8	12	10	12	12	11	10	SE	
	E	10	8	10	8	15	10	20	12	20	12	18	10	16	12	16	12	14	12	E	
	SE	11	7	9	7	9	7	18	14	18	16	20	15	15	12	15	12	15	13	NE	
(SHADE)	S	11	5	9	5	8	5	16	10	22	14	22	14	16	13	14	12	14	11	N	
	SW	11	7	9	7	9	7	11	7	13	9	15	10	24	15	20	19	24	17	NW	
	W	10	8	10	8	8	8	10	8	12	8	16	10	22	16	26	18	26	18	W	
	NW	4	4	4	4	4	4	5	4	7	6	10	8	12	10	17	15	18	15	SW	
	N	2	2	2	2	2	2	2	2	4	4	8	8	10	10	10	10	8	8	S (SHADE)	
	12" BRICK																				
(SHADE)	NE	9	8	9	7	9	6	9	5	11	6	12	7	12	7	11	8	11	8	SE	
	E	14	10	14	10	14	10	12	8	14	10	13	12	16	12	16	10	16	10	E	
	SE	13	8	13	8	13	8	13	9	15	9	15	11	15	13	18	13	15	10	N	
	S	12	8	13	10	10	7	10	7	10	7	13	7	16	10	18	12	17	11	NE	
	SW	13	8	13	8	13	8	13	9	13	9	13	11	15	11	15	11	17	13	NW	
	W	14	10	14	10	14	10	12	8	12	8	12	8	12	8	14	10	18	12	W	
(SHADE)	NW	9	8	9	7	9	6	9	5	9	6	9	6	9	7	11	8	11	8	SW	
	N	6	6	4	4	4	4	4	4	4	4	4	4	4	4	6	6	8	8	S (SHADE)	
	8" CONCRETE OR STONE OR 12" CONCRETE BLOCK																				
	NE	7	2	5	4	5	4	5	4	11	8	15	11	17	13	15	11	11	8	SE	
	E	2	0	16	10	26	14	26	14	20	12	18	12	16	12	14	12	12	10	E	
	SE	9	4	9	7	21	12	23	13	22	15	17	15	15	12	15	13	13	11	N	
(SHADE)	S	5	3	5	3	6	3	19	10	23	16	25	17	19	16	14	11	12	9	NE	
	SW	9	4	7	4	9	2	11	6	15	13	27	20	29	19	27	20	13	11	NW	
	W	8	6	8	6	8	6	10	8	14	10	22	16	30	20	29	20	16	12	W	
	NW	5	4	5	2	5	4	6	4	9	3	13	11	20	15	21	16	9	8	SW	
	N	2	2	2	2	2	2	4	4	6	6	9	8	10	10	8	8	6	6	S (SHADE)	
	12" CONCRETE OR STONE																				
(SHADE)	NE	7	2	7	4	7	4	13	9	13	9	11	9	11	10	13	12	11	10	SE	
	E	12	8	10	8	12	8	20	12	20	14	18	12	14	12	18	12	16	12	E	
	SE	11	7	11	7	9	7	13	11	20	13	20	13	17	13	15	12	15	13	N	
	S	11	5	8	5	8	5	8	5	15	10	20	15	22	17	19	13	14	11	NE	
	SW	11	7	11	7	9	7	9	7	11	9	13	11	22	17	24	17	22	15	NW	
	W	12	8	10	8	10	8	12	8	12	8	14	10	10	12	26	16	24	16	W	
(SHADE)	NW	7	5	7	4	7	4	7	5	7	6	9	8	11	10	16	13	20	15	SW	
	N	2	2	2	2	2	2	2	2	4	4	6	6	9	8	10	10	8	8	S (SHADE)	

*Table 2-42 is for 40 degrees latitude. It may be used for south latitude for February 20 and October 23.

TABLE 2-43

**Total Equivalent Temperature Differentials for
Walls for May 21 and July 23***

NORTH LATITUDE	SUN TIME														SOUTH LATITUDE
	A.M.						P.M.								
	8	10	12	2	4	6	8	10	12						
	EXTERIOR COLOR D = DARK L = LIGHT														
	D	L	D	L	D	L	D	L	D	L	D	L	D	L	
FRAME															
NE	24	12	26	14	16	12	14	12	16	16	16	16	12	12	SE
E	32	16	38	20	34	18	14	14	16	16	16	16	12	12	E
SE	15	8	28	18	30	20	26	18	18	16	16	16	12	12	NE
S	-2	-2	6	2	24	14	32	22	28	22	18	16	12	12	N
SW	-2	-2	2	0	8	6	28	24	42	30	44	30	26	22	NW
W	-2	-2	2	2	8	8	22	14	42	30	50	36	24	24	W
NW	-2	-2	2	0	8	6	14	12	26	22	42	28	36	28	SW
(SHADE) N	-2	-2	0	0	6	6	12	12	16	16	14	14	10	10	S (SHADE)
4" BRICK OR STONE VENEER + FRAME															
NE	0	-2	26	14	22	12	12	8	14	12	16	16	14	14	SE
E	4	2	32	16	33	19	16	16	14	14	16	16	14	14	E
SE	4	0	22	12	30	18	28	18	20	16	16	16	14	14	NE
S	-2	-2	0	0	14	8	26	18	20	20	22	18	14	14	N
SW	2	0	2	0	4	4	14	10	34	24	38	28	36	26	NW
W	2	0	2	2	6	4	12	10	28	20	42	30	44	30	W
NW	-2	-2	0	0	4	4	10	8	14	14	32	24	36	28	SW
(SHADE) N	-2	-2	0	0	2	2	8	8	12	12	14	14	10	10	S (SHADE)
8" HOLLOW TILE OR 8" CINDER BLOCK															
NE	2	2	2	2	22	12	18	12	12	8	14	12	16	14	SE
E	6	4	14	6	26	14	28	16	22	14	14	12	16	14	E
SE	4	2	4	2	18	10	22	14	22	16	16	14	16	14	NE
S	2	2	2	2	4	2	14	8	26	16	28	18	22	16	N
SW	4	2	4	2	4	2	8	6	14	12	28	20	32	22	NW
W	6	4	6	4	6	4	8	6	12	10	20	16	32	24	W
NW	2	2	2	2	4	2	6	4	10	8	14	12	24	20	SW
(SHADE) N	0	0	0	0	0	0	2	2	8	8	12	12	12	12	S (SHADE)
8" BRICK OR 12" HOLLOW TILE OR 12" CINDER BLOCK															
NE	4	4	4	4	12	4	18	10	16	10	12	8	12	10	SE
E	10	8	10	8	16	10	20	12	20	12	16	10	16	12	E
SE	10	6	8	6	8	6	16	12	20	14	18	14	14	12	NE
S	6	4	6	4	6	4	6	4	12	8	18	12	18	14	N
SW	10	6	8	6	8	6	10	6	12	8	14	10	22	14	NW
W	10	6	8	6	8	6	8	6	12	8	16	10	22	18	W
NW	4	4	4	4	4	4	6	4	8	6	10	8	12	10	SW
(SHADE) N	2	2	2	2	2	2	2	2	4	4	8	8	10	10	S (SHADE)
12" BRICK															
NE	10	8	10	8	10	6	10	6	12	8	14	8	14	8	SE
E	14	10	14	10	14	10	12	8	14	10	16	12	16	10	E
SE	12	8	12	8	12	8	12	8	14	10	16	12	16	12	N
S	10	8	10	8	8	6	8	6	10	6	12	8	14	10	NE
SW	12	8	12	8	12	8	12	8	12	10	12	10	14	10	NW
W	14	10	14	10	14	10	12	8	12	8	12	8	14	10	W
NW	10	8	10	8	10	6	10	6	10	6	10	6	12	8	SW
(SHADE) N	6	6	4	4	4	4	4	4	4	4	4	4	6	6	S (SHADE)
8" CONCRETE OR STONE OR 8" OR 8" CONCRETE BLOCK															
NE	8	6	8	4	6	4	6	4	12	8	16	12	16	12	SE
E	8	6	16	10	26	14	26	14	20	12	16	12	14	12	E
SE	8	4	8	6	18	12	20	14	20	14	16	14	14	12	N
S	4	3	4	3	6	3	14	8	18	14	20	14	16	14	NE
SW	8	4	6	4	8	4	10	6	16	12	24	18	28	18	NW
W	8	6	8	6	6	6	10	8	14	10	22	16	30	20	W
NW	6	4	6	2	6	4	6	6	8	8	14	12	22	16	SW
(SHADE) N	2	2	2	2	2	2	4	4	6	6	8	8	10	10	S (SHADE)
12" CONCRETE OR STONE															
NE	8	6	8	4	8	4	16	10	16	10	12	10	14	12	SE
E	12	8	10	8	12	8	20	12	20	14	18	12	14	12	E
SE	10	6	10	6	8	6	16	10	16	12	18	12	14	12	N
S	6	6	6	4	6	4	6	4	12	8	16	12	18	14	NE
SW	10	6	10	6	8	6	8	6	10	8	12	10	20	16	NW
W	12	8	10	8	10	8	12	8	14	10	18	12	26	16	W
NW	8	6	8	4	8	4	8	6	8	6	10	8	20	14	SW
(SHADE) N	2	2	2	2	2	2	2	2	4	4	6	6	10	10	S (SHADE)

*Table 2-43 is for 40 degrees North latitude. It may be used for 40 degrees South latitude for January 21 and November 21.

TABLE 2-44

Total Equivalent Temperature Differentials for Walls for June 21*

NORTH LATITUDE	SUN TIME												SOUTH LATITUDE							
	A.M.						P.M.													
	8	10	12	2	4	6	8	10	12											
	EXTERIOR COLOR D = DARK L = LIGHT																			
	D	L	D	L	D	L	D	L	D	L	D	L								
FRAME																				
(SHADE)	NE	26	13	28	15	17	12	14	12	16	16	12	12	8	6	4	4	SE		
	E	32	16	38	20	34	18	14	14	16	16	16	16	12	12	8	8	E		
	SE	14	7	26	17	28	19	25	18	18	16	16	16	12	12	8	6	NE		
	S	-2	-2	5	2	21	13	28	20	26	21	17	16	12	12	8	8	N		
	SW	-2	-2	2	0	8	6	27	23	40	29	42	29	25	21	8	6	NW		
	W	-2	-2	2	2	8	8	22	14	42	30	50	36	24	24	10	10	W		
	NW	-2	-2	2	0	8	6	14	12	27	22	44	29	38	27	8	6	SW		
	N	-2	-2	0	0	6	6	12	12	16	16	14	14	10	10	6	6	S (SHADE)		
4" BRICK OR STONE VENEER + FRAME																				
(SHADE)	NE	0	-2	28	15	23	13	12	8	14	12	16	16	14	14	12	12	8	6	SE
	E	4	2	32	16	33	19	16	16	14	14	16	16	14	14	12	10	8	8	E
	SE	4	0	20	11	28	17	26	17	19	16	16	16	14	14	12	10	8	8	NE
	S	-2	-2	0	0	12	7	23	16	25	19	21	17	14	14	10	10	6	6	N
	SW	2	0	2	0	4	4	14	10	32	23	36	27	34	25	12	10	8	8	NW
	W	2	0	2	2	6	4	12	10	28	20	42	30	44	30	18	16	8	8	W
	NW	-2	-2	0	0	4	4	10	8	14	14	33	25	38	27	14	12	8	8	SW
	N	-2	-2	0	0	2	2	8	8	12	12	14	14	14	14	10	10	6	6	S (SHADE)
6" HOLLOW TILE OR 6" CINDER BLOCK																				
(SHADE)	NE	2	2	2	2	23	13	19	13	12	8	14	12	16	14	14	12	10	10	SE
	E	6	4	14	8	26	14	28	16	22	14	14	12	16	14	16	12	12	10	E
	SE	4	2	4	2	17	9	20	13	21	15	16	14	16	14	14	12	10	8	NE
	S	2	2	2	2	3	2	12	7	23	15	25	17	20	15	14	12	10	8	N
	SW	4	2	4	2	4	2	8	6	14	12	27	19	31	21	27	19	10	8	NW
	W	6	4	6	4	6	4	8	6	12	10	20	16	32	24	34	24	20	16	W
	NW	2	2	2	2	4	2	6	4	10	8	14	12	25	21	33	25	12	10	SW
	N	0	0	0	0	0	0	2	2	8	8	12	12	12	12	12	12	8	8	S (SHADE)
8" BRICK OR 12" HOLLOW TILE OR 12" CINDER BLOCK																				
(SHADE)	NE	4	4	4	4	13	4	19	11	17	10	12	8	12	10	12	12	12	10	SE
	E	10	8	10	8	16	10	20	12	20	12	16	10	16	12	16	12	14	12	E
	SE	9	6	8	6	8	6	15	11	19	13	17	14	14	12	14	12	14	12	NE
	S	5	4	5	4	5	4	5	4	11	7	16	11	17	13	13	12	11	10	N
	SW	9	6	8	6	8	6	9	8	11	8	14	10	21	14	25	17	21	15	NW
	W	10	8	8	6	8	6	10	8	12	8	16	10	22	18	26	18	26	18	W
	NW	4	4	4	4	4	4	6	4	8	6	10	8	12	10	19	16	21	17	SW
	N	2	2	2	2	2	2	2	2	4	4	8	8	10	10	10	10	8	8	S (SHADE)
12" BRICK																				
(SHADE)	NE	10	8	10	8	10	6	10	6	13	8	15	8	15	8	12	8	12	8	SE
	E	14	10	14	10	14	10	12	8	14	10	16	12	16	12	16	10	16	10	E
	SE	12	8	11	8	11	8	11	8	11	8	13	10	15	11	15	12	14	10	N
	S	9	8	9	7	7	6	7	6	7	6	9	6	11	7	13	9	13	10	NE
	SW	12	8	11	8	11	8	11	8	11	8	11	10	11	10	13	10	15	12	NW
	W	14	10	14	10	14	10	12	8	12	8	12	8	12	8	14	10	18	12	W
	NW	10	8	10	8	10	6	10	6	10	6	10	6	10	8	12	8	12	8	SW
	N	6	6	4	4	4	4	4	4	4	4	4	4	4	4	6	6	8	8	S (SHADE)
8" CONCRETE OR STONE OR 6" OR 8" CONCRETE BLOCK																				
(SHADE)	NE	8	6	8	4	6	4	6	4	12	8	17	12	19	14	17	12	12	10	SE
	E	8	6	16	10	26	14	26	14	20	12	16	12	16	12	14	12	12	10	E
	SE	8	4	8	6	17	11	19	13	19	13	15	14	14	12	14	12	12	10	N
	S	4	3	4	3	5	3	12	7	16	13	18	13	15	13	11	10	9	8	NE
	SW	8	4	8	4	8	4	10	6	15	12	23	17	25	17	23	17	12	10	NW
	W	8	6	8	6	8	6	10	8	14	10	22	16	30	20	28	20	16	12	W
	NW	8	4	6	2	6	4	6	6	8	8	14	12	23	16	25	19	10	8	SW
	N	2	2	2	2	2	2	4	4	6	6	8	8	10	10	8	8	6	6	S (SHADE)
12" CONCRETE OR STONE																				
(SHADE)	NE	8	8	8	4	8	4	17	11	17	10	12	10	12	10	14	12	12	10	SE
	E	12	8	10	8	12	8	20	12	20	14	18	12	14	12	16	12	16	12	E
	SE	9	6	9	6	8	6	15	9	17	11	17	12	15	12	14	12	14	12	N
	S	7	5	5	4	5	4	5	4	11	7	14	11	16	13	15	12	11	10	NE
	SW	9	6	9	6	8	6	8	6	10	8	12	10	19	15	21	16	19	14	NW
	W	12	8	10	8	10	8	12	8	12	8	14	10	18	12	26	18	24	16	W
	NW	8	6	8	4	8	4	8	6	8	6	10	8	12	10	21	14	23	17	SW
	N	2	2	2	2	2	2	2	2	4	4	6	6	8	8	10	10	8	8	S (SHADE)

*Table 2-44 is for 40 degrees North latitude. It may be used for 40 degrees South latitude for December 22.

TABLE 2-45
**Outside Design Temperatures And Latitudes
 For Various Cities In The United States**

STATE	CITY	DESIGN TEMP.		NORTH LATITUDE, DEGREES
		DB	WB	
ALABAMA	ANNISTON	95	75	33
	BIRMINGHAM	95	78	33
	MOBILE	95	80	31
ALASKA	JUNEAU	65	52	58
ARIZONA	PHOENIX	105	76	33
	TUCSON	105	72	32
ARKANSAS	LITTLE ROCK	95	78	35
CALIFORNIA	FRESNO	105	74	37
	LOS ANGELES	90	70	34
	SACRAMENTO	100	72	38
	SAN FRANCISCO	85	65	38
COLORADO	DENVER	95	64	40
	PUEBLO	95	65	38
CONNECTICUT	HARTFORD	93	75	42
DELAWARE	WILMINGTON	95	78	40
DISTRICT OF COLUMBIA	WASHINGTON	95	78	39
FLORIDA	JACKSONVILLE	95	78	30
	MIAMI	91	79	26
GEORGIA	ATLANTA	95	76	34
	SAVANNAH	95	78	32
HAWAII	HONOLULU	83	73	21
IDAHO	BOISE	95	65	44
	POCATELLO	95	65	43
ILLINOIS	CHICAGO	95	75	43
	PEORIA	96	76	43
	SPRINGFIELD	98	77	42
INDIANA	EVANSVILLE	95	78	38
	FORT WAYNE	95	75	41
	INDIANAPOLIS	95	76	40
IOWA	DES MOINES	95	78	42
	DUBUQUE	95	78	42
	SIOUX CITY	95	78	42
KANSAS	KANSAS CITY	100	76	39
	WICHITA	100	75	38
KENTUCKY	ASHLAND	95	76	38
	LOUISVILLE	95	78	38
LOUISIANA	NEW ORLEANS	95	80	30
	SHREVEPORT	100	78	32
MAINE	PORTLAND	90	73	44
MARYLAND	BALTIMORE	95	78	39
MASSACHUSETTS	BOSTON	92	75	42
	HOLYOKE	93	75	42

TABLE 2-45 (CONTINUED)

**Outside Design Temperatures And Latitudes
For Various Cities In The United States**

STATE	CITY	DESIGN TEMP.		NORTH LATITUDE, DEGREES
		DB	WB	
MICHIGAN	DETROIT	95	75	42
	GRAND RAPIDS	95	75	43
MINNESOTA	DULUTH	93	73	47
	MINNEAPOLIS	95	75	45
MISSISSIPPI	JACKSON	95	78	32
	KANSAS CITY	100	76	39
MISSOURI	SPRINGFIELD	100	75	37
	ST. LOUIS	95	78	39
MONTANA	BILLINGS	90	66	46
	HELENA	95	67	46
NEBRASKA	LINCOLN	95	78	41
	OMAHA	95	78	41
NEVADA	RENO	95	65	39
NEW HAMPSHIRE	CONCORD	90	73	43
NEW JERSEY	TRENTON	95	78	40
NEW MEXICO	ALBUQUERQUE	95	70	35
	SANTA FE	95	65	36
NEW YORK	ALBANY	93	75	43
	BUFFALO	93	73	43
	NEW YORK	95	75	41
NORTH CAROLINA	ASHEVILLE	93	75	36
	GREENSBORO	95	78	36
NORTH DAKOTA	BISMARCK	95	73	47
OHIO	CINCINNATI	95	78	39
	CLEVELAND	95	75	42
OKLAHOMA	OKLAHOMA CITY	101	77	35
	TULSA	101	77	36
OREGON	PORTLAND	90	68	45
PENNSYLVANIA	PHILADELPHIA	95	78	40
	PITTSBURGH	95	75	40
RHODE ISLAND	PROVIDENCE	93	75	42
SOUTH CAROLINA	CHARLESTON	95	78	33
	GREENVILLE	95	75	35
SOUTH DAKOTA	RAPID CITY	95	70	44
TENNESSEE	CHATTANOOGA	95	76	35
	MEMPHIS	95	78	35
TEXAS	DALLAS	100	78	33
	EL PASO	100	69	32
	GALVESTON	95	80	29
	HOUSTON	95	80	30
	SAN ANTONIO	100	78	29
UTAH	SALT LAKE CITY	95	64	41
VIRGINIA	NORFOLK	95	78	37
	RICHMOND	95	78	38
	ROANOKE	95	78	37
WASHINGTON	SEATTLE	85	65	48
	SPOKANE	95	65	47
WEST VIRGINIA	CHARLESTON	95	75	42
WISCONSIN	EAU CLAIRE	95	75	45
	MADISON	95	75	43
	MILWAUKEE	95	75	43
WYOMING	CHEYENNE	95	65	41

TABLE 2-46

Approximate Time of Day at which Solar Heat Gains are a MaximumFor Latitude North of 20 Degrees in Northern Hemisphere
Unequal Window Areas in Various Walls

WINDOWS IN 4 WALLS	WINDOWS FACE IN FOLLOWING DIRECTIONS		SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS	
	LARGEST GLASS AREAS IN THESE WALLS	SMALLEST GLASS AREAS IN THESE WALLS	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE
	N AND S NE AND SW	E AND W SE AND NW	10 OR 2 8 OR 4	2 3	10 OR 2 8 OR 4	2 3
	E AND W SE AND NW	S AND N SW AND NE	9 OR 4 8 OR 4	3 4	8 OR 4 8 OR 4	3 3

WINDOWS IN 3 WALLS	WINDOWS FACE IN FOLLOWING DIRECTIONS		SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS	
	LARGEST GLASS AREAS IN THESE WALLS	SMALLEST GLASS AREAS IN THESE WALLS	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE
	N	E AND W	8 OR 4	3	8 OR 4	3
	N AND S	W	2	2	2	2
	N AND S	E	10	1	10	1
	NE	SE AND NW	8	8 OR 3	8	3
	NE AND SW	NW	4	3	4	3
	NE AND SW	SE	8	3	8	2
	E	S AND N	8	10 OR 2	8	10 OR 2
	E AND W	N	8 OR 4	3	8 OR 4	3
	E AND W	S	9 OR 4	3	8 OR 4	3
	SE	SW AND NE	8	9 OR 2	8	2
	SE AND NW	NE	8	4	8	4
	SE AND NW	SW	4	4	4	4

WINDOWS IN 3 WALLS	LARGEST GLASS AREAS IN THESE WALLS	SMALLEST GLASS AREAS IN THESE WALLS	S	E AND W	10 OR 2	2	10 OR 2	2
			SW	SE AND NW	4	3	4	3
			W	S AND N	4	3	4	3
			NW	SW AND NE	4	4	4	3

WINDOWS IN 2 WALLS	WINDOWS FACE IN FOLLOWING DIRECTIONS		SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS	
	LARGEST GLASS AREAS IN THESE WALLS	SMALLEST GLASS AREAS IN THESE WALLS	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE
	N	E	8	2	8	2
	N	W	4	3	4	3
	NE	SE	8	2	8	2
	NE	NW	8	4	8	3
	E	N	8	8 OR 2	8	10 OR 2
	E	S	8	10 OR 1	8	10 OR 1
	SE	NE	8	9 OR 3	8	11 OR 1
	SE	SW	9	2	9	2
	S	E	10	1	10	1
	S	W	2	2	2	2
	SW	SE	3	3	3	3
	SW	NW	4	3	4	3
	W	N	4	3	4	3
	W	S	4	3	4	3
	NW	NE	4	4	4	4
	NW	SW	4	4	4	3

NOTES:

1. Figures set "10 or 2" mean one of two different things:

- (a) the excess solar heat gain may be a maximum and have approximately equal values at two different hours of the day.
- (b) The excess solar heat gain may have a maximum value at only one of the two hours given, and not at the remaining hour.

Which of the two interpretations to use can be determined only for a particular problem.

- In the above tables for windows in more than one wall, combinations of directions through which the sun cannot possibly shine at one time have been omitted. For example, such combinations as north and south, or east and west are not tabulated. For such combinations use either direction alone. Thus, if there are windows in both the east and west walls, use the time of day for the one wall having the largest window area. Similarly, for rooms having windows in north and south walls, use the time of day for windows in only the south wall.
- Buildings having large areas of skylights in their roofs will probably have their maximum solar heat gain, at, or near noon.
- If roofs are insulated, the better the insulation, the more closely the time of day when the cooling load is a maximum will tend to approach the time given in the columns headed "floor above."
- The above table is for typical proportions of windows, walls and roof and for average wall, window and roof construction. For special conditions or unusual installations, a check of the heat gain at times which differ from those given in the tables, is recommended.

TABLE 2-47

Approximate Time of Day at which Solar Heat Gains are a Maximum

For Latitudes North of 20 Degrees in Northern Hemisphere
Equal (Approximately) Window Areas in Various Walls

WINDOWS FACE IN FOLLOWING DIRECTIONS	SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS		WINDOWS IN 4 WALLS
	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE	
N, S, E AND W	8 OR 4	3	8 OR 4	3	
NE, SW, SE AND NW	8 OR 4	3	8 OR 4	3	

WINDOWS FACE IN FOLLOWING DIRECTIONS	SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS		WINDOWS IN 3 WALLS
	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE	
N, E AND W	8 OR 4	3	8 OR 4	3	
N, S AND W	4	3	4	3	
N, S AND E	8	10 OR 1	8	2	
NE, SE AND NW	8	9 OR 3	8	3	
NE, SW AND NW	4	3	4	3	
NE, SW AND SE	8	8 OR 3	8	2	
E, W AND S	8 OR 4	3	8 OR 4	3	
SE, NW AND SW	4	3	4	3	

WINDOWS FACE IN FOLLOWING DIRECTIONS	SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS		WINDOWS IN 2 WALLS
	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE	
N AND E	8	8 OR 2	8	2	
N AND W	4	3	4	3	
NE AND SE	8	9 OR 2	8	2	
NE AND NW	8 OR 4	3	8 OR 4	3	
E AND S	8	10 OR 1	8	1	
SE AND SW	9 OR 3	2	9 OR 3	2	
S AND W	4	3	4	3	
SW AND NW	4	3	4	3	

WINDOWS FACE IN FOLLOWING DIRECTIONS	SHADES BEHIND WINDOWS		AWNINGS ON WINDOWS		WINDOWS IN 1 WALL
	FLOOR ABOVE	ROOF ABOVE	FLOOR ABOVE	ROOF ABOVE	
N	-	2	-	2	
NE	8	2	8	2	
E	8	8 OR 2	8	2	
SE	9	10 OR 2	9	11 OR 2	
S	12	1	12	2	
SW	3	2	3	2	
W	4	3	4	3	
NW	4	4	4	3	

NOTES:

1. Figures set "10 or 2" may mean one of two different things:

- the excess solar heat gain may be a maximum and have approximately equal values at two different hours of the day.
- The excess solar heat gain may have a maximum value at only one of the two hours given, and not at the remaining hour.

Which of the two interpretations to use can be determined only for a particular problem.

- In the above tables for windows in more than one wall, combinations of directions through which the sun cannot possibly shine at one time have been omitted. For example, such combinations as north and south, or east and west are not tabulated. For such combinations use either direction alone. Thus, if there are windows in both the east and west walls, use the time of day for the one wall having the largest window area. Similarly, for rooms having windows in north and south walls, use the time of day for windows in only the south wall.
- Buildings having large areas of skylights in their roofs will probably have their maximum solar heat gain, at, or near noon.
- If roofs are insulated, the better the insulation, the more closely the time of day when the cooling load is a maximum will tend to approach the time given in the columns headed "floor above."
- The above table is for typical proportions of windows, walls and roof and for average wall, window and roof construction. For special conditions or unusual installations, a check of the heat gain at times which differ from those given in the tables, is recommended.

APPENDIX C

Solar Assisted Space Heating System

SOLAR ASSISTED SPACE HEATING SYSTEM

This system was designed to meet the heating requirements of 28 buildings on the Mississippi State University campus. These buildings are being heated by steam from a central plant at the present time. This set of buildings was selected because of the availability of energy consumption data. Maximum consumption of natural gas occurred in the month of February for the year considered, 1977-78. The heating load was obtained by subtracting the base natural gas consumption from the total consumption and assuming that the efficiency of natural gas to produce heat is 30 percent.

The system uses flat plate collectors, a heat exchanger, a storage tank and a heat pump. The system configuration is shown in Figure 1. The heat pump delivers 10^7 Btu/hr. to the buildings. Initially, requirements for 10^7 Btu/hr. output power are evaluated and later, requirements to meet the total heating loads are concluded.

OPERATION

Solar radiation falling on the flat plate collector is converted into heat energy and is carried by the working fluid. The heat exchanger extracts the heat energy from the working fluid and transfers it to water. This high temperature water is stored in the storage tank and/or goes directly to the heat pump as the source of heat.

A water to water[^] heat pump is used to take heat from high temperature storage water and to deliver it to the inside of the building. The water to water heat pump in the heating mode is shown in Figure 2. The system will operate satisfactorily as long as the source temperature is not less than

Fig 1 Layout of Solar Asisted Heating System

60°F. The Compressor has two stages. If T_{SH} is less than 120°F, both compressor stages work, otherwise the first stage of the compressor works only, and fluid by-passes the second stage. An auxiliary source is provided to share demand if collector output is not sufficient to meet the heating load. The relationship between source water temperature and coefficient of performance for various delivered water temperatures is shown in Figure

3.

Fig 2 HEAT PUMP IN HEATING MODE

Fig 2 Heat Pump Components

Fig. 3 Heat Pump Performance Curve

SPECIFICATIONS

Westinghouse Templifier, water to water heat pump, was used in the system. It had the capacity to deliver 10^7 Btu/hr. with delivery water temperature as high as 220°F and source water temperature as low as 60°F .

DESIGN AND CALCULATIONS

Maximum monthly (February) natural gas consumption = 28.8×10^{10} Btu

Base consumption = 8.0×10^{10} Btu

Natural gas consumption on hourly basis for heating only is

$$\frac{(28.8-8)10^{10} \frac{\text{Btu}}{\text{month}} \times 0.3}{28 \frac{\text{days}}{\text{month}} \times 24 \frac{\text{Hours}}{\text{Day}}} \quad \text{or} \quad 9.3 \times 10^7 \frac{\text{Btu}}{\text{Hr.}}$$

since capacity of heat pump is 10^7 Btu/hr. Therefore, 9.3 heat pumps are required to meet the heating load of these buildings.

Looking at the heat pump performance data such as source water temperature, delivery water temperature, flow rates and temperature requirement for delivery water flowing inside the building, the following assumptions are reasonable:-

- i Delivery water temperature, $T_{\text{BH}} = 200^\circ\text{F}$.
- ii Building outlet temperature, $T_{\text{BL}} = 170^\circ\text{F}$.

The following relation can be used to calculate the mass flow rate on the building side of the heat pump.

$$\dot{q} = \dot{m}_1 C_p (T_{\text{BH}} - T_{\text{BL}}) \quad (1)$$

$\dot{q}$ = Capacity of heat pump, Btu/hr.

C_p = specific heat of water, Btu/lb_m^oF.

T_{BH} and T_{BL} are defined earlier. Water is the heat transfer fluid.

Substituting values for $\dot{q}$, C_p , T_{BH} , T_{BL} , mass flow rate $\dot{m}_1$ is found to be 667 gallons/minute.

Assume a heat exchanger with effectiveness of 0.5 meets the system

requirements. Assuming that the hot fluid on the collector side of the heat exchanger has the minimum value for $\dot{m}C_p$, then effectiveness of the heat exchanger, E , is defined by the relation: -

$$E = \frac{T_{CH} - T_{CL}}{T_{CH} - T_{SL}} \quad (2)$$

Where T_{CH} = temperature of hot fluid at inlet to the heat exchanger, $^{\circ}\text{F}$.

It is also the temperature at the outlet of collector panel.

T_{CL} = Temperature of the hot fluid at the outlet of the heat exchanger, $^{\circ}\text{F}$. This is also the temperature at the inlet of the collector panel.

Sunwave 420 flat plate solar collector is used in this system. The relation between collector efficiency and the difference in inlet and outlet temperatures is shown in Figure 4 for various levels of insolation. At Mississippi State, average insolation over the year is $196 \text{ Btu/ft.}^2\text{hr.}$ and in the month of February ambient temperature can be assumed equal to 30°F . Then Figure 4 gives the efficiency of the collector for a given value of the temperature difference. The inlet and outlet temperature difference across the solar collector is taken to be 60°F which is in the neighborhood of typical operating range recommended by manufacturer, shown in Figure 4. As recommended by the manufacturer of the heat pump, for the conditions specified earlier, source water outlet temperature, T_{SL} , is 115°F and flow rate, $\dot{m}_2$, in this loop is assumed to be 756 gallons per minute.

Fig 4 Solar Collector Efficiency verses Collector inlet and outlet temperature difference

Using their information and solving equation 2:-

$$T_{CH} = 235^{\circ}\text{F.}$$

Since we assumed, $T_{CH} - T_{CL} = 60^{\circ}\text{F}$

This gives $T_{CL} = 175^{\circ}\text{F}$

For

$$\dot{q} = 7.56 \times 10^6 \frac{\text{Btu}}{\text{hr.}}$$

$$C_p = 1 \text{ Btu/lb}_m^{\circ}\text{F}$$

and $T_{CH} - T_{CL} = 60^{\circ}\text{F}$

Using simple energy balance, similar to equation 1, mass flow rate through the collector is equal to 252 gallons per minute.

The source water inlet temperature, T_{SH} can be calculated by using an energy balance, similar to equation 1:-

For $\dot{q} = 10^7 \text{ Btu/hr.}$

$$T_{SL} = 115^{\circ}\text{F}$$

$$\dot{m} = 756 \text{ gallons per minute}$$

$$C_p = 1 \text{ Btu/hr.ft}^2.$$

The value of T_{SH} is found to be

$$T_{SH} = 135^{\circ}\text{F}$$

COLLECTOR AREA

Collector area is obtained by the following relation.

$$\dot{q} = A Q_{in} \cdot \eta_{col.} \left(43560 \frac{\text{ft}^2}{\text{acre}} \right) \quad (3)$$

Where

$\dot{q}$ = collector output in Btu/hr.

A = collector area in acres to obtain $\dot{q}$ Btu/hr.

Q_{in} = insolation, Btu/hr.ft²

For $\dot{q} = 7.56 \times 10^6$ Btu/hr.

$$\eta_{col} = 0.48$$

$$Q_{in} = 196 \text{ Btu/hr.ft}^2$$

Collector area A is found to be 1.8447 acres per $10^7 \frac{\text{Btu}}{\text{hr.}}$

Since in total about nine heat pumps will be required, therefore total collector area is 16.6 acres. This analysis does not take into account heat losses from storage and pipes. Depending upon the insulation, losses will further increase the collector area.

Table 1 shows electrical energy input to the compressor of the heat pump for various values of source water temperature at inlet to the heat pump.

Table 2 shows the consumption of natural gas, fuel oil and electricity for various months of the year.

Table 1 Source water temperature, COP and electrical energy relationship for heat pump

$T_{SH} (F)$	COP	$\dot{E} \left(\frac{Btu}{hr} \right)$	T_{SH}	COP	$\dot{E} \left(\frac{Btu}{hr} \right)$
160	5.7	1.75×10^6	105	3.15	3.17×10^6
155	5.35	1.87×10^6	100	3.10	3.22×10^6
150	5.05	1.98×10^6	95	3.05	3.28×10^5
145	4.75	2.1×10^6	90	3.00	3.33×10^6
140	4.4	2.27×10^6	85	2.93	3.41×10^5
135	4.1	2.44×10^6	80	2.90	3.44×10^6
130	3.85	2.6×10^6	75	2.80	3.57×10^6
125	3.55	2.82×10^6	70	2.75	3.63×10^6
120	3.35	2.98×10^6	68	2.70	3.7×10^5
115	3.25	3.07×10^6	65	2.68	3.73×10^6
110	3.20	3.12×10^6	60	2.65	3.77×10^6

Table 2 Energy consumption for steam power plant

Total Consump. Btu.	Fuel Oil	Electricity Btu	Natural Gas Btu 1978-79	
281978 x 10 ⁶	----	14574 x 10 ⁶	267,404 x 10 ⁶	Jan. 1979
308071 x 10 ⁶	2892 x 10 ⁶	16513 x 10 ⁶	288,666 x 10 ⁶	Feb. 1978
217762 x 10 ⁶	1911 x 10 ⁶	13026 x 10 ⁶	202,825 x 10 ⁶	March 1978
128622 x 10 ⁶	----	15704 x 10 ⁶	112,918 x 10 ⁶	April 1978
115656 x 10 ⁶	----	15039 x 10 ⁶	100,617 x 10 ⁶	May 1978
117165 x 10 ⁶	----	20543 x 10 ⁶	96,622 x 10 ⁶	June 1978
110354 x 10 ⁶	----	21528 x 10 ⁶	88,826 x 10 ⁶	July 1978
105646 x 10 ⁶	----	22609 x 10 ⁶	83,037 x 10 ⁶	Aug. 1978
118991 x 10 ⁶	----	24059 x 10 ⁶	94,932 x 10 ⁶	Sept. 1978
123882 x 10 ⁶	----	18823 x 10 ⁶	105,059 x 10 ⁶	Oct. 1978
143219 x 10 ⁶	----	18284 x 10 ⁶	124,953 x 10 ⁶	Nov. 1978
248440 x 10 ⁶	----	14303 x 10 ⁶	234,137 x 10 ⁶	Dec. 1978

SUMMARY

Total heat load	$= 9.3 \times 10^7 \text{ Btu/hr.}$
Average insolation	$= 196 \text{ Btu/ft}^2 \text{ hr.}$
Capacity of heat pump	$= 10^7 \text{ Btu/hr.}$
No. of heat pumps required	$= 9$
Collector area (Flat plate collector)	$= 16.8 \text{ acres}$
Total area (with packing density of 0.8)	$= 20.75 \text{ acres}$
Effectiveness of heat exchanger	$= 0.5$
Collector efficiency	$= 0.48$
Coefficient of performance	$= 4.1$
Electrical energy input to the compressor of heat pump	$= 2.44 \times 10^6 \frac{\text{Btu}}{\text{hr.}} (715 \text{ KWhr})$

Temperatures and mass flow rates are shown in Figure 1.

APPENDIX D
Space Cooling System Design

SPACE COOLING SYSTEM DESIGN

This system uses absorption cold generator to produce chilled water. The objective is to utilize the waste heat energy rejected by the organic Rankine cycle and to produce refrigeration to meet the cooling loads of the campus buildings. The waste heat energy is available in the form of hot water. The absorption cold generator used in this system is manufactured by "TRANE". It is a single stage unit and can operate in the temperature range of 165°F to 270°F.

OPERATING CYCLE

Absorption cold generator uses lithium bromide-water, absorption refrigeration cycle. The block diagram of this cycle is shown in Figure 1. The major components include concentrator, condenser, evaporator and absorber. During operation, the pressure in the absorber and evaporator is less than that in the concentrator and condenser. However, the pressure in the whole cycle is less than one atmosphere.

System water at 53°F enters the evaporator tubes and is chilled. The refrigerant (water) flows from the condenser into the evaporator. The temperature in the evaporator is less than that of the system water. This temperature difference causes heat transfer from system water to the refrigerant, consequently, the refrigerant vaporizer. The unvaporized refrigerant is collected in the evaporator pan. The evaporator tubes are kept wet by spraying the refrigerant using a pump. The vapors of the refrigerant pass toward the absorber.

In the absorber, the refrigerant vapor is absorbed and condensed releasing heat. Heat of vaporization is released at the rate of 1000 Btu per mass of refrigerant when it converts from vapor to liquid at constant

Fig 1 Block Diagram for Absorption Refrigeration Cycle

temperature and pressure. Intermediate lithium bromide solution is sprayed over absorber tube bundle to increase rate of phase change from vapor to liquid. This solution is obtained by mixing concentrated solution coming from the concentrator with the dilute solution coming from the absorber. The reason for using intermediate solution is that greater quantity of solution is required than is available from the concentrator. Also, if concentrated solution alone is used, it might crystallize. Cooling tower water flows through the absorber tube bundle to carry away the heat liberated during absorption. As refrigerant vapor is absorbed, the solution becomes increasingly dilute and must be circulated back to the concentrator to increase its concentration.

In the concentrator, refrigerant is recovered by boiling the absorbent solution from hot water. The absorbent solution becomes concentrated and returns to the absorber as an intermediate solution. The dilute solution is pumped continuously from the absorber to the concentrator.

In condenser, high temperature vapor from the concentrator is condensed. Heat of condensation is removed by the cooling water. This cooling water is the same which was used as cooling medium in absorber. The condensed refrigerant flows through an orifice to the evaporator.

SPECIFICATIONS

"TRANE" Absorption cold generator

Model No. ABSC11A

Nominal capacity = 1125 tons

Input temperature range: 160°F to 270°F

Capacity design range: 225-1125 tons

1-pass condenser

2-pass absorber

Pump motor rating: 15 hp

Power input to motor: 15.1KW

3-pass evaporator

Maximum allowable design tons: 1255 tons

DESIGN AND CALCULATION

Given Design Conditions

Heat rejected from organic rankine cycle system, $\dot{q}_{orc} = 2200$ tons

Entering chilled water temperature, $T_{EH} = 53^{\circ}\text{F}$

Leaving chilled water temperature, $T_{EL} = 42^{\circ}\text{F}$

Entering cooling water temperature, $T_{AL} = 85^{\circ}\text{F}$

Leaving hot water temperature, $T_{CL} = 200^{\circ}\text{F}$

Entering hot water temperature, $T_{CH} = 235^{\circ}\text{F}$

Chilled water flow rate, $\dot{m}_E = 1500 \frac{\text{gallons}}{\text{min.}}$

Fouling factor for evaporator, absorber and condenser = 0.0005

Using these conditions: --

Chilled water temperature drop, $T_{ED} = T_{EH} - T_{EL}$
 $= 53 - 42$

$$T_{ED} = 11^{\circ}\text{F}$$

Hot water temperature drop, $T_{CD} = T_{CH} - T_{CL}$
 $= 235 - 200$

$$T_{CD} = 35^{\circ}\text{F}$$

Since chilled water flow rate and temperature drop are given, amount of heat extracted from the chilled water (design tons, $\dot{q}_{DT}$) can be calculated using the relation: --

$$\dot{q}_{DT} = \frac{\dot{m}_E \left(\frac{\text{gal.}}{\text{min.}} \right) \times 8.33 \left(\frac{\text{lb}_m}{\text{gal.}} \right) \times 60 \left(\frac{\text{min}}{\text{hr}} \right) \times C_p \left(\frac{\text{Btu}}{\text{lb}_m^{\circ}\text{F}} \right) \times T_{ED} (^{\circ}\text{F})}{12000 \frac{\text{Btu/hr}}{\text{ton}}}$$

CHART 1 - Equivalent Steam Pressure

CHART 2 - Part Load Performance with Economizer - Unit ADSC-11A

substituting,

$$\dot{m}_E = 1500 \text{ gpm}$$

$$C_p = \text{specific heat of water, } 1 \frac{\text{Btu}}{\text{lb}_m \text{ } ^\circ\text{F}}$$

$$T_{ED} = 11^\circ\text{F}$$

$\dot{m}_E$ and T_{ED} are defined previously.

Design tons, $\dot{q}_{DT} = 687.2 \text{ tons}$

Using the chart 1, for leaving hot water temperature of 200°F ,

Equivalent steam pressure = 2 psig

The size of the machine is selected by using the information on entering cooling water temperature, leaving chilled water temperature and steam pressure. An absorption cold generator whose available capacity at the specified conditions is equal to or greater than the calculated design tons is the right one.

Therefore, for: --

enter cooling water temperature = 85°F

steam pressure = 2 psig

leaving chilled water temperature = 42°F

and entering the Table 2, available capacity is 731 tons which

is slightly higher than the value for design tons. Table 2 represents: --

absorption cold generator model ABSC11A

nominal tons = 1125

available tons, $\dot{q}_{AT} = 731$

Table 2 is based on cooling water flow rate of 4050 gpm, fouling factor of 0.0005 and three evaporator passes.

Since chilled water flow rate, $\dot{m}_E$ is 1500 gpm, and evaporator has three passes, by interpolation on 3-pass line in Chart 4, between 102% and 106%,

TABLE 2-311A—Available Capacity

ENTERING COOLING WATER TEMP., °F.	STEAM PRESSURE PSIG	LEAVING CHILLED WATER TEMPERATURE						
		40	42	44	45	46	48	50
80	12	1142	1193	1238	1255	1287	1332	1373
	10	1103	1148	1193	1215	1255	1278	1329
	8	1066	1086	1131	1157	1181	1231	1271
	6	994	1024	1068	1094	1123	1181	1250
	4	912	948	990	1023	1047	1114	1200
	2	839	875	922	950	979	1047	1138
85	14	1013	1069	1125	1153	1181	1260	1305
	12	968	1024	1069	1103	1127	1181	1271
	10	911	959	1013	1041	1069	1123	1177
	8	845	889	935	958	999	1053	1125
	6	771	816	865	891	923	981	1058
	2	696	731	782	810	843	909	960
90	14	810	867	923	957	1000	1143	1193
	12	757	823	888	914	944	1081	1138
	10	710	775	839	863	892	1046	1091
	8	654	716	778	809	834	987	1035
	6	605	677	740	764	784	912	951
	4	551	626	689	713	733	859	899
	2	501	573	636	661	681	793	835

NOTE: CAPACITIES GIVEN ARE BASED ON 4050 GPM COOLING WATER, 2 PASS EVAPORATOR AND .0005 FOULING FACTOR.

CHART 311A — Hot Water

CHART 411A — Chilled Water

CHART 511A — Cooling Water

Evaporator capacity correction = 103.89 percent
 Pressure drop = 22 feet of water

The evaporator tons is calculated using the relation: --

$$\dot{q}_{ET} = C_E \times \dot{q}_{AT}$$

Where

$\dot{q}_{ET}$ = evaporator tons

C_E = evaporator correction factor, 103.89 percent

$\dot{q}_{AT}$ = available tons, 731 tons

substituting these values,

$$\dot{q}_{ET} = 759.4 \text{ tons}$$

We define condenser operating ratio as the ratio of design tons to evaporator tons. Therefore,

$$\begin{aligned} \text{Condenser operating ratio} &= \frac{687.2}{759.4} \\ &= 0.905 \end{aligned}$$

Using the cooling water Chart 5, for condenser operating ratio of 0.905: --

cooling water mass flow rate, $\dot{m}_A$ = 3200 gpm

pressure drop = 35 ft of water

The unit load ratio or simply the load ratio is defined as the ratio of design tons to nominal tons. Therefore,

$$\begin{aligned} \text{Load ratio} &= \frac{687.2}{1125} \\ &= 0.611 \end{aligned}$$

Using Chart 6, for load ratio of 0.611 and steam pressure of 2 psig:--

Full load steam rate = 17.5 lb_m/hr-ton

For equivalent steam rate of 17.5 lb_m/hr-ton and hot water temperature drop of 35°F, using Chart 7: --

CHART 6 Steam Consumption Rate and Cooling Water Temperature Rise.

CHART 7—Hot Water Consumption Rate

Full load hot water rate = $8.0 \text{ lb}_m/\text{min-ton}$

Full load hot water consumption is given by the relation: --

$$\frac{(\text{Full load hot water})}{\text{consumption}} = \frac{(\text{Full load hot})}{\text{water rate}} \times \text{Design tons.}$$

For full load hot water rate of $8.0 \text{ lb}_m/\text{min-ton}$ and design tons of 687.2

$$\text{Full load hot water consumption} = 5497.6 \text{ lb}_m/\text{min}$$

$$\text{Average hot water temperature} = \frac{T_{CH} + T_{CL}}{2}$$

$$= \frac{235 + 200}{2}$$

$$= 217.5^\circ\text{F}$$

At average temperature, density of hot water as found from Chart 7 is $7.92 \text{ lb}_m/\text{gallon}$. Therefore, hot water flow rate $\dot{m}_C$ (gpm) is given by

$$\dot{m}_C = \frac{5497.6 \text{ lb}_m/\text{min}}{7.92 \text{ lb}_m/\text{gal.}}$$

$$\dot{m}_C = 694 \text{ gpm}$$

The rise in cooling water temperature is obtained from Chart 6. To use this Chart we need the ratio: --

$$\begin{aligned} \frac{\dot{m}_A \text{ (gpm)}}{\dot{q}_{DT} \text{ (tons)}} &= \frac{3200 \text{ gpm}}{687.2} \\ &= 4.65 \text{ gpm/design ton} \end{aligned}$$

Then entering Chart 6 at load ratio of 0.611, moving vertically upward to 2 psig steam pressure line and then to the right to 4.65 gpm/design-ton, cooling water temperature rise is 12.4°F .

$$\begin{aligned} \text{Therefore, leaving cooling water temperature} &= 85 + 12.4 \\ &= 97.4^\circ\text{F} \end{aligned}$$

HOT WATER ENERGY CONSUMPTION, $\dot{q}_{CT}$

$$\begin{aligned}\dot{q}_{CT} &= \dot{m}_C C_P (T_{CH} - T_{CL}) \\ &= \frac{5497.6 \left(\frac{\text{lb}_m}{\text{min}} \right) \times 60 \left(\frac{\text{min}}{\text{hr}} \right) \times 1 \left(\frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}} \right) \times 35^\circ\text{F}}{12000 \frac{\text{Btu/hr}}{\text{Ton}}}\end{aligned}$$

$$\dot{q}_{CT} = 962 \text{ Tons}$$

Hence 962 tons of energy input from hot water produces 687.2 tons of refrigeration.

Since waste heat in the form of hot water from organic Rankine cycle is 2200 tons, a total of 1571 tons of refrigeration will be obtained. Since output of absorption cold generator is 687.2 tons, two such absorption cold generators in combination with one small unit of 200 tons output will be sufficient to utilize the waste heat from organic Rankine cycle. Also, the temperature of the leaving hot water from absorption cold generator is 200°F . This water can be used to meet campus hot water requirements.

DETERMINATION OF PART LOAD HOT WATER CONSUMPTION

To obtain part load energy consumption on over-all basis for the system, a series of representative outside conditions should be selected. Then building loads, hourly energy consumption and number of hours of operation for each outside condition can be obtained. Procedure for such evaluation is explained by the following example:--

Assume 92°F dry bulb temperature and 78°F wet bulb temperature are the outside design conditions. Assume that at part load is 550 tons (80% of design load) and outside conditions are 80°F dry bulb temperature and 70°F wet bulb temperature.

Energy input and heat rejection are assumed proportional to load. Tower discharge temperature, T_{AL} is directly proportional to wet bulb temperature and heat rejection. Since in this system cooling tower provides discharge temperature of 85°F at 78°F wet bulb temperature (a 7°F approach) and 100 percent load, at part load condition, the water temperature out of the tower will be

$$70 + (0.8 \times 7) = 75.6^{\circ}\text{F}$$

Using Chart 2, for 80 percent design load and 85°F tower discharge water temperature

Percent Energy Input = 76 percent

$$\text{Hot water Consumption} = 0.76 \times \dot{m}_C$$

$$= 0.76 \times 694$$

$$\text{Hot Water Consumption} = 527 \text{ gpm}$$

Reference

"TRANE" Absorption Cold Generator Manual

APPENDIX E**Solar Electric System**

SOLAR ELECTRIC SYSTEM

The system shown in Figure 1 uses a continuously tracking parabolic concentrator as the solar collector. The collected heat energy is carried by liquid oil to the freon boiler where exchange of heat takes place between the hot liquid oil and the cold freon which becomes superheated vapor and drives a turbine in the organic Rankine Cycle. Turbine, in turn, operates an electric generator to produce an electrical output. The turbine works using an inlet temperature of 465°F or higher and has the capacity to produce 500KW electrical output. Our interest is to design a one megawatt system, so two such turbines will be required, and design requirements will be based accordingly.

Acurex parabolic trough concentrating solar collectors, Model 3001, will be used as the basic unit for the collector part of the system. The following are the specifications for this model. The model 3001 Acurex parabolic trough solar collector shown in Figure 2-a has the capability to heat liquids or gases between 140°F to 600°F with reasonable efficiency. The relationship between collector efficiency and insolation, ambient temperature, and average fluid temperature is shown in Figure 2-b. Each unit is assembled in eight modules with a collection area of 480 ft^2 . The reflecting surface is aluminum lighting sheet mounted on structure. The receiver tube is 1.25 in. in diameter and is made from mild steel.

Fig. 1 SOLAR ELECTRIC SYSTEM

Fig2 ACUREX PARABOLIC TROUGH
CONCENTRATING SOLAR COLLECTOR

1 — Reflecting Lighting Sheet
2 — Shadow Band Tracker

3 — Absorbing Receiver Tube
4 — Motor Drive

(a)

*Based on experimental data for a clear day, normal incidence, and no dust loss.

(b)

ACUREX PARABOLIC TROUGH CONCENTRATING SOLAR COLLECTOR

I. MODEL 3001
SPECIFICATIONS

1. Module size (nominal)	6-ft aperture x 10-ft length
(1.83 m x 3.05 m)
2. Collection area per module
(plan reflector area less
receiver shadow)	58.3 ft ² (5.36 m ²)
3. Rotational axis above ground	3.5 ft (1.07 m)
4. Nominal assembled length of
standard group of 8 modules
(includes allowance
for support posts)	84' 7-1/4" (25.8 m)
5. Reflector material	Anodized aluminum reflecting
lighting sheet
6. Reflector reflectance	0.75 - 0.80
7. Rim angle	90°
8. Nominal receiver area
per module	1.64 ft ² (0.15 m ²)
9. Geometric concentration ratio	36
10. Receiver data:	
a. Receiver absorptance
(see note e)	0.93
b. Receiver emittance
(see note e)	0.15
c. Fluid temperature
operating range	140°F to 600°F
(60°C to 316°C)
d. Fluid flowrate range	1.0 gpm to 15 gpm
(4.5 l/m to 68 l/m)
e. Pressure drop range
(per standard 84 ft row)	2.0 psi to 10 psi
(96 N/m ² to 479 N/m ²)
11. Module weight (each)	275 lbs (125 kg)
12. Support post weight (each)	37 lbs (16.8 kg)

I. MODEL 3001 -- SPECIFICATIONS (Continued)

13. Motor/gear weight (at center of 84-foot row)	144 lbs (65.3 kg)
14. Distributed weight per group	5.6 lbs/ft ²
(27.2 kg/m ²)
15. Environmental:	
a. Wind-operational (no loss in performance)	35 mph (56 km/h)
b. Wind operational (will track sun with minor loss in performance)	50 mph (81 km/h)
c. Wind-stowed (no major structural yielding)	100 mph (161 km/h)
d. Hail (no performance or structure damage)	Up to 0.5 in. dia @ 51 ft/sec
(Up to 1.3 cm dia @ 15.5 m/sec)
e. Seismic	Zone 3
f. Ambient operating	-20°F to +140°F
(-29°C to +60°C)
g. Ambient storage	-40°F to +150°F
(-40°C to +66°C)
16. Sun tracker system	
a. Tracking accuracy	±0.25°
b. Desteer mode	5° off focus
c. Stow	Clockwise or counterclockwise
(fast mode)
d. Tracking motor	1/8 hp (0.093 kW)
gear motor @ 10% duty cycle
or less

DESIGN AND CALCULATIONS

The system requires a minimum temperature T_{RH} of 465°F and, at the same time, 31.4×10^6 Btu/hr should be rejected to the freon at the thermal boiler. Initially it is assumed that the temperature of the collector working fluid at inlet and outlet manifolds of the freon boiler is 596°F and 485°F respectively. Selection of heat exchanger must be based on these temperatures.

The working fluid in the collector loop can be an oil and toluene is selected instead of freon for the purpose of this analysis. The properties of the toluene at average temperature will be used. At an average temperature of 540.5°F toluene has specific heat, C_p , of 0.41 Btu/lb $^{\circ}\text{F}$ and density of $53.8 \frac{\text{lb}}{\text{ft}^3}$.

Using this information, the mass flow rate of the collector working fluid can be obtained using the equation:

$$\dot{q}_1 = C_p \dot{m} (T_{HB} - T_{LB}) \quad (1)$$

where $\dot{q}_1$ = amount of heat rejected by collector working fluid, Btu/hr.

C_p = specific heat of collector working fluid at average temperature
Btu/lb $^{\circ}\text{F}$

T_{HB} = Temperature at inlet manifold of freon thermal boiler, $^{\circ}\text{F}$

T_{LB} = Temperature at outlet manifold of freon thermal boiler

$$\dot{q}_1 = 31.4 \times 10^6 \text{ Btu/hr.}$$

$$C_p = 0.41 \text{ Btu/lb. } ^{\circ}\text{F}$$

$$T_{HB} = 596^{\circ}\text{F}$$

$$T_{LB} = 485^{\circ}\text{F}$$

$$\dot{m} = 6.9 \times 10^5 \frac{\text{lb}}{\text{hr}}$$

The purpose of the solar collector is to raise the temperature of the

working fluid from 485°F to a temperature greater than 596°F to provide the heat input to the boiler. It is found that losses from pipe and storage result in a 1.5°F decrease in temperature of the fluid. So the outlet temperature of the solar collector is 597.5°F for

$$T_{\text{HC}} = 597.5^{\circ}\text{F}$$

$$T_{\text{CL}} = 485^{\circ}\text{F}$$

Using previous values of C_p and $\dot{m}$ for the collector working fluid, the amount of heat $\dot{q}_2$ (Btu/hr) that needs to be collected from the solar collector is

$$\begin{aligned}\dot{q}_2 &= 0.41(6.9 \times 10^5)(597.5 - 485) \\ &= 31.82 \times 10^6 \text{ Btu/hr}\end{aligned}$$

For these inlet and outlet temperatures of solar collector and for the solar radiation of 281 Btu/hr-ft^2 (for best month, May), collector efficiency is 44 percent. Therefore output of each model 3001 parabolic trough is given by:

$$q_i = (281) 0.44 \times 480$$

$$q_i = 59347 \text{ Btu/hr}$$

To collect $3.182 \times 10^7 \text{ Btu/hr}$, 536 parabolic troughs will be required.

The mass flow rate for each unit = $1290 \text{ lb}_m/\text{hr}$

Each receiver tube has a diameter of 1.25 inches so flow velocity through the receiver tube is given by

$$V_f = (1290 \text{ lb}_m/\text{hr}) \left(\frac{\text{ft}^3}{54.5 \text{ lb}_m} \right) \left(\frac{4 \times 144}{3.1428(1.25)^2 \text{ ft}^2} \right) \left(\frac{1 \text{ hr}}{3600 \text{ sec}} \right)$$

$$V_f = 0.77 \text{ ft/sec.}$$

The allowable velocity range is below 10 ft/sec .

Assuming 12-hr storage of hot fluid, storage must be able to contain $8.28 \times 10^6 \text{ lb}_m$. If storage space has cube shape of equal dimensions, then every dimension must be 54 ft with a total surface area of 17496 ft^2 .

HEAT LOSSES

(a) STORAGE

We assume that storage space is insulated by a 6-inch thick layer of fiber glass. Then

$$q_{LS} = U_f A_s (T_s - T_a)$$

q_{LS} = Heat loss from the storage space to surroundings, Btu/hr

A_s = surface area of storage space, ft^2

T_s = temperature of storage fluid, $^{\circ}\text{F}$

T_a = surrounding temperature, 75°F

U_f = overall heat transfer coefficient, $\frac{\text{Btu}}{\text{hr ft}^2 ^{\circ}\text{F}}$

For 5 miles per hour wind speed, over a 6 inch thick wall of fiberglass, $U_f = 0.044 \text{ Btu/hr ft}^2 ^{\circ}\text{F}$

Therefore

$$q_{LS} = (0.044 \frac{\text{Btu}}{\text{hr ft}^2 ^{\circ}\text{F}}) (17496 \text{ ft}^2) (522.5^{\circ}\text{F})$$

$$q_{LS} = 0.402 \times 10^6 \text{ Btu/hr}$$

Assume pipe losses. due to convection and radiation, to the surroundings are $18128 \frac{\text{Btu}}{\text{hr}}$

The total losses are $0.420128 \times 10^6 \text{ Btu/hr}$

HEAT OF FRICTION

Diameter of receiver pipe = 1.25 ft

Cross-sectional area of pipe = 1.227 ft^2

Mass flow rate through each parabolic trough = $1290 \frac{\text{lb}_m}{\text{hr}}$

velocity = 0.77 ft/sec

Reynolds number Re_D is given by

$$Re_D = \frac{V_f D}{\nu}$$

where V_f = flow velocity ft/sec

D = diameter of pipes, ft

ν = kinematic viscosity of fluid at mean temperature, ft^2/sec

For a mean temperature of $542.5^\circ F$, ν is $1.06 \times 10^{-6} \frac{ft^2}{sec}$

Therefore

$$Re_D = \frac{0.77 \times 1.25}{12 \times 1.06 \times 10^{-6}}$$

$$Re_D = 75668$$

Since Reynolds number is greater than 3000, the flow is turbulent.

Friction factor, f_T , for turbulent flow is given by

$$F_T = 0.0032 + \frac{0.221}{(Re_D)^{0.237}}$$

$$F_T = 0.01862$$

We assume an equivalent pipe length of 86 ft, which includes actual pipe length of 84 ft and equivalent length due to pipe connections. The the pressure drop along each pipe line is given by

$$P_f = 0.0808 f_T S V_F^2 \frac{L_e}{D}$$

where

P_F = pressure drop between the two ends of line, psi

V_F = fluid velocity, ft/sec

S = specific gravity of fluid

L_e = equivalent pipe length, ft

In this equation pipe diameter D must be expressed in inches. Therefore

$$P_F = (0.0808)(0.01862)\left(\frac{54.5}{62.4}\right)(0.77)^2\left(\frac{86}{1.25}\right)$$

$$P_F = 0.0536 \text{ psi}$$

Also

$$(\text{HP})_{\text{Loss}} = \frac{\text{gpm} \times P_f}{1715}$$

where $(\text{HP})_{\text{Loss}}$ = Horsepower lost due to friction

gpm = mass flow rate in gallons per minute

$$\text{Power Loss} = \frac{2.95 \text{ gpm} \times 0.0536}{1715} = 182 \text{ ft-lb/hr}$$

Total heat added because of friction = 128 Btu/hr

This amount is negligible.

Then the total losses are 0.420128×10^6 Btu/hr. Including the effect of friction and subtracting losses from the collector input, the available energy at the freon thermal boiler is 31.4×10^6 Btu/hr. This amount is required to produce one megawatt of electrical power.

COLLECTOR AREA

No. of parabolic troughs = 536

Collector area for a unit = 480 ft^2

Total collector area = 5.9 acres

Assuming packing density = 0.8

Space required = 7.38 acres

SUMMARY

System output	= one megawatt
Insolation (Best system performance)	= 281 Btu/hr -ft^2 (in May)
No. of parabolic troughs	= 536
Working fluid is Toluene	
Collector outlet temperature	= 597.5°F
Collector inlet temperature	= 485°F
Thermal Boiler inlet temperature (collector side)	= 596°F
Thermal Boiler outlet temperature (Collector side)	= 485°F
Total mass flow rate	= 1616 gpm
mass flow rate through each parabolic trough	= 2.95 gpm
Total heat collected by collectors	= $32.53 \times 10^6 \frac{\text{Btu}}{\text{hr}}$
Total heat extracted at freon boiler to produce one megawatt electrical output	= $31.4 \times 10^6 \frac{\text{Btu}}{\text{hr}}$
Collector Cost @ \$18.75/ft ² (installed)	= 4.9×10^6 Dollars

APPENDIX F

Flat Plate Solar Collector System

FLAT PLATE SOLAR COLLECTOR SYSTEM

Objective

The objective of this assignment is to determine the type and total area of flat plate solar collector which is capable to generate enough energy to be used for domestic hot water or domestic heating space for MSU campus.

Selection of Collectors and Systems

Two types of collectors, made by Lennox, have been selected for our design. The serial numbers of the collectors are as follows:

1. LSC 18-1 Double Glass Collector
2. LSC 18-1S Single Glass Collector

Collector performance and flow rate vs. pressure drop are shown in Figure 3 and Figure 4 for the above collectors.

Two systems have been designed: one for domestic space heating and the other for domestic hot water. These two systems are shown in Figure 1 and Figure 2.

Solar Postition and Insolation Values for 32 Degree North Latitude

The solar insolation value has been taken from reference 1 for 32 degrees north latitude and collector facing south at tilt angle of 42 degrees. Collector efficiency is maximum at tilt angle of 42 degrees and 32 degrees north latitude for winter conditions.

Collector Specification

Nominal collector area, 18 sq. ft.

Effective absorber area, 15.4 sq. ft.

Stable to 850F^o

FIGURE 1

- (1) Circulator Pump.
- (2) Automatic Differential Thermostat.
- (3a) Collector Temperature Sensor.
- (3b) Storage Temperature Sensor.
- (4) Swing check valve to prevent night time Thermosyphon action.
- (5) Tempering valve to reduce stored water to safe temperature.
- (6) Temperature and pressure relief valve.
- (7) Automatic air ventilation.
- (8a) Heat exchanger to store heat from collectors in stored water.
- (8b) Heat exchanger to transfer heat to space heating system.
- (9) Plenum water-to-air heat exchanger, retrofit in existing forced air furnace or part of fan-coil unit.

- (10) Space heating control thermostat, controls hydronic circulator pump in addition to any blowers.
- (11) Backup heat source which energizes only when stored solar heat is exhausted.
- (15) Expansion tanks, (required on closed systems), operate at small positive internal pressure.

FIGURE 3

LSC18-1 AND LSC18-1S FLOW RATE vs. PRESSURE DROP

FIGURE 4

Recommended flow rate through collector, .3 to .7 gpm

Collector fluid capacity, .3 gal.

Collector fluid (50-50 Dowtherm SR-1 or Equivalent):

SR-1 Data

Density, 1.045 g/ml (at 160F°)

Viscosity, 1.4 centipoise (at 160F°)

Specific heat, .85 BTU/lbF° (at 160F°)

Boiling point, 232F°

Freezing point, -34F°

Collector net weight (lbs)

LCS 18-1S, 1.23

LSC 18-1, 150

Calculations

This calculation is performed to determine the area and number of collectors to be used for the load requirement for severe weather conditions. The severe weather conditions are assumed to be July 21 and Jan. 21 for fiscal year of 1977-1978.

Given Conditions

42 degrees tilt angle (winter)

32 degrees north latitude

10 hours solar incident for each day of Jan.

12 hours solar incident for each day of July

31 days in month of Jan. and July

26.5 average temperature, F°, for Jan. 21, 1978

81.0 average temperature, F°, for July 21, 1978

20 gal/person-day hot water usage

211.8 BTU/HR-ft², average hourly solar incident for 10 hours a day in month of Jan. for tilt angle 22 degrees.

201.8 BTU/HR-ft², average hourly solar incident for 12 hours a day in month of July for tilt angle 42 degrees.

168.0 BTU/HR-ft², average hourly solar incident for 12 hours a day in month of Jan. for tilt angle of 42 degrees.

The energy collected by the collector is given by the following,

$$Q_c = Q_{inc} \times \text{Collector efficiency.}$$

Collector efficiency can be determined from the collector performance,

Figure 3², at ratio of $\frac{(T_{in} - T_{amb})}{Q_{inc}}$ where

T_{in} = Collector inlet temperature, F°

T_{amb} = outside air temperature, F°

Q_{inc} = incident solar radiation (BTU/hr-ft²) at 32 degrees north latitude and at the given tilt angle

Jan. 21, 1977, 32 north latitude and 42 degrees tilt angle

$$\frac{T_{in} - T_{amb}}{Q_{inc}} = \frac{110 - 26.5}{211.8} = .394$$

from performance curve, Figure 3² reading:

Eff. = .52, single glass, SG, collector

Eff. = .54, double glass, DG, collector

$$Q_{SG} = (211.8 \frac{\text{BTU}}{\text{HR-ft}^2}) (.52) (10 \frac{\text{HR}}{\text{DAY}}) = 1101.3 \text{ BTU/Day-ft}^2$$

$$Q_{DG} = (211.8 \frac{\text{BTU}}{\text{HR-ft}^2}) (.54) (10 \frac{\text{HR}}{\text{DAY}}) = 1143.72 \text{ BTU/Day-ft}^2$$

$$Q_{SG} = (1101.3 \frac{\text{BTU}}{\text{DAY-ft}^2}) (31 \frac{\text{Day}}{\text{month}}) = 34147.0 \frac{\text{BTU}}{\text{month-ft}^2}$$

$$Q_{DG} = (1143.72 \frac{\text{BTU}}{\text{Day-ft}^2}) (31 \frac{\text{Day}}{\text{month}}) = 35455.0 \frac{\text{BTU}}{\text{month-ft}^2}$$

Assume 80% storage efficiency and 60% delivery efficiency, the useful energy per sq. ft. of collector is given by

$$Q_{usg} = (34142.0) (.8) (.6) = 16388.0 \text{ BTU/month-ft}^2$$

$$Q_{udg} = (35455.0) (.8) (.6) = 17018.4 \text{ BTU/month-ft}^2$$

Heating load for 29 buildings, in MSU campus, is equal to 10×10^9 BTU/month of Jan. Therefore, the area of the collector required for space heating is given by

$$A = \left(\frac{\text{Heating Load}}{Q_{\text{USG}} \text{ or } Q_{\text{UDG}}} \right) \left(\frac{\text{Nominal Collector Area, Ft}^2}{\text{Effective Absorber Area, Ft}^2} \right)$$

$$A_{\text{SG}} = \left(\frac{10 \times 10^9}{16388.0} \right) \left(\frac{18}{15.4} \right) = 7.0 \times 10^5 \text{ ft}^2$$

or

$$A_{\text{SG}} = 16.0 \text{ Acres}$$

$$\text{No. of collector} = 4.0 \times 10^4, \text{ single glass}$$

$$A_{\text{DG}} = \left(\frac{10 \times 10^9}{17018.4} \right) \left(\frac{18}{15.4} \right) = 6.86 \times 10^5 \text{ ft}^2$$

or

$$A_{\text{DG}} = 15.64 \text{ Acres}$$

$$\text{No. of collectors} = 3.8111 \times 10^4, \text{ double glass}$$

Energy required for hot water/person-month is given by the following,

$$\begin{aligned} Q/\text{person-month} &= (20 \text{ gal/day}) \left(\frac{8.33 \text{ lb}}{1 \text{ gal.}} \right) (1.0 \frac{\text{BTU}}{\text{LB } ^\circ\text{F}}) (110^\circ\text{F}) \left(\frac{31 \text{ day}}{\text{month}} \right) \\ &= 568106.0 \frac{\text{BTU}}{\text{month-person}} \end{aligned}$$

$$\text{Collector Area, FT}^2/\text{person} = \frac{Q/\text{person-month}}{Q_{\text{USG}} \text{ or } Q_{\text{UDG}}}$$

$$\text{Area} = 34.66 \text{ FT}^2/\text{person, single glass}$$

or

$$\text{Area} = 33.38 \text{ FT}^2/\text{person, double glass}$$

July 21, 1978, 32 degrees north latitude and 22 degrees tilt angle.

$$\frac{T_{\text{in}} - T_{\text{amb}}}{Q_{\text{inc}}} = \frac{110 - 81}{201.8} = .143$$

From collector performance, Figure 3, at .143 results

Eff. of single glass, SG, Collector = .73

Eff. of double glass, DG, Collector = .70

$$Q_{SG} = (201.8)(.73)(12)(31) = 54800.8 \text{ BTU/}(\text{month-FT}^2)$$

$$Q_{DG} = (201.8)(.70)(12)(31) = 52548.7 \text{ BTU/}(\text{month-FT}^2)$$

Assume 80% storage efficiency and 60% delivery efficiency, so useful energy per sq. ft. of collector is given by,

$$Q_{USG} = (54800.8)(.80)(.60) = 26304.0 \frac{\text{BTU}}{\text{month-ft}^2}$$

$$Q_{UDG} = (52548.7)(.80)(.60) = 25223.0 \frac{\text{BTU}}{\text{month-ft}^2}$$

$$\text{Collector area, FT}^2/\text{person} = \frac{568106.0 \text{ BTU/}(\text{month-person})}{Q_{USG} \text{ or } Q_{UDG}}$$

$$= 21.6 \text{ FT}^2, \text{ single glass.}$$

$$= 22.5 \text{ FT}^2, \text{ double glass.}$$

July 21, 1978, 32 north latitude and 42 degrees tilt angle.

$$\frac{T_{in} - T_{amb}}{Q_{inc}} = \frac{110-81}{169} = 0.17$$

From Collector Performance at 0.17 read

Effi. of single glass, SG, Collector = .70

Effi. of double glass, DG, collector = .68

$$Q_{SG} = (169)(.70)(12)(31) = 44007.6 \text{ BTU/}(\text{month-FT}^2)$$

$$Q_{DG} = (169)(.68)(12)(31) = 42750.2 \text{ BTU/}(\text{month-FT}^2)$$

Assume 80% storage efficiency and 60% delivery efficiency, the useful energy per sq. ft. of collector is given by,

$$Q_{USG} = (44007.6)(.80)(.60) = 21123.64 \text{ BTU/}(\text{month-ft}^2)$$

$$Q_{UDG} = (42750.2)(.80)(.60) = 20520.0 \text{ BTU/}(\text{month-ft}^2)$$

$$\text{Collector Area, FT}^2/\text{person} = \frac{568106.0 \text{ BTU/}(\text{month-person})}{Q_{USG} \text{ or } Q_{UDG}}$$

$$= 26.89\text{FT}^2, \text{ single glass.}$$

or $= 27.68\text{FT}^2, \text{ double glass.}$

References:

1. Principles of Solar Engineering, Frank Kreith/ Jan F. Kreider pp. 671.
2. Engineering Data, Accessories, pp. 3, August 15, 1976.

APPENDIX G

Central Solar Receiver

(Cross-Section View of Solar Power Tower System)

(FIG-1)

Fig 2 Advanced Central Receiver System
(100 MWe Commercial Plant)

MAJOR SYSTEMS SPECIFICATIONS AND CHARACTERISTICS

SYSTEM	PARAMETER	CONFIGURATION FINAL ADVANCED BASELINE
ELECTRIC	New Power	100MW
	Gross Power	112MW
	Cycle Efficiency	43.1%
RECEIVER	Nominal Thermal Power	887.64×10^6 Btu/hr
	Maximum Thermal Power	1331.5×10^6 Btu/hr
	Receiver temp - in	555°F
	Receiver temp - out	1100°F
	Flow Rate	8.07×10^6 lb/hr
	Receiver mid-point EL	174m = 511 ft
STORAGE	Operating Time	3 hr
	Energy	1067 Btu
	Quantity	16.8×10^6 lb
	Volume	340×10^3 lb
EPG	Turbine in pressure	1800 psig
	Superheater temp.	1000°F
	Reheater Temp.	1000°F
COLLECTOR	Mirror Area	8.823285×10^6 ft ²
	No. of Heliostats	17908

Figure 3. Receiver Heat Losses

APPENDIX H

Geothermal Energy System

GEOHERMAL ENERGY SYSTEM

This system uses geothermal energy as a substitute to the steam power plant for heating of the campus buildings. The system configuration is shown in figure 1. It uses a heat pump to take energy from the ground water at low temperature and deliver it to the buildings. A two-stage electric motor driven refrigerant compressor discharges high pressure gas to the condenser. Heat is absorbed by the water, circulating through the building and condenser. In the condenser, vapor refrigerant changes to liquid at constant temperature and heat is rejected. When the liquid refrigerant passes through first pressure reducing valve, flash collector tank and second pressure reducing valve, the refrigerant pressure is reduced to that of the evaporator and a liquid gas mixture is produced. In this arrangement, a portion of the vapor is bled to the inlet of the second compressor stage, to improve the efficiency of the process in a 2-stage unit. In the evaporator, the liquid-gas mixture absorbs heat from the ground water, more vapor is produced and the cycle repeats.

Fig 1 Geothermal Energy System

Soil strata at Mississippi State is approximately represented by figure 2. The surface layer is about 160 feet deep. The intermediate layer is impervious to water and is about 1200 feet deep. Underneath this impervious layer is Tuscaloosa sand, which holds water under pressure. When pipe is bored down to the Tuscaloosa sand, water rises up to the pervious layer. Drawdown is about 23 feet and with this rate of removal of water, water table is expected to move downward at the rate of 2 to 3 feet per year. A multistage pump is required because of high hydraulic head.

Since output of Templifier water-to-water heat pump is 10^7 Btu/hr., requirement for this amount of energy output is evaluated and finally the requirements for total heating load are concluded.

Fig 2 Soil strata and its characteristics and pumping system

DESIGN AND CALCULATION

Westinghouse Templifier Heat Pump

Heat Pump Capacity $= 10^7 \text{ Btu/hr.}$

Natural gas consumption by steam

Power plant for heating in February $= 9.3 \times 10^7 \text{ Btu/hr.}$

Source water temperature, $T_{sh} = 68^\circ\text{F.}$

Assume

Inlet building water temperature, $T_{BH} = 180^\circ\text{F}$

Outlet building water temperature, $T_{BL} = 160^\circ\text{F}$

Outlet source water temperature, $T_{SL} = 55^\circ\text{F}$

For

$$T_{BH} = 180^\circ\text{F}$$

$$T_{SH} = 68^\circ\text{F}$$

Coefficient of performance, $\text{COP} = 2.9$

Electrical energy input to the compressor of the heat pump, $\dot{E}$ is calculated using the relation:-

$$\dot{E}(\text{KW}) = \frac{\dot{q}(\text{Btu/hr.})}{\text{COP} \times 3412 \frac{\text{Btu/hr.}}{\text{KW}}}$$

Where $\dot{q}$ = thermal output of the heat pump substituting the values for COP and $\dot{q}$

$$\dot{E} = \frac{10^7 \text{ Btu/hr.}}{2.9 \times 3412 \frac{\text{Btu/hr.}}{\text{KW}}}$$

$$\dot{E} = 1010 \text{ KW}(3.45 \times 10^6 \text{ Btu/hr.})$$

For every 10^7 Btu./hr. power supplied to the building, 6.55×10^6 Btu/hr. will be extracted from the water and rest 3.45×10^6 Bru/hr. will be supplied in the form of electrical energy to the compressor.

Mass flow rate $\dot{m}_p$ can be calculated using the relation:-

$$\dot{q}_w = \dot{m}_p \cdot c_p (T_{SH} - T_{SL}) (60 \times 8.33)$$

Where $\dot{q}_w$ = Energy extracted from water per hour, $\frac{\text{Btu}}{\text{hr.}}$

$\dot{m}_p$ = Mass flow rate of the water pump, gpm

c_p = Specific heat of water, $\text{Btu/lb}_m^\circ\text{F}$

T_{SH}, T_{SL} = High and low temperatures of source water, $^\circ\text{F}$.

For $c_p = 1 \text{ Btu/lb}_m^\circ\text{F}$,

$$T_{SH} = 68^\circ\text{F}$$

$$T_{SL} = 55^\circ\text{F}$$

$$\dot{q}_{\text{water}} = 6.55 \times 10^6 \text{ Btu/hr.}$$

$$\dot{m}_p = 1009 \text{ gpm.}$$

Mass flow rate $\dot{m}_B$ is calculated using the relation

$$\dot{q}_B = \dot{m}_B \cdot c_p (T_{BH} - T_{BL}) (60 \times 8.33).$$

$\dot{q}_B$ = rate of energy output of heat pump, Bru/hr.

T_{BH}, T_{BL} and c_p are defirred previously and substituting the values of

$\dot{q}_B, T_{BH}, T_{BL}$ and c_p , $\dot{m}_B$ is found to be 1000 gpm.

Pressure developed by the water pump is given by the equation:-

$$P = \frac{\gamma h}{144}$$

Where P = pressure developed by pump, psi

γ = specific weight of water, lb_m/ft^3

h = total hydraulic head in feet.

For γ is $62.4 \text{ lb}_m/\text{ft}^3$, and h is 260 feet,

$$P = \frac{62.4 \times 260}{144}$$

$$P = 112 \text{ psi}$$

Horse power of the pump is calculated using the relation.

$$HP = \frac{\dot{m}_p P}{1715}$$

Where

HP = hydraulic horsepower developed by pump.

$\dot{m}_p$ = capacity of pump, gpm.

P is defirred previously, and is in psi

Therefore

$$HP = \frac{1009 \times 112}{1715}$$

$$HP = 65.8 \text{ hp (49 kw)}$$

Electrical energy input to the pump, $\dot{E}_p$, is given by

$$\dot{E}_p = \frac{HP}{\eta_m \eta_p}$$

Where η_m = efficiency of electric motor

η_p = efficiency of pump

For $\eta_m = 0.9$

$$\eta_p = 0.9$$

$$\dot{E}_p = \frac{65.8}{0.9 \times 0.9}$$

$$\dot{E}_p = 81.23 \text{ hp (60.6 KW)}$$

Since total heating load is nine times the output of the heat pump, in total, nine heat pumps and nine water pumps of size mentioned earlier will be required. The system has no storage facility. Water is disposed off into drainage ditch after taking heat out of it. Water can be pumped back into the aquifier but that will cost extra amount of money and danger of lowering water table will be eliminated.

LEGAL ASPECTS

According to the Mississippi law, there is no legal restriction to take any amount of water out of ground. However, such a continuous and huge amount of water taken out of the ground is expected to lower the water table at faster rate. Records of Starkville water supply authority show that water consumption by Starkville community lowers the water table at the rate of one foot per year. As long as water is not polluted as in this system, Mississippi law does not prohibit disposal of this water into the nearby flood stream. This will save the huge cost incurred in pumping water back into the aquifier under pressure.

APPENDIX I

System Considerations and Evaluation

INTRODUCTION

The purpose of this section is to define several alternative energy systems which will meet the energy demands of the institution and carry out a preliminary analysis of these systems with regard to component efficiency, size, and cost. It is presumed that the primary energy source is the sun, using the typical interface devices: solar cells, flat plate collectors, and concentrating collectors. Attention will be "focused" on the seasonal monthly demands and the availability of solar energy during equivalent periods. Later, a computer study will be made of the energy availability and its demand on an hour-by-hour basis. The intent of the preliminary analysis is to isolate the probable system for an indepth analysis and uncover any potential problem areas.

Energy Demand

The institution monthly demand for electrical and fossil fuel energy has been given in a previous report [1]. Electrical demand was recorded also for a recent February and July week [1, p. 17-18]. Generally, the demand ran from 3 mw during late evening to 4.5 mw during mid-day in February; the July demand ran from 4 mw during late evening to 6 mw during mid-day. Consumption is higher in the summer since a portion of the load is used for cooling. Thus, it is assumed that the February figures are more realistic of a true need; however, at least one building (Allen) has electrical resistance heating. In view of the uncertainties with regard to present electrical needs an average value of 4 mw (over a twenty-four hour day) was selected as the yearly electrical demand.

Heating and cooling load calculations were performed which were in good agreement with the actual consumption [1, p. 46,55]. Heating demand was greatest during January-February at a rate of 2×10^{10} Btu/month, the December, March demand about half this rate. The cooling demand during June-September was rather steady at 6×10^9 Btu/month.

In general, it takes approximately one Btu of heat energy to produce one Btu of direct heating or one Btu of indirect cooling. However, electrical generation is accomplished at about 10% efficiency using low temperature collectors. A comparison between the energy demand and the solar energy required is summarized in Table 1 below.

Table 1. Institutional energy demand compared with the solar energy to produce it.

	<u>Electric</u>	<u>Heating</u>	<u>Cooling</u>
<u>Demand</u>	3.3×10^8 Btu/day	6.7×10^8 Btu/day	2×10^8 Btu/day
<u>Solar Energy Needed</u>	3×10^9	6.7×10^8	2×10^8

It is seen that the solar energy needed for electrical generation dominates the energy requirements of the institution, but this demand is relatively constant on a monthly basis. However, heating and cooling requirements are seasonal. More collector space will be needed for heating compared to cooling. The situation is compounded by a decrease in the availability of solar energy during the winter months. Thus, a major factor when comparing systems will be the ability to use idle collector capacity during the off-winter months.

SYSTEMS

A review of methods to meet the energy requirements with solar energy led to two (2) probable methods for electrical generation and three (3) probable methods for heating and cooling. A schematic of these systems is shown in Figures 1-2.

Electrical

(E1) Photo-voltaic array

(E2) Organic Rankine cycle (ORC)

The view is taken throughout this section that generated electricity can be sold to TVA and bought back later for roughly the same cost. Thus, no consideration is given to electrical storage. Of course, any component or system that requires hot fluid can collect that fluid during the day for evening use. This will reduce the size and cost of the components since storage is a relatively low cost item.

Heating and Cooling

(HC1) Direct heat. Cooling by absorption chiller.

(HC2) Direct heat. Cooling by centrifugal chiller.

(HC3) Organic Rankine cycle condenser as a heat source for (HC1)

ELECTRICAL SYSTEM E1

ELECTRICAL SYSTEM E2

Fig. 1. Two methods for electrical generation from solar energy.

HEATING AND COOLING SYSTEM HC1

HEATING AND COOLING SYSTEM HC2

Fig. 2. Three methods for heating and cooling from solar energy.

HEATING AND COOLING SYSTEM HC3

Fig. 2. (Continued).

System HC1 uses a solar collector to generate a hot fluid for direct heating. Storage is provided for evening heat. An absorption chiller operates directly from the hot fluid. The system is simple but does not allow for usage of the excess collector capacity during the non-winter months. System HC2 uses the hot fluid directly for heating, but includes an organic Rankine cycle to drive a centrifugal chiller. The turbine is coupled directly to a generator so that excess collector capacity can be used for electrical generation. System HC3 uses the hot fluid directly to drive an organic Rankine cycle for full utilization of the collector capacity and to supply various amounts of electrical power the year around. The normally rejected condenser heat is up-graded (higher condenser temperatures) for direct heating or for operating the absorption chiller.

COMPONENT PERFORMANCE AND COST

Solar Cells

The information below was obtained from reference [2] which relies on 1976 cost figures. Future performance of solar cells is speculation based upon a comparison with the evolution of transistors.

	<u>Now</u>	<u>Future</u>
<u>Installed Cost</u>	\$10/watt	\$1-2/watt
<u>Efficiency</u>	8-10%	20%

Solar Collectors

Two types of collectors were considered: (1) flat plate, (2) concentrating. The former absorbs the total radiant energy (direct + diffuse) while the latter absorbs only the direct beam radiant energy. Efficiency curves are shown in Figure 3 for an Acurex concentrating collector and a Solar King flat plate collector [3]. The Solar King unit represents the most efficient flat plate collector on the market today. It is apparent that solar energy is collected most efficiently at the lower mean collector temperature (average between inlet and outlet

T_f = average collector temperature

T_a = ambient temperature

q = solar energy (Btu/hr-ft²)

Fig. 3. Efficiency of collectors

temperatures). This temperature is nearly the fluid exit temperature since typical temperature changes across the collector are 10° - 20° . Flat plate collectors have good efficiency at low collection temperatures, but don't perform well above 200°F . They can be superior for direct heating. Concentrating collectors hold their efficiency over a large temperature range and are superior for use with organic Rankine cycles.

Solar heat flux for an average Mississippi State winter or summer month [4] is shown in Table 2 under flat plate collector. A program is available which takes this information and gives the direct beam radiation for a particular locale and time of year. Direct beam, N-S tracking, radiation is shown in Table 2 under concentrating collector. The total heat collected is given by the product of solar heat flux and efficiency. Also included in Table 2 is the average collector cost obtained from reference [2].

Table 2. Solar heat flux and collector cost.

	<u>Flat Plate</u>	<u>Concentrating</u>
<u>Solar heat flux</u>		
(a) Winter	1400 $\frac{\text{Btu/day}}{\text{ft}^2}$ (160 $\frac{\text{Btu/hr}}{\text{ft}^2}$)	1000 (120)
(b) Summer	2100 (240)	1400 (160)
<u>Installed Cost</u>		
(a) Now	\$14/ ft^2	\$19/ ft^2
(b) Future	\$12/ ft^2	\$14/ ft^2
<u>Footage for direct</u> <u>winter heating</u>		
(a) 200°F Fluid	$2.0 \times 10^6 \text{ ft}^2$	$1.75 \times 10^6 \text{ ft}^2$
(b) 150°F Fluid	$1.3 \times 10^6 \text{ ft}^2$	$1.5 \times 10^6 \text{ ft}^2$

Chillers

Absorption chillers are rated at 250° inlet water or steam for nominal capacity. The coefficient of performance (COP) at this temperature is 0.65. The COP drops to 0.4 with inlet water at 200°. The performance becomes negligible at around 160°-170°. Centrifugal chillers have a much higher COP equal to 5-6, but they must be driven by electric motors or ORC turbines. Thus, the overall performance depends on the efficiency of the process converting heat energy to useful work. Past solar applications have relied on absorption chillers. However, the use of ORC with centrifugal chillers having a combined COP equal to 0.8-1, appears more promising for future applications [5]. Installed cost [6] for absorption chillers today is \$210/ton while centrifugal chillers are slightly less at \$180/ton. This price includes cooling towers.

The institution cooling load for the summer averages 700 tons over a twenty-four hour day. Since sizing should be based on the maximum load, calculations showed that a typical late afternoon summer day required 2100 ton maximum. A unit size of 1400 tons was selected for this preliminary study because (1) chillers have excess nominal capacity with higher than rated energy inputs, (2) storage capacity, which is a lower cost item, can be charged during off-peak hours and used as a reserve. Storage capacity and minimum chiller tonnage will be determined later by the computer studies since an hour-by-hour systems approach will be necessary.

The collector footage necessary to meet the cooling requirements with absorption chillers is summarized below:

Concentrating Collector	Flat Plate Collector
$4.23 \times 10^5 \text{ ft}^2$ (250°F)	$4.10 \times 10^5 \text{ ft}^2$ (250°)
$3.88 \times 10^5 \text{ ft}^2$ (200°)	$2.90 \times 10^5 \text{ ft}^2$ (200°)

(1) Flat plate collectors at low operating temperatures appear more promising for use with absorption chillers.

(2) The collector footage to meet the cooling loads is an order of magnitude less than the collector footage to meet the heating loads.

Turbines

Organic Rankine cycle turbines are now past the prototype stage but are not yet being mass produced. Present installed cost [2] for ORC turbines (including heat exchangers, pumps, and cooling tower) is 500/kw which is much higher than conventional steam turbine units. Predicted future cost based on increased demand is \$400/kw.

The efficiency of various Rankine cycles is shown in Figure 4 with toluene and freon 113 looking the most promising. Airesearch Manufacturing Company has advertised a one megawatt R-11 unit with a 350°F inlet temperature and a cycle efficiency of 15 percent. Sunstrand offers a 600 kw toluene system (600°F inlet temperature) with cycle efficiencies up to 21 percent. Recently, Honeywell reported [5] on their R-113 Rankine cycle cooling system built by Barber-Nichols Engineering Company with a cycle efficiency of 15.6 percent.

An analysis of present heating and cooling systems depends on the cycle efficiencies at various turbine inlet and exhaust temperatures. Cycle efficiencies were calculated for a range of temperatures using an 80 percent turbine efficiency and 50 percent pump efficiency and they are given in Table 3.

SOURCES: Low-Temperature organic and steam efficiencies computed by R. E. Barber "Solar Powered Rankine Cycle Engine Cycles—Characteristics and Costs," June 1976, with the following assumptions: Expander efficiency 80 percent, Pump efficiency 50 percent, Mechanical efficiency 95 percent, Condensing temperature 95°F, Regeneration efficiency 80 percent, High side pressure loss 5 percent, Low side pressure loss 8 percent.

*High-temperature steam efficiencies from National Power Survey Advisory Panel Report on Energy Conservation, December 1974, page 102.

Fig. 4. Temperature dependence of Rankine cycle devices.

Table 3. Efficiency of Rankine cycles using freon 113.

<u>Outlet Temperature</u>	<u>Inlet Temperature</u>		
	<u>400°</u>	<u>300°</u>	<u>200°</u>
250°	.125	.05	-
200°	.140	.09	-
150°	.180	.125	.05
100°	.210	.150	.105
50°	.225	.200	.150

The organic Rankine cycles are supplied with heat energy directly from the collectors. Since collector efficiency decreases with the turbine inlet temperature it is the collector--ORC system efficiency which is of fundamental importance. Table 4 has been constructed to show the square feet of collector required to produce one kilowatt of electrical energy.

Table 4. Concentrating collector--Rankine cycle system efficiency (ft²/kw).

<u>Turbine Outlet Temperature</u>	<u>Turbine Inlet Temperature</u> *		
	<u>400°</u>	<u>300°</u>	<u>200°</u>
250°	490 (1165)**	978 (1824)	-
200°	438 (1040)	544 (1013)	-
150°	335 (796)	395 (735)	784 (1276)
100°	291 (694)	320 (596)	384 (626)
50°	272 (648)	245 (456)	271 (442)

*Add 30° for collector outlet temperature

**Parenthesis denotes winter

Thirty degrees was added to the turbine inlet temperature for collector temperature, allowing for a heat exchanger interface. The figures reflect

the solar energy available during the summer while parentheses reflect the solar energy available during the winter. For summer months (100° condenser temperature) the turbine efficiency dominates and combined efficiencies improve with higher collection temperatures. For winter months (50° condenser temperature) the collector efficiency dominates and combined efficiencies improve with lower collection temperatures. Thus, the solar heat collection temperature should be near 400°F in the summer and gradually allowed to drop until the heat collection temperature is near 200°F in the winter. This procedure will be followed when optimizing system performance and establishing excess collector footage in the off-winter months.

Storage

The main storage item is heat storage in the winter for evening heat collected during the sunlight hours. Additional storage for hot water peak cooling loads will be small compared to the heating storage.

If 6.7×10^8 Btu/day is required, it will be collected over an effective $1400/160$ (see Table 2) = 8.75 hours. Additional heat must be collected over these hours to supply the remaining 15.25 hours or storage for 15.25/24 fraction of the total per day-- 4.25×10^8 Btu. If stored water is circulated through the buildings for a net 25°F change:

$$\text{mass} = \frac{Q}{C T} = .17 \times 10^8 \text{ lb}$$

now

$$\text{volume} = \frac{\text{mass}}{\text{density}} = \frac{.17 \times 10^8}{60}$$

or $2.8 \times 10^5 \text{ ft}^3 = 7.93 \times 10^3 \text{ m}^3$. Figure 5 shows the cost of buried tanks based on size [2]. The cost per unit volume is approximately \$35/m³ or a total cost of \$280,000. If other fluids are used for storage (with probable heat capacities near 0.5) the cost would double.

SOURCE: Means Building Construction Cost Data, 1975, pages 18, 20, 22, 34, 184, 205-206, 258.

Fig. 5. Cost of buried tanks

ELECTRICAL SYSTEM COST

Electrical generation is achieved by (1) solar cells, (2) organic Rankine cycle turbine-generator. The solar cell cost per watt was reported earlier. The cost of the second method essentially includes collector plus turbines. Table 4 indicates that 291 ft^2 of collector per kilowatt generated will be required during the summer months while that number increases to $442 \text{ ft}^2/\text{kw}$ for the winter months. Assuming an average yearly value of $366 \text{ ft}^2/\text{kw}$ (it would be necessary to buy some electricity in the winter and sell some electricity in the summer) and using the reported cost figures, the following summary compares the methods.

	<u>Now</u>	<u>Future</u>
(1) Solar Cells		
(a) 8.75 hour solar day	\$10/watt	\$1.50/watt
(b) 24 hour day	\$27.43/watt	\$4.11/watt
(2) ORC		
(a) 8.75 hour solar day	\$ 6.88/watt	\$5.52/watt
(b) 24 hour day	\$18.87/watt	\$15.14/watt

For four megawatts over a twenty-four hour day,

ORC (now): \$75.5 million

Solar cells (future): \$16.5 million

HEATING AND COOLING SYSTEM (HC1) COST

	Cost (millions)
(1) Collector (based on flat-plate, winter heating)	
$1.3 \times 10^6 \text{ ft}^2 @ \$14/\text{ft}^2$	\$18.2
(2) Hot Storage	.3
(3) Back up boiler (2.8×10^7 Btu/hr or 2300 tons @ \$280/ton)	.6
(4) Absorption chiller (1400 tons @ \$210/ton rated capacity, i.e., divide by .4)	<u>.7</u>
TOTAL	19.8

HEATING AND COOLING SYSTEM (HC2) COST

	Cost (millions)
(1) Collector (based on concentrating, winter heating)	
$1.5 \times 10^6 \text{ ft}^2 @ \$19/\text{ft}^2$	\$28.5
(2) Hot storage	.3
(3) Back-up boiler	.6
(4) Centrifugal chiller (14 tons @ \$180/ton)	.25
(5) Turbine package (1 mw to run chiller plus an additional 3 mw for electrical generation)	
4 mw @ \$500/kw	<u>2.0</u>
SUBTOTAL	31.65
(6) Return on electrical generation	
(a) 3 equivalent full months of heating, no return	-
(b) 5 1/2 months of cooling:	$5.7 \times 10^6 \text{ kw-hr}$
(i) total possible $\frac{1.5 \times 10^6 \text{ ft}^2}{291 \text{ ft}^2/\text{kw}}$ over 9 hours	
or $46390 \frac{\text{kw-hr}}{\text{day}}$	
(ii) needed for cooling: $-11810 \frac{\text{kw-hr}}{\text{day}}$	
(c) 3 1/2 months of no heating or cooling	$3.87 \times 10^6 \text{ kw-hr}$
(i) $\frac{1.5 \times 10^6 \text{ ft}^2}{366 \text{ ft}^2/\text{kw}}$ over 9 hours	
or $36885 \frac{\text{kw-hr}}{\text{day}}$	
SUBTOTAL	<u>$9.58 \times 10^6 \text{ kw-hr}$</u>
(d) electrical capacity needed	
4 mw x 24 hours/year	$35 \times 10^6 \text{ kw-hr}$
(e) equivalent savings by replacing part of electrical system	20.7 million
$\frac{9.58}{35} \times 75.5 \text{ million}$	
NET COST	11 million

HEATING AND COOLING SYSTEM (HC3) COST

I. Heat: 6.7×10^8 Btu/day at 150°F

Turbine condenser temperature at 175°

<u>Turbine Inlet</u>	<u>η</u>	<u>Heat Out</u>	<u>Work</u>	<u>Heat In</u>
400°	.16	6.7×10^8	1.3×10^8	8×10^8
300°	.11	6.7×10^8	$.8 \times 10^8$	7.5×10^8

II. Cool: $[2 \times 10^8 \text{ Btu/day}] \div 0.4 = 5 \times 10^8$ for 200° chiller

Turbine condenser temperature at 225°P

<u>Turbine Inlet</u>	<u>—</u>	<u>Heat Out</u>	<u>Work</u>	<u>Heat In</u>
400°	.13	5×10^8	$.75 \times 10^8$	5.75×10^8
300°	.07	5×10^8	$.4 \times 10^8$	5.4×10^8

(1) Collector (based upon heating needs)

at 430° gets 195 Btu/ft²-day; 4.10×10^6 ft² needed @ \$19/ft²

at 330° gets 312 Btu/ft²-day; 2.40×10^6 ft² needed @ \$19/ft²

400° inlet 77.9 million

300° inlet 45.6 million

(2) Hot storage and back-up boiler .9 million

(3) Absorption chiller .7 million

(4) Turbine package [see item (5)]

maximum size needed during summer

with one unit at 21,530 kw-hr/day = .9 mw over 24 hours

and another unit at 92,783 = 3.86 mw

400° inlet: 4.76 mw @ \$500/kw or 2.38 million

300° inlet: 2.23 mw @ \$500/kw or 1.11 million

(5) Return on electrical generation

(a) 3 months of heating (direct turbine work)

400° inlet for 38078 kw-hr/day

300° inlet for 23,433

(b) 5 1/2 months of cooling

need 5.7×10^8 Btu/day at 430° , collecting 511 Btu/ft²-day

or 1.11×10^6 ft² collector needed from 4.1×10^6 ft² available

need 5.4×10^8 Btu/day at 330° , collecting 638 Btu/ft²-day

or $.846 \times 10^6$ ft² collector needed from 2.4×10^6 ft² available.

Generation from two sources:

(i) turbine work while condensing at 225° and supplying
heat to chiller at 200° .

$$\text{at } 430^\circ\text{F: } \frac{1.11 \times 10^6 \text{ ft}^2}{.464 \text{ ft}^2/\text{kw}} \times 9 \text{ hrs (solar day)} = 21,530 \frac{\text{kw-hr}}{\text{day}}$$

$$\text{at } 330^\circ\text{F: } \frac{.846 \times 10^6}{761 \text{ ft}^2/\text{kw}} \times 9 \text{ hrs} = 10,005$$

(ii) turbine work from remaining collector footage and condensing
at 100°F

$$\text{at } 430^\circ\text{F: } \frac{3.0 \times 10^6 \text{ ft}^2}{291 \text{ ft}^2/\text{kw}} \times 9 \text{ hrs} = 92,783 \frac{\text{kw-hr}}{\text{day}}$$

$$\text{at } 330^\circ\text{F: } \frac{1.55 \times 10^6 \text{ ft}^2}{320} \times 9 \text{ hrs} = 43,593$$

(c) 3 1/2 months of no heating and cooling

$$\text{at } 430^\circ\text{F: } \frac{4.1 \times 10^6 \text{ ft}^2}{.470 \text{ ft}^2/\text{kw}} \times 9 \text{ hrs} = 78,510 \frac{\text{kw-hr}}{\text{day}}$$

$$\text{at } 330^\circ\text{F: } \frac{2.4 \times 10^6 \text{ ft}^2}{388} \times 9 \text{ hrs} = 55,670$$

	400° inlet	$30.5 \times 10^6 \frac{\text{kw-hr}}{\text{year}}$
SUBTOTAL	300° inlet	16.8×10^6

(d) electrical capacity needed

4 mw x 24 hours/year

$35 \times 10^6 \frac{\text{kw-hr}}{\text{year}}$

(e) equivalent savings by replacing

part of ORC electrical system 400° inlet -65.7 million

300° inlet -36.2 million

NET COST 400°F inlet 16.2 million
300°F inlet 12.1 million

COST SUMMARY

The cost of complete systems is summarized below. The cost was based upon the premise that electrical energy can be bought or sold at equivalent prices any time of the year. Thus, yearly averages were used, and any excess average electrical power generated from the heating-cooling part of complete system was used to reduce the size of the electrical generation system. Only component costs were considered, and no allowances were made for maintenance, replacement, etc.

<u>Electrical</u> (+)	<u>Heating and Cooling</u>	<u>Total Cost</u>
ORC (present)	{ System (HC1)	95.3 million
	{ System (HC2)	86.5
	{ System (HC3)	87.6
Solar Cells (future)	{ System (HC1)	36.3
	{ System (HC2)	43.6
	{ System (HC3)	56.9

Institution energy cost during 77-78 year: 1.6

The cost of the collectors completely dominates the expense of the total energy systems. While relative cost of individual collectors is important one can not overlook the efficiency and type of radiation collected (direct beam or diffuse). In all cases the number of collectors can be substantially reduced by collecting energy at the lowest possible temperature. At collection

temperatures below 200°F, flat plate collector performance is competitive with concentrating collectors. Since improvements in collector performance and cost can be expected in the near future, a final decision on the approach should be delayed as long as possible.

Since the heating load for the institution requires almost an order of magnitude more collector footage than the cooling load, the major differences in system costs is attributed to how this excess footage is used for electrical generation, thereby reducing the system cost of the latter. System HC1 with the absorption chiller made use of the cheaper flat plate collectors and no means was available to use the excess collector footage. Systems (HC2) and System (HC3) both used concentrating collectors to drive an ORC. Thus, additional turbine capacity was added at relatively little cost to make full use of collectors. This pay-back reduced the cost of the ORC system used for electrical power.

In the future it is expected that the cost of solar cells will substantially drop making them much more attractive for power generation than the ORC. Here the payback costs are in terms of the cheaper solar cells, and the advantages of System (HC2) and System (HC3) are cost. The advantage of the absorption chiller in System (HC1) rests with the cost of flat plate collectors. If concentrating collectors prove to be cheaper in the near future, it would be better to use System (HC2).

REFERENCES

- [1] Powe, R. E., et. al., "Mid-South Solar Total Energy Institutional Analysis" MSSU-EIRS-GE-80-1, Engineering and Industrial Research Station, Mississippi State University, 1979.
- [2] Anon, "Application of Solar Technology to Today's Energy Needs", Office of Technology Assessment, Washington, DC., June, 1978.
- [3] Solar Engineering Master Catalog and Solar Industry Index, Solar Energy Industries Association, Dallas, Tex., 1979.
- [4] McWhorter, J. C., Climatological and Solar Radiation Relationship, Bulletin 715, Mississippi State University.
- [5] Anderson, M., "Accolade at Honeywell Plaza", Solar Age, June, 1979, p. 32-36.
- [6] Hailey, R., Trane Co., Jackson, MS., Private Communication.