A METHOD FOR DETERMINING THE INSTALLED CAPACITY OF AN UNDERFLOOR ELECTRICAL RESISTANCE HEATING AND ENERGY STORAGE SYSTEM

BY

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B.S., Georgia Institute of Technology, 1983

A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

Kansas State University
Manhattan, Kansas

1985

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CHAPTER 1

INTRODUCTION

An electric heat-storage system is a unique type of heating system wherein heating elements are buried in a layer of sand approximately one and a half feet below the building's floor surface. Electrical energy is supplied to the heating elements, or electrical resistance heating mats, where it is converted into thermal energy and stored in the sand bed and soil beneath the floor slab. This heat reservoir serves to warm the entire building by means of heat conducted up through the floor slab. Through convection and radiation from the floor surface, the building interior may be maintained at any desired temperature.

Inherent in this type of system is a lag between the time energy is supplied to the heating mats and the time the effects of such input are felt within the building. Operators, however, may be able to use this time lag characteristic to their advantage. For many years heating systems, and cooling systems for that matter, have been designed and operated to meet instantaneous demands. Utility companies are designed to have the installed capacity to meet the sum of these demands. Peak energy demands for industrial and commercial activity generally occur between 9:00 a.m. and 5:00 p.m. during any typical working day, whereas after hours energy demands are substantially decreased. Consequently "peaks" and "valleys" of energy demand occur.

Because the utilities have the ability to meet energy demands during the "peak" hours, there are hours during any given day when a utility may be operating at half-capacity or less. As a savings incentive for consumers, some utilities offer reduced rates during the "off-peak" hours. The time lag characteristic of a heat-storage system makes it possible for the operator of said system to take advantage of the reduced rates offered during these "off-peak" hours.

The purpose of the work described herein is to provide a clear and concise method for determining the heating needs of any given commercial building in the state of Kansas and the size of a heat-storage system which will meet these needs. To accomplish this, a one-dimensional computer program was developed to model an existing heat-storage system presently operating in the warehouse area at the Kansas Power and Light Service Center located in Olathe, Kansas. This program is capable of approximating temperatures within the warehouse and beneath the concrete slab. Using these temperature values, heat flows are calculated. Also, using this program, several parameters such as system operating cycle, soil property values, edge insulation thickness, earth berm height and building thermal transmittance value (U-value) have been varied to determine their effects on the sizing of a heat-storage system. With a working knowledge of the heat flows, such as edge losses, as well as the effects of varying system parameters on these heat flows, a system may be designed to minimize energy usage, or rather the cost of maintaining a particular building at design temperature. Finally a brief economic comparison has been made between heat-storage and conventional heating systems.

CHAPTER 2

KANSAS POWER AND LIGHT BUILDING DESCRIPTION

The Kansas Power and Light (KP&L) Service Center to be used as a model for this analysis was built in 1981. A heat-storage system was also installed at this time to meet the warehouse heating requirements. This heating system consists of eighteen electrical resistance heating mats located 18" below the warehouse floor surface. Each mat is 36 feet by three feet in size and is rated at 2.611 KW for a total installed capacity of 47.0 KW. See Figure 1 for a distribution of the heating mats. Two thermostats, one located on the east wall of the warehouse and the other on the west wall, control the operation of the heating mats. During the 1984-85 heating season, the thermostats were set to activate the heating mats between the hours of 4:00 p.m. and 8:00 a.m. whenever the interior building temperature fell below 60^{o}F.

The KP&L warehouse, an 80.5' x 75.6' x 17.25' structure, has a predominantly metal exterior with concrete walls extending above ground level to the north and east. The north wall is concrete to a height of seven and a half feet with earth berm covering approximately 84% of it. To the east, a combination of effects exists. The southeast half of the wall surface is completely exposed to the atmosphere with the floor slab sitting on grade while earth berm gradually inclines to a height of four feet over the remaining half of the wall surface. An office building adjoins the warehouse at the south wall. This office space is not heated by the heat-storage system. A roof covered loading dock adjoins the warehouse west wall.

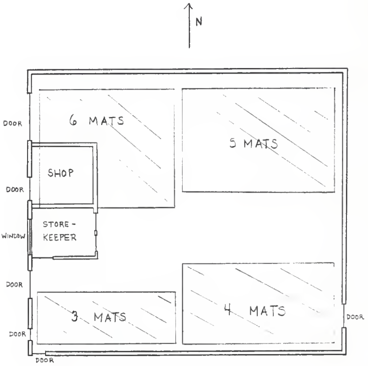


FIGURE 1: Location of the Heating Mats

Besides the building specifications, two other sources of information were of vital use to this work: hourly energy consumption data provided by KP&L and temperature data recorded with the use of copper-constantan thermocouples placed at several locations within the warehouse, underneath the floor surface and at varying distances from the north wall. See Figure 2 for a layout of the thermocouple locations. In order to facilitate burial of the thermocouples, they were attached to wooden poles, each 12 feet in length. Contractors drilled six holes, each hole four inches in diameter, where thermocouple poles were later buried. These pole locations are seen in Figure 3 as well. Several thermocouples were attached to the walls and ceiling of the building interior to measure surface temperatures while three others were hung to measure the room air temperature. All thermocouple data were recorded at four hour intervals on a 40 channel data logger left undisturbed inside the warehouse. Data gathered from these thermocouples and the metered electrical data were used to verify the computer program developed for this analysis.

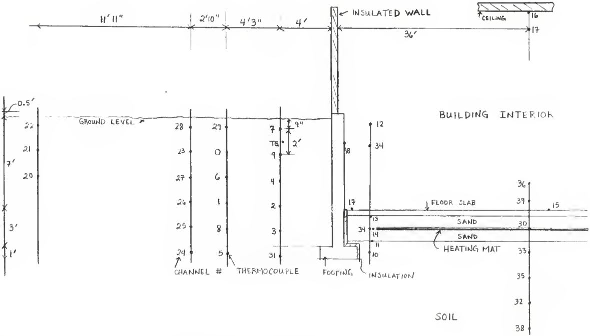


FIGURE 2: Thermocouple Locations

CHAPTER 3

THE COMPUTER MODEL

Model Description

A two-dimensional, transient, finite difference computer program was developed previously to model temperature distributions and heat flows in the storage bed, building and surrounding earth adjacent to and underneath the building at the KP&L site (1). However, repeated runs of this detailed program for the purpose of the work described here are too costly. For this reason, the one-dimensional program described here was developed. It has the same capabilities as the two-dimensional model, but executes in less time and is, therefore, less expensive to use.

The one-dimensional program (see Appendix B) approximates the following temperatures: TS, TG, TU, TD1, TC, TW, all of which are labeled on Figure 3. A seventh temperature, TR, is also calculated within the program and represents the warehouse room air temperature. The soil temperature, TD2, at a depth of 9.42 feet below the slab surface is not estimated within the program but steadily increased from a value of 72^{o}F to 76^{o}F during the heating season. This temperature range was obtained from the measured data and establishes a lower bound for the computer program. Using these temperatures, the following heat flows and energy storages are calculated: QDS, the energy stored in the soil below the sand bed; QS, the energy stored in the sand bed; QUS, the energy stored in the floor slab; QE, the edge losses through the foundation footing; QG, the energy stored in the ground outside of the foundation footing; QU2, the heat gain to the warehouse; QC, the energy lost through the ceiling; QW, the energy lost

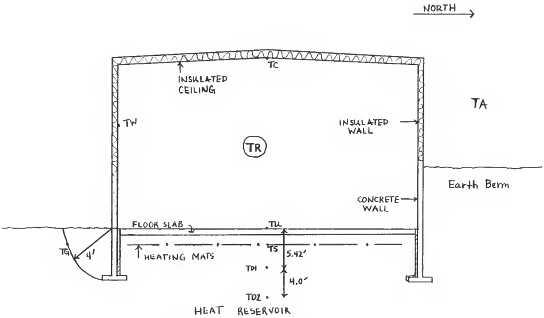


FIGURE 3: Typical Building Cross Section

through the walls; and QD2, the portion of the energy lost downward to the soil. These quantities are labeled in Figure 4, which shows the electrical analogy used to facilitate program development.

Many parameter values, resistances and convection coefficients, for example, are initialized at the beginning of the program. Their values and an illustration of how they are determined can be seen in Appendix A. The actual heat input to the mats, QIN, in Btu/hr per ft^2 of floor area and the average ambient temperature value, TA, are read into the program on a daily basis. Because the slab and below grade soil temperatures respond slowly and are, to a large degree, insensitive to rapid changes (see Graph 1) in the ambient air temperature, the average daily ambient temperature is used rather than approximating a new ambient temperature each hour. The values of QIN were obtained from the metered electrical data sent by KP&L. The following temperatures: TS, TU, TD1, TD2, TR, TC, TW and TG are initialized with values measured by the thermocouples on October 12, 1984.

Once beyond the initialization of the various parameters, the program calculates a series of heat flows and storages using the First Law of Thermodynamics and equations based on a finite difference form of Fourier's Law of Heat Conduction. Using an hourly time step and temperature values at the beginning of the hour increment, temperature gradients with respect to time are calculated at the nodes TS, TG and TD1. Heat flows/storages corresponding to nodes beneath the floor surface, namely QS, QDS, QG, QE, QU1, QD1, and QD2 are then calculated. Because of the low air capacitance value, CA, a time step of fifteen minutes is used to calculate the warehouse room air temperature, TR. This is to insure that TR remains stable. Once calculated, TR is incremented to account for the heating load supplied by the warehouse lighting (see Appendix C) and the heating losses

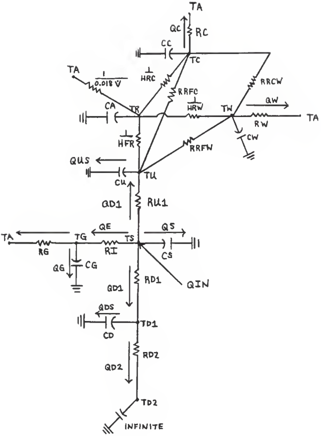
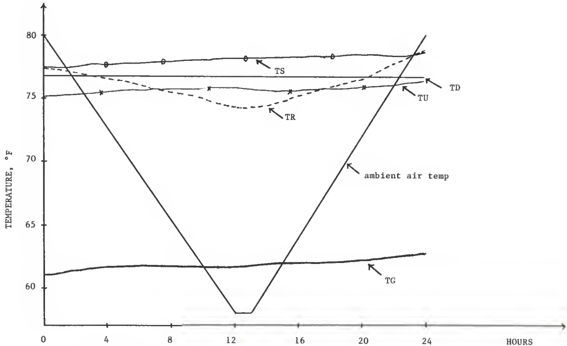


FIGURE 4: Electrical Analogy



GRAPH 1: HOURLY TEMPERATURE RESPONSES WITH A STEP CHANGE OF AMBIENT AIR TEMPERATURE

experienced due to an infiltration rate of 0.21 air changes per hour (see Appendix D). Using this new room temperature and radiation and convection coefficients for the interior warehouse surfaces, a new temperature TRBAR is determined (2). TRBAR is, in effect, the "average" room air temperature in the warehouse during the entire hour. The heat flows/storage QC, QW, QU2 and QUS are then calculated based on TRBAR. At the end of each hour, all temperatures are incremented to their new values before the program begins calculations for the following hour. Heat flows and heat storages are summed so that daily, monthly and heating season totals may be determined. After a period of 24 hours, the program reads a new QIN and TA. Calculations for a new day using an hourly time step begin again. At present the program is set up to make calculations for the months of October, 1984 through May, 1985, the period for which data is available.

The program also generates other auxiliary information. The average ambient temperature for each month is computed. Heating degree days using a base temperature of 65^{o}F and heating degree days using the actual room temperature value are calculated for each month.

Model Verification

The computed results were verified by comparison of computed to measured temperatures. Hourly temperature values were generated for March 13, 1985. An early spring day was chosen so that the effects of the initial conditions would no longer be seen. Corresponding temperature readings were gathered from the actual data taken at the KP&L site. These computed temperature values and the actual readings are shown in Table 1 at four hour intervals. TS is the calculated temperature at the heating mat level and corresponds to thermocouple #30 in Figure 2. TU is the

TABLE 1

HOURLY TEMPERATURES FOR March 13, 1985

TIME	MorC[a]	TU °F	TD °F	TR °F	TW °F	TC °F	TS °F	TG °F
04:00	M	70.3	79.2	65.6	63.3	66.5	78.5	46.2
	C	69.2	77.0	66.1	65.0	65.8	76.8	47.7
08:00	M	70.5	79.2	65.6	64.1	67.6	79.8	46.2
	C	69.4	77.0	66.2	65.2	66.0	77.4	47.8
12:00	M	70.1	79.1	65.5	65.6	69.8	79.8	46.4
	C	69.7	77.0	66.4	65.4	66.2	78.0	48.0
16:00	M	70.5	79.1	65.5	66.1	70.3	79.4	46.7
	C	70.0	77.0	66.7	65.7	66.5	78.6	48.1
20:00	M	70.9	79.2	65.4	64.7	68.6	79.1	46.9
	C	70.3	77.0	66.9	65.9	66.7	79.1	48.3
24:00	M	71.0	79.1	65.5	63.8	67.4	78.9	46.4
	C	70.7	77.0	67.2	66.2	67.0	79.6	48.4

[a]"M or C" measured or calculated

calculated floor surface temperature and corresponds to thermocouple #15. TD is the calculated temperature at a depth of 5'5" beneath the slab surface. It corresponds to thermocouple #35. Each of these calculated temperatures agrees quite well with its measured counterpart, $\pm$ 2.2^{o}F in difference at most. For example, at 4:00 p.m. (16:00), TU-calculated (TU-C) is 0.5^{o}F lower than the actual measured value while TD-C and TS-C are 2.1^{o}F and 0.8^{o}F lower than their measured values.

TW is the calculated temperature of the wall surface and its measured value corresponds to the average of thermocouples #18 and #19 in Figure 2. TC is the calculated value of the ceiling surface temperature and corresponds to thermocouple #16, also in Figure 2. One final node inside the warehouse is TR, the room temperature. Its measured values are recorded by thermocouple #10. Simulation of the building interior is difficult because two auxiliary heaters, located in the southwest area of the warehouse, were used at random during the entire heating season. By "at random" it is meant that the auxiliary heaters were not operated according to any predetermined operating cycle, just when KP&L employees felt a need for some additional heating. This effect can be seen in Graph #1 where the average daily measured room temperature stayed fairly constant, possibly due to the use of the auxiliary heaters.

Thermocouples #7 and #9 were used to represent the soil temperature, TG. Refer to Figure 2 for a comparison of the locations of TG and thermocouples #7 and #9. Because TG lies approximately half-way between thermocouples 7 and 9, its actual value should behave similar to the average values of these thermocouples. Table 1 shows this to be true.

In addition to the measured and computed data comparison at each temperature node, a sensitivity analysis was done to determine the percentage of error in individual heat flows (i.e., QD1, QU1, etc.) caused by one degree in difference between the computed and measured temperature values. Appendix E explains the steps of this analysis in more detail while Table 2 shows the results. For example, if the calculated value of TS is one degree higher than its measured value, the quantity QU1 will too high by 12.5%. Because the heat flows and energy storage calculations are based on energy balances at each temperature node, an overestimation of QU1 means that the calculated sum of QE, QS and QD1 is too low by that same amount. The sum of the heat flowing into a node will always equal the amount leaving plus the energy stored at that node.

To exactly match measured data with computed values is an impossibility with the extremely simplified model being used here. For instance, during the month of December, TD may be $2^{o}F$ higher than the actual data while in March it may be $2^{o}F$ too low. Graphs 2-5 were developed to allow comparison of the computed temperatures to that of the measured data over an entire heating season. It is seen that over an entire heating season, the program generates temperature values which, on the average, compare quite favorably to measured data, and for the purposes of this work, the computer program estimates heat flows/storages which are of acceptable accuracy.

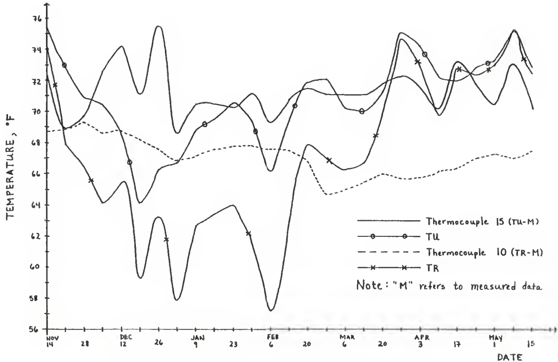
Model Response

Once verified, the program was run through the entire heating season. Information generated was used to develop Graph 6 which shows the direction of heat flows and energy storage on a monthly basis. Also shown are the average outdoor and indoor temperature profiles. Table 2 shows the heat flows and energy storage as percentages of the monthly heat input over the

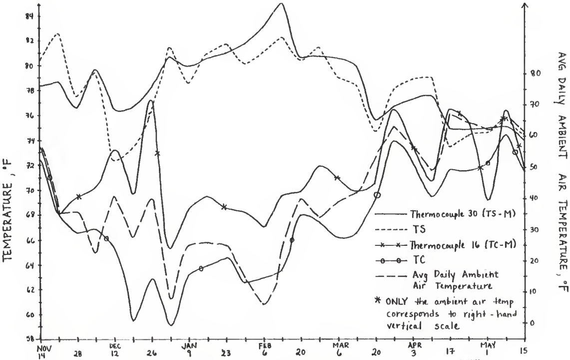
TABLE 2

ERROR PERCENTAGE OF HEAT FLOWS

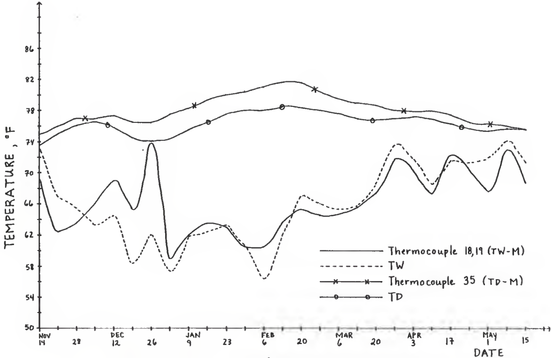
NODE	TYPICAL RANGE OF TEMPERATURE DIFFERENCE	ERROR PERCENTAGE OF HEAT FLOW PER DEGREE IN DIFFERENCE
TS	2°F	12.5% of QU1
		100.0% of UD1
		3.3% of QE
TU	2°F	12.5% of QU1
TD1	2°F	100.0% of QD1
		20.0% of QD2
TG	5°F	3.3% of QE



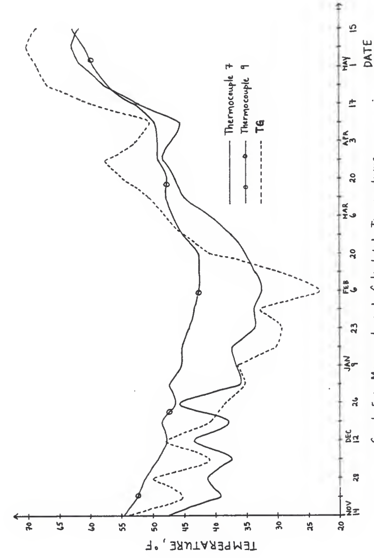
Graph 2: Measured and Calculated Temperatures



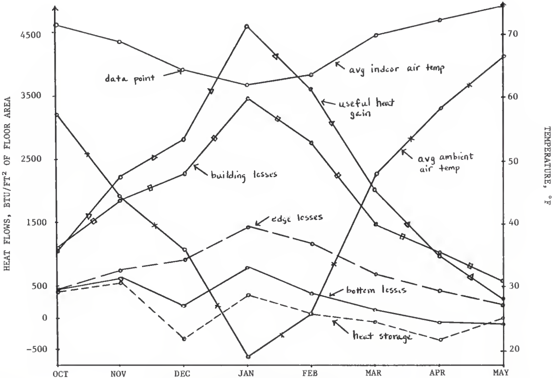
Graph 3 : Measured and Calculated Temperatures



Graph 4 : Measured and Calculated Temperatures



Graph 5 : Measured and Calculated Temperatures



GRAPH 6: MONTHLY HEAT FLOW DIRECTIONS

TABLE 3

MONTHLY HEAT FLOWS AND ENERGY STORAGE

MONTH	TOTAL HEAT INPUT (QIN)	HEAT GAIN TO BUILDING		BUILDING LOSSES		HEAT STORAGE		EDGE LOSSES		BOTTOM LOSSES	
		TOTAL	% of QIN	TOTAL	% of QIN	TOTAL	% of QIN	TOTAL	% of QIN	TOTAL	% of QIN
OCT. '84	2209.4	1025.9	46.4 [a]	1072.6	48.6	407.0	18.4 [b]	404.4	18.3 [c]	372.3	16.9 [d]
NOV.	4130.4	2225.6	53.9	1864.8	45.2	567.3	13.7	741.8	18.0	595.4	14.4
DEC.	3559.9	2804.1	78.8	2267.0	63.7	-327.0	-9.2	911.8	25.6	+171.9	4.8
JAN. '85	7196.5	4613.4	64.1	3479.7	48.4	369.8	5.1	1426.9	19.8	786.5	10.9
FEB.	5243.5	3602.0	68.7	2752.1	52.5	91.7	1.8	1166.7	22.3	381.6	7.3
MAR.	2709.4	2008.1	74.1	1731.6	63.9	-94.1	-3.5	688.4	25.4	107.5	4.0
APR.	941.8	981.5	104.2	1023.6	108.7	-381.4	-40.5	413.7	43.9	-72.6	-7.7
MAY	381.8	297.6	78.0	582.3	152.5	7.3	1.9	202.2	53.0	-125.3	-32.8
TOTALS	26732.5	17558.2	66.6	14773.8	56.0	640.7	2.4	5956.0	22.6	2217.3	8.4

NOTE: All heat flows are in 8tu/ft^2 of floor area, a + b + c + d = 100% of QIN; positive heat flows are heat gains; negative heat flows are heat rejection.

heating season. Using this table and Graphs 2-6, an overall understanding of how the system responds to ambient air temperature changes can be reached.

During the first two weeks of October, a warm-up period was experienced, meaning a sizeable portion of the heat input (approximately 19%) was used to warm up the sand and soil below the floor slab. During the last two weeks of October, the system was shut off in order to allow placement of the thermocouple poles and monitoring of the warm-up period. The ambient air temperature began to fall and energy stored in the heat reservoir was drawn upward to meet heating needs. In November the ambient temperature continued to decline. The rate of heat gain to the building increased to meet heating needs as a result. Energy was stored at a lesser rate than the previous month. During December the indoor warehouse air temperature remained relatively steady above $60^{o}F$ causing the heating mats to turn off and on periodically, being off for several consecutive days for several periods during the month. In order to maintain the building air temperature, heat was drawn from storage at a greater rate. Energy consumption reached its maximum rate during January due to the declining ambient air temperature. The mats were "on" every day during January and February. Energy storage rates increased to replace heat lost during December. From February until May the weather continued to warm up. Less heat was needed to maintain the warehouse at its design temperature, and the system operated intermittantly until finally the system was turned off and remained off in mid May.

Approximately 66.6% of the total heat input during the heating season was used to meet the heating requirements of the building. Nearly 31.0% of the heat input was lost through the footing insulation and downward to the soil. The balance of the heat input, 2.4%, remained in the heat reservoir at the end of May.

CHAPTER 4

ESTIMATING THE DESIGN HEATING LOAD

The design heating load is by definition the amount of heat required to maintain a space at indoor design air temperature during outdoor design weather conditions. It is equal in magnitude to the sum of the transmission losses through the space walls, roof and floor and the heating load associated with infiltration and ventilation. The ASHRAE Handbook of Fundamentals (3) provides a detailed procedure for estimating the design heating load for any given building.

Table 4 shows an illustrative example of the design heating load determination for the KP&L warehouse in Olathe, Kansas. The indoor and outdoor design air temperature values used are $60^{o}F$ and $0^{o}F$. The thermal resistance values for the walls and ceiling are 13.0 $hr \cdot ft^2 \cdot {}^{o}F/BTU$ and 30.0 $hr \cdot ft^2 \cdot {}^{o}F/Btu$ respectively. The infiltration rate for the warehouse area is an estimated 0.5 air changes per hour. The heating losses associated with infiltration are, at best, a rough estimate because it is difficult to determine the rate of outside air leaking into the warehouse. The methods of determining the air leakage rate are based more on experience than on scientific knowledge. Another factor contributing to the difficulty in determining the heat losses due to infiltration is the presence of the loading dock to the west of the warehouse. The warehouse doors are opened and closed on demand for the purposes of loading or unloading building materials. The rate of air entering these doors is, again, difficult to

TABLE 4: KP&L DESIGN HEATING LOAD

SURFACE	RATE OF HEAT LOSS, BTU/HR
ROOF	$q = UA\ (\Delta T)$ $= (1/30.0)(6086.0)(60-0) = 12{,}172$
WALLS ABOVE GRADE	$q = UA\ (\Delta T)$ $= (1/13.0)(3691.0)(60-0) = 17{,}035$
WALLS BELOW GRADE	$q = UA\ (\Delta T)$ $= (0.624)(80.5)(60-22) = 1{,}909$
DOORS	$q = UA\ (\Delta T)$ $= (1.154)(306.0)(60-0) = 11{,}922$
FLOOR PERIMETER	$1 = F_2P\ (\Delta T) = 6{,}626$ $= (0.624)(80.5)(60-22) + (2)(0.52)(75.6)(60-0)$
FLOOR SLAB	$q = UA\ (\Delta T)$ $= (0.02)(6086.0)(60-22) = 4{,}625$
INFILTRATION	$q = 0.018\ \dot{V}\ (\Delta T)$ $= 0.018\ (52{,}490)(60-0) = 56{,}689$
VENTILATION	NONE
	TOTAL DESIGN HEATING LOAD = 110,987 BTU?HR

All temperatures are in °F; U-values are in Btu/ft^2 hr °F; areas are in ft^2; perimeter P is in feet; f_2 is in Btu/hr ft^2 °F and $\dot{V}$ is in ft^3/hr.

estimate. Two auxiliary heaters are used in the KP&L warehouse to offset part of the heat losses due to infiltration.

The total design heating load including infiltration heat losses is 110,978 Btu/hr for the KP&L warehouse. Because of heat losses to the soil and through the building footings and energy storage beneath the floor surface, the actual installed capacity of the heat-storage system must be some multiple of the design heating load. This multiple value is called the system's oversize factor.

CHAPTER 5

DETERMINATION OF THE OVERSIZE FACTOR

Oversize factors vary from one type of heating system to another. For the purpose of determining the oversize factor associated with the heat-storage system at the KP&L site, Graph 7 has been developed. It shows the monthly rates of heat gain and total heat input as functions of the monthly average ambient air temperature. The heat gain to the warehouse was determined using the computer program (QUZ in the previous discussion). The oversize factor associated with this particular heating system is the ratio of the total rate of heat input to the rate of heat gain at outdoor design conditions or

$$\text{OVERSIZE FACTOR} = \frac{\text{RATE OF HEAT INPUT TO MATS AT } T_o = 0^oF}{\text{RATE OF HEAT GAIN BY BUILDING AT } T_o = 0^oF}$$

$$= \frac{76{,}269 \text{ Btu/hr}}{51{,}073 \text{ Btu/hr}}$$

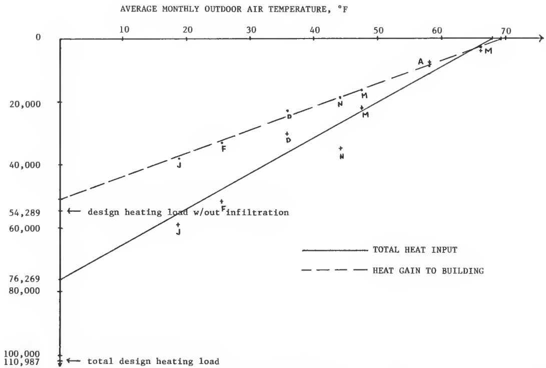
$$= 1.5$$

This indicates that to meet the heating needs of the KP&L warehouse, the installed capacity of the heat-storage system must be equal to a factor of 1.5 times the design heating load, or

INSTALLED CAPACITY = 1.5 * 100,978 Btu/hr = 44.4 KW.

From the building specifications, the KP&L heat-storage system has an installed capacity of 47.0 KW and is, therefore, capable of meeting the warehouse heating needs.

The design heating load estimate was determined using an infiltration rate of 0.5 air changes per hour. The actual use rate at design



GRAPH 7: OVERSIZE FACTOR DETERMINATION

temperature was 51,073 Btu/hr. This indicates that the design heating load estimate was too high, perhaps due to an overestimate of the infiltration rate or the auxiliary heaters carrying part of the actual building load. In either case, the difference between the design estimate and the actual demand (49,905 Btu/hr) is less than the infiltration component in the design estimate (56,689 Btu/hr).

CHAPTER 6

CORRECTION FACTORS FOR PARAMETER VALUES OTHER THAN THOSE OF BASE CASE

The oversize factor is not only dependent upon the type of heating system but of other parameters as well. Soil properties, system operating cycle and edge insulation thickness may influence the oversize factor associated with a heat-storage system. The oversize factor estimated in the previous chapter is applicable only to the KP&L warehouse. The set of design conditions at this site will be referred to as the "base case" for the remainder of this chapter and the next. Changing any of the base case design conditions may affect the oversize factor. For instance, using concrete with a higher value of thermal conductivity for the floor slab increases the heat gain to the warehouse and as a result, the oversize factor for the system will be smaller. Soil, sand and concrete properties (see Table 5) were varied from their base values to determine the effects, if any, on the building heat gain and energy storage. Refer to Table 6a and 6b. Edge insulation thickness and building thermal transmittance wree also varied and results of this can be seen in Table 6c. One final parameter, the system operating cycle, was varied from eight hours on per day to 24 hours on per day. Changing the operating cycle had no noticeable effect on heat gain, losses or energy storage.

In order to determine the oversize factor for a heat-storage system under design conditions other than those of the base case, correction factors as functions of material properties and edge insulation thickness have been estimated and can be seen in Graphs 8-15. The oversize factor

Table 5

PROPERTIES OF MATERIALS

(Range of Values from References Indicated)

MATERIAL	TEMP °F	DENSITY lbm/ft^3	HEAT CAPACITY Btu/lbm °F	THERMAL CONDUCTIVITY Btu/ft hr °F
Air [a]	68	0.0735	0.2406	0.0146
Clay [b]	68	91.0	0.21	0.739
Concrete [c]	68	119 - 144	0.21	0.47 - 0.81
Fiberglass Insulation [d]	68	3.25	0.157	0.22 per foot of insulation
Sand [e]		100 - 112.4	0.20	1.14 - 1.41
Soilstone [f]	68	135 - 144	0.17	0.94 - 1.20

a, d: Reference (3)
b, c: Reference (6)
e, f: Reference (7)

Table 6a

EFFECTS OF PARAMETER VARIATIONS

PARAMETER	PARAMETER VALUE	HEAT INPUT (QIN) Btu/ft^2	a HEAT GAIN TO BUILDING % of QIN	BUILDING LOSSES % of QIN	b HEAT STORAGE % of QIN	c EDGE LOSSES % of QIN	d BOTTOM LOSSES % of QIN
SOILSTONE DENSITY, lbm/ft^3	144.0*	26372.6	66.4	55.9	2.3	22.6	8.7
	140.0	26372.6	66.4	56.0	2.3	22.6	8.7
	135.0	26372.6	66.4	55.9	2.3	22.6	8.7
SOILSTONE THERMAL CONDUCTIVITY, Btu/ft^3 hr °F	1.20*	26372.6	66.4	55.9	2.3	22.6	8.7
	1.05	26372.6	66.7	56.1	2.3	22.7	8.3
	0.94	26372.6	67.1	56.3	2.3	22.7	7.9
SAND DENSITY, lbm/ft^3	112.4	26372.6	66.4	55.9	2.3	22.6	8.7
	107.0	26372.6	66.4	55.9	2.3	22.6	8.7
	100.0*	26372.6	66.4	55.9	2.3	22.6	8.7

NOTE: a + b + c + d = 100% of QIN, * base case value; QIN is the total heat input from October, 1984 through May, 1985.

Table 6b

EFFECTS OF PARAMETER VARIABLES

PARAMETER	PARAMETER VALUE	HEAT INPUT (QIN) Btu/ft^2	a HEAT GAIN TO BUILDING % of QIN	BUILDING LOSSES % of QIN	b HEAT STORAGE % of QIN	c EDGE LOSSES % of QIN	d BOTTOM LOSSES % of QIN
SAND THERMAL CONDUCTIVITY, Btu/ft•hr•°F	1.14*	26372.6	66.4	55.9	2.3	22.6	8.7
	1.25	26372.6	66.7	56.1	2.3	22.5	8.5
	1.41	26372.6	67.1	56.3	2.3	22.4	8.2
CONCRETE DENSITY lbm/ft^3	119.0*	26372.6	66.4	55.9	2.3	22.6	8.7
	130.0	26372.6	66.4	55.9	2.3	22.6	8.7
	144.0	26372.6	66.4	55.9	2.3	22.6	8.7
CONCRETE THERMAL CONDUCTIVITY, Btu/ft•hr•°F	0.47*	26372.6	66.4	55.9	2.3	22.6	8.7
	0.68	26372.6	67.9	56.9	2.3	22.3	7.5
	0.81	26372.6	68.5	57.3	2.3	22.2	7.0

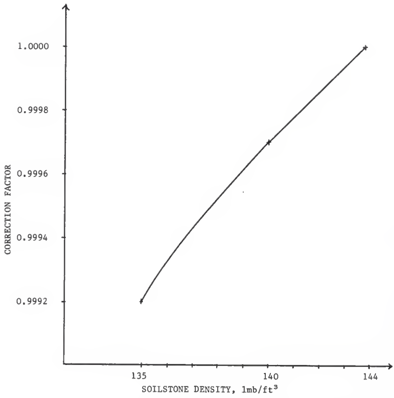
NOTE: a + b + c + d = 100 % of QIN; * base case value; QIN is the total heat input from October, 1984 through May, 1985.

Table 6c

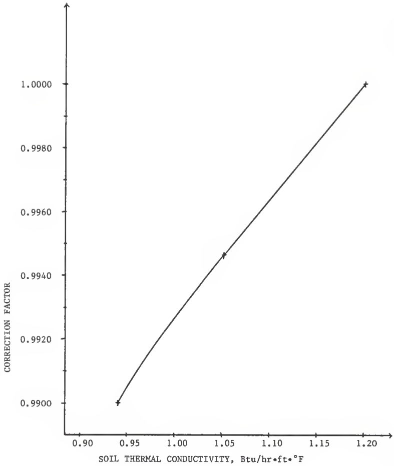
EFFECTS OF PARAMETER VARIATIONS

PARAMETER	PARAMETER VALUE	HEAT INPUT (QIN) Btu/ft²	a HEAT GAIN TO BUILDING % of QIN	BUILDING LOSSES % of QIN	b HEAT STORAGE % of QIN	c EDGE LOSSES % of QIN	d BOTTOM LOSSES % of QIN
FOOTING INSULATION RESISTANCE, hr ft² °F/Btu	No Insulation	26372.6	64.5	54.6	2.3	27.1	6.1
	3.0	26372.6	65.6	55.3	2.3	24.6	7.6
	6.0*	26372.6	66.4	56.0	2.3	22.6	8.7
	9.0	26372.6	67.1	56.4	2.4	20.8	9.7
BUILDING THERMAL TRANSMITTANCE, Btu/ft² hr °F	0.08	26372.6	58.5	44.8	2.6	23.9	15.0
	0.11*	26372.6	66.4	56.0	2.3	22.6	8.7
	0.15	26372.6	73.4	65.7	2.2	21.4	3.0
	0.20	26372.6	80.4	75.6	2.0	20.2	-2.6

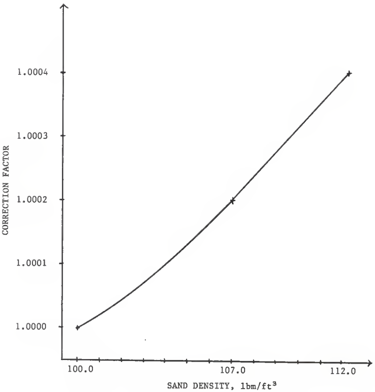
NOTE: a + b + c + d = 100% of QIN; * base case value, QIN is the total heat input from October, 1984 through May, 1985.



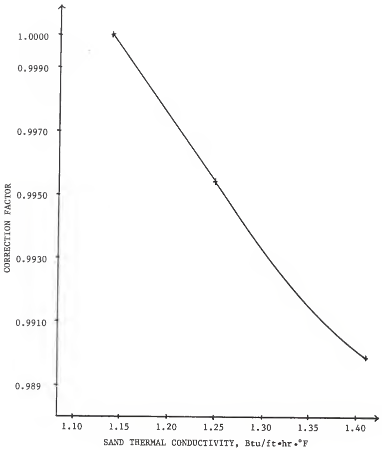
GRAPH 8: CORRECTION FACTOR VS. SOILSTONE DENSITY VARIATIONS



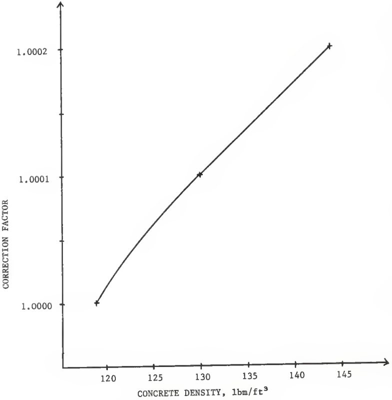
GRAPH 9: CORRECTION FACTORS VS. SOIL THERMAL CONDUCTIVITY VARIATIONS



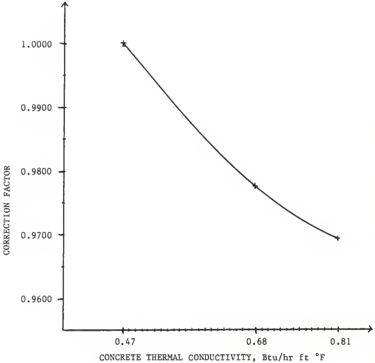
GRAPH 10: CORRECTION FACTORS VS. SAND DENSITY VARIATIONS



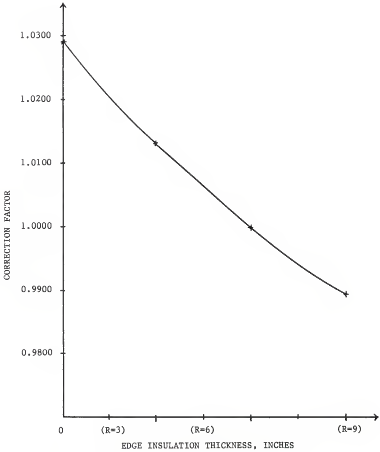
GRAPH 11: CORRECTION FACTORS VS. SAND THERMAL CONDUCTIVITY VARIATIONS



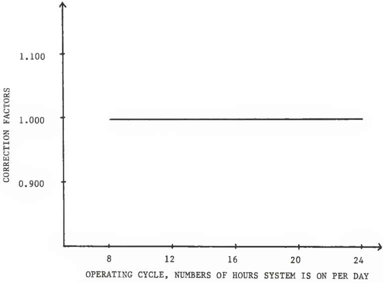
GRAPH 12: CORRECTION FACTORS VS. CONCRETE DENSITY VARIATIONS



GRAPH 13: CORRECTION FACTORS VS. CONCRETE THERMAL CONDUCTIVITY VARIATIONS



GRAPH 14: CORRECTION FACTORS VS. EDGE INSULATION THICKNESS VARIATIONS



GRAPH 15: CORRECTION FACTORS VS. SYSTEM OPERATING CYCLE VARIATIONS

for the new set of design conditions is simply the product of the base case oversize factor (1.5) and the correction factors. For instance, the oversize factor for a heat-storage system where the concrete thermal conductivity has a value of 0.81 Btu/hr ft ^{o}F is 1.5 times 0.97, or 1.46.

Although the results show the greatest sensitivity is to structure thermal characteristics, correction factors for buildings with thermal transmittance values other than the base case value are not necessary. The effect of the building U-value on the installed capacity of a heat-storage system is accounted fdor in the calculation of the design heating load. A similar situation exists for the case of earth berm covering part of one or more wall surfaces. One final variable that may affect the system oversize factor is the outdoor design air temperature, T_o. This analysis is based on a value of 0^{o}F which is applicable to any area of Kansas. Therefore, no correction factors for variations in T_o are deemed necessary for the State of Kansas.

The effect of adding edge insulation is relatively small contrary to the effect of additional insulation estimated in the ASHRAE (3) data. Adding two inches of insulation (R = 6) to the footings of the KP&L building reduced the edge heat loss rate by 17% of that experienced with no edge insulation. According to the ASHRAE data, adding insulation of R = 4.17 to basement wall surfaces four feet deep will reduce the rate of heat loss by approximately 29%. However, the ASHRAE data applies to conventional above-the-floor heating systems. The heat-storage system is more characteristic of a heated basement. As such, the rate of edge heat losses experienced by a heat-storage system are greater than those for a conventional system. Using additional insulation would have a smaller effect on the rate of edge losses from a heat-storage system as opposed to that of a conventional heating system.

CHAPTER 7

THE OPTIMUM DEPTH OF THE HEATING ELEMENTS

One other design condition warrants mentioning in this text: the depth of the resistance heating mats. At the KP&L site, the heating elements are located 18" below the floor slab surface. The computer program developed for this analysis was not used to determine the effects of any variation from the heating element depth of 18" because work of this nature has already been done; the details of which have been published in (9) and (10).

Because the heating mats are located below the floor slab, the downward heat losses associated with a heat-storage system are greater than those of a conventional system. However, the economic justification for using a heat-storage system as opposed to a conventional method of heating is the ability to take advantage of reduced electrical rates offered during off-peak hours. The time lag characteristic of a heat-storage system makes this possible. Moving the heating mats closer to the floor slab decreases the storage potential and shortens the length of the time lag. If the mats are too close to the slab surface, the time lag may be so short that a costly mid-day heating boost will be needed.

Moving the heating elements to deeper levels has two main effects. One, the heat losses through the footings and downward to the soil will increase. This, in turn, requires an increase ofd the heat input in order to meet a given heating load. An increase in the rate of heat input requires that the heating mats be operated at higher temperatures. The maximum operating temperature of the heating mats is the limiting factor in this case and depends upon the type of heating elements used. Secondly, the heating mats may be placed too deep for the heating system to respond quickly enough to rapid changes in weather conditions. This will cause periods of over and under heating.

To determine the optimum depth for heating mat placement, a compromise must occur between the length of the desired time lag and the acceptable percentage of downward heat losses. According to the reports (9) and (10), the optimum depth is approximately 18" below the floor slab surface providing a time lag of 10 - 14 hours.

CHAPTER 8

DETERMINATION OF THE INSTALLED HEATING SYSTEM CAPACITY

Once the design heating load for a building has been estimated (see Chapter 4) and correction factors have been determined for design conditions other than those of the base case (see Chapter 6), the installed capacity of the heat-storage system may be calculated. The installed capacity is equal to the produce of the corrected oversize factor and the design heating load, or

INSTALLED CAPACITY = 1.5 * Design Heating Load * Product of all correction factors

For example, given a building with an estimated design heating load of 75,000 Btu/hr and the following design conditions:

3" of edge insulation (R = 9)

thermal conductivity of the floor slab = 0.75 Btu/hr ft^2 ^oF

thermal conductivity of the soil at the designated building location = 0.94 Btu/hr ft^2 ^oF,

the installed capacity of a heat-storage system which would meet this heating load requirement is

$$\text{INSTALLED CAPACITY} = 1.5 * 75{,}000 \frac{BTU}{hr} * CF_{SLAB} * CF_{SOIL} * CF_{INSUL}$$

$$= 106{,}459 \text{ Btu/hr (31 KW)}$$

where CF_{SLAB} = correction factor for the slab conductivity from Graph 13 = 0.972

CF_{SOIL} = correction factor for the soil conductivity from Graph 9 = 0.99

CF_{INSUL} = correction for edge insulation from Graph 14 = 0.99

The effective oversize factor for this case is 1.5 * 0.972 * 0.99 * 0.99 = 1.43.

CHAPTER 9

A BRIEF ECONOMIC COMPARISON

Slab heating systems require more energy input than conventional systems (i.e., gas or oil heating, electric heat pump) in order to maintain a space at a given design temperature due to increase edge and bottom heat losses. The economic justification for using a heat-storage system is the ability to utilize reduced electrical rates which may be offered during off-peak hours.

In this chapter, a brief economic comparison will be made between the heat-storage system at the KP&L site and a conventional system, also capable of meeting the warehouse heating requirement, on the basis of the seasonal energy use.

During the period October 1, 1984 to May 31, 1985, the heat-storage system at at the KP&L site consumed a total of 26,373 Btu/ft^2 of floor area or 47,026 KW - HR; of this only, 31,310 KW - HR was useful heat gain to the building interior. The balance of the energy input was either stored in the heat reservoir or lost to the soil and building footings. A conventional system would need to supply the same amount of useful heat gain to the warehouse in order to maintain the same level of heating. The total energy consumption of the conventional system would be equal to the sum of the useful heat gain to the building and heat losses. For a conventional heating situation, no energy would be stored but there would be an edge loss rate of approximately 11,137 Btu/hr (refer to Table 4 for the sum of floor perimeter and floor slab heat losses). The total amount of edge losses per square foot of floor area for a conventional heating warehouse would be

$$QELC = 11{,}137\ \frac{Btu}{hr} * \frac{24\ hr}{day} * \frac{DD}{(T_i - T_o)}\ /\ (6085.8\ ft^2$$

where DD = total number of degree days during the heating season using a base temperature of 65 ^oF

T_i = indoor design air temperature

T_o = outdoor design air temperature

Floor area = 6085.8 ft^2 .

Using the computer program, the total energy consumption of the conventional system was estimated to be 21,366 Btu/ft^2 of floor area or 38,098 KW - hr, approximately 20% less than that of the heat-storage system.

The KP&L heat-storage system operates on a 16 hour on/8 hour off cycle. Assuming that the electrical rates are reduced during these sixteen hours each day, two-thirds of the conventional energy consumption will occur at these reduced rates. Equating the total seasonal energy cost of the heat-storage system to that of the conventional system, the maximum "off-peak" electrical rate which would make usage of the heat-storage system economically desirable can be determined as a function of the electrical rate offered during "peak" operating hours.

operating cost of heat-storage system = operating cost of conventional system

$$47{,}026\ KW - HR * A = A * (2/3) * 38{,}098\ KW - HR + B * (1/3) * 38{,}098\ KW - HR$$

where A = reduced electrical rate during "off-peak" hours in \$/KW - HR

B = electrical rate during "peak" hours

Reducing, $A = 0.60 * B$.

If the "off-peak" electrical rate is 60% of the "on-peak" electrical rate, then the seasonal energy costs of each system would be equal. If the reduced rates are less than 60% of the "on-peak" rates, then as far as energy costs are concerned, the heat-storage system would be the better choice on the basis of energy cost alone. Capital cost differences in the two systems are not considered in this determination.

A similar economic comparison was made by Van Gerpen and Shapiro, the authors of a report entitled "Analysis of Slab Heated Buildings"(10). They concluded that a ratio of off-peak to peak rates of 0.70 or less would make under-slab heating economically competitive with direct electric resistance heating. This ratio is comparable to the value of 0.60 obtained in this analysis.

Because a variety of factors may be encountered in a rate structure, it is difficult to discuss all of the favorable features which could result from operation of a heat-storage system. For example, there should be a reduced "demand" charge, if such is included in a rate structure. There may be, however, a higher "connected load" charge, if such exists. The complete economic analysis would need to be made for the rate schedule in the service area in which installation is contemplated.

CHAPTER 10

SUMMARY AND CONCLUSION

A one-dimensional, finite difference computer program was developed for the purpose of approximating temperature and heat flow distributions characteristic of buildings using underfloor electrical resistance heating systems. A variable time step was used to maintain program stability.

Computed temperature profiles were compared to actual measured data over the entire heating season. On the average, the computed results modeled the measured data quite favorably. The magnitude and direction of heat flows and energy storage were estimated based on the computed temperature values.

The computer model was used to determine the effects of variations in material properties, building thermal transmittance, edge insulation thickness, system operating cycle, and ambient air temperature. Results of these parameter variations were presented in the form of graphs and tables. The effects of changing the depth of the heating elements were also discussed.

A method for determining the design heating load for a given building was outlined briefly. The oversize factor characteristic of heat-storage system operating under a particular set of design conditions was estimated. Correction factors for parameter values differing from these design conditions were determined using the computer model. The installed capacity of a heat-storage system was defined as a function of the building design heating load, oversize factor and correction factors.

Finally, an economic comparison was made between a heat-storage system and a conventional heating system on the basis of seasonal energy costs.

The purpose of this text was to provide a clear and concise method of sizing underfloor heat-storage systems for commercial buildings in Kansas. The conclusion of this study is that the installed capacity of a heat-storage system should be .15 times the design heating load for a given building. Energy costs for the heat-storage and conventional heating systems will be the same if an off-peak electrical rate exists for 16 hours per day at a value of 0.6 times the peak rate.

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APPENDIX A

DETERMINATION OF PROGRAM VARIABLES

APPENDIX A

This appendix illustrates the determination of values assigned to variables within the computer program. For a physical representation of these variables refer to Figure 5. Because the actual material properties at the KP&L site are not known, a trial and error process was used to determine which combination of variable values produced temperature profiles closest to those of the measured data. The range of property values used are shown in Table 5. The following is a list of variable values chosen as input for the program and an illustration of how they were determined. All material densities are in lbm/ft^3; heat capacities are in Btu/lbm ^oF while thermal conductivities are in Btu/ft·hr·^oF.

CG: The thermal capacitance of the soil outside the building footings to the north, east and west sides of the warehouse

$$CG = VG * \rho * C_p = 154.3 \text{ Btu/ft}^2 \ ^oF$$

where VG = the volume, in ft^3, of a section of soil 0.502 feet thick and a surface area of 12.56 ft^2.

$$\frac{\text{exposed building perimeter}}{\text{floor area}} = 0.502 \text{ ft/ft}^2$$

$$\pi * (4.0 \text{ ft})^2 / 4 = 12.56 \text{ ft}^2$$

ρ = soilstone density = 144.0

C_p = soilstone heat capacity = 0.17

CU: the thermal capacitance of the floor slab (0.5 ft thick)

$$CU = 0.5 \text{ ft} * \rho * C_p = 15.1 \text{ Btu/ft}^2 \ ^oF$$

where ρ = concrete density = 144.0

C_p = concrete heat capacity = 0.21

CS: the thermal capacitance of the sand bed (2.0 feet thick)

$$CS = 2.0 \text{ ft} * \rho * C_p = 45.0 \text{ Btu/ft}^2 \,^oF$$

where ρ = sand density = 112.4

C_p = sand heat capacity = 0.20

CD: the thermal capacitance of the soil (6'11" thick) beneath the sand bed

$$CD = 6.92 \text{ ft} * \rho * C_p = 169.4 \text{ Btu/ft}^2 \cdot {}^oF$$

where ρ = soilstone density = 144.0

C_p = soilstone heat capacity = 0.17

CA: the thermal capacitance of the air inside the warehouse (17.25 ft in height)

$$CA = 17.25 \text{ ft} * C_p * \rho = 0.31 \text{ Btu/ft}^2 \cdot {}^oF$$

where ρ = air density = 0.0735

C_p = air heat capacity = 0.2406

CC: the thermal capacitance of the roof (9.25 inch thick)

$$CC = 9.25/12.0 \text{ ft} * \rho * C_p * 1.5 = 0.60 \text{ Btu/ft}^2 \,^oF$$

where ρ = fiberglass insulation density = 3.25

C_p = fiberglass insulation heat capacity = 0.157

A factor of 1.5 was used because of the presence of a metal shell covering the insulation.

CW: the thermal capacitance of the wall (4.0 inches thick)

$$CW = 4.0/12.0 \text{ ft} * \rho * C_p * 1.5 = 0.26 \text{ Btu/ft}^2 \,^oF$$

where ρ = density of fiberglass insulation = 3.25

C_p = heat capacity of fiberglass = 0.157

A factor of 1.5 was used because of the presence of an outer metal shell covering the wall surfaces and steel webbing inside the walls.

RU1: the thermal resistance of the concrete floor and one foot of sand

$$RU1 = 0.5 \text{ ft/k-concrete} + 1.0 \text{ ft/k-sand} = 1.94 \text{ hr}\cdot\text{ft}^2\cdot{}^{o}\text{F/Btu}$$

where k-concrete = concrete thermal conductivity = 0.47

k-sand = sand thermal conductivity = 1.14

RD1: the thermal resistance of one foot of sand and 2'11" of soilstone

$$RD1 = 1.0 \text{ ft/k-sand} + 2.92 \text{ ft/k-soilstone} = 3.14 \text{ hr ft}^2\cdot{}^{o}\text{F/Btu}$$

where k-sand = sand thermal conductivity = 1.14

k-soilstone = soilstone thermal conductivity = 1.20

RD2: the thermal resistance of four feet of soilstone

$$RD2 = 4.0 \text{ ft/k-soilstone} = 4.26 \text{ hr}\cdot\text{ft}^2\cdot{}^{o}\text{F/Btu}$$

where k-soilstone = 0.94

RW: the thermal resistance of the walls in hr ft^2 ^{o}F/Btu

RW = 13.0 (building specifications)

RC: the thermal resistance of the roof in hr ft^2 ^{o}F/Btu

RC = 30.0 (building specifications)

HRW: represents the natural convection heat transfer coefficient in Btu/hr$\cdot ft^2 \cdot {}^{o}F$ for the interior wall surfaces

$$HRW = 0.19\ (\Delta T)^{0.33} = 0.38 \quad (3)$$

where

$\Delta T = 8^oF$

HRC: represents the natural convection heat transfer coefficient in Btu/hr·ft^2·^oF for the ceiling

$$HRC = 0.12 \frac{\Delta T}{L}^{0.25} \quad (3)$$

where

L = 80.5 feet

HFR: represents the natural convection heat transfer coefficient in Btu/hr·ft^2 ^oF for the floor

$$HFR = 0.22 (\Delta T)^{0.33} = 0.40 \quad (3)$$

RRFC: represents the reciprocal of the radiation heat transfer coefficient between the floor and ceiling

$$q_{F-C} = h_{F-C} (T_F - T_C) = \left[\sigma(T_F^4 - T_C^4)/[\frac{1}{\varepsilon_F} + \frac{1}{\varepsilon_C} - 2 - \frac{1}{F_{F-C}}]\right]\left[\frac{T_F - T_C}{T_F - T_C}\right] \quad (5)$$

where

q_{F-C} = radiant heat exchange between the floor and ceiling

T_F = floor temperature

T_C = ceiling temperature

h_{F-C} = heat transfer coefficient between floor and ceiling in Btu/hr·ft^2·^oF

ε_F = floor emissivity = 0.40 (3)

ε_C = ceiling emmissivity = 0.90 (3)

F_{F-C} = view factor between floor and ceiling = 0.62 (4)

σ = 0.1714 x 10^{-8} Btu/hr ft^2 $^oR^4$

(Stephan-Boltzmann constant)

Linearizing,

$$[T_F^4 - T_C^4]/[T_F - T_C] \approx 4\bar{T}^3$$

where

$\bar{T}$ = the average of T_C and T_F in $^oR = 72^oF = 532^oR$

Therefore,

$$h_{F-C} = \frac{4\sigma\bar{T}^3}{\frac{1}{\varepsilon_F} + \frac{1}{\varepsilon_C} - 2 + \frac{1}{F_{F-C}}}$$

and RRFC = $1/h_{F-C}$ = 3.28 $ft^2 \cdot hr \cdot {}^oF/Btu$

RRFW: represents the reciprocal of radiation heat transfer coefficient between the floor and the walls.

$$h_{F-W} = \frac{4\sigma\bar{T}^3}{\frac{1}{\varepsilon_F} + \frac{1}{\varepsilon_W} - 2 + \frac{1}{F_{F-W}}}$$

where

$\varepsilon_W = 0.90$

$F_{F-W} = 0.38$

RRFW = $1/h_{F-W}$ = 4.33 $ft^2 \cdot hr \cdot {}^oF/Btu$

RRCW: represents the reciprocal of radiation heat transfer coefficient between the ceiling and the walls

$$h_{C-W} = \frac{4\sigma\bar{T}^3}{\frac{1}{\varepsilon_C} + \frac{1}{\varepsilon_W} - 2 + \frac{1}{F_{C-W}}}$$

RRCW = $1/h_{C-W}$ = 2.91 $hr \cdot ft^2 \cdot {}^oF/Btu$

RI: represents the thermal resistance between nodes TS and TG; the footing insulation is R-6 according to the building specifications

RG: represents the thermal resistance between node TG and the ambient air at ground level

The total resistance from the node TS to the ambient air is the sum of RI and RG. From ASHRAE (3), the U-value for an uninsulated basement wall four feet deep is 0.906 Btu/hr ft^2 ^oF.

$$U - \text{normalized} = \frac{P}{A} * 0.906 = 0.0345 \text{ Btu/hr}\cdot ft^2\cdot {}^oF$$

$$R - \text{normalized} = 1/U\text{-normalized} = 29.0 \text{ hr}\cdot ft^2\cdot {}^oF/\text{Btu}$$

where P = exposed perimeter of warehouse = 232.0 ft

A = floor area = 6086.0 ft^2

The resistance from the footing to the ambient air is 29.00 hr · ft^2· ^oF/Btu. The footing insulation is R-6. Therefore, the total thermal resistance from node TS to the ambient air is 35.0 hr·ft^2·^oF/Btu. Knowing that the heat flow paths approximately follow a set of concentric circular patterns (see Figure 6), the heat flow path length is 6.28 feet (1/4 of the circumference of a circle with a radius of four feet). The node TG is approximately 4.0 feet from the building and 1.92 feet deep. This corresponds to a distance of 1.78 feet from the ground level along the heat flow path. To esimate RG, use:

$$\frac{RG}{R} = \frac{1.78 \text{ ft}}{6.28 \text{ ft}}$$

where R = 29.0 hr·ft^2·^oF/Btu

Therefore, RG = 8.2 hr·ft^2·^oF/Btu and

$$RI = 35.0 - 8.2 = 26.8 \text{ hr}\cdot ft^2\cdot {}^oF/\text{Btu}.$$

These values were initially used as input to the program. Through the trial and error process of matching computed values to measured data, these resistances were later adjusted to:

$$RG = 6.0\ hr\cdot ft^2\cdot {}^{\circ}F/Btu$$

$$RI = 26.0\ hr\cdot ft^2\cdot {}^{\circ}F/Btu$$

for a total resistance of 32.0 $hr\cdot ft^2\cdot {}^{\circ}F/Btu$.

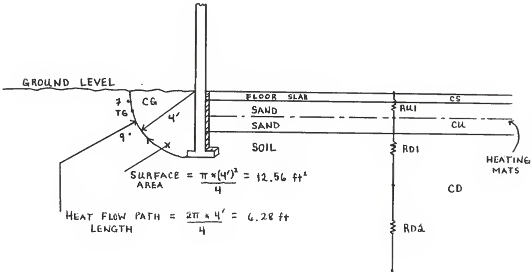

FIGURE 5: Physical Representation of Program Variables

APPENDIX B

COMPUTER PROGRAM

```
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OPTIONS IN EFFECT:  NOLIST   MAP NOXREF NOGOSTMT NODECK   SOURCE NOTERM   OBJECT FIXED  NOTEST NOTRMFLG   SRCFLG
                    NOSYM NORENT   SDUMP AUTODBL(NONE)   NOSXM
                      OPT(2) LANGLVL(77) NOFIPS   FLAG(I)  NAME(MAIN  )  LINECOUNT(60)      CHARLEN(500)

                  *....*...1.........2.........3.........4.........5.........6.........7.*.......8

                  C THIS PROGRAM SIMULATES THE DEEPHEAT STORAGE SYSTEM ON A LONG-
                  C TERM BASIS.
ISN        1            CHARACTER*9 MOA
ISN        2            INTEGER NOAT
                  C BUILDING AND OTHER PARAMETERS
ISN        3            J = 1
ISN        4            I = 0
ISN        5            JJJ = 1
ISN        6            DELTP = 0.25
ISN        7            L = 80.5
ISN        8            W = 75.5
ISN        9            FAREA = L * W
ISN       10            HI = 4.0
ISN       11            PI = 3.14159
ISN       12            GLIGHT = 24700 * 5/24/ (L * W)
                  C SOIL PROPERTIES
ISN       13            ROG = 144.0
ISN       14            CPG = 0.17
                  C THE FOLLOWING ARE PROPERTY SPECIFICATIONS, ALL PER SQUARE FOOT OF
                  -C FLOOR. FOR A DEFINITION OF THESE QUANTITIES, SEE ACCOMPANYING
                  C SKETCHES.
ISN       15            CS = 44.96
ISN       16            CD = 169.32
ISN       17            CU = 15.12
ISN       18            CA = 0.31
ISN       19            CW = 0.29
ISN       20            CC = 0.60
ISN       21            RO1 = 3.14
ISN       22            RU1 = 1.94
ISN       23            RO2 = 4.26
ISN       24            HFR = 0.40
ISN       25            HRW = 0.35
ISN       26            HRC = 0.0627
ISN       27            RG = 6.00
ISN       28            RI = 25.00
ISN       29            VG = (2*(L+W)/(L*W)) *PI*(HI**2)/4.0
ISN       30            CG = VG * ROG * CPG
                  C CALCULATE QUANTITIES NEEDED FOR THE ROOM AIR TEMPERATURE CHANGES
ISN       31            S1 = HFR + HRW + HRC
ISN       32            Z = S1 * DELTP / CA
ISN       33            RFR = 1.0 / HFR
ISN       34            RRW = 1.0 / HRW
ISN       35            RRC = 1.0 /HRC
ISN       36            RRFW = 4.23
ISN       37            RRFC = 3.23
ISN       38            RRCW = 2.91
ISN       39            RW = 13.0
ISN       40            RC = 30.0
ISN       41            SOMW = 1.0/RRW + 1.0/RRFW + 1.0/RRCW + 1.0/RW
ISN       42            SOMC = 1.0/RRC + 1.0/RRFC + 1.0/RRCW + 1.0/RC
                  C HERE ARE THE INITIAL TEMPERATURES . OCTOBER 1, 12:00:01 AM
ISN       43            TS = 71.1
```

```
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                 *....*...1.........2.........3.........4.........5.........6.........7.*.......8
ISN      44           TU = 72.0
ISN      45           TDI = 68.7
ISN      46           TR = 72.0
ISN      47           TA = 52.0
ISN      48           TW = 70.0
ISN      49           TC = 73.5
ISN      50           TG = 67.5
ISN      51           TO2 = 72.0
ISN      52           TPSAR = TR
               C INITIALIZE THE ANNUAL TOTALS
ISN      53           ACCONV = 0.0
ISN      54           AGC2 = 0.0
ISN      55           AGC1 = 0.0
ISN      56           ADS = 0.0
ISN      57           ADDS = 0.0
ISN      58           ADCS = 0.0
ISN      59           ACU1 = 0.0
ISN      60           ACU2 = 0.0
ISN      61           AGDI = 0.0
ISN      62           AGC = 0.0
ISN      63           AMODTR = 0.0
ISN      64           AOD2 = 0.0
ISN      65           AGIN = 0.0
ISN      66           ASUM = 0.0
ISN      67           ADW = 0.0
ISN      68           AQE = 0.0
ISN      69           ADS = 0.0
ISN      70           AMDC6S = 0.0
               C READ IN THE DATA WHERE :
               C      NOS IS THE NAME OF THE MONTH
               C      NDAY IS THE NUMBER  OF DAYS IN THE MONTH
               C      TLOI IS THE "NORMAL" LOW TEMPERATURE ON FIRST OF MONTH
               C      THII IS THE "NORMAL" HIGH TEMPERATURE ON FIRST OF MONTH
               C      GL IS THE LOW TEMPERATURE CHANGE DURING THE MONTH
               C      GH IS THE HIGH TEMPERATURE CHANGE DURING THE MONTH
ISN      71         8 READ (5,11) MOS,NDAY,TLOI,THII,GL,GH
ISN      72        11 FORMAT (A9,I2,2F5.1,2F6.1)
ISN      73           IF (MOS.EQ.'NOVEMBER ') TO2 = 72.5
ISN      75           IF (MOS.EQ.'DECEMBER ') TO2 = 73.0
ISN      77           IF (MOS.EQ.'JANUARY  ') TO2 = 74.0
ISN      79           IF (MOS.EQ.'FEBRUARY ') TO2 = 74.0
               C CALULATE THE INITIAL MID-POINT TEMPERATURE AND CONVERT
               C TEMPERATURE CHANGES FOR MONTH TO TEMPERATURE CHANGES PER DAY
               C      TMIDI = (THII + TLOI ) / 2.0
               C      GL = GL / NDAY
               C      GH = GH / NDAY
               C      GM = ( GL + GH ) / 2.0
               C PRINT OUT HEADINGS
ISN      81           PRINT20
ISN      82        20 FORMAT ( ///,5X,'PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN E
                     2XTREMELY SIMPLIFIED MODEL')
ISN      83           PRINT25,MOS
ISN      84        25 FORMAT ( /,5X,'HERE ARE PREDICTED RESULTS FOR THE MONTH OF ',A9)
ISN      85           PRINT30
ISN      86        30 FORMAT ( /,5X,'TEMPERATURES ARE AVERAGE DAILY, R: HEAT FLOWS ARE T
                     2OTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.')
```

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LEVEL 1.4.0 (OCT 1984)          VS FORTRAN          DATE: OCT 25, 1985    TIME: 10:07:18      NAME: MAIN    PAGE:    3

                 *....*...1.........2.........3.........4.........5.........6.........7.*.......8

ISN      87           PRINT35
ISN      88        35 FORMAT ( //,5X,'DAY',5X,'TS',4X,'TU',4X,'TO',4X,'TR',4X,'TW',
                     24X,'TC',4X,'TA',4X,'TG')
ISN      89           PRINT36
ISN      90        36 FORMAT ( 16X,'QS',4X,'QU1',5X,'QUS',4X,'QU2',5X,'QO1',5X,'QOS',
                     25X,'QO2',4X,'QW',4X,'QC',4X,'QE',4X,'QG',4X,'SUM',4X,'QIN'//)
ISN      91           PRINT40,JJJ,TS,TU,TO1,TR,TW,TC,TA,TG
ISN      92        40 FORMAT ( 5X,I5,F7.1,7F6.1,4X,'INITIAL TEMPERATURES AT THE START OF
                     2 THE MONTH',//)
                 C SAVE THE INITIAL TEMPERATURES ON THE FIRST OF THE MONTH
ISN      93           TSS = TS
ISN      94           TUS = TU
ISN      95           TO1S = TO1
ISN      96           TGS = TG
ISN      97           TRS = TR
ISN      98           TWS = TW
ISN      99           TCS = TC
                 C INITIALIZATION OF MONTHLY TOTALS: USED IN OBTAINING MONTHLY AVERAGES
ISN     100           TOC2 = 0.0
ISN     101           TOC1 = 0.0
ISN     102           TOCONV = 0.0
ISN     103           TATOT = 0.0
ISN     104           TRTOT = 0.0
ISN     105           TQS = 0.0
ISN     106           TQUS = 0.0
ISN     107           TQOS = 0.0
ISN     108           TQU1 = 0.0
ISN     109           TQU2 = 0.0
ISN     110           TQO1 = 0.0
ISN     111           TQO2 = 0.0
ISN     112           TQIN = 0.0
ISN     113           TSUM = 0.0
ISN     114           TQW = 0.0
ISN     115           TQC = 0.0
ISN     116           TQE = 0.0
ISN     117           TQG = 0.0
                 C FOR HEATING DEGREE-DAYS
ISN     118           THDD65 = 0.0
ISN     119           THDDTR = 0.0
                 C START OF THE DO-LOOP FOR DAILY CALCULATIONS
ISN     120           DO 100 J=1,NDAT
                 C      TLO = TLOI + GL * J
                 C      THI = THII + GH * J
                 C      THIO = THIOI + GP * J
                 C READ HEAT INPUT AND AVERAGE AMBIENT TEMPERATURES FOR EACH DAY
ISN     121           READ (5,12) Q,TA
ISN     122        12 FORMAT ( F6.3,F5.2)
ISN     123           QIN1 = Q * 24 / 16
                 C INITIALIZATION OF DAILY TOTALS: USED IN OBTAINING DAILY AVERAGES
                 C AND TOTALS
ISN     124           SHDDTR = 0.0
ISN     125           SHDD65 = 0.0
ISN     126           SOCONV = 0.0
ISN     127           SOC2 = 0.0
ISN     128           SOC1 = 0.0
ISN     129           SOELC = 0.0
```

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                      *....*...1.........2.........3.........4.........5.........6.........7.*.......8
ISN       130              SST = 0.0
ISN       131              SUT = 0.0
ISN       132              SOIT = 0.0
ISN       133              SRT = 0.0
ISN       134              SWT = 0.0
ISN       135              SCT = 0.0
ISN       136              SAT = 0.0
ISN       137              SGT = 0.0
ISN       138              SQS = 0.0
ISN       139              SQUS = 0.0
ISN       140              SQDS = 0.0
ISN       141              SQU1 = 0.0
ISN       142              SQU2 = 0.0
ISN       143              SQD1 = 0.0
ISN       144              SQD2 = 0.0
ISN       145              SQIN = 0.0
ISN       146              SSUM = 0.0
ISN       147              SQW = 0.0
ISN       148              SQC = 0.0
ISN       149              SQE = 0.0
ISN       150              SQG = 0.0
                     C START THE DO-LOOP FOR HOURLY CALCULATIONS
ISN       151              DO 150 I=1,24
ISN       152              QIN2 = 0.0
ISN       153              QW = 0.0
ISN       154              QC = 0.0
ISN       155              QU2 = 0.0
ISN       156              QCONV = 0.0
ISN       157              QC2 = 0.0
ISN       158              QC1 = 0.0
                     C THE FOLLOWING THREE STATEMENTS DEFINE AMBIENT TEMPERATURE VALUES
                     C     IF (I.LT.6) TA = TNID - (TNID-TLO)/6.0 * I
                     C     IF (I.GE.6.AND.I.LT.15) TA = TLO + (THI-TLO)/9.0 * (I-6)
                     C     IF (I.GE.15) TA = THI - (THI-TNID)/9.0 * (I-15)
ISN       159              TATOT = TATOT + TA
ISN       160              TRTOT = TRTOT + TR
                     C HEATERS ON FROM 4:00 PM TO 8:00 AM
ISN       161              IF (I.GT.16.OR.I.LT.9) THEN
ISN       162                 QIN = QIN1
ISN       163              ELSE
ISN       164                 QIN = QIN2
ISN       165              ENDIF
                     C IF ROOM TEMPERATURE IS GREATER THAN 60 F, SHUT OFF INPUT ENTIRELY
                     C     IF (TR.GT.60.0) QIN = QIN2
                     C IF MAT TEMPERATURE IS GREATER THAN 85 F, SHUT OFF INPUT ENTIRELY
                     C     IF (TS.GT.85.0) QIN = QIN2
                     C THE FOLLOWING THREE STATEMENTS CALCULATE THE STORAGE TEMPERATURE
                     C DERIVATIVES
ISN       166              DTSDT = QIN/CS - ((TS-TU)/RU1 + (TS-TD1)/RD1 + (TS-TG)/RI)/CS
ISN       167              DTDDT = ((TS -TD1)/RD1 - (TD1 - TD2)/RD2)/CD
ISN       168              DTGDT = ((TS - TG)/RI + ( TA - TG)/RG)/CG
                     C THE FOLLOWING STATEMENTS CALCULATE HEAT FLOWS FOR HEAVY SURFACES
                     C AND THE ENERGY STORED
ISN       169              QS = CS * DTSDT
ISN       170              QDS = CD * DTDDT
ISN       171              QG = CG * DTGDT
```

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                *....*...1.........2.........3.........4.........5.........6.........7.*.......8
ISN     172           QU1 = (TS - TU)/RU1
ISN     173           QD1 = (TS - TD1)/RD1
ISN     174           QD2 = (TD1 - TD2)/RD2
ISN     175           QE = (TS - TG)/RI
ISN     176           SUM = QS + QU1 + QD1 + QE
                C THE ITER LOOP (BELOW) CALCULATES THE AIR TEMPERATURE CHANGE DURING
                C THE NEXT HOUR INTERVAL IN DELTP INCREMENTS. ALSO CALCULATED ARE
                C THE WALL AND CEILING TEMPERATURE CHANGES AND TEMPERATURES, PLUS
                C HEAT EXCHANGES BETWEEN THE AIR AND ALL SURROUNDING SURFACES.
                C SEE DR. BALL FOR DETAILS
ISN     177           D1 = 0.0
ISN     178           DO 200 ITER =1,4
                C THE "4" IN THE ABOVE STATEMENT EQUALS 1.0/DELTP.
ISN     179           S2 = HFR * TU + HRW * TW + HRC * TC
ISN     180           TR = (S2 + ( TR * S1 - S2) * EXP(-I))/S1
ISN     181           TR = TR + QLIGHT * DELTP * 0.68 /CA
ISN     182           TR = TR + 0.0529 * (TA - TR)
ISN     183           S3 = S2/S1
ISN     184           TRBAR = SS + ((TR-SS) * ( 1.0 - EXP(-Z)))/ S1
ISN     185           DTWDT = ((TRBAR-TW)/RRW + (TU-TW)/RRFW + (TC-TW)/RRCW +
                     2(TA-TW)/RW)/CW
ISN     186           DTCDT = ((TRBAR-TC)/RRC + (TU-TC)/RRFC + (TW-TC)/RRCW + (TR-TC)/
                     2RC)/CC
ISN     187           DTUDT = ((TS-TU)/RU1 - (TU-TRBAR)/RFR - (TU-TW)/RRFW -(TU-TC)
                     2/RRFC)/CU
ISN     188           C1 = D1 + DTUDT * DELTP
ISN     189           QW = QW + ((TW-TA)/RW)*DELTP
ISN     190           QC = QC + ((TC-TA)/RC) * DELTP
ISN     191           QU2 = QU2 + ((TU-TRBAR)/RFR + (TU-TW)/RRFW + (TU-TC)/RRFC
                     2) * DELTP
ISN     192           TW = TW + DTWDT * DELTP
ISN     193           TC = TC + DTCDT * DELTP
ISN     194           TU = TU + DTUDT * DELTP
ISN     195      200 CONTINUE
ISN     196           QUS = CU * D1
ISN     197           QCONV = QU2
ISN     198           IF (I.GT.16.OR.I.LT.9) THEN
ISN     199             QC2 = QU2
ISN     200           ELSE
ISN     201             QCI = QU2
ISN     202           ENDIF
                C HEAVY SURFACE TEMPERATURES AT THE HOUR END
ISN     203           TS = TS + DTSDT
ISN     204           TD1 = TD1 + DTDDT
ISN     205           TG = TG + DTGDT
                C THE FOLLOWING STATEMENTS SUM THE ENERGY STORAGE AND FLOW AND
                C TEMPERATURES
ISN     206           SQCONV = SQCONV + QCONV
ISN     207           SQC2 = SQC2 + QC2
ISN     208           SQC1 = SQC1 + QC1
ISN     209           SQS = SQS + QS
ISN     210           SQUS = SQUS + QUS
ISN     211           SQGS = SQGS + QGS
ISN     212           SQU1 = SQU1 + QU1
ISN     213           SQU2 = SQU2 + QU2
ISN     214           SQD1 = SQD1 + QD1
```

```
               *....*...1.........2.........3.........4.........5.........6.........7.*.......8
ISN                 SQQ2 = SQQ2 + QQ2
ISN                 SQIN = SQIN + QIN
ISN                 SSUM = SSUM + SUM
ISN                 SQW = SQW + QW
ISN                 SQC = SCC + QC
ISN                 SQE = SCE + QE
ISN                 SQG = SCG + QG
ISN                 SST = SST + TS
ISN                 SUT = SUT + TU
ISN                 SQIT = SQIT + TC1
ISN                 SRT = SRT + TR
ISN                 SWT = SWT + TW
ISN                 SCT = SCT + TC
ISN                 SAT = SAT + TA
ISN                 SGT = SGT + TG
ISN                 MOD65 = 65.0 - TA
ISN                 IF (MOD6S.LT.0.0) THEN
ISN                    GO TO 250
ISN                 ELSE
ISN                    SMOD6S = SMOD65 + MOD6S/24
ISN                    TMOD6S = TMOD6S + MOD6S/24
ISN                 ENDIF
ISN             250 MODTR = TR - TA
ISN                 IF (MODTR.LT.0.0) THEN
ISN                    GO TO 251
ISN                 ELSE
ISN                    SMODTR = SMODTR + MODTR/24
ISN                    TMODTR = TMODTR + MODTR/24
ISN                 ENDIF
ISN             251 CONTINUE
ISN             150 CONTINUE
ISN                 I = 24
ISN                 Z1 = SST/I
ISN                 Z2 = SUT/I
ISN                 Z3 = SQIT/I
ISN                 Z4 = SRT/I
ISN                 Z5 = SWT/I
ISN                 Z6 = SCT/I
ISN                 Z7 = SAT/I
ISN                 Z8 = SGT/I
ISN                 SQELC = 11137.0 * 24 * SMOD6S /60.0 / (L*W)
ISN                 SQCONV = SQELC + SQCONV
ISN                 SQC2 = (2.0/3.0) * SQELC + SQC2
ISN                 SQC1 = (1.0/3.0) * SQELC + SQC1
ISN                 TQCONV = TQCONV + SQCONV
ISN                 TQC2 = TQC2 + SQC2
ISN                 TQC1 = TQC1 + SQC1
ISN                 TQS = TQS + SQS
ISN                 TQUS = TQUS + SQUS
ISN                 TQOS = TQOS + SQOS
ISN                 TQU1 = TQU1 + SQU1
ISN                 TQU2 = TQU2 + SQU2
ISN                 TQO1 = TQO1 + SQO1
ISN                 TQO2 = TQO2 + SQO2
ISN                 TQIN = TQIN + SQIN
ISN                 TSUM = TSUM + SSUM
```

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                        *....*...1.........2.........3.........4.........5.........6.........7.*.......8
ISN      271                 TQW = TQW + SQW
ISN      272                 TQC = TQC + SQC
ISN      273                 TQE = TQE + SQE
ISN      274                 TQG = TQG + SQG
ISN      275                 PRINT300,J,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8
ISN      276           300 FORMAT ( 5X,I3,F7.1,7F6.1)
ISN      277                 PRINT301,SQS,SQU1,SQUS,SQU2,SQD1,SQDS,SQD2,SQW,SQC,SQE,SQG,
                            2SSUN,SQIN
ISN      278           301 FORMAT ( 13X,F7.1,F7.1,F6.1,F7.1,2F9.1,5F6.1,2F7.1/)
ISN      279           100 CONTINUE
ISN      280                 PRINT305,NDAT
ISN      281           305 FORMAT ( //,5X,'TOTAL HEAT FLOWS OVER THE ',I3,' DAY PERIOD :
                          2 '/)
ISN      282                 PRINT306
ISN      283           306 FORMAT ( 11X,'QS',5X,'QU1',5X,'QUS',5X,'QU2',5X,'QD1',/)
ISN      284                 PRINT307,TQS,TQU1,TQUS,TQU2,TQD1
ISN      285           307 FORMAT ( 5X,5F8.1,/)
ISN      286                 PRINT308
ISN      287           308 FORMAT ( 10X,'QDS',5X,'QD2',6X,'QW',6X,'QC',6X,'QE',6X,'QG',5X,
                          2'SUN',5X,'QIN'/)
ISN      288                 PRINT309,TQDS,TQD2,TQW,TQC,TQE,TQG,TSUN,TQIN
ISN      289           309 FORMAT ( 5X,8F8.1,/)
                     C CALCULATE THE AMBIENT AVERAGE TEMPERATURE, AAT
ISN      290                 AAT = TATOT/NDAT/24
ISN      291                 PRINT310,AAT
ISN      292           310 FORMAT ( 5X,'AMBIENT AVERAGE TEMPERATURE = ',F7.1,1X,'F',/)
                     C CALCULATE THE ROOM AVERAGE TEMPERATURE
ISN      293                 RAT = TRTOT/NDAT/24
ISN      294                 PRINT311,RAT
ISN      295           311 FORMAT ( 5X,'ROOM AVERAGE TEMPERATURE = ',F7.1,1X,'F',/)
ISN      296                 PRINT312,THDD65
ISN      297           312 FORMAT ( 5X,'HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE =
                          2',F7.1,//)
ISN      298                 PRINT313,THDDTR
ISN      299           313 FORMAT ( 5X,'HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE
                          2= ',F7.1,/)
ISN      300                 AQCONV = AQCONV + TQCONV
ISN      301                 AQC2 = AQC2 + TCC2
ISN      302                 AQC1 = AQC1 + TCC1
ISN      303                 AQS = AQS + TQS
ISN      304                 AQUS = AQUS + TQUS
ISN      305                 AQDS = AQDS + TQDS
ISN      306                 AQU1 = AQU1 + TQU1
ISN      307                 AQU2 = AQU2 + TQU2
ISN      308                 AQD1 = AQD1 + TQD1
ISN      309                 AQC = AQC + TQC
ISN      310                 AHDDTR = AHDDTR + THDDTR
ISN      311                 AQD2 = AQD2 + TQD2
ISN      312                 AQIN = AQIN + TQIN
ISN      313                 ASUN = ASUN + TSUN
ISN      314                 AQW = AQW + TQW
ISN      315                 AQE = AQE + TQE
ISN      316                 AQG = AQG + TQG
ISN      317                 AHDD65 = AHDD65 + THDD65
                     C FOLLOWING STATEMENT RETURNS CONTROL TO READ STATEMENT UNLESS
                     C MARCH IS DONE
```

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LEVEL 1.4.0 (OCT 1984)          VS FORTRAN          DATE: OCT 25, 1985    TIME: 10:07:18      NAME: MAIN    PAGE:   8

                    *....*...1.........2.........3.........4.........5.........6.........7.*.......8

ISN     318          IF (MOA.NE.'MAT      ') GO TO 6
ISN     319          PRINT314
ISN     320      314 FORMAT ( //8X,'DAY',7X,'TS',4X,'TU',4X,'TD',4X,'TR',4X,'TW'
                    2,4X,'TC',4X,'TA',4X,'TG'/)
ISN     321          J = J-1
ISN     322          PRINT315,J,TS,TU,TD1,TR,TW,TC,TA,TG
ISN     323      315 FORMAT ( 5X,I3,3X,8F6.1,5X,'(FINAL TEMPERATURES AT THE END OF THE
                    2HEATING SEASON)')
ISN     324          PRINT316
ISN     325      316 FORMAT ( //5X,'TOTAL HEAT FLOWS OVER THE HEATING SEASON :')
ISN     326          PRINT317
ISN     327      317 FORMAT ( //,12X,'QS',6X,'QU1',6X,'QUS',6X,'QU2',6X,'QD1'
                    2,6X,'QDS',6X,'QD2',7X,'QW')
ISN     328          PRINT318,AQS,AQU1,AQUS,AQU2,AQD1,AQDS,AQD2,AQW
ISN     329      318 FORMAT ( 5X,8F9.1)
ISN     330          PRINT330
ISN     331      330 FORMAT ( //,12X,'QC',7X,'QE',7X,'QG',6X,'SUN',6X,'QIN',6X,'QC2'
                    2,6X,'QCI',4X,'QCONV')
ISN     332          PRINT331,AQC,AQE,AQG,ASUN,AQIN,AQC2,AQCI,AQCONV
ISN     333      331 FORMAT ( 5X,8F9.1)
ISN     334          PRINT319,AHDD65
ISN     335      319 FORMAT ( //,5X,'HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE
                    2 = ',F7.1)
ISN     336          PRINT320,AHDDTR
ISN     337      320 FORMAT ( //,5X,'HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATUR
                    2RE = ',F7.1)
ISN     338          STOP
ISN     339          END
```

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF OCTOBER

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TU	TC	TR	TW	TC	TA	TG							
		QS	QL1	QUS	QU2	QG1		QGS	QG2	QW	QC	QE	QG	SUM	QIN
1	71.1	72.0	65.7	74.0	70.0	73.5	52.0	67.5	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	72.0	70.8	65.4	59.3	58.2	62.5	52.0	65.8							
		64.0	12.2	-29.6	42.1	23.5		41.4	-17.9	50.1	15.5	5.9	-50.1	107.3	107.3
2	71.9	70.2	69.1	70.1	69.0	69.1	60.0	64.0							
		-31.3	21.7	3.3	16.4	22.2		38.8	-16.6	16.5	7.5	7.3	-8.9	0.0	0.0
3	71.1	70.5	69.5	71.2	70.1	70.0	65.0	64.1							
		-23.1	7.7	5.1	2.5	14.0		29.4	-19.4	9.3	4.0	6.5	10.1	0.0	0.0
4	70.7	71.0	69.4	72.8	71.5	71.3	71.0	65.4							
		-10.3	-4.2	10.3	-15.2	9.5		24.1	-14.6	0.9	0.2	9.0	27.8	0.0	0.0
5	71.2	70.9	69.6	71.1	70.0	70.1	42.0	49.8							
		-9.6	2.3	-9.1	11.5	12.1		25.9	-13.7	14.9	6.5	4.9	-10.4	68.9	68.9
6	73.3	71.5	69.5	72.5	71.4	71.3	65.0	66.0							
		137.9	21.4	24.2	-3.2	26.3		39.0	-12.7	6.2	2.5	6.7	14.8	192.2	192.2
7	75.9	73.1	70.0	73.4	72.2	72.3	65.0	66.5							
		102.1	34.1	22.5	11.0	44.5		55.6	-11.1	13.5	5.8	8.6	2.6	189.4	189.4
8	77.9	74.5	70.4	74.2	73.1	73.3	43.0	66.5							
		78.9	41.5	13.2	22.2	57.1		66.2	-9.1	18.9	6.2	10.5	-5.9	188.2	188.2
9	79.5	75.7	70.6	74.3	73.6	74.0	51.0	66.1							
		92.1	47.2	14.6	32.5	65.9		72.7	-6.8	23.5	10.4	12.3	-8.2	187.4	187.4
10	80.8	77.1	71.3	77.0	75.8	76.0	67.0	66.4							
		55.6	45.7	26.2	18.7	72.4		76.7	-4.3	15.2	7.1	13.2	15.8	187.0	187.0
11	81.4	78.4	71.7	78.1	77.5	77.2	67.0	67.3							
		1.6	36.6	14.4	22.0	73.8		79.6	-1.7	18.4	8.1	15.0	12.0	125.0	125.0
12	82.1	79.4	72.2	79.5	78.2	78.4	70.0	68.3							
		54.1	33.3	17.5	15.5	74.1		75.4	0.7	15.5	6.7	12.8	19.8	156.9	186.5
15	81.6	79.9	72.6	79.4	78.5	78.5	67.0	69.0							
		-101.7	21.6	-4.1	25.3	69.7		66.9	3.2	20.5	9.2	11.7	3.7	1.2	1.2
14	80.3	79.5	72.9	79.2	76.1	76.3	53.0	69.3							
		26.5	17.3	-4.5	21.4	60.5		55.6	5.2	15.6	9.2	10.7	5.6	119.0	115.0

15	81.3	78.7	73.5	78.3	75.7	76.5	53.0	68.4							
		5.9	51.1	-18.6	49.8	61.2		54.2	7.0	32.8	14.7	11.8	-50.2	108.9	109.9
16	80.1	77.2	75.5	74.5	73.5	74.2	52.0	66.0							
		-100.2	56.4	-28.2	64.9	50.9		42.3	8.6	39.7	17.8	13.0	-43.7	0.0	0.0
17	78.1	75.3	75.7	71.6	70.3	71.7	47.0	63.0							
		-85.5	37.5	-35.7	74.3	35.6		24.0	9.7	44.1	19.8	13.8	-50.9	0.0	0.0
18	76.4	75.9	75.6	75.2	72.1	72.5	60.0	61.6							
		-84.2	30.7	-0.3	31.2	19.5		9.6	10.3	22.2	9.8	13.5	6.4	0.0	0.0
19	75.1	72.8	73.9	70.4	69.5	73.0	49.0	60.9							
		-52.3	28.3	-30.4	59.6	10.2		-0.2	10.5	37.7	16.9	13.2	-34.3	0.0	0.0
20	74.0	71.1	73.4	68.7	67.7	63.5	43.0	53.9							
		-51.5	35.0	-22.4	58.7	1.5		-8.8	10.3	36.4	16.3	14.0	-29.5	0.0	0.0
21	72.9	69.5	73.5	67.9	65.3	67.4	49.0	57.5							
		-45.5	37.4	-14.5	52.1	-6.3		-16.1	9.8	33.0	14.7	14.4	-19.0	0.0	0.0
22	72.0	68.8	73.6	66.7	65.7	65.3	47.0	56.0							
		-40.4	38.3	-16.3	54.9	-12.7		-21.9	9.5	34.5	15.4	14.7	-21.5	0.0	0.0
23	71.1	67.8	73.5	65.5	64.4	65.1	45.0	54.6							
		-35.1	41.1	-16.6	57.8	-18.2		-26.7	8.5	35.5	16.1	15.2	-23.4	0.0	0.0
24	70.5	66.9	75.3	64.9	63.9	64.4	46.0	55.4							
		-34.3	41.9	-10.3	52.3	-25.1		-30.6	7.5	33.0	14.7	15.6	-14.3	0.0	0.0
25	69.6	66.6	75.1	65.6	54.5	64.8	51.0	55.2							
		-25.5	37.0	1.1	55.9	-26.9		-55.3	6.4	24.8	11.0	15.2	6.3	0.0	0.0
26	69.2	67.1	72.9	67.2	66.0	56.1	53.0	54.4							
		-11.6	26.5	11.4	14.9	-28.5		-33.9	5.3	14.7	6.5	13.7	28.5	0.0	0.0
27	69.1	67.6	72.7	57.5	66.7	66.8	53.0	56.0							
		-2.0	15.0	5.6	12.4	-25.1		-32.5	4.2	14.1	6.2	12.1	24.2	0.0	0.0
28	69.7	66.7	72.6	54.2	63.1	63.9	42.0	55.3							
		53.2	35.8	-26.0	62.1	-22.0		-35.2	3.2	39.1	17.6	13.2	-40.6	80.2	80.2
29	71.6	66.2	72.5	64.0	52.9	63.5	44.0	53.4							
		114.5	65.4	7.7	57.6	-7.5		-9.9	2.6	34.9	15.6	16.6	-21.3	189.4	189.4
30	73.7	67.5	72.5	55.7	64.6	65.1	48.0	52.8							
		82.5	76.6	26.5	49.7	9.2		6.6	2.6	30.6	13.7	19.2	0.0	187.4	187.4
31	74.5	69.9	72.5	69.7	58.6	68.7	60.0	54.3							
		1.1	59.2	38.4	19.3	15.5		12.6	2.9	19.7	6.9	18.8	42.1	94.6	94.6

TOTAL HEAT FLOWS OVER THE 31 DAY PERIOD :

QS	QU1	QUS	QU2	QO1
159.4	1016.4	-16.1	1032.9	657.0

QOS QO2 QW QC QE QG SUM QIN

353.1 3.9 745.4 331.8 376.5 -190.1 2209.4 2209.4

AMBIENT AVERAGE TEMPERATURE = 37.1 F

ROOM AVERAGE TEMPERATURE = 71.2 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 269.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 433.3

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF NOVEMBER

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TU	TJ	TR	TW	TC	TA	TG							
		QS	QU1	QUS	QU2	QD1		QD3	QD2	QW	QC	QE	QG	SUM	QIN
1	74.6	70.9	72.6	70.7	69.3	39.7	60.0	33.9	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	73.3	70.2	72.6	57.5	56.3	57.3	43.0	34.7							
		-71.2	43.3	-20.3	64.4	5.7		9.2	0.3	35.9	17.9	17.6	-21.6	0.0	0.0
2	73.0	53.3	72.6	64.2	53.2	64.3	35.0	32.4							
		-7.8	57.1	-33.9	91.1	3.0		2.4	0.6	32.2	23.5	18.9	-31.0	71.3	71.3
3	73.5	63.3	72.6	66.8	63.7	65.1	91.0	91.3							
		66.5	39.7	23.7	43.6	5.1		5.3	0.5	27.1	12.0	20.6	18.7	188.2	188.2
4	75.2	70.1	72.7	58.3	37.8	66.1	94.0	52.9							
		33.0	34.0	25.6	33.1	18.7		17.9	1.2	23.3	11.3	20.6	25.1	136.3	136.3
3	74.3	70.4	72.8	67.9	66.8	67.5	46.0	33.3							
		-33.0	51.5	-11.4	63.0	13.9		12.1	1.8	38.5	17.3	19.6	-9.8	0.0	0.0
6	72.3	33.3	72.8	37.3	56.2	66.8	47.0	32.9							
		-62.6	42.3	-14.3	97.3	1.2		-0.8	2.0	35.3	15.9	18.6	-9.0	0.0	0.0
7	71.9	65.6	72.8	69.8	48.6	66.7	61.0	94.2							
		-23.3	29.4	14.9	14.4	-6.3		-8.3	1.8	13.9	6.1	16.9	43.9	12.3	12.9
5	71.4	49.5	72.8	69.6	66.4	56.7	56.0	36.2							
		-22.9	18.8	-3.6	22.4	-10.0		-11.3	1.5	19.3	8.5	14.1	21.4	0.0	0.0
9	71.0	69.3	72.7	69.1	57.9	68.2	37.0	97.3							
		-17.7	17.8	-3.7	24.6	-12.8		-13.9	1.0	20.2	9.0	12.7	11.8	0.0	0.0
10	72.5	63.2	72.5	54.7	53.7	64.6	36.0	93.7							
		167.0	34.7	-25.1	30.1	0.5		0.0	0.7	47.6	21.4	15.6	-59.6	238.1	238.1
11	77.1	54.2	72.7	44.2	33.2	54.1	36.0	52.3							

		218.4	131.6	17.8	50.5	32.2		51.0	1.2	50.1	22.5	22.4	-44.2	381.6	381.6
12	80.2	70.4	73.0	60.6	65.6	60.6	41.0	50.3							
		78.5	122.4	35.0	62.0	55.8		52.5	2.7	45.6	20.4	27.0	-12.5	285.0	283.0
13	81.3	75.1	75.3	71.0	69.5	70.4	52.0	51.5							
		3.0	39.0	41.9	56.5	55.0		54.5	4.5	32.5	14.7	27.3	29.5	155.5	155.3
14	66.5	75.3	73.6	74.1	73.0	73.5	59.0	53.3							
		-41.5	65.3	23.1	39.5	53.4		47.2	6.2	25.7	11.4	24.7	45.4	102.5	102.5
15	76.3	74.9	73.6	71.4	70.4	71.3	43.0	54.7							
		-110.6	49.0	-30.2	79.6	39.3		31.5	7.5	47.1	21.1	22.4	-16.5	0.0	0.0
16	76.4	72.5	74.3	67.0	66.7	67.8	36.0	52.6							
		-95.3	53.5	-46.4	100.4	20.5		12.7	8.2	54.8	25.5	22.1	-45.0	0.0	0.0
17	76.5	73.2	74.0	66.0	65.2	66.1	37.0	50.5							
		72.2	76.5	-15.0	92.7	18.3		5.7	5.6	51.9	23.3	24.0	-25.6	151.0	191.0
18	73.2	70.1	74.1	65.6	64.6	63.7	33.0	48.6							
		170.2	111.1	11.1	95.5	57.8		28.7	5.2	54.6	24.5	28.1	-26.4	347.3	347.3
19	81.7	71.4	74.4	66.6	65.6	66.7	35.0	47.2							
		66.7	127.5	22.2	103.0	55.5		45.5	10.4	56.5	25.4	31.8	-17.3	281.8	281.8
20	82.1	72.3	74.6	66.8	65.5	67.2	32.0	45.5							
		-27.8	121.4	4.6	116.7	57.2		45.2	12.0	62.6	28.1	53.5	-22.7	184.1	184.1
21	82.6	72.8	74.3	67.5	67.0	68.1	36.0	45.2							
		55.1	120.5	13.7	105.5	55.4		45.0	13.4	57.2	25.7	34.5	-2.4	275.4	275.4
22	84.0	74.4	75.2	73.4	65.4	70.3	43.0	45.5							
		55.6	116.5	25.2	85.4	66.7		51.7	15.0	48.7	21.8	35.1	25.5	280.3	280.3
23	84.3	75.8	75.5	71.6	70.6	71.6	45.0	47.2							
		-24.5	100.0	13.3	92.5	67.4		50.7	16.8	51.0	22.5	34.3	17.5	185.1	185.1
24	53.1	76.5	75.8	73.5	72.5	73.2	50.0	45.0							
		-78.2	52.3	9.6	72.5	56.7		38.4	18.5	41.4	15.5	51.6	56.1	52.4	92.4
25	80.5	76.4	73.5	73.6	72.0	73.3	51.0	51.0							
		-122.4	30.1	-11.0	67.2	58.5		15.3	19.3	35.9	17.5	27.7	28.1	0.0	0.0
26	76.6	75.4	74.3	73.2	72.1	72.7	53.0	52.7							
		-84.9	40.2	-16.7	57.1	20.7		1.1	15.6	55.3	15.8	24.1	25.6	0.0	0.0
27	77.2	73.8	75.5	68.5	67.5	68.7	37.0	52.1							
		-45.7	50.3	-47.9	98.8	5.5		-5.5	15.4	56.6	25.5	23.1	-37.7	33.6	53.6
28	77.3	70.9	75.9	65.5	63.5	66.6	36.0	50.0							
		71.1	50.3	-17.6	58.1	11.9		-7.2	15.1	54.5	26.5	25.3	-30.8	188.6	188.6
29	75.3	71.2	73.3	67.9	66.9	67.0	45.0	45.2							
		92.6	59.4	20.3	79.6	25.4		6.5	15.1	42.9	15.7	27.7	3.1	245.0	245.0
30	80.8	71.3	76.0	66.3	66.0	67.2	34.0	46.5							
		-8.6	103.5	1.6	105.0	37.0		17.5	19.5	59.1	26.5	25.5	-27.6	225.1	225.1

TOTAL HEAT FLOWS OVER THE 30 DAY PERIOD :

QS	QU1	QUS	QU2	QO1
302.4	2243.0	16.0	2231.8	544.7

QOS	QO2	Q4	QC	QE	QG	SUM	QIN
566.3	251.4	1250.5	574.4	731.3	-126.0	4130.4	4130.4

AMBIENT AVERAGE TEMPERATURE = 44.2 F

ROOM AVERAGE TEMPERATURE = 68.5 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 624.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 725.6

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF DECEMBER

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TU QS	TG QU1	TA QUS	TW QU2	TC QO1	TA	TG QOS	QO2	QW	QC	QE	QG	SUM	QIN
1	81.4	72.0	76.0	66.9	69.5	67.1	54.0	47.5	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	91.5	72.3	75.1	58.2	57.3	63.2	39.0	47.4							
		2.2	109.5	13.5	95.5	40.1		22.7	17.4	32.1	25.4	31.3	-2.5	182.9	182.5
2	81.4	72.9	76.2	67.6	66.6	67.9	34.0	46.7							
		4.1	107.1	-3.8	111.0	39.5		21.8	18.1	60.3	27.1	52.0	-15.0	185.1	183.1
3	82.4	72.0	76.4	65.2	64.4	65.9	24.0	44.5							
		72.0	126.4	-14.1	140.7	45.5		26.6	18.5	74.6	55.6	54.0	-47.8	278.6	278.6
4	82.1	71.9	76.5	66.1	65.2	66.5	30.0	42.7							
		-74.5	127.2	5.3	123.2	45.6		25.8	19.8	65.0	29.2	36.5	-14.5	133.0	133.0
3	79.4	70.9	76.6	64.1	52.3	54.8	23.0	41.0							
		-155.3	106.0	-32.6	135.5	23.0		2.7	20.5	74.4	35.5	55.6	-56.8	0.0	0.0
6	77.0	69.0	75.6	60.0	59.2	61.1	13.0	37.7							
		-21.7	116.3	-45.7	162.5	7.8		-12.3	20.0	85.5	38.5	36.6	-65.0	155.0	155.0
7	74.1	57.9	75.5	63.6	52.6	53.6	35.0	37.0							
		76.0	127.2	30.6	36.2	12.0		-7.7	19.7	50.8	22.8	58.0	50.4	255.2	253.2
8	78.2	70.0	75.5	65.5	65.0	55.3	43.0	55.5							
		-59.6	103.2	27.9	74.9	13.5		-6.0	19.5	41.9	18.8	35.8	50.0	92.9	52.5

9	74.4	70.3	76.4	66.4	67.3	63.0	47.0	42.7							
		-100.7	65.7	9.1	63.3		0.7	-18.4	19.1	37.5	16.8	91.3	49.0	0.0	0.0
10	74.6	70.5	76.2	57.2	56.2	67.0	43.0	44.8							
		-58.7	53.2	-15.1	72.6	-12.2		-30.4	18.3	42.9	19.2	27.6	20.3	0.0	0.0
11	73.3	65.7	75.0	63.1	57.0	67.5	31.0	46.3							
		-44.3	45.0	-1.2	46.2	-20.8		-37.5	17.1	29.9	13.1	24.5	41.6	0.0	0.0
12	72.3	66.6	73.6	65.3	64.5	65.3	41.0	47.9							
		-41.7	45.4	-26.5	72.6	-26.3		-42.1	13.5	43.3	19.9	22.6	-4.5	0.0	0.0
13	71.5	65.9	75.5	42.8	61.2	62.3	32.0	45.3							
		-49.3	53.9	-39.7	95.1	-32.0		-46.3	14.3	94.1	24.3	22.9	-39.9	0.0	0.0
14	71.7	53.2	75.3	61.5	50.6	61.5	33.0	44.9							
		77.3	79.2	-4.3	53.6	-27.5		-40.7	12.5	47.2	21.2	24.6	-15.3	153.4	153.4
15	73.3	60.6	75.1	63.1	64.0	64.4	45.0	45.3							
		76.3	83.5	30.2	43.0	-13.9		-25.6	11.7	27.5	12.2	25.4	38.5	171.6	171.6
16	73.3	66.4	74.5	66.6	65.3	65.0	49.0	47.5							
		-73.0	61.5	13.6	45.2	-12.4		-23.4	11.0	30.5	13.6	23.5	28.1	0.0	0.0
17	71.9	67.0	74.6	62.1	51.1	62.4	29.0	47.0							
		-60.9	59.6	-44.3	104.9	-21.8		-31.8	10.0	99.9	26.8	22.9	-49.7	0.0	0.0
18	72.1	54.3	74.6	56.7	37.3	59.2	22.0	43.3							
		68.9	92.4	-29.2	121.9	-19.7		-28.7	9.0	66.2	29.8	26.2	-60.4	167.8	167.8
19	73.5	64.1	74.3	39.3	58.4	59.5	23.0	41.0							
		30.5	113.9	9.8	104.0	-9.1		-17.3	8.2	56.0	25.1	29.7	-22.4	165.0	165.0
20	74.3	64.9	74.4	60.2	39.2	60.3	23.0	39.9							
		37.1	116.0	12.9	102.9	-1.2		-9.0	7.8	55.8	25.0	31.6	-12.2	183.6	183.6
21	74.2	56.4	74.3	63.5	62.5	63.1	41.0	40.7							
		-35.4	95.0	27.3	70.1	-1.0		-8.5	7.5	39.5	17.6	31.0	32.5	92.6	92.6
22	72.7	66.4	74.3	61.9	50.9	62.0	31.0	41.2							
		-96.6	73.3	-20.0	38.7	-11.0		-18.2	7.1	59.4	24.9	29.1	-11.9	0.0	0.0
23	73.3	65.7	74.1	63.0	62.0	62.7	41.0	41.7							
		-67.5	64.6	-1.7	56.3	-24.1		-30.4	6.3	38.7	17.3	27.1	24.4	0.0	0.0
24	72.3	64.4	74.0	93.5	97.6	59.0	21.0	40.7							
		163.6	94.6	-26.4	123.4	-14.0		-19.4	5.4	67.7	30.9	28.9	-50.3	273.1	273.1
25	79.1	54.1	73.9	58.1	37.2	58.5	21.0	38.0							
		103.3	133.3	9.4	126.3	6.4		3.2	9.1	65.7	30.0	34.0	-34.9	251.9	281.5
26	76.2	56.3	74.0	63.2	62.1	62.3	40.0	33.9							
		7.7	123.8	43.4	74.8	16.7		11.3	5.4	40.6	18.1	34.9	41.3	183.1	183.1
27	73.8	59.3	74.0	66.2	67.1	67.4	54.0	42.4							
		-33.0	82.1	43.7	37.8	14.0		5.3	9.7	24.0	10.6	31.3	78.4	52.2	92.2
28	74.7	71.7	74.0	72.2	71.0	71.0	65.0	47.9							
		-98.5	33.4	23.8	8.3	9.2		-0.7	5.9	10.9	4.7	25.0	94.4	0.0	0.0

DAY	TS	TU	TO	TR	TB	TC	TA	TG							
		QS	QU1	QUS	QU2	QC1		QDS	QD2	QW	QC	QE	QG	SUM	QIN
29	73.3	71.2	74.0	68.5	57.5	68.3	46.0	50.7							
		-46.1	23.4	-34.2	63.1	-3.4		-9.1	5.7	39.9	17.9	21.1	2.5	0.0	0.0
30	73.7	68.3	74.0	53.0	52.0	53.4	28.0	45.7							
		45.5	54.6	-47.4	112.6	-2.4		-7.5	5.4	63.1	29.4	22.9	-60.3	134.6	134.6
31	76.7	65.7	74.0	60.3	59.9	61.3	24.0	45.0							
		210.0	120.6	-3.4	124.1	19.2		13.8	5.4	56.3	29.8	26.9	-55.6	376.7	376.7

TOTAL HEAT FLOWS OVER THE 31 DAY PERIOD :

QS	QU1	QUS	QU2	QD1
-115.5	2731.4	-77.8	2810.2	25.5

QDS	QD2	QW	QC	QE	QG	SUM	QIN
-337.3	373.9	2527.6	703.5	307.4	-64.9	3535.9	3555.9

AMBIENT AVERAGE TEMPERATURE = 35.7 F

ROOM AVERAGE TEMPERATURE = 64.1 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 907.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 679.4

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF JANUARY

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TU	TO	TR	TB	TC	TA	TG							
		QS	QU1	QUS	QU2	QC1		QDS	QD2	QW	QC	QE	QG	SUM	QIN
1	76.6	66.8	74.0	60.3	59.5	61.3	24.0	43.4	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	80.3	66.6	74.2	56.1	57.3	35.2	9.0	40.3							
		122.5	157.4	-4.6	172.1	45.9		45.1	0.8	89.2	40.2	36.5	-69.6	372.3	372.3
2	81.4	66.7	74.6	57.9	57.2	59.1	3.0	35.4							
		-0.3	192.1	4.1	178.0	53.5		51.2	2.4	90.5	40.9	42.3	-66.0	277.2	277.2
3	80.5	64.9	74.7	56.6	57.8	53.6	11.0	32.1							
		-75.4	159.1	3.1	163.0	44.9		40.9	4.0	56.4	39.9	44.7	-40.1	182.2	162.2
4	79.3	67.2	74.9	60.4	59.5	61.1	23.0	31.0							
		-37.2	150.2	6.9	141.2	33.6		28.5	5.1	73.0	32.5	44.6	0.8	191.3	191.3

5	78.0	57.7	78.1	61.9	50.7	62.1	24.0	31.5							
		-24.6	135.5	6.6	128.9	27.3		21.4	6.0	57.7	39.6	43.6	13.5	181.7	181.7
6	74.3	58.8	76.2	64.6	63.6	64.5	35.0	33.6							
		-2.9	118.8	24.1	54.4	23.5		17.3	6.6	50.8	22.8	41.4	51.4	181.2	181.2
7	76.4	57.0	75.3	64.5	53.8	69.0	33.0	36.0							
		9.0	109.0	4.3	104.5	24.0		16.8	7.2	55.5	25.5	35.2	27.3	181.2	181.2
8	78.6	69.4	75.4	53.6	62.7	54.0	27.0	36.8							
		4.2	113.5	-3.1	122.5	24.5		16.8	7.7	65.5	25.6	38.6	-0.7	180.7	180.7
9	75.6	66.5	75.5	62.7	61.5	63.2	25.0	36.5							
		-2.4	120.4	-7.5	127.0	22.9		15.6	9.3	68.1	30.6	38.8	-7.4	180.7	180.7
10	76.7	58.6	75.6	62.2	61.4	62.8	24.0	36.0							
		10.5	126.2	-4.1	130.4	23.5		15.1	8.9	55.0	31.0	35.4	-8.8	155.5	155.9
11	79.2	67.1	75.7	55.2	57.4	59.5	7.0	33.5							
		28.1	147.5	-31.3	179.2	26.8		17.5	5.3	93.3	42.1	42.0	-64.8	244.3	244.3
12	80.5	65.7	75.8	56.1	55.2	57.4	2.0	25.5							
		72.0	179.3	-13.7	193.1	34.1		24.2	10.0	55.5	44.4	46.7	-63.8	332.2	332.2
13	81.7	57.1	75.9	60.6	59.7	61.1	22.0	28.4							
		62.7	151.8	44.4	136.9	43.5		32.5	10.5	65.6	31.1	45.1	23.6	337.2	337.2
14	82.5	69.3	76.2	62.5	61.6	63.1	22.0	29.7							
		12.5	164.7	23.4	140.5	48.6		36.6	12.1	73.1	32.5	48.7	17.5	276.0	276.0
15	81.9	53.5	76.4	41.3	50.3	62.4	14.0	29.5							
		-64.7	153.9	-11.6	155.8	43.1		25.5	13.2	86.0	38.7	48.2	-15.0	180.5	180.5
16	80.8	53.3	76.5	63.4	62.5	63.9	26.0	30.3							
		-38.5	139.9	10.4	125.4	33.0		15.0	14.0	67.3	30.2	46.7	25.6	180.7	180.7
17	80.9	70.1	76.6	64.3	53.4	64.7	26.0	32.2							
		41.2	133.2	9.6	123.5	32.6		15.0	14.6	65.3	25.3	45.0	28.6	252.0	252.0
18	82.0	71.0	76.7	65.3	64.4	65.7	30.0	34.0							
		55.5	135.5	15.7	120.0	35.8		24.5	15.3	63.5	28.5	44.3	28.7	275.5	275.5
19	82.8	70.3	76.9	61.2	60.4	62.5	9.0	33.0							
		12.2	152.5	-29.4	182.7	44.5		28.6	16.2	55.1	42.5	45.7	-51.0	255.4	255.4
20	83.3	53.3	77.1	57.2	36.5	58.3	-4.0	28.8							
		77.4	190.1	-23.4	215.5	51.1		33.9	17.2	111.8	50.4	50.5	-81.4	365.1	365.1
21	84.2	63.5	77.3	50.2	59.4	61.2	13.0	26.4							
		-25.3	194.9	24.3	170.3	53.0		34.6	18.4	85.5	38.5	53.3	-0.4	275.3	275.3
22	83.0	69.9	77.4	52.8	61.5	53.5	21.0	27.3							
		-77.4	152.6	16.3	147.0	42.9		23.5	15.4	75.5	33.5	51.5	26.4	180.7	180.7
23	51.7	70.5	77.5	54.0	63.2	54.6	25.0	29.2							
		-40.7	140.0	5.2	136.7	32.4		12.4	20.0	70.4	31.7	48.6	32.1	180.2	180.2
24	81.1	70.8	77.6	65.0	64.1	65.4	29.0	31.4							
		-15.9	127.4	5.3	122.5	26.8		6.5	20.3	64.8	25.1	46.8	36.8	180.7	180.7

```
25   50.8  70.3  77.6  63.3  62.4  64.0  21.0  32.4
           -7.1 129.5 -15.4 145.2  24.6         4.2  20.9  76.6  34.9  44.7  -0.9 151.5 191.8

26   52.4  63.6  77.7  61.6  51.0  62.7  15.0  31.5
          134.3 155.3  -3.3 160.1  35.1        14.4  20.7  53.0  37.4  46.6 -16.5 372.2 372.2

27   83.1  70.6  77.9  63.6  54.1  65.3  25.0  32.5
          -47.0 153.6  20.5 124.7  40.9        19.5  21.3  54.6  29.0  46.9  33.3 154.4 154.4

28   52.3  71.1  77.5  63.7  62.5  64.6  23.0  33.2
          -37.0 136.0 -12.5 151.0  53.7        11.8  21.9  75.3  39.7  45.3  -7.4 190.0 150.0

29   81.5  70.7  77.9  64.2  63.3  64.8  25.0  33.3
          -27.1 134.6  -0.7 135.2  27.7         5.6  22.1  70.5  31.5  44.5  11.3 179.5 179.8

30   86.1  59.5  77.9  41.6  56.9  62.6  15.0  32.7
         -101.9 130.2 -56.9 161.6  17.0        -9.2  22.2  84.7  38.1  43.7 -27.5  59.0  89.0

31   90.4  56.8  77.9  56.1  55.5  57.8  -3.0  23.1
          109.5 165.6 -44.0 210.4  18.4        -3.5  22.0 109.1  45.9  47.1 -32.1 340.8 340.5

TOTAL HEAT FLOWS OVER THE  31 DAY PERIOD :

     Q3     QU1      QU5     QU2     QC1

  120.5  4505.6   -17.3  4623.1  1075.6

    QO3     QO2      QW      QC      QE      QG     SUM     QIN

  657.0   413.6  2404.3  1081.3  1394.3  -263.5  7196.4  7195.4

AMBIENT AVERAGE TEMPERATURE =    15.8 F

ROOM AVERAGE TEMPERATURE =    61.7 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE =  1430.9

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE =  1328.4


PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF FEBRUARY

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY    TS    TU    TO    TR    TW    TC    TA    TG
             Q5   QU1   QU3   QL2   QO1   QO3   QO2    QW    QC    QE    QG   SUM   QIN

 1   81.5  65.6  77.3  55.1  54.4  50.7  -3.0  25.7    INITIAL TEMPERATURES AT THE START OF THE MONTH

 1   51.4  65.6  77.9  56.2  55.5  57.5   3.0  25.4
```

		-1.6	193.0	1.5	192.0	26.4		15.5	10.9	96.8	43.6	51.6	-38.5	270.0	270.0
2	60.3	65.9	78.0	57.1	56.3	58.2	7.0	23.8							
		-72.7	160.9	1.7	179.2	19.5		8.1	11.4	91.0	41.8	52.4	-15.0	180.0	180.0
3	79.2	66.1	75.0	36.3	37.5	59.2	13.0	23.7							
		-44.0	153.4	3.3	160.0	9.5		-2.0	11.4	92.0	38.9	51.3	8.8	180.2	180.2
4	79.4	59.5	75.0	55.3	56.5	60.1	17.0	24.6							
		54.5	159.5	11.4	145.3	10.5		-0.8	11.4	75.5	34.4	50.6	20.4	273.3	275.5
5	80.5	66.5	75.0	37.4	36.7	55.7	8.0	24.4							
		34.9	172.0	-9.5	121.9	18.2		6.3	11.5	93.8	42.2	51.8	-22.3	276.7	276.7
6	61.0	65.2	76.1	57.2	56.4	55.4	8.0	23.2							
		16.5	162.5	-0.2	162.8	22.0		10.3	11.5	93.0	41.9	53.2	-15.9	274.3	274.3
7	82.1	66.4	75.2	57.1	36.4	[illegible]	5.0	22.3							
		75.4	153.1	0.2	165.8	29.2		17.1	12.2	94.9	42.7	53.1	-14.2	352.8	352.8
8	62.7	67.0	75.3	53.7	56.6	53.5	14.0	22.6							
		-3.0	188.1	24.8	153.1	34.1		21.3	12.8	82.7	37.2	55.5	21.3	274.8	274.8
9	82.0	69.6	78.4	64.4	63.5	64.7	31.0	25.8							
		-53.6	153.5	37.6	115.5	28.2		14.8	13.5	59.8	26.8	52.1	73.8	180.2	180.2
10	61.3	70.5	78.3	64.7	63.8	65.2	27.0	23.3							
		-19.7	123.5	1.7	128.2	22.1		8.2	13.8	68.0	30.8	48.2	39.5	180.3	160.5
11	80.5	69.8	76.5	61.6	60.6	62.7	14.0	29.6							
		-22.7	136.7	-26.3	165.4	18.6		4.5	14.0	85.6	39.0	47.1	-16.4	179.8	179.8
12	81.3	65.7	75.3	60.5	60.0	61.7	15.0	29.1							
		51.5	154.6	-6.1	161.0	20.6		6.4	14.2	83.1	37.4	49.1	-8.2	273.0	275.0
13	62.2	63.4	78.6	62.9	52.1	63.5	24.0	25.7							
		41.3	135.6	22.7	135.3	27.6		12.1	14.5	70.2	31.5	48.3	23.9	276.2	276.2
14	81.3	63.9	76.6	62.6	61.9	63.5	20.0	30.6							
		-117.7	141.1	-6.9	148.1	20.8		5.9	14.9	77.4	34.8	46.8	4.4	91.0	51.0
15	75.2	63.5	76.6	51.3	60.5	52.1	10.0	30.5							
		-150.3	119.1	-30.0	149.5	-2.4		-17.1	14.7	78.5	35.4	44.1	-6.2	0.0	0.0
16	76.2	66.3	75.3	63.6	62.8	63.8	34.0	32.1							
		139.5	121.6	21.5	99.7	-3.4		-17.5	14.0	53.1	23.8	42.5	30.7	300.2	300.2
17	73.7	69.5	76.4	64.2	63.2	64.5	30.0	34.4							
		9.3	126.2	11.7	114.3	9.5		-4.2	13.7	61.4	27.6	41.9	24.5	187.0	167.0
18	73.9	70.4	76.4	63.6	64.6	63.9	35.0	36.3							
		13.1	116.1	15.9	102.0	11.5		-2.0	13.6	55.0	24.7	40.3	33.4	183.1	183.1
19	80.3	71.3	76.4	66.7	65.7	66.8	36.0	36.4							
		17.5	111.6	10.6	100.9	14.3		0.7	13.6	54.5	24.6	38.8	29.6	182.4	182.4
20	79.6	71.9	76.4	67.9	67.0	67.9	40.0	40.4							
		-54.0	56.3	6.1	90.1	11.1		-2.4	13.6	49.7	22.3	36.5	35.1	91.5	91.9
21	78.1	72.9	75.4	71.2	70.1	70.3	54.0	44.0							

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          -96.6   65.3  17.7   48.4    -1.4   -14.7  13.3  29.6  13.2  31.8  72.7    0.0    0.0

 22   76.4  72.4  78.2  63.4  68.3  89.2  43.0  48.7
          -63.2   49.2 -22.3   72.2   -13.4   -26.1  12.6  43.2  19.4  27.5  20.7    0.0    0.0

 23   73.2  70.7  78.1  67.0  68.0  87.0  80.0  47.2
          -49.6   55.2 -27.5   92.3   -21.6   -33.2  11.6  49.2  21.6  25.8  -3.1    9.8    9.8

 24   76.5  59.3  77.5  64.5  63.6  64.8  33.0  46.3
          174.8   90.6 -11.4  102.2    -5.3   -20.2  10.7  56.8  25.4  28.0 -23.3  283.9  283.9

 25   79.9  70.3  77.9  65.3  65.5  66.4  40.0  45.5
          116.4  113.4  22.0   36.0    14.5     4.4  13.4  47.0  21.1  31.4   8.2  281.0  281.0

 26   81.2  71.7  77.9  66.7  65.7  60.5  34.0  45.6
            7.2  117.6   9.5  107.9    25.0    14.2  10.9  58.6  26.3  32.8 -13.7  182.6  162.6

 27   81.4  72.1  78.0  67.0  65.1  67.3  34.0  44.9
            6.3  114.5   4.8  109.5    25.7    14.5  11.2  59.2  26.6  33.7  -9.9  182.2  182.2

 23   80.7  72.5  78.1  65.2  66.2  69.0  43.0  45.4
          -39.3   93.4  14.3   34.0    20.6     8.9  11.7  46.4  20.8  32.7  23.4   92.2   92.2

TOTAL HEAT FLOWS OVER THE  28 DAY PERIOD :

      QS      QU1      QUS      QU2      QD1

   -58.6   3713.7   113.8   3558.4    383.3

     QOS      QD2       Q4       QC       QE       QG      SUM      QIN

    34.4    353.9   1597.0   352.8   1200.0   305.7   5243.3   5243.3

AMBIENT AVERAGE TEMPERATURE =    25.6 F

ROOM AVERAGE TEMPERATURE =    83.2 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE =  1101.9

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE =  1052.8


PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF MARCH

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY     TS    TU    TD    TR    TW    TC    TA    TG
              QS    QU1   QUS   QU2   QD1   QOS   QD2    QW    QC    QE    QG   SUM    QIN

  1   80.2  73.1  78.1  69.5  68.3  57.4  43.0  46.0    INITIAL TEMPERATURES AT THE START OF THE MONTH
```

1	78.9	73.5	78.1	71.0	69.5	70.6	53.0	47.4							
		-103.6	67.9	5.6	62.3	6.7		-9.1	11.7	36.8	16.4	29.2	39.9	0.0	0.0
2	77.0	72.7	78.0	69.4	59.4	65.2	44.0	46.3							
		-72.1	53.3	-23.2	76.6	-7.3		-16.5	11.3	45.1	20.2	26.1	6.9	0.0	0.0
3	79.6	71.9	77.9	70.5	59.2	59.7	53.0	50.2							
		-52.3	45.7	-1.9	47.2	-17.0		-27.6	10.6	29.9	13.3	23.6	39.0	0.0	0.0
4	79.5	71.1	77.7	47.9	60.5	67.7	49.0	50.9							
		34.9	54.1	-20.0	74.3	-16.8		-26.5	9.6	44.1	19.8	22.7	-9.0	94.8	94.8
5	77.4	59.6	77.6	54.7	63.7	59.5	31.0	43.0							
		126.5	32.4	-17.0	109.6	-2.1		-11.1	9.0	60.5	27.2	26.0	-46.6	243.1	243.1
6	79.0	70.2	77.6	60.3	65.3	65.2	39.0	47.5							
		33.9	103.4	20.6	85.6	11.0		2.1	8.8	45.5	21.7	29.0	-5.1	183.4	183.4
7	75.0	74.3	77.6	70.3	59.8	73.1	55.0	49.2							
		-30.0	53.6	36.6	44.5	10.9		1.9	8.9	27.1	12.0	27.7	51.6	92.4	92.4
8	77.3	73.3	77.6	70.9	69.5	70.5	50.0	91.3							
		-82.3	55.6	-4.1	59.9	1.9		-6.9	8.9	36.7	16.4	24.5	19.5	0.0	0.0
9	76.2	72.5	77.5	63.9	66.3	69.6	43.0	52.1							
		-59.5	46.4	-16.9	63.6	-9.3		-17.8	8.5	38.9	17.3	22.4	6.1	0.0	0.0
10	75.1	71.6	77.4	69.7	58.6	69.2	51.0	52.7							
		-45.9	42.9	-9.1	51.8	-17.3		-25.1	7.7	32.6	14.6	20.7	13.9	0.0	0.0
11	74.2	70.6	77.2	68.7	67.7	68.3	49.0	93.2							
		-37.2	40.9	-13.9	55.0	-23.1		-29.9	6.8	34.5	15.4	19.4	2.5	0.0	0.0
12	75.3	53.6	77.0	65.8	64.8	65.8	38.0	52.1							
		120.2	67.7	-18.1	36.0	-14.5		-20.4	5.5	45.6	22.3	21.2	-35.4	194.6	194.6
13	78.3	73.0	77.0	66.7	65.7	56.5	42.0	50.7							
		193.5	101.1	23.2	77.6	8.6		3.0	5.6	43.6	19.5	29.3	-9.7	288.5	288.5
14	80.2	71.8	77.1	68.3	57.3	58.1	43.0	50.4							
		31.3	104.7	24.5	75.8	23.5		17.5	6.0	44.8	20.1	27.5	-2.0	187.0	187.0
15	80.0	72.9	77.2	69.6	66.6	69.4	45.0	50.5							
		-42.2	89.2	11.4	76.7	21.6		15.2	6.6	43.6	19.5	27.3	5.3	94.1	94.1
16	78.3	73.1	77.2	70.2	65.2	69.5	47.0	51.0							
		-100.5	65.3	-4.1	70.0	9.3		2.4	6.9	40.9	18.3	25.4	9.5	0.0	0.0
17	76.5	72.2	77.2	69.1	66.1	68.9	45.0	51.2							
		-71.8	53.2	-19.1	72.5	-4.8		-11.6	6.7	42.7	19.2	23.4	-1.4	0.0	0.0
18	75.3	71.6	77.1	70.0	58.9	69.4	53.0	52.0							
		-34.9	46.1	0.0	46.1	-13.3		-19.9	6.2	29.4	13.1	21.6	29.7	19.4	19.4
19	74.5	71.6	77.0	70.4	69.3	69.7	55.0	53.6							
		-37.7	35.8	-1.7	36.5	-18.5		-23.9	9.5	26.3	11.7	19.4	29.0	0.0	0.0
20	74.7	71.3	75.9	69.6	68.7	69.2	53.0	54.8							
		-3.7	40.5	-3.0	43.9	-14.7		-21.4	4.7	29.1	18.0	13.4	11.5	86.2	86.2

21	76.5	71.5	75.7	59.5	60.5	59.1	51.0	55.2					
	112.3	60.2	8.5	51.3	-2.8	-7.0	4.2	32.3	14.4	19.6	2.9	189.8	189.8
22	75.5	72.5	76.3	73.4	69.3	59.9	51.0	55.4					
	78.8	74.1	13.4	55.5	13.2	9.0	4.2	33.8	19.1	21.3	3.8	187.4	187.4
23	79.2	73.4	75.8	70.8	69.7	70.4	49.0	53.4					
	-13.3	71.5	7.3	64.4	18.2	13.5	4.6	33.3	17.1	22.0	-3.6	98.6	98.6
24	74.0	73.0	75.5	69.6	68.6	69.5	44.0	54.5					
	-92.1	61.3	-15.6	78.3	9.0	4.0	9.0	45.5	20.4	21.6	-20.9	0.0	0.0
25	73.1	72.2	74.5	63.9	67.9	65.7	44.0	53.4					
	88.1	71.9	-4.7	76.6	8.7	3.7	5.0	44.1	19.5	22.7	-15.2	191.3	191.3
26	78.8	73.0	70.5	73.0	71.8	74.0	61.0	54.7					
	-8.0	65.9	35.7	28.3	14.4	9.2	5.3	19.9	8.7	22.4	48.2	94.8	94.8
27	75.0	75.1	77.0	74.7	73.5	73.8	53.0	57.9					
	-64.0	35.6	12.0	24.4	3.3	2.8	5.9	19.4	8.6	19.1	41.6	0.0	0.0
28	76.3	75.1	77.0	74.4	73.3	73.6	51.0	53.5					
	-38.5	22.3	-7.3	29.7	0.0	-5.4	5.4	22.7	10.1	16.2	22.6	0.0	0.0
29	76.1	73.4	75.5	70.4	59.4	70.2	45.0	55.9					
	-41.6	31.8	-28.6	70.5	-6.0	-11.2	9.2	43.4	19.5	19.8	-36.0	0.0	0.0
30	76.5	71.3	75.6	87.3	55.4	57.4	39.0	56.1					
	74.2	53.2	-24.3	89.4	-2.8	-7.6	4.8	90.6	22.7	18.7	-90.2	153.4	193.4
31	73.3	70.5	75.3	55.8	54.9	66.0	34.0	52.9					
	164.2	103.1	1.1	104.0	17.1	12.3	4.8	57.0	29.6	24.1	-51.9	310.6	310.6

TOTAL HEAT FLOWS OVER THE 31 DAY PERIOD :

QS	QU1	QUS	QU2	Q01
34.1	1951.1	-35.6	1997.2	10.1

QOS	QO2	QW	QC	QE	QG	SUM	QIN
-199.8	209.9	1131.1	333.2	704.0	84.5	2709.4	2709.4

AMBIENT AVERAGE TEMPERATURE = 47.8 F

ROOM AVERAGE TEMPERATURE = 69.5 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 538.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 877.4

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF APRIL

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TW QS	TC QU1	TR QU3	TW QU2	TC QD1	TA	TG QD3	QD2	CW	QC	CE	QG	SUM	CIN
1	80.7	70.6	75.9	65.9	64.9	66.0	34.0	51.4	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	80.3	71.6	77.0	57.4	55.4	67.4	39.0	50.7							
		-33.1	111.1	18.2	92.5	26.9		21.6	5.5	50.5	22.7	27.4	-15.6	132.2	132.2
2	80.0	72.9	77.1	70.3	59.3	69.9	49.0	50.8							
		-6.3	83.9	23.7	84.9	22.6		16.5	6.1	37.3	16.7	27.0	15.5	132.2	152.2
3	75.5	74.3	77.2	72.9	71.3	72.2	57.0	52.8							
		-93.6	35.1	15.6	42.3	13.4		6.9	6.5	27.2	12.1	24.2	41.3	0.0	0.0
4	77.2	74.2	77.2	72.4	71.3	71.5	54.0	54.7							
		-59.1	37.5	-11.7	45.4	0.7		-5.8	6.5	31.9	14.5	20.5	15.5	0.0	0.0
5	76.0	72.6	77.1	65.5	56.3	69.4	45.0	54.5							
		-52.7	41.0	-31.1	72.6	-8.1		-14.5	6.2	43.5	15.5	15.9	-18.5	0.0	0.0
6	76.0	70.3	77.0	67.7	60.6	67.5	43.0	53.3							
		-35.4	50.6	-23.5	74.4	-15.2		-20.8	5.6	43.7	15.6	20.0	-21.5	16.1	16.1
7	75.9	70.0	75.9	65.9	65.9	66.7	43.0	52.1							
		105.1	71.1	-1.6	72.7	-3.5		-13.3	5.0	42.5	18.5	21.6	-14.5	152.5	192.5
8	77.7	70.4	76.8	66.9	55.9	56.7	41.0	51.1							
		67.0	90.3	9.3	60.5	6.3		1.5	4.6	45.5	20.6	24.4	-16.5	188.2	188.2
9	79.0	71.1	75.5	67.2	56.3	67.2	40.0	50.2							
		46.9	57.4	10.5	86.7	15.7		10.7	5.0	48.5	21.7	26.5	-14.4	186.5	186.5
10	79.0	72.3	77.0	65.6	56.7	69.4	43.0	50.5							
		-32.5	64.5	21.7	62.6	16.1		10.7	5.4	36.5	16.2	26.4	20.7	54.1	94.1
11	77.7	73.3	77.0	71.7	70.7	71.1	55.0	52.3							
		-64.9	55.4	10.0	45.3	5.9		0.3	5.6	28.8	12.5	23.6	54.8	0.0	0.0
12	75.3	74.1	77.0	74.4	73.2	73.3	65.0	55.4							
		-42.9	28.1	15.6	12.3	-4.7		-10.1	5.4	15.2	5.9	19.4	62.4	0.0	0.0
13	75.6	73.8	75.9	72.5	71.4	71.8	56.0	57.6							
		-26.5	21.6	-18.7	40.5	-9.7		-14.7	5.0	25.5	12.7	16.7	10.5	0.0	0.0
14	74.9	72.3	75.6	69.9	68.9	69.6	49.0	57.3							
		-34.0	31.9	-25.5	58.6	-14.2		-19.6	4.4	36.5	16.5	16.2	-17.1	0.0	0.0
15	74.1	71.2	76.7	69.7	66.6	59.1	53.0	55.8							
		-32.5	55.9	-9.0	44.0	-19.1		-22.5	3.7	28.5	12.5	16.0	0.7	0.0	0.0
16	73.3	71.3	76.5	71.0	63.8	70.0	50.0	57.7							
		-20.5	23.5	6.6	21.5	-22.7		-25.6	2.5	18.1	8.0	14.7	24.2	0.0	0.0

17	73.2	72.0	73.4	72.8	71.5	71.6	57.0	59.6							
		-4.9	15.2	14.5	1.5	-23.8		-25.5	2.1	5.4	3.6	12.5	41.7	0.0	0.0
18	73.3	73.2	75.2	75.2	74.0	73.7	73.0	63.0							
		10.7	1.9	22.1	-20.5	-22.2		-23.4	1.2	-2.0	-1.1	9.6	58.2	0.0	0.0
19	73.7	74.0	75.1	75.4	74.2	74.1	72.0	55.6							
		16.1	-4.7	5.2	-4.9	-18.7		-19.2	0.5	4.1	1.7	7.3	32.4	0.0	0.0
20	74.6	74.4	75.0	75.9	74.7	74.5	73.0	67.7							
		14.5	-5.1	5.3	-11.5	-15.4		-15.3	-0.1	3.1	1.2	5.9	27.5	0.0	0.0
21	74.3	74.9	75.9	75.7	75.4	75.2	75.0	69.4							
		15.0	-7.3	2.8	-16.2	-12.9		-11.7	-0.5	0.8	0.2	4.6	27.2	0.0	0.0
22	74.6	74.7	73.8	75.0	73.8	73.5	55.0	59.5							
		7.1	-1.5	-12.4	10.7	-9.7		-8.8	-0.9	14.5	6.4	4.4	-11.0	0.0	0.0
23	74.5	73.7	75.6	73.1	71.5	72.3	60.0	58.3							
		-4.6	13.3	-16.9	27.4	-9.2		-8.1	-1.1	22.1	9.8	5.6	-28.8	0.0	0.0
24	74.3	72.9	75.7	72.4	71.3	71.5	60.0	66.9							
		-13.5	17.4	-6.4	25.9	-10.7		-9.3	-1.4	20.8	9.2	6.9	-21.2	0.0	0.0
25	74.1	73.0	75.7	73.7	72.5	72.5	67.0	66.6							
		-8.1	13.4	6.7	4.6	-12.3		-10.5	-1.7	10.1	4.4	6.9	8.5	0.0	0.0
26	74.0	73.3	73.6	74.2	73.0	73.0	66.0	67.2							
		-0.7	5.3	4.5	1.9	-12.5		-10.4	-2.1	9.3	4.0	6.3	9.6	0.0	0.0
27	74.0	73.1	75.6	72.5	71.5	71.9	61.0	66.9							
		-4.3	10.0	-12.1	22.3	-12.2		-9.8	-2.4	19.7	8.7	6.5	-17.2	0.0	0.0
28	73.8	72.5	75.5	73.2	72.0	72.1	65.0	66.4							
		-5.1	12.1	2.0	10.1	-12.9		-10.1	-2.8	13.0	5.7	6.8	1.1	0.0	0.0
29	73.7	73.0	75.4	73.3	72.3	72.4	56.0	66.6							
		-2.5	5.1	2.2	6.9	-13.1		-10.0	-3.1	11.7	5.1	6.6	4.2	0.0	0.0
30	73.7	73.3	75.4	74.3	73.1	73.0	49.0	67.2							
		1.6	3.2	6.7	-1.5	-12.5		-9.4	-3.4	7.5	3.2	5.1	13.4	0.0	0.0

TOTAL HEAT FLOWS OVER THE 30 DAY PERIOD :

QS	QU1	QUS	QU2	QD1
-322.3	1015.4	41.5	573.0	-192.3

QOS	QD2	QW	QC	QE	QG	SUM	QIN
-260.1	57.7	704.5	313.3	441.0	256.4	941.8	941.8

AMBIENT AVERAGE TEMPERATURE = 58.1 F

ROOM AVERAGE TEMPERATURE = 71.5 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 256.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 415.4

PERFORMANCE OF THE HEAT STORAGE SYSTEM USING AN EXTREMELY SIMPLIFIED MODEL

HERE ARE PREDICTED RESULTS FOR THE MONTH OF MAY

TEMPERATURES ARE AVERAGE DAILY, F; HEAT FLOWS ARE TOTALS DAILY, BTU/SQUARE FOOT OF FLOOR AREA.

DAY	TS	TU	TD	TR	T4	TC	TA	TG							
		QS	QU1	QUS	QU2	QD1		QGS	QD2	QW	QC	QE	QG	SUM	QIN
1	73.7	73.9	75.4	74.5	73.5	73.2	69.0	67.6	INITIAL TEMPERATURES AT THE START OF THE MONTH						
1	74.6	75.3	73.4	73.0	71.9	72.1	62.0	67.1							
		67.8	15.2	-4.5	19.7	-6.4		-2.7	-3.7	18.3	9.1	6.8	-13.7	63.5	63.5
2	76.8	73.3	75.4	72.9	71.7	72.0	60.0	66.2							
		131.2	39.7	11.1	28.4	10.2		13.7	-3.5	21.6	9.6	9.7	-15.2	150.8	190.8
3	78.4	74.6	75.5	73.7	72.6	72.9	60.0	65.4							
		25.1	46.2	15.6	32.3	22.3		25.1	-2.8	23.1	10.3	12.0	-9.8	107.5	107.5
4	77.9	75.5	73.6	75.4	74.2	74.4	63.0	65.5							
		-50.3	21.2	11.7	19.4	13.1		20.1	-2.0	16.9	7.5	13.6	9.8	0.0	0.0
5	76.9	73.6	75.7	75.8	74.6	74.8	65.0	66.1							
		-34.6	13.0	-0.3	15.9	9.5		11.0	-1.5	15.9	7.0	10.1	9.8	0.0	0.0
6	76.3	75.7	73.8	76.1	74.9	75.0	58.0	66.8							
		-21.5	6.3	-0.8	9.1	4.4		5.7	-1.3	12.7	5.6	8.8	13.6	0.0	0.0
7	76.0	75.3	75.8	76.0	74.8	74.9	64.0	67.6							
		-14.2	5.2	-5.6	3.3	1.3		2.4	-1.1	12.5	5.5	7.8	9.6	0.0	0.0
8	75.7	75.2	75.8	75.3	74.2	74.3	66.0	67.6							
		-12.5	6.3	-7.2	13.3	-1.0		0.1	-1.1	15.1	6.7	7.2	-0.1	0.0	0.0
9	75.4	74.9	75.6	75.5	74.5	74.3	66.0	68.1							
		-3.5	5.9	-0.7	6.7	-2.9		-1.5	-1.1	11.6	5.1	6.8	6.6	0.0	0.0
10	75.2	75.0	75.8	75.9	74.7	74.7	70.0	68.7							
		-5.0	5.0	2.6	0.4	-4.1		-2.9	-1.2	8.6	3.7	6.1	11.6	0.0	0.0
11	75.2	75.9	75.4	77.1	75.9	75.7	75.0	69.9							
		2.3	-5.1	10.7	-13.9	-4.3		-3.0	-1.3	1.6	0.5	5.0	25.8	0.0	0.0
12	75.3	75.6	75.8	75.7	74.5	74.6	67.0	70.3							
		0.5	-1.5	-11.1	9.7	-3.6		-2.2	-1.6	13.9	6.1	4.6	-8.8	0.0	0.0
13	75.2	74.3	73.7	74.1	72.5	73.2	62.0	69.2							
		-3.4	5.2	-15.1	23.5	-4.2		-2.9	-1.5	20.2	9.0	5.4	-23.8	0.0	0.0
14	74.3	75.4	73.7	72.5	71.4	71.8	58.0	67.5							

		-17.6	17.2	-16.1	33.4	-6.4		-4.9	-1.6	24.8	11.0	6.8	-31.8	0.0	0.0
18	74.4	72.9	75.7	72.8	71.4	71.6	61.0	66.1							
		-13.3	15.6	-3.4	23.0	-9.3		-7.8	-1.8	19.1	8.5	7.7	-13.0	0.0	0.0
16	74.1	72.6	75.5	72.1	71.0	71.2	60.0	68.3							
		-15.3	15.3	-3.0	24.7	-11.7		-9.5	-2.1	20.2	9.0	8.1	-13.2	0.0	0.0
17	73.8	72.4	75.6	72.3	71.1	71.3	62.0	64.8							
		-12.1	17.5	-0.5	18.0	-13.6		-11.2	-2.4	16.5	7.4	8.3	-3.0	0.0	0.0
18	73.8	72.2	75.5	72.0	70.9	71.0	61.0	64.8							
		-5.3	16.4	-3.8	20.3	-14.9		-12.1	-2.3	18.2	8.0	8.3	-5.8	0.0	0.0
19	73.4	72.4	75.4	73.3	71.8	71.6	66.0	64.8							
		-4.5	12.5	7.1	8.3	-15.7		-12.8	-3.2	10.6	4.6	7.9	12.9	0.0	0.0
20	73.3	72.9	75.4	73.9	72.7	72.7	69.0	63.9							
		2.5	5.9	5.7	-2.9	-15.4		-11.7	-3.6	6.9	2.9	7.0	19.8	0.0	0.0
21	73.4	73.0	75.3	73.3	72.2	72.3	65.0	56.4							
		2.5	3.3	-3.9	9.3	-14.3		-10.3	-4.0	13.3	8.8	6.4	0.7	0.0	0.0
22	73.4	72.7	78.2	72.9	71.8	71.9	64.0	66.4							
		-1.3	3.8	-3.6	12.1	-13.7		-9.4	-4.3	14.4	6.3	6.5	-2.9	0.0	0.0
23	73.4	72.8	78.2	73.8	72.3	72.5	67.0	66.6							
		-0.4	7.6	4.3	3.2	-13.6		-8.9	-4.6	9.8	4.8	6.3	8.2	0.0	0.0
24	73.3	73.4	78.1	74.9	73.6	73.5	72.0	67.6							
		6.0	1.3	12.3	-10.8	-12.8		-7.9	-4.9	3.0	1.2	5.5	23.3	0.0	0.0
25	73.7	73.9	75.1	75.4	74.1	74.0	72.0	63.9							
		10.1	-3.6	6.2	-9.8	-11.0		-5.9	-5.1	3.9	1.6	4.5	17.2	0.0	0.0
26	73.9	74.7	75.1	76.3	73.6	75.3	77.0	70.4							
		14.3	-6.1	14.1	-23.1	-3.8		-3.8	-8.3	-2.7	-1.4	3.3	30.1	0.0	0.0
27	74.2	74.4	75.0	74.3	73.2	73.4	64.0	70.8							
		6.1	-2.9	-16.1	15.4	-6.5		-1.2	-5.4	17.1	7.6	3.4	-22.7	0.0	0.0
25	74.2	73.6	78.0	73.9	72.7	72.6	65.0	69.4							
		-4.2	6.4	-5.5	12.0	-6.6		-1.2	-5.4	14.2	6.3	4.4	-13.2	0.0	0.0
25	74.1	73.8	75.0	74.8	73.6	73.6	70.0	69.2							
		-1.5	4.2	7.2	-3.1	-7.2		-1.7	-3.5	6.7	2.8	4.5	7.6	0.0	0.0
30	74.1	74.6	75.0	76.3	73.1	74.6	78.0	70.3							
		6.7	-3.7	13.2	-17.1	-6.7		-1.2	-5.5	0.1	-0.2	3.6	22.9	0.0	0.0
31	74.3	74.4	75.3	74.7	73.6	73.7	66.0	70.4							
		3.7	-1.8	-11.4	9.8	-5.8		0.1	-5.5	14.0	6.2	3.6	-14.3	0.0	0.0

TOTAL HEAT FLOWS OVER THE 31 DAY PERIOD :

QS	QU1	QUS	QU2	QD1
25.2	302.2	9.3	292.3	-154.5

QOS	QO2	QW	QC	QE	QG	SUM	QIN
-57.8	-96.7	402.5	176.6	208.0	38.6	381.8	381.8

AMBIENT AVERAGE TEMPERATURE = 66.2 F

ROOM AVERAGE TEMPERATURE = 74.4 F

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 41.0

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 254.6

DAY	TS	TU	TO	TR	TW	TC	TA	TG	
31	74.3	74.1	75.0	74.4	73.3	73.4	65.0	70.0	(FINAL TEMPERATURES AT THE END OF THE HEATING SEASON)

TOTAL HEAT FLOWS OVER THE HEATING SEASON :

QS	QU1	QUS	QU2	QO1	QOS	QO2	QW
146.4	17593.9	34.2	17559.3	2559.5	1075.5	1532.3	10203.1

QC	QE	QG	SUM	QIN	QC2	QC1	QCONV
4571.4	5962.5	40.3	26372.6	26372.6	14231.3	7134.5	21365.9

HEATING DEGREE-DAYS BASED ON 65 F BASE TEMPERATURE = 5167.8

HEATING DEGREE-DAYS BASED ON ACTUAL ROOM TEMPERATURE = 5775.9

APPENDIX C

LIGHTING LOAD DETERMINATION

APPENDIX C

The purpose of this appendix is to estimate the rate of heat input to the warehouse from the lights. From the building specifications, the warehouse contains:

19 - 250 watt high pressure sodium lamps

4 - surface mounted fluorescent lamps at 160 W each

8 - surface mounted fluorescent lamps at 80 W each.

A lamp efficiency of 83% was assumed.

The total lighting load supplied to the warehouse is:

$$19 * \frac{250W}{0.83} = 19,532 \quad \frac{Btu}{hr}$$

$$4 * \frac{160W}{0.83} = 2,632 \quad \frac{Btu}{hr}$$

$$8 * \frac{80W}{0.83} = 2,632 \quad \frac{Btu}{hr}$$

24,796 Btu/hr

The lights are on approximately 9 hours during the average working day. To account for the change in the warehouse air temperature, the lighting load was treated as a steady rate of heat input to the building interior.

$$\text{Equivalent Lighting Load} = \left(24{,}792 \ \frac{\text{Btu}}{\text{hr}} * \frac{9 \text{ hr}}{\text{day}} \right) * \frac{20 \text{ "work" days}}{30 \text{ days in month}} \ / \ 24 \text{ hr}$$

$$= 6{,}322 \text{ Btu/hr}$$

$$\text{or } 1.04 \ \frac{\text{Btu}}{\text{hr}} \text{ per sq ft of floor area}$$

The change in room temperature due to the lighting load over a fifteen minute period is:

$$\Delta TR = 1.04 \ \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} * 0.25 \text{ hr} \ / \ CA = 0.84 \ ^{o}F$$

where CA = thermal capacitance of air = 0.31 $\text{Btu/ft}^2 \cdot {}^{o}F$

The new room air temperature after the fifteen minute interval is

$$TR_{NEW} = TR_{OLD} + 0.84 \ ^{o}F.$$

APPENDIX D

CHANGE IN ROOM TEMPERATURE DUE TO INFILTRATION

APPENDIX D

The estimated design heating load with an infiltration rate of 0.5 air changes per hour is 110,987 Btu/hr. Without heat losses due to infiltration, the heating load is 54,289 Btu/hr. The actual rate of energy consumption at outdoor design conditions is approximately 76,269 Btu/hr (refer to Graph 7). This indicates that the actual infiltration rate is between zero and 0.5 air changes per hour. To determine the actual air leakage rate, V:

actual heat loss rate = 76,269 - 54,289 = 21,890 Btu/hr due to infiltration

$$V = 20,352 \ \frac{ft^3}{hr} \qquad \frac{21,980 \text{ Btu/hr}}{0.018 * (T_i - T_o)}$$

where T_i = indoor design air temperature = 60^oF

T_o = outdoor design air temperature = 0^oF

Therefore, the actual air leakage rate is 20,352 ft^3/hr or 0.21 air changes per hour.

The change in room air temperature, T_R, due to an infiltration rate of 0.21 air changes per hour over a fifteen minute period is:

$$\Delta T_R = 0.21 * DELTP * (TA - TR)$$

where DELTP = 0.25 hr

TA = outdoor air temperature in ^oF

TR = warehouse air temperature in ^oF

The new room air temperature in the warehouse is:

$$TR_{NEW} = TR_{OLD} + 0.0525 * (TA - TR).$$

APPENDIX E

SENSITIVITY ANALYSIS

APPENDIX E

The purpose of this sensitivity analysis is to determine the error percentage of heat flow rates which would result in the calculated temperatures of nodes TS, TU, TD and TG each varied one degree from their actual values. Using Fourier's Law of Heat Conduction:

$$Q = (T_I - T_{I-1})/R$$

where $T_I - T_{I-1} = 1^oF$ of difference between the computed and measured temperature at node TS, TU, TG, or TD

R = thermal resistance

Differentiating,

$$dQ = dT_I/R - dT_{I-1}/R + \frac{(T_I - T_{I-1})}{-R^2} * dR$$

Therefore, $dQ \ \alpha \ \frac{d(T_I - T_{1-1})}{R} = \frac{1^oF}{R}$

where dQ = the difference in the rate of heat flow

$d(T_I - T_{I-1}) = 1^oF$

For the error percentage in the rate of heat flow (QU1) between nodes TS and TU caused by one degree of variation of either calculated temperature from its measured value:

$$dQ \ \alpha \ \frac{1}{R} = \frac{1}{1.94} = 0.515 \text{ Btu/hr}\cdot\text{ft}^2$$

$$Q = \frac{(TS - TU)}{R} = 4.12 \text{ Btu/hr}\cdot\text{ft}^2$$

where TS = average temperature at nodes TS = 79^oF

TU = average temperature at node TU = 70^oF

$R = 1.94 \text{ hr}\cdot\text{ft}^2\cdot{}^\circ\text{F/Btu}$

error percentage $= \frac{dQ}{Q} = \frac{0.515}{4.12} * 100 = 12.5\%$ of QU1

This same approach was used to determine error percentages of heat flow rates between nodes TS and TD1, TS and TG and TD1 and TD2. The results of this sensitivity analysis are seen in Table 5.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. H.D. Ball, Dr. C.K. Spillman, and Dr. R.L. Gorton for serving as committee members for my thesis. I would especially like to thank Dr. R.L. Gorton for all his time and guidance during the development of this work. Thank you, Dr. Gorton, for having patience enough to work with this green engineer.

I would also like to express my gratitude to the Kansas Electric Utilities Research Program (KEURP) for supporting this project. A sincere thank you goes out to R.C. Loux, Director of KEURP, and Alan Kettle, Project Engineer, for their help.

Finally, I would like to thank Mary Lough for what may someday be referred to as the world's most efficient typing job.

VITA

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A METHOD FOR DETERMINING THE INSTALLED CAPACITY OF AN UNDERFLOOR ELECTRICAL RESISTANCE HEATING AND ENERGY STORAGE SYSTEM

BY

CAROL ELAINE SMITH

B.S., Georgia Institute of Technology, 1983

An Abstract of a Master's Thesis

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

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ABSTRACT

Underfloor electrical resistance heating and storage systems may be economically more desirable than conventional heating systems in areas where utility companies offer reduced electrical rates during off-peak hours. The time lag characteristic of such heat storage systems makes it possible for the consumer to take advantage of the reduced electrical rates.

An investigation of underfloor heating systems was initiated with the development of a two-dimensional, transient finite difference model representing the building, storage bed and surrounding earth. However, for the purposes of this work, the detailed model proved to be too expensive for repeated use. For this reason, a simplified one-dimensional finite difference model was developed. This model is capable of estimating temperature and heat flow distributions characteristic of buildings using underfloor heating systems.

The model was used to determine the effects of variations in parameters such as system operating cycle, edge insulation thickness, material properties and building thermal transmittance.

Results of this study were used to provide a method for determining the installed capacities of underfloor electrical resistance heating and energy storage systems for commercial buildings in Kansas.