SCHOOL OF MECHANICAL AND AEROSPACE ENGINEERING

OKLAHOMA STATE UNIVERSITY

Feasibility of the Implementation of Solar Heat Sources for Bridge Deck Applications

Project # 76-06-2

by

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REPORT

to

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1. INTRODUCTION

Deicing salts have caused damage and early failure of the concrete cover and corrosion of reinforcing steel of concrete bridge decks. The use of wax to internally seal Portland Cement concrete bridge decks and the use of monomers to polymerize concrete have been researched as methods to repair deteriorated decks and to prevent the penetration of salt into the concrete. Both methods require heating the concrete to a depth of two inches to temperatures of 160° to 190°F. Electrical and propane heating systems are expensive to buy and operate. Solar equipment may be more simple and uses a source of energy that is both free and non-polluting.

Although solar collectors have been studied and used for many years in heating air and water (1, 2)[1], no studies were found on using solar collectors to heat concrete slabs.

The objective of this study is to evaluate the feasibility of using solar collection equipment to heat concrete bridge decks for the purposes of polymerizing or internally sealing them. The concrete slab must be heated to temperatures of 160° to 190°F at a depth of approximately two inches below the surface.

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[1] References cited are shown in Appendix A

Problem analysis will include:

(1) Predicting various surface heat flux conditions from assumed weather data (solar irradiation) and arbitrarily specified collector and reflector parameters.

(2) Predicting local temperatures at different locations in the concrete slab for various surface heat flux conditions with the use of the Fourier Equation for heat conduction.

(3) Predicting the performance of flat plate solar collector with flat reflector using Hottel's equation for collector performance. In regard to the collector performance, important variables will be the effect of surface blackening, the number of glazing material, orientation of the reflector with respect to the collector, and the opening angle between the collector and the reflector.

(4) Developing and constructing an optimum solar collector design based on the information obtained from the analysis.

(5) Testing the solar collection equipment on Portland Cement concrete slabs under a variety of weather conditions.

2. SOLAR IRRADIATION

This section outlines the method by which the total solar irradiation on the horizontal slab can be estimated at any instant. This information is necessary for predicting the surface heat flux of the slab and the temperature profile in the slab.

Direct Normal Solar Intensity

For practical calculations, a simple procedure is available for estimating the intensity of direct solar radiation at the earth's surface during clear days. The value of direct normal solar intensity I_{DN} for a clear day can be calculated by (3)

$$I_{DN} = \frac{A}{\exp\,(B/\sin\beta)} \qquad (2.1)$$

where

A = apparent solar irradiation at air mass = 0

B = atmospheric extinction coefficient

β = solar altitude

The values of A and B vary during the year because of seasonal changes in water vapor and dust content of the atmosphere, and also because of the changing earth-sun distance. The values for A and B are listed in Table I, Appendix B. These values were taken from ASHRAE Handbook of Fundamentals (3). These data are representative of conditions on average cloudless days. For locations where clear dry skies predominate and at high elevations, values in Table I for A and B should be multiplied by the clearness factor given by Threlkeld and Jordan (4). For Stillwater, Oklahoma, the clearness factor is about 0.97.

In Equation (2.1) the solar altitude angle β is the angle in the vertical plane between the sun's rays and the projection of the sun's rays on the horizontal plane. It is the angle of the sun above the horizon. It can be shown by analytic geometry that the following relationship is true (3)

$$\text{Sin } \beta = \text{Cos L Cos } \delta \text{ Cos H} + \text{Sin L Sin } \delta \tag{2.2}$$

where

L = local latitude

δ = solar declination (i.e. the angular position of the sun at solar noon with respect to the plane of the equator)

H = hour angle, solar noon being zero, and each hour equaling 15 degrees of longitude with mornings positive and afternoons negative.

The solar declination angle δ can be found from the approximate equation given below (1)

$$\delta = 23.45 \text{ Sin } [360 \frac{284 + n}{365}] \tag{2.3}$$

where n is the day of the year.

Therefore from Equations (2.1 - 2.3) the direct normal solar intensity for a clear day can be estimated.

Direct Solar Intensity

The irradiation of a surface at any instant by direct solar radiation may be calculated if the direct intensity I_{DN} normal to sun's rays at the location is known. This requires that we find the component I_D which is perpendicular to the given surface. With the angle of incidence θ known, we have the general relation (5)

$$I_D = I_{DN} \text{ Cos } \theta \tag{2.4}$$

where Cos θ is given by Equation (2.5) for a tilted surface and by Equation (2.5a) for a horizontal surface.

$$\text{Cos } \theta = \text{Cos } \beta \text{ Cos } \gamma \text{ Sin } \epsilon + \text{Sin } \beta \text{ Cos } \epsilon \tag{2.5}$$

where

ϵ = tilt angle of the surface from the horizontal

γ = wall solar azimuth

When the surface is horizontal, ϵ = 0 deg. and:

$$\text{Cos } \theta_H = \text{Sin } \beta \tag{2.5a}$$

From Equations (2.4) and (2.5a) the direct solar intensity for a horizontal surface can be estimated.

Diffuse Solar Intensity

The diffuse solar radiation from a clear sky that falls on a horizontal surface is given approximately by (3)

$$I_{dH} = CI_{DN} \tag{2.6}$$

where C, the sky diffuse radiation factor, is given in Table I, Appendix B.

Total Solar Intensity

The total solar radiation I_T incident upon a horizontal surface at any instant may be calculated by

$$I_T = I_D + I_{dH} + I_R \tag{2.7}$$

where I_R is the solar radiation directed upon a surface by other surfaces, this will be discussed in the next section under the topic of Collector-Reflector model.

3. PERFORMANCE OF FLAT PLATE COLLECTOR WITH FLAT REFLECTOR

This section outlines the method by which the total reflected energy falling on a flat plate collector can be estimated. Also the heat loss calculations for flat plate collectors are presented.

The use of diffuse and specular flat reflectors to enhance the performance of flat plate solar collectors have been explored by many investigators. Reflecting surfaces can be used to increase the energy yield of flat plate solar collectors in two ways: by increasing the total collection area, and by redirecting the solar radiation to move nearly normal incidence on the collector, where it is absorbed with greater efficiency. The latter is particularly important when the flat plate collector can not be tilted to the optimum angle of exposure to the sun.

In a study done by Seitel (6) it has been shown that specular reflectors are more effective than diffuse reflectors, if south-facing reflectors are used with collectors which are elongated in the east-west direction. In this study these orientations will be adopted.

Collector-Reflector Model

Figure (3.1) shows a collector of length C and a reflector of length R which have a common side of length L and include an angle B.

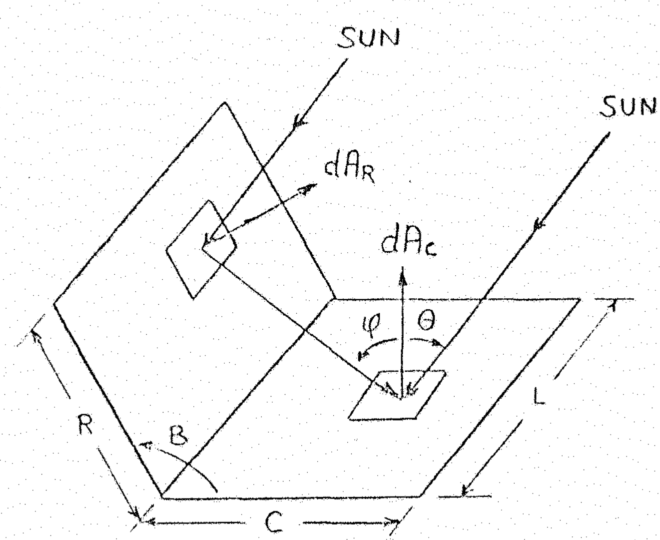

Figure 3.1 Geometry and Nomenclature

The collector is exposed to solar radiation from the sky, and to reflected radiation from the reflector.

The solar radiation from the sky that falls on the collector is composed of direct and diffuse components. Equations for estimating the direct and diffuse sky radiation were introduced in Section 2, see Equations (2.4) and (2.6). Therefore the total direct contribution from the sky on the flat plate collector is

$$I_{DT} = I_D + I_{dH} \tag{3.1}$$

The reflected radiation is also composed of direct and diffuse components. If the reflector is specular the contribution from the reflected direct sky radiation on the flat plate collector is

$$I_{DS} = I_D \rho_s f \text{ Cos } \varphi \tag{3.2}$$

ρ_s = fraction of incident radiation reflected

f = fraction of the collector illuminated by reflection

φ = the angle at which the reflected radiation strikes the collector

and the contribution from the reflected diffuse sky radiation on the flat plate collector is

$$I_{dHS} = F_{RC}\left(\frac{1 + \text{Cos B}}{2}\right) \rho_s I_{dH} \tag{3.3}$$

where $\left(\frac{1 + \text{Cos B}}{2}\right)$ is the portion of the sky dome that the tilted reflector would see if it is assumed that the diffuse solar radiation is uniformly distributed over the sky. This term is the conversion factor for sky diffuse radiation on a tilted surface as given by Lin and Jordan (7). F_{RC} is the configuration factor between the collector and the reflector. It is the fraction of diffuse radiation leaving the reflector surface which would fall directly on the collector surface. For this problem F_{RC} is given by

$$F_{RC} = F_{CR} = 1 - \frac{\text{Sin B}}{2} \tag{3.4}$$

Therefore the total specular contribution from the reflector to the collector is

$$I_R = I_{DS} + I_{dHS} \tag{3.5}$$

In order to evaluate the contribution from the reflected direct sky radiation on the flat plate collector, Equation (3.2), we need to know the values of f and φ at any instant. f can be defined as the ratio of the illuminated area per unit length to the absorbing area per unit length, thus

$$f = \frac{\text{illuminated area per unit length}}{\text{absorbing area per unit length}} = \frac{W}{C} \tag{3.6}$$

Figure (3.2) shows the projection of the collector and the reflector on a North-South plane. From the geometry shown

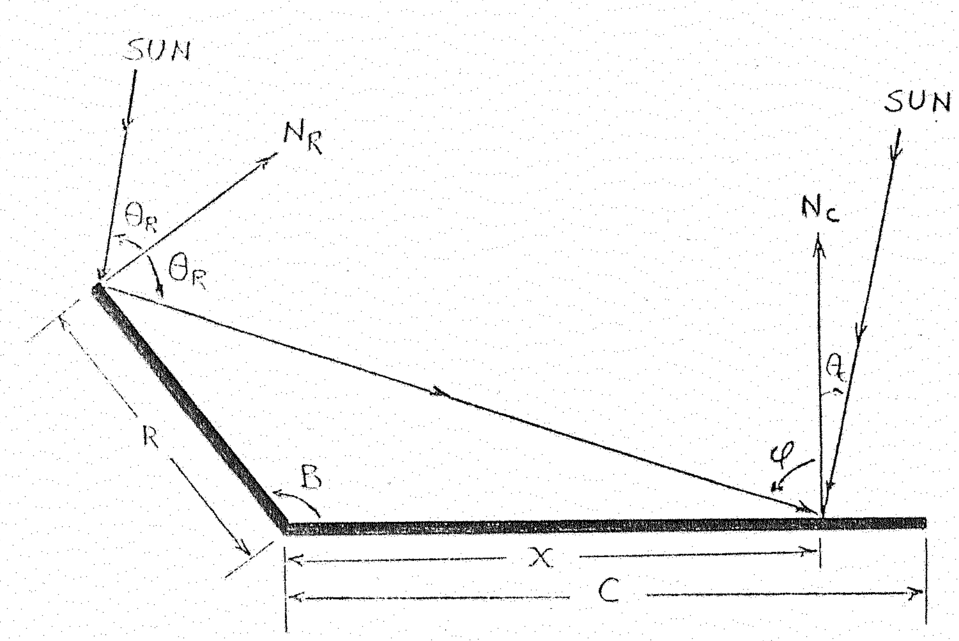

Figure 3.2 Projection of the Collector and the Reflector on the N-S Plane

on this figure it can be shown that the illuminated area is

$$W = C - X = C - R(\text{Cos } B + \text{Sin } B \tan \varphi) \tag{3.7}$$

Now, using the defining equation for f, Equation (3.6), the expression for f becomes

$$f = \frac{W}{C} = 1 - \frac{R}{C}\ (\text{Cos } B + \text{Sin } B \tan \varphi) \qquad (3.8)$$

From Figure (3.2) and geometry the angle at which the reflected radiation strikes the collector can be found to be

$$\varphi = B - \theta_R \qquad (3.9)$$

where θ_R is the incident angle of the sun's rays on the reflector surface. The incident angle was expressed by Equation (2.5) as

$$\text{Cos } \theta = \text{Cos } \beta \text{ Cos } \gamma \text{ Sin } \epsilon + \text{Sin } \beta \text{ Cos } \epsilon \qquad (2.5)$$

For a south facing reflector the wall azimuth angle (ψ) is zero, and the relation between the wall solar azimuth (γ) and the solar azimuth (ϕ) becomes

$$\gamma = \phi \qquad (3.10)$$

where the solar azimuth (ϕ) could be found using the following equation

$$\text{Sin } \phi = \text{Cos } \delta \text{ Sin } H \;/\; \text{Cos } \beta \qquad (3.11)$$

Thus to obtain the incident angle on a south facing reflector Equation (2.5) becomes

$$\text{Cos } \theta_R = \text{Cos } \beta \text{ Cos } \phi \text{ Sin } B - \text{Sin } \beta \text{ Cos } B \qquad (3.12)$$

where $\epsilon = 180° - B$

Having found the expressions for f and φ, Equation (3.2) can now be evaluated.

Collector Heat Loss

Part of the direct solar radiation, diffuse sky radiation, and reflected solar radiation incident upon the collector may be directly transmitted through the glass cover, part may be reflected, and part may be absorbed. Energy exchange by convection may occur between the glass outer surface and the outside air. Also, the glass outer surface may transfer heat by long-wave radiation exchange with the sky and the surrounding objects. In general, the rate of useful heat gain by the concrete slab through the glass cover is given by

$$\dot{q}_{useful} = I_T(\tau\alpha) - \dot{q}_{T\ loss} \tag{3.13}$$

where

I_T = total rate of incident solar radiation (direct + diffuse + reflected) on the collector, see Equation (2.7).

$(\tau\alpha)$ = transmittance-absorptance product of cover system for solar radiation

$\dot{q}_{T\ loss}$ = rate of energy losses from the collector to the surroundings by radiation and convection. The losses due to reflection from the cover(s) are included in the term $(\tau\alpha)$.

Now each term in Equation (3.13) will be analyzed separately:

(1) The total rate of incident solar radiation, I_T

The total solar radiation incident upon a horizontal surface was discussed in Section 2, and the final working equation was given by Equation (2.7).

(2) Transmittance-absorptance product, $(\tau\alpha)$

Of the radiation passing through the glass cover(s) and striking the slab, some is reflected back to the glass.

However, all this radiation is not lost since some is reflected back to the slab. This situation is illustrated in Figure (3.3).

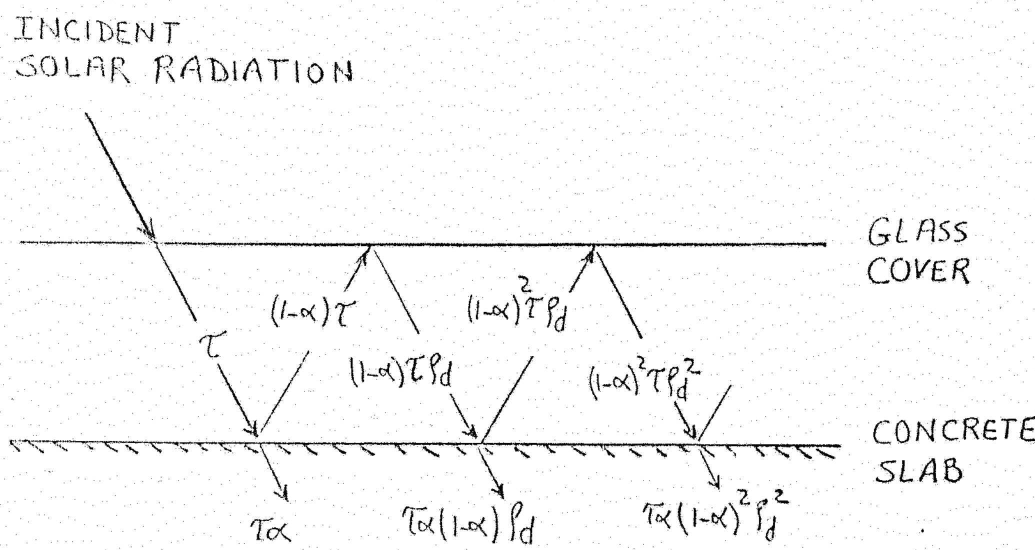

Figure 3.3 Absorption of Solar Radiation by Concrete Slab

Of the energy arriving at the concrete slab, $\tau\alpha$ is absorbed and $(1 - \alpha)\tau$ is reflected back to the glass cover. The reflection from the concrete slab is more diffuse than specular so that the fraction $(1 - \alpha)\tau$ that strikes the glass cover is diffuse radiation and $(1 - \alpha)\tau\rho_d$ is reflected back to the concrete slab. The multiple reflection continues and the energy absorbed by the slab as given by (1) is

$$(\tau\alpha) = \frac{\tau\alpha}{1 - (1-\alpha)\rho_d} \qquad (3.14)$$

where

τ = transmittance allowing for both reflection and absorption

α = angular absorptance of the concrete slab

ρ_d = diffuse reflectance

According to Duffie and Beckman (1), the diffuse reflectance can be estimated by using the specular reflection of the cover system at an incidence angle of 60°.

In order to evaluate Equation (3.14), we need to know the total transmittance, τ. The transmittance allowing for both reflection and absorption, τ is

$$\tau = \tau_r \tau_\alpha \tag{3.15}$$

Transmittance due to absorption, τ_α is

$$\tau_\alpha = e^{-KL} \tag{3.16}$$

where

K = extinction coefficient, assumed to be constant in the solar spectrum

L = actual path of the radiation through the medium

Transmittance due to reflection, τ_r, for a system of n covers, all the same material given by (1) is

$$\tau_{r,n} = \frac{(1-\rho)}{1 + 2(n-1)\rho} \tag{3.17}$$

where ρ is the reflectance of the glass cover.

The reflectance of the glass cover, ρ, can be obtained from Fresnel's relation for the reflection of nonpolyarized radiation passing from a medium 1 with refractive index n_1, to medium 2, with refractive index n_2.

$$\rho = \frac{1}{2}\left[\frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} + \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}\right] \tag{3.18}$$

where θ_1 and θ_2 are the angles of incidence and refraction. The angles θ_1 and θ_2 are related to the indicies of refraction by Snell's law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} \tag{3.19}$$

Thus if the indicies of refraction and the angle of incidence are known, reflectance can be obtained from Equation (3.19) and (3.18).

Knowing the total transmittance from Equation (3.15), transmittance-absorptance product, $(\tau\alpha)$, given by Equation (3.14) can now be evaluated.

(3) Rate of energy loss from the collector, $\dot{q}_{T\ loss}$

The heat loss coefficient for the collector is the result of convection and radiation between parallel plates. The energy transfer between the concrete slab and the first glass cover is exactly the same as between any other two adjacent glass plates and is also equal to the energy lost due to the surroundings from the top glass cover. (This is not true at any instant of time if energy storage in the glass is considered or if the glass absorbs solar energy). An empirical equation for the heat loss coefficient was developed by Klein (8), following the basic procedure of Hottel and Woertz (9). The relationship for the heat loss coefficient is

$$U_t = \left(\frac{N}{(344/T_p)\,[(T_p - T_a)/(N+F)]^{0.31}} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma(T_p + T_a)(T_p^2 + T_a^2)}{[\epsilon_p + 0.0425N(1-\epsilon_p)]^{-1} + [(2N + f - 1)/\epsilon_g] - N} \tag{3.20}$$

where

N = number of glass covers

$F = (1.0 - 0.04h_w + 5.0 \times 10^{-4} h_w^2)(1 + 0.058N)$

ϵ_g = emmittance of glass

ϵ_p = emmittance of concrete slab

T_a = ambient temperature (°K)

T_p = surface temperature of slab (°K)

σ = Stafan-Boltzman constant

h_w = wind heat transfer coefficient, W/m² °C

The heat loss from flat plates exposed to outside winds are found from a dimensional expression given by McAdams (10) which relates the heat transfer coefficient in $\frac{W}{m^2\,°C}$ to the wind speed in m/s.

$$h_w = 5.7 + 3.8V \tag{3.21}$$

Knowing the overall heat loss coefficient, the rate of energy loss can be found as

$$\dot{q}_{T\ loss} = U_T(T_p - T_a) \tag{3.22}$$

From Equations (2.7), (3.14), and (3.32) the three terms of Equation (3.13), namely I_T, $(\tau\alpha)$, and $\dot{q}_{T\ loss}$ can be determined. Knowing these terms the useful energy rate can now be evaluated from Equation (3.13). This evaluated heat gain rate is the actual amount of energy that is used for heating up the concrete slab.

4. TEMPERATURE PROFILE

This section outlines the method by which temperature profile in the slab can be predicted for various surface heat flux conditions. The slab gains heat from the top by solar radiation (useful energy) and normally loses heat from the bottom to the surroundings by convection.

Heat Equation

Assuming a one-dimensional transient problem, consider a system of length Δx in the x direction with cross sectional area A normal to the x direction. The important energy terms are the conduction into and out of the system, generation, and storage. The energy balance on the system is

$$q\big|_x + \dot{E}_g = q\big|_{x+\Delta x} + \dot{E}_s \qquad (4.1)$$

where

$$q\big|_x = -\left[KA\frac{\partial t}{\partial x}\right]_x \qquad \text{Conduction}$$

$$\dot{E}_g = g'''(A\,\Delta x) \qquad \text{Generation}$$

$$q\big|_{x+\Delta x} = -\left[KA\frac{\partial t}{\partial x}\right]_{x+\Delta x} \qquad \text{Conduction}$$

$$\dot{E}_s = \rho\, c\,(A\,\Delta x)\frac{\partial t}{\partial \theta} \qquad \text{Storage}$$

For the case of no heat generation ($\dot{E}_g = 0$), after some manipulation Equation (4.1) becomes

$$\frac{\partial^2 t}{\partial x^2} = \frac{1}{\alpha}\frac{\partial t}{\partial \theta} \qquad \text{(Heat Equation)} \qquad (4.2)$$

Equation (4.2) is the working equation for obtaining the temperature distribution in the concrete slab.

Solution of Heat Equation

The solution of heat equation is done in two steps.

The first step is to obtain a system of ordinary differential equations to approximate the behavior of the heat equation. This is done by finite difference formulation. Divide the x direction into equally spaced nodes, Δx apart. This is shown in Figure 4.1.

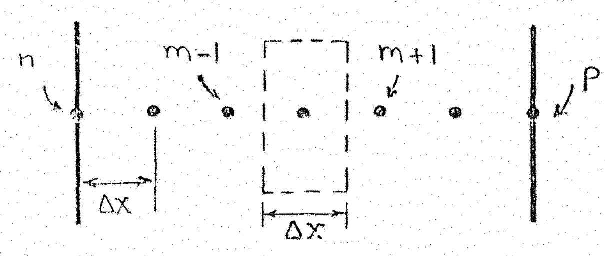

Figure 4.1 Nodal-point arrangement

As an approximation, let the temperature of each node represent the temperature of a thin plane wall Δx thick surrounding the node as labled in Figure 4.1.

Energy balance for the interior node m is

$$q_{m-1,\,m} = q_{m,\,m+1} + \dot{E}_{sm} \qquad (4.3)$$

where

$$q_{m-1,\ m} = KA \frac{t_{m-1} - t_m}{\Delta x}$$

$$q_{m,\ m+1} = KA \frac{t_m - t_{m+1}}{\Delta x}$$

$$\dot{E}_{sm} = \rho c A \Delta x \frac{dt_m}{d\theta}$$

Substituting the rate equations into the energy equation and rearranging, the resulting ordinary differential equation for the interior node is found to be

$$\rho c A \Delta x \frac{dt_m}{d\theta} = \frac{KA}{\Delta \theta} (t_{m-1} - 2t_m + t_{m+1}) \qquad (4.4)$$

A similar equation can be written for each of the interior nodes.

Energy balance for surface node n is

$$q_o = q_{n,\ n+1} + \dot{E}_{sn} \qquad (4.5)$$

where

q_o = total useful solar irradiation on the slab (see equation 3.13)

$$q_{n,\ n+1} = KA \frac{t_n - t_{n+1}}{\Delta x}$$

$$\dot{E}_{sn} = \rho c A \frac{\Delta x}{2} \frac{dt_n}{d\theta}$$

Substituting the rate equations into Equation (4.5), the resulting ordinary differential equation for the surface node is

$$\frac{q_o}{A} = \frac{K}{\Delta x} (t_n - t_{n+1}) + \frac{\rho c \Delta x}{2} \frac{dt_n}{d\theta} \qquad (4.6)$$

Energy balance for the end node, P is

$$q_{p-1,\,p} = q_p + \dot{E}_{sp} \tag{4.7}$$

where

$$q_{p-1,\,p} = KA\,\frac{t_{p-1} - t_p}{\Delta x}$$

$$q_p = hA\,(t_p - t_\infty)$$

$$\dot{E}_{sp} = \rho\, cA\,\frac{\Delta x}{2}\,\frac{dt_p}{d\theta}$$

Substituting the rate equations into the energy equation and rearranging, the resulting ordinary differential equation for the end node is found to be

$$\frac{\rho c A \Delta x}{2}\,\frac{dt_p}{d\theta} = \frac{KA}{\Delta x}\,(t_{p-1} - t_p) + hA(t_\infty - t_p) \tag{4.8}$$

The second step is to obtain a numerical solution to this system of ordinary differential equations. The Crank-Nicolson method of solution was chosen to solve these differential equations.

Since this is an initial-value problem, we will know the solution $t^{(\nu)}$ at some point in time $\theta^{(\nu)}$, and we will be seeking to find the solution $t^{(\nu + 1)}$ at some later time $\theta^{(\nu + 1)} = \theta^{\nu} + \Delta\theta$. The Crank-Nicolson method uses the arithmetic mean value of the derivatives at the beginning and the end of the time interval. In order to find $t^{(\nu + 1)}$ using the Crank-Nicolson method one would use

$$t^{(\nu + 1)} = t^{(\nu)} + \frac{1}{2}\left[\left.\frac{dt}{d\theta}\right|^{(\nu)} + \left.\frac{dt}{d\theta}\right|^{(\nu + 1)}\right]\Delta\theta \tag{4.9}$$

This can be generalized for the system of equations we are using. The values of the derivatives in these equations can be found from the system of the differential equations, that is Equations (4.4), (4.6), and (4.8).

Using the Crank-Nicolson method of solution, the set of simultaneous equations to be solved are

For the surface node

$$2t_1^{(\nu+1)} - t_2^{(\nu+1)} = t_2^{(\nu)} + \left(\frac{\Delta x}{k}\right)\left[\left(\frac{q_o}{A}\right)^{\nu} + \left(\frac{q_o}{A}\right)^{\nu+1}\right] \qquad (4.10)$$

For the interior nodes

$$t_{m-1}^{(\nu+1)} - 4t_m^{(\nu+1)} + t_{m+1}^{(\nu+1)} = -t_{m-1}^{(\nu)} - t_{m+1}^{(\nu)} \qquad (4.11)$$

For the end node (4.12)

$$2t_{p-1}^{(\nu+1)} - \left(4 + 2\frac{h\Delta x}{k}\right) t_p^{(\nu+1)} = -2t_{p-1}^{(\nu)} + 2\frac{h\Delta x}{k} t_p^{(\nu)} - 4\frac{h\Delta x}{k} t_\infty$$

In these equations r, as given by Equation (4.13) was set equal to unity.

$$r = \frac{K\Delta\theta}{C\rho(\Delta x)^2} \qquad (4.13)$$

The advantage of using the implicit Crank-Nicolson method is that it is stable for any value of r, although small values are more accurate. Values much larger than unity are not desirable. Furthermore, by using the average value of the derivatives to move ahead in time, the solution should be more accurate than the explicit method.

5. COMPUTER PROGRAM

A computer program was developed with the main objective of predicting the temperature profile in the concrete slab. To achieve this objective, the useful energy from the sun that is used to heat up the concrete slab should be first determined. To evaluate this energy, the following four preliminary steps should be taken.

(1) Calculate the direct normal solar intensity, and direct and diffuse intensities that fall on the flat plate collector.

(2) Optimize the opening angle between the collector and the reflector, if reflector is to be used.

(3) Calculate the direct and diffuse reflected energy that falls on the collector, if reflector is to be used.

(4) Calculate the useful energy, the energy that is used to heat up the concrete slab (including all the losses).

With the help of the theory introduced in the first four sections, four different subroutines were developed to fulfill these steps.

A listing of the computer program is given in Appendix C.

Subroutine SUN

This subroutine in general calculates the solar angles (hour angle, declination, altitude, and azimuth), sunrise, sunset, and the direct normal solar intensity from sunrise to sunset. Then the direct and diffuse solar intensities on the flat plate collector are calculated from the direct normal intensities.

The inputs to this subroutine are the longitude and latitude of the location of interest, and the month and day of the year.

Subroutine OPTIM

This subroutine optimizes the opening angle between the collector and the reflector. The optimization is done by comparing the total reflected energy on the collector from sunrise to sunset for different opening angles and choosing the angle that yields the most fallen energy on the collector. In the case of no reflectors, this subroutine should be omitted.

Subroutine COLREF

This subroutine takes the optimized opening angle as an input and calculates the direct and diffuse reflected intensities that fall on the collector for that particular opening angle from sunrise to sunset. In the case of no reflectors, this subroutine should be omitted.

Subroutine PERFOR

This subroutine basically calculates the amount of useful solar energy that falls on the concrete slab. By using the information from the three mentioned subroutines, it calculates the fraction of the total energy falling on the collector that is transmitted through the glass cover(s) and absorbed in the concrete slab. The difference between this energy and the energy that is lost from the top of the collector by convection and radiation (which is calculated from Hottel's Equation) is the useful energy.

The input to this subroutine is the extinction coefficient of glass, glass thickness, number of glass covers, emittance of the concrete slab, absorptance of the concrete slab, emittance of glass, wind velocity, and maximum temperature and variation in temperature for the day of interest (this information is used to calculate the air temperature at any instant of time).

Main Program

The objective of the main program is to predict the temperature profile in the concrete slab that is heated from the top by solar radiation (useful energy) and losses heat from the bottom to the surroundings by convection. This program in addition to the four mentioned subroutines employs subroutine TRDG77 to solve the set of simultaneous equations which result from applying the Crank-Nicolson method for the temperature profile calculations.

The inputs to this program are the heat capacity, density, thermal conductivity of the concrete, number of interior nodes (which is used for Crank-Nicolson method of solution), convection heat transfer co-efficient, initial temperature of the slab, and total depth of the slab.

The theoretical results will be presented, discussed and compared with the experimental results in Section 7, under the topic of results and discussion.

6. EXPERIMENTAL MODEL

This section describes the construction of the experimental model and the experimental procedures used for data acquisition.

Construction of the Model

After sufficient information was obtained from the analysis, a Portland Cement concrete slab with dimensions of 8' x 5' x 10.5' (Specified by OHD) elongated in the east-west direction, was constructed using reinforcing bars. The concrete mixture used for constructing the reinforced concrete slab was very similar to the mixture that is used by the Oklahoma Highway Department. The size and arrangement of the reinforcing bars used in the concrete slab were very similar to the actual concrete beam bridges built by the OHD. The arrangement and size of the bars are given in Figures 1 and 2 of Appendix D respectively. The concrete slab was elevated a minimum of one foot from the ground in order to simulate the one-dimensional heat flow situation encountered with an actual bridge deck. Thermocouples were placed in the slab at different locations and depths in order to determine the temperature variations in the slab. Figure 3 and Table I of Appendix D respectively, show the position and dimensional locations of the thermocouples in the slab. As part of the solar collection equipment to heat the concrete slab a 6' x 3' collector with two glass covers was used. The location of the solar collector on the slab is shown in Figure 3, Appendix D. A specular reflector with dimensions of 5' x 8' made of aluminum sheets was attached on the north side of the concrete slab (south facing reflector). The reflector was built so that the opening angle between the reflector and the collector would be adjustable.

Data Acquisition

In order to verify the theoretical model experimentally, it was necessary to know the hourly solar intensity, the hourly temperature distribution in the slab, and the opening angle between the collector and the reflector.

The temperature histories were obtained from the thermocouples and a pyronometer was used to determine the solar input. The opening angle between the collector and the reflector was measured directly.

The experimental results will be presented, discussed, and compared with the theoretical results in the next section under the topic of results and discussion.

7. RESULTS AND DISCUSSION

The predicted temperatures at different locations in the concrete slab for various surface heat flux conditions from assumed weather data for Stillwater, Oklahoma, for the 21st day of each month of a year, are given in Appendix E. For these predicted temperatures the effects of concrete surface blackening and the number of glazing material were also investigated.

Comparing the predicted temperatures with and without surface being black, shows that surface blackening increases the temperatures at the location of our interest (approximately two inches below the surface) by as much as 15°F for the given input data. This increase in temperature due to surface blackening is a function of outside temperature, but nevertheless, it always shows an appreciable amount of increase in the temperatures. These comparisons are made in Table I, Appendix F, for the months of January and June.

The effects of the number of glazing material is demonstrated in Table II of Appendix F for a collector with one and two glass covers on a black surface. Increase in the number of glass covers reduces the heat loss from the top of the collector due to radiation and convection, but it also decreases the amount of energy that falls on the concrete slab, due to more reflection from glass covers and absorption in the glass covers. For this study, the comparison of the predicted temperatures show that using two glass covers on the collector in the long run would yield better results. Also in Table II, along with the predicted temperatures, the amount of energy that falls on the collector and collector performance parameters are given. It can be seen that as the number of glass covers increases heat loss decreases along with a decrease in the transmittance-absorptance product.

From the observations made above, it was decided to predict the temperature distribution for a period of twelve months in the concrete slab that has been blackened and uses two glass covers on the collector. These temperature predictions are given in Table I, Appendix E. Note that the time corresponding to these temperatures is the amount of time past sunrise. For the input parameters used in this study, these predictions show that under clear skies and with the use of reflectors, the concrete slab can be heated to temperatures of 160° - 190°F for a depth of approximately two inches in the months of March, April, May, June, July, and August. In these months the temperatures would definitely meet the required limits. These predicted temperatures are very sensitive to the input air temperatures if we assume that the rest of the input parameters are reasonably correct. The input air temperatures are the maximum daily temperature and the variation in the daily temperature, that is the difference between the maximum and minimum daily temperatures. These values were obtained from

Climatological data (11) for Stillwater, and an average monthly value from the data of the last three years were obtained.

The predicted temperatures for a depth of two inches below the surface in the slab for the month of September is about 150°F. With a little variation in the input temperatures for this month in the favorable direction, the predicted temperatures for this month would easily meet the required temperature.

For the months of February and October, the predicted temperatures for a depth of two inches below the surface in the slab reaches a maximum of approximately 130°F. If the daily temperature reaches a higher value than the assumed value, the temperatures at the specified location can reach the specified temperatures.

For the months of January, November, and December, according to the predicted values the maximum temperatures for a depth of two inches is between 90° - 100°F which makes the possibility of meeting the required temperatures doubtful unless for extremely hot days during these months.

A summary of the maximum predicted temperatures at the depth of 2.1 inches below the surface of the concrete slab and the optimized opening angle between the collector and the reflector for the 21st day of each month of a year are given in Table II of Appendix E. Also in this table, the effects of surface blackening and the number of glazing material on the maximum temperature are demonstrated. Along with the predicted temperatures for the twelve months, all the input parameters, and the following hourly information is given. The direct normal intensity (IDN), direct intensity (ID), direct diffuse intensity (IDIF), total direct solar contribution (WD), direct reflected radiation (IDR), direct diffuse reflected radiation (IDIFR), total reflected solar contribution (WS), total solar contribution (WT), heat loss from the top (QTLS), useful energy input (WIN), transmittance-absorptance product (TAPH), air temperature (TAF), solar altitude (ALT), and solar azimuth (AZM). In addition to the above information, the optimized angle between the reflector and the collector and the time of sunrise and sunset are also given.

The experimental data referred to in Section 6 are tabulated in Tables I-IV of Appendix G. These data were obtained under a variety of weather conditions. Weather conditions were one of the main factors encountered in heating the concrete slab. Heating the slab was possible on hazy, cloudless days and on clear to partly cloudy days. Solar intensities were higher on partly cloudy days as shown in Appendix G. Note that these intensities are direct, plus diffuse intensities on a horizontal plate, plus some reflection from the surrounding objects, but the reflection from the reflectors is not included.

The best long term results were obtained from the theoretical analysis when the surface of the concrete slab was painted black and a solar collector with two glass covers attached to a specular reflector was used. Therefore, most of the experimental data were obtained under these conditions as shown in Tables II-IV of Appendix G. The experimental data shown in Table I were obtained with natural surface color of the concrete slab. The data of Table I show that although the solar intensities for that particular day were reasonably high, the temperatures at a depth of two inches below the surface of the slab did not get as high as one would expect. Now taking the data shown in Tables II-IV, the solar intensities are generally lower than the intensities of Table I, but the temperatures are considerably higher. This increase in temperature is mainly due to the surface blackening effect. The experimental data of Table II-IV show that the temperatures at a depth of two inches below the surface can be reached to the specified limits, which in fact supports the theoretical results.

In these experiments, the opening angle between the reflector and the collector was set at an angle of 100°. But according to the theoretical analysis, the optimized opening angle is 90° (see Table II, Appendix E). With the available experimental facilities we were not able to reach this optimum angle, therefore, the next best opening angle was chosen for these experiments.

In order to compare the theoretical results with the experimental data, the computer program was run for the opening angle of 100°, these theoretical results are included in Table V of Appendix G for comparison. The experimental data of Table IV for July 26, shows that at about 4:00 p.m. the temperature of the slab at a depth of two inches below the surface reaches a maximum of about 173°F. The theoretical predictions show (see Table V) that at the same time of the day, and the same depth, the maximum slab temperature is about 181° F. This comparison very well supports the theoretical predictions. According to this comparison, the theoretical temperature differs from the experimental temperature for the month of July by about 5%. The experimental and theoretical solar intensities also compare reasonably well. The experimental intensities are slightly higher because of the reflection from the surrounding objects.

8. CONCLUSIONS

From the theoretical and experimental results presented and discussed in Section 7 of this study, it could be concluded that it is possible to heat the concrete slab by using solar collection equipment to temperatures of 160° to 190°F for a depth of approximately two inches below the surface for the purpose of polymerizing or internally sealing them.

The theoretical results show that this heating is definitely possible for the months of March, April, May, June, July, and August for a concrete slab that has been blackened and uses two glass covers on a collector that is attached to a reflector. For the month of September, for temperatures slightly warmer than the average daily temperatures, this heating is possible. For the months of February and October, this heating is possible if the daily temperatures are higher than the daily normal temperatures. For the months of January, November, and December, this heating seems to be doubtful except for exceptionally hot days.

The experimental results support the theoretical predictions for the month of July. The predicted results for this month differed from the experimental results by about 5%, which is reasonably good. More experimental data are required to conclusively demonstrate the validity of the present model for the rest of the months.

In these predictions it was assumed that reflectors are always present. The disadvantage of having reflectors present is that if more than one collector is to be used on a bridge span, reflectors could cause shading problems and this would drastically drop the efficiency of the solar collecting system.

The major benefit of this study should be a reduction in the cost of polymerizing or internally sealing concrete bridge decks. The estimate of possible cost savings at this time is not possible.

APPENDIX A

References Cited

Note: pages 36-42 are deleted

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APPENDIX B

Solar Radiation Related Data

TABLE I

Solar Radiation Related Data

DATE	A Btuh/sq ft	B Air Mass^{-1}	C
Jan. 21	390	0.142	0.058
Feb. 21	385	0.144	0.060
Mar. 21	376	0.156	0.071
Apr. 21	360	0.180	0.097
May 21	350	0.196	0.121
June 21	345	0.205	0.134
July 21	344	0.207	0.136
Aug. 21	351	0.201	0.122
Sept. 21	365	0.177	0.092
Oct. 21	378	0.160	0.073
Nov. 21	387	0.149	0.063
Dec. 21	391	0.142	0.057

APPENDIX C

Computer Listing

```
$JOB NOSUBCHK,TIME=120
C
C
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    + THIS PROGRAM DETERMINES TEMPERATURES AS A FUNCTION OF TIME IN A    +
C    + ONE-DIMENSIONAL SYSTEM GAINING HEAT FROM ONE END AND LOSING HEAT   +
C    + FROM BOTH ENDS. THE HEAT LOSS FROM THE BOTTOM IS ACCORDING TO      +
C    +       DU/DX = H * (U - TAF)                                         +
C    + WHERE TAF IS THE VARIABLE AMBIENT TEMPERATURE, AND                 +
C    + H IS THE HEAT TRANSFER COEFFICIENT.                                +
C    + THE SYSTEM IS GAINING HEAT BY SOLAR IRRADIATION.                   +
C    + A SUBROUTINE IS EMPLOYED TO CALCULATE THE HOURLY SOLAR IRRADIATION+
C    + A SUBROUTINE IS EMPLOYED TO SOLVE THE SET OF EQUATIONS WHICH       +
C    + RESULT FROM APPLYING THE CRANK-NICOLSON METHOD.                    +
C    + A SUBROUTINE IS EMPLOYED TO OPTIMIZE THE OPENING ANGLE             +
C    + BETWEEN THE COLLECTOR AND THE REFLECTOR.                           +
C    + A SUBROUTINE IS EMPLOYED TO CALCULATE THE TOTAL ENERGY             +
C    + THAT FALLS ON THE COLLECTOR.                                       +
C    + A SUBROUTINE IS EMPLOYED TO CALCULATE THE HEAT LOSS FROM           +
C    + THE TOP DUE TO RADIATION AND CONVECTION.                           +
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C
      DIMENSION U(50,4), USTART(50),TPC(50)
      DIMENSION  HR(50),GID(50),BETAD(50),PHID(50),PHI(50),BETA(50)
      DIMENSION WD(50),WS(50),WT(50),DIFFH(50),TAPH(50),TA(50)
      DIMENSION TAF(50),QTLOS(50),WIN(50),GI(50),GIR(50),GIDR(50)
      REAL  LONG,LAT
      REAL  LONGD,LATD
      G1=1.0
      G2=1.526
      ALPHAT=0.95
      RHOS=0.95
      KK=1
      K=1
   50 CONTINUE
C
C     INPUT PARAMETERS FOR SUBROUTINE SUN, DAY= DAY OF THE YEAR,
C     LONG = LONGITUDE, LAT = LATITUDE, M = MONTH
C     ALL THE ANGELS IN SUBROUTINE SUN SHOULD BE IN RADIANS.
C
      READ(5,1)  DAY,LONG,LAT,M
    1 FORMAT(F6.2,2F7.4,I2)
C
C     INPUT PARAMETERS FOR SUBROUTINE PERFOR, AK = EXTINCTION COEFF. ,
C     BL = GLASS THICKNESS,L = NO. OF GLASS COVERS, TMAXF = MAX. TEMP. IN DEG. F
C     TVARF = TEMP. VARIATION IN DEG. F , EMCP = EMITTANCE OF PLATE ,
C     EGLS = EMITTANCE OF GLASS , VMLH = WIND VELOCITY IN MILE/HR .
C
      READ 300,AK,BL,L,TMAXF,TVARF,EMCP,EGLS,VMLH
  300 FORMAT(F6.4,F5.3,I1,F8.3,F6.2,2F5.3,F4.1)
      CALL       SUN(DAY,LONG,LAT,GID,BETAD,HR,PHID,SS,SR,M,DELTAD,PHI,
     *BETA,DIFFH)
      CALL           COLREF(BD,WT,WD,WS,DAY,LONG,LAT,M,GI,GIR,GIDR)
      LONGD=LONG*57.296
      LATD=LAT*57.296
C
C     CALCULATE THE INITIAL TEMPERATURE IN DEGREES F . UIN
C
      TMR=(3.1416/12.)*SR
```

```
      VSR=56.29+29.32*COS(TMR)+38.48*SIN(TMR)-3.48*COS(2.*TMR)-8.35*SIN(
     *2.*TMR)
      UIN=TMAXF-((TVARF*VSR)/100.)
C
C     THE INPUTS SHOULD BE EXPRESSED IN UNITS OF INCHES,SECONDS,POUNDS,AND F .
C     READ IN SYSTEM PARAMETERS. C = HEAT CAPACITY, RHO = DENSITY,
C     COND = THERMAL CONDUCTIVITY, NOINT = NO. OF INTERIOR NODES,
C     ALPHA = H/COND, XL = TOTAL DEPTH ,H = HEAT TRANSFER COEFFICIENT .
C
      READ 100,C,RHO,COND,NOINT,ALPHA,XL,H
  100 FORMAT(F5.3,F9.6,F11.9,I3,F6.3,F6.2,F10.7)
C
C     COMPUTE INITIAL VALUES OF TEMPS,DELTA X, AND DELTA T.
C
      T=0.0
      TH=0.0
      TOUT=100.0
      XINT=NOINT
      N=NOINT+1
      DX=XL/XINT
      DT=C*RHO*DX**2/COND
      DTH=DT/3600.0
      RHOF=RHO*1728.0
      CONDF=COND*43200.0
      HF=H*518400.0
      WRITE(6,31) C
   31 FORMAT(1H1,/////,11X,' HEAT CAPACITY = ',F4.2,' BTU/LBM-F')
      WRITE(6,32) RHOF
   32 FORMAT(1H0,10X,' DENSITY = ',F6.2,' LBM/FT**3')
      WRITE(6,33) CONDF
   33 FORMAT(1H0,10X,' THERMAL CONDUCTIVITY = ',F4.2,' BTU/HR-FT-F')
      WRITE(6,34) HF
   34 FORMAT(1H0,10X,' HEAT TRANSFER COEFF.= ',F6.2,' BTU/HR-F-FT**2')
      WRITE(6,35) UIN
   35 FORMAT(1H0,10X,' INITIAL TEMP. = ',F6.2,' F')
      WRITE(6,37) NOINT
   37 FORMAT(1H0,10X,' NO. OF INTERIOR NODES = ',I2)
      WRITE(6,38) XL
   38 FORMAT(1H0,10X,' DEPTH OF SLAB = ',F6.2,' INCHES')
      WRITE(6,41) DTH
   41 FORMAT(1H0,////,11X,' TIME INTERVAL = ',F5.2,' HR')
      WRITE(6,42) DX
   42 FORMAT(1H0,10X,' DISTANCE INTERVAL = ',F5.2,' INCHES')
      DO 10 I=1,N
   10 USTART(I)=UIN
      PRINT 199
  199 FORMAT(/57H1SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD
     *  /)
      PRINT 200, T, (USTART(I), I=1,N)
  200 FORMAT(/5H T = F5.2, 6H HOURS / (1H 11F8.2))
C
C     GET COEFFICIENTS OF SYSTEM.
C
      U(1,4)=UIN
      HR(1)=0.0
      DO 15 J=1,49
      HR(J+1)=HR(J)+0.5
      IF((HR(J)-SR) .LE. 0.1)  GO TO 15
        IF(HR(J) .LT. SR)  GO TO 15
        IF(HR(J) .GE. SR)  GO TO 21
```

```
      IF(SS-HR(J) .LE. 0.1)  GO TO 23
        IF(HR(J) .GT. SS)  GO TO 23
   21 U(1,1)=0.0
      U(1,2)=2.0
      U(1,3)=-1.0
      U(N,1)=2.0
      U(N,2)=-4.0-2.0*ALPHA*DX
      U(N,3)=0.0
      DO 20 I=2,NOINT
      U(I,1)=1.0
      U(I,2)=-4.0
   20 U(I,3)=1.0
      TPF=U(1,4)
      TPC(J)=(5./9.)*(TPF-32.)
      TP=TPC(J)
      CALL        PERFOR(AK,BL,L,TMAXF,TVARF,EMCP,EGLS,VMLH,J,TAPH,TAF,
     *QTLOS,WIN,DAY,LONG,LAT,M,TP)
      U(1,4)=USTART(2)+(0.00000193)*(DX/COND)*(WIN(J)+WIN(J+1))
      U(N,4)=-2.0*USTART(N-1)+2.0*ALPHA*DX*USTART(N)-4.0*ALPHA*DX*TAF(J)
      DO 30 I=2,NOINT
   30 U(I,4)=-USTART(I-1)-USTART(I+1)
C
C     COMPUTE VALUES.
C
      T=T+DT
      CALL TRDG77 (U,N)
C
C     PUT NEW VALUES INTO USTART AND SEE IF TIME TO PRINT OUT.
C
      DO 40 I=1,N
   40 USTART(I)=U(I,4)
      IF (T-TOUT) 21, 22, 22
   22 TH=T/3600.0
      PRINT 200,TH, (U(I,4), I=1,N)
      TOUT=TOUT+100.0
        IF(HR(J)-SS) 15,15,23
   15 CONTINUE
   23 CONTINUE
      WRITE(6,61) L
   61 FORMAT(1H1,/////,11X,' NO. OF GLASS COVERS = ',I1)
      WRITE(6,62) G1
   62 FORMAT(1H0,10X,' INDEX OF REFRACTION FOR AIR = ',F3.1)
      WRITE(6,63) G2
   63 FORMAT(1H0,10X,' INDEX OF REFRACTION FOR GLASS = ',F5.3)
      WRITE(6,64) AK
   64 FORMAT(1H0,10X,' EXTINCTION COEFFICIENT = ',F5.3,' 1/INCH')
      WRITE(6,65) BL
   65 FORMAT(1H0,10X,' GLASS THICKNESS = ',F5.3,' INCH')
      WRITE(6,73)
   73 FORMAT(1H0,10X,' SURFACE COLOR = BLACK')
      WRITE(6,66) EGLS
   66 FORMAT(1H0,10X,' EMITTANCE OF GLASS = ',F4.2)
      WRITE(6,67) EMCP
   67 FORMAT(1H0,10X,' EMITTANCE OF PLATE = ',F4.2)
      WRITE(6,68) ALPHAT
   68 FORMAT(1H0,10X,' ABSORPTANCE OF THE PLATE = ',F4.2)
      WRITE(6,72) RHOS
   72 FORMAT(1H0,10X,' REFLECTOR REFLECTANCE = ',F4.2)
      WRITE(6,69) VMLH
   69 FORMAT(1H0,10X,' WIND VELOCITY = ',F5.1,' MILE/HR')
```

```
      WRITE(6,70) TMAXF
   70 FORMAT(1H0,10X,' MAXIMUM TEMP. = ',F5.2,' DEGREES F')
      WRITE(6,71) TVARF
   71 FORMAT(1H0,10X,' TEMP. VARIATION = ',F5.2,' DEGREES F')
      WRITE(6,6) M,DELTAD
    6  FORMAT(1H1,10X,' MONTH = ',I2,26X,' DECLINATION = ',F7.2,' DEGREE
     *S')
      WRITE(6,7) LATD,SR
    7 FORMAT(1H0,10X,' LATITUDE = ',F6.2,' DEGREES',11X,' SUNRISE = ',F5
     *.2,' HOUR')
      WRITE(6,8) LONGD,SS
    8 FORMAT(1H0,10X,' LONGITUDE = ',F6.2,' DEGREES',10X,' SUNSET = ',F5
     *.2,' HOUR')
      WRITE(6,9) BD
    9 FORMAT(1H0,10X,' OPENING ANGLE = ',F5.1,' DEGREES',8X,'LOCATION =
     *STILLWATER')
      WRITE(6,3)
    3 FORMAT(1H0,13X,'HR',13X,'IDN',12X,'ID',12X,'IDIF',12X,'WD',11X,'
     *IDR',11X,'IDIFR',10X,'WS')
      DO 5 I=1,49
      WRITE(6,2) HR(I),GID(I),GI(I),DIFFH(I),WD(I),GIR(I),GIDR(I),WS(I)
    2 FORMAT(1H ,11X,F5.2,10X,F5.1,10X,F5.1,10X,F5.1,10X,F5.1,10X,F5.1,1
     *0X,F5.1,9X,F5.1)
    5 CONTINUE
      WRITE(6,12)
   12 FORMAT(1H1,/////,14X,'HR',13X,'WT',12X,'QTLS',12X,'WIN',11X,'TAPH'
     *,11X,'TAF',13X,'ALT',11X,'AZM')
      DO 60 I=1,49
      WRITE(6,11) HR(I),WT(I),QTLOS(I),WIN(I),TAPH(I),TAF(I),BETAD(I),
     *PHID(I)
   11 FORMAT(1H ,11X,F5.2,10X,F5.1,10X,F5.1,10X,F5.1,10X,F5.2,10X,F5.1,1
     *0X,F5.1,9X,F5.1)
   60 CONTINUE
      KK=KK+1
      IF(KK-K)  50,50,51
   51 CONTINUE
      WRITE(6,4)
    4 FORMAT(1H1)
      STOP
      END
C
C

      SUBROUTINE  SUN(DAY,LONG,LAT,GID,BETAD,HR,PHID,SS,SR,M,DELTAD,PHI,
     *BETA,DIFFH)
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C     +       THIS SUBROUTINE CALCULATES THE HOUR ANGLE,THE              +
C     +       SOLAR DECLINATION,THE SOLAR ALTITUDE,THE SOLAR             +
C     +       AZIMUTH,THE SUNRISE,THE SUNSET,DIRECT NORMAL               +
C     +       SOLAR INTENSITY,AND DIFFUSE SOLAR INTENSITY.               +
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      DIMENSION  HR(50),GID(50),BETAD(50),PHID(50),PHI(50),BETA(50)
      DIMENSION DIFFH(50)
      REAL  LONG,LAT
      HR(1)=0.0
        DO 40 I=1,49
      HR(I+1)=HR(I)+0.5
C
```

```
C     CALCULATE THE HOUR ANGLE, H
C
       IF(HR(I).GT. 12.0) GO TO 15
      H=0.2618*(12.0-HR(I))
      GO TO 20
   15 H=0.2618*(HR(I)-12.0)
C
C     CALCULATE THE DECLINATION IN DEGREES, DELTAD
C
   20 DELTA=0.40928*SIN((284.0+DAY)*6.2832/365.0)
      DELTAD=DELTA*57.296
C
C     CALCULATE THE SOLAR ALTITUDE IN DEGREES,BETAD
C
      SINB=COS(LAT)*COS(H)*COS(DELTA)+SIN(LAT)*SIN(DELTA)
      BETA(I)=ARSIN(SINB)
      BETAD(I)=BETA(I)*57.296
C
C     CALCULATE THE SOLAR AZIMUTH IN DEGREES, PHID
C
      SINPHI=COS(DELTA)*SIN(H)/COS(BETA(I))
      PHI(I)=ARSIN(SINPHI)
      PHID(I)=PHI(I)*57.296
C
C     CALCULATE SUNRISE, SR  AND  SUNSET,  SS
C
      COSHSS=-SIN(LAT)*SIN(DELTA)/COS(LAT)*COS(DELTA)
      HSS=ARCOS(COSHSS)*3.8197
      SR=12.0-HSS
      SS=12.0+HSS
C
C     CALCULATE THE DIRECT NORMAL SOLAR IRRADIATION IN BTU/HR-FT**2 ,GID
C     CALCULATE THE DIFFUSE SOLAR INTNSITY ON HORIZONTAL
C     SURFACE IN BTU/HR-FT**2 ,DIFFH
C
      IF((HR(I)-SR) .LE. 0.1)  GO TO 30
      IF(SS-HR(I) .LE. 0.1)  GO TO 30
       IF(HR(I) .LT. SR .OR. HR(I) .GT. SS) GO TO 30
      IF(M .EQ. 1)  GO TO 1
      IF(M .EQ. 2)  GO TO 2
      IF(M .EQ. 3)  GO TO 3
      IF(M .EQ. 4)  GO TO 4
      IF(M .EQ. 5)  GO TO 5
      IF(M .EQ. 6)  GO TO 6
      IF(M .EQ. 7)  GO TO 7
      IF(M .EQ. 8)  GO TO 8
      IF(M .EQ. 9)  GO TO 9
      IF(M .EQ. 10) GO TO 10
      IF(M .EQ. 11) GO TO 11
      IF(M .EQ. 12) GO TO 12
C
C     THE VALUES OF A,B,AND C WHERE OBTAINED FROM ASHREA HANDBOOK
C     FOR THE 21ST DAY OF EACH MONTH
C     A,APPARENT SOLAR CONSTANT
C     B,ATMOSPHERIC EXTINCTION COEFFICIENT
C     C,SKY DIFFUSE FACTOR
C
    1 A=390.0
      B=0.142
      C=0.058
```

```
      GO TO 25
    2 A=385.0
      B=0.144
      C=0.06
      GO TO 25
    3 A=376.0
      B=0.156
      C=0.071
      GO TO 25
    4 A=360.0
      B=0.180
      C=0.097
      GO TO 25
    5 A=350.0
      B=0.196
      C=0.121
      GO TO 25
    6 A=345.0
      B=0.205
      C=0.134
      GO TO 25
    7 A=344.0
      B=0.207
      C=0.136
      GO TO 25
    8 A=351.0
      B=0.201
      C=0.122
      GO TO 25
    9 A=365.0
      B=0.177
      C=0.092
      GO TO 25
   10 A=378.0
      B=0.160
      C=0.073
      GO TO 25
   11 A=387.0
      B=0.149
      C=0.063
      GO TO 25
   12 A=391.0
      B=0.142
      C=0.057
      GO TO 25
   25 COSZ=SINB
      GID(I)=A/EXP(B/COSZ)
      DIFFH(I)=C*GID(I)
      GO TO 40
   30 GID(I)=0.0
      DIFFH(I)=0.0
      BETAD(I)=0.0
      PHID(I)=0.0
   40 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE    COLREF(BD,WT,WD,WS,DAY,LONG,LAT,M,GI,GIR,GIDR)
```

```
C
C      +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C      +        THIS SUBROUTINE CALCULATES THE POWER ABSORBED BY       +
C      +        THE COLLECTOR FROM DIRECT SOLAR RADIATION(NORMAL+      +
C      +        DIFFUSE) AND THE POWER ABSORBED BY THE COLLECTOR       +
C      +        FROM THE REFLECTED RADIATION FROM THE SPECULAR         +
C      +        REFLECTOR (DIRECT REFLECTED + DIFFUSE REFLECTED ).     +
C      +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
       DIMENSION  HR(50),GID(50),BETAD(50),PHID(50),PHI(50),BETA(50)
       DIMENSION GI(50),WD(50),WS(50),WT(50),GIR(50),GIDR(50),DIFFH(50)
       REAL  LONG,LAT
       CALL         OPTIM(BR,DAY,LONG,LAT,M)
       CALL         SUN(DAY,LONG,LAT,GID,BETAD,HR,PHID,SS,SR,M,DELTAD,PHI,
      *BETA,DIFFH)
C
C      DIRECT CONTRIBUTION
C
       BD=BR*57.296
       HR(1)=0.0
       DO 40 I=1,49
       HR(I+1)=HR(I)+0.5
C      CALCULATE THE INCIDENT ANGLE, MEASURED FROM THE COLLECTOR NORMAL
       COSTEC=SIN(BETA(I))
C      CALCULATE THE DIRECT SOLAR INTENSITY , GI
       GI(I)=GID(I)*COSTEC
C      CALCULATE THE ENERGY THAT FALLS ON THE COLLECTOR(DIRECT+DIFFUSE) , WD
       WD(I)=GI(I)+DIFFH(I)
C
C      SPECULAR CONTRIBUTION
C
C      CALCULATE THE INCIDENT ANGLE OF THE TILTED SURFACE (REFLECTOR)
C      BR IS THE OPENING ANGLE, ANGLE BETWEEN THE COLLECTOR AND THE REFLECTOR
       COSTER=COS(BETA(I))*COS(PHI(I))*SIN(BR)-SIN(BETA(I))*COS(BR)
       TETR=ARCOS(COSTER)
C      PHEE IS THE ANGLE AT WHICH THE REFLECTED RADIATION STRIKES THE COLLECTOR
       PHEE=BR-TETR
       IF(PHEE .LT. 0.0)   GO TO 1
       IF(PHEE .GE. 1.5708)   GO TO 1
C      F IS THE FRACTION OF THE COLLECTOR ILLUMINATED BY REFLECTION
       F=1.0-(COS(BR)+SIN(BR)*TAN(PHEE))
       IF(F .LT. 0.0)   GO TO 1
       IF(F .GT. 1.0)   GO TO 3
       GO TO 4
     3 F=1.0
     4 CONTINUE
C      CALCULATE THE REFLECTED SOLAR INTENSITY , GIR
C      RHOS IS THE FRACTION OF THE INCIDENT RADIATION REFLECTED
       RHOS=0.95
       GIR(I)=GID(I)*F*COS(PHEE)*RHOS
C      CALCULATE THE DIFFUSE REFLECTED SOLAR INTENSITY , GIDR
       GIDR(I)=(1.0-SIN(BR/2.0))*((1.0+COS(BR))/2.0)*DIFFH(I)*RHOS
C      CALCULATE THE ENERGY THAT FALLS ON THE COLLECTOR FROM THE
C      REFLECTOR(DIRECT REFLECTED+DIFFUSE REFLECTED) , WS
       GO TO 2
     1 GIR(I)=0.0
       GIDR(I)=0.0
     2 WS(I)=GIR(I)+GIDR(I)
C
C      TOTAL CONTRIBUTION
```

```
C
C----  CALCULATE THE TOTAL ENERGY THAT FALLS ON THE COLLECTOR , WT
       WT(I)=WD(I)+WS(I)
    40 CONTINUE
       RETURN
       END
C
C
       SUBROUTINE  OPTIM(BR,DAY,LONG,LAT,M)
C
C      ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C      +       THIS SUBROUTINE OPTIMIZES THE OPENING ANGLE,THAT        +
C      +       IS THE ANGLE BETWEEN THE COLLECTOR AND THE REFLECTOR.   +
C      +       THE OPTIMIZATION IS BASED ON THE MAXIMUM ENERGY THAT    +
C      +       FALLS ON THE COLLECTOR FROM THE REFLECTED               +
C      +       RADIATION FROM THE SPECULAR REFLECTOR.                  +
C      ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
       DIMENSION  BT(21),WSMAX(50),WS(50),DIFFH(50),GIR(50),GIDR(50)
       DIMENSION  HR(50),GID(50),BETAD(50),PHID(50),PHI(50),BETA(50)
       DATA WSMAX/50*0.0/
       REAL  LONG,LAT
       CALL        SUN(DAY,LONG,LAT,GID,BETAD,HR,PHID,SS,SR,M,DELTAD,PHI,
      *BETA,DIFFH)
       RHOS=0.95
       BT(1)=0.0
       HR(1)=0.0
       DO 50 J=1,19
       DO 40 I=1,49
       HR(I+1)=HR(I)+0.5
       COSTER=COS(BETA(I))*COS(PHI(I))*SIN(BT(J))-SIN(BETA(I))*COS(BT(J))
       TETR=ARCOS(COSTER)
       PHEE=BT(J)-TETR
       IF(PHEE .GE. 1.5708)  GO TO 34
       IF(PHEE .LT. 0.0 .AND. GID(I) .NE. 0.0)  GO TO 34
       F=1.0-(COS(BT(J))+SIN(BT(J))*TAN(PHEE))
       IF(F .LT. 0.0 .AND. GID(I) .NE. 0.0)  GO TO 34
       IF(F .GT. 1.0)  GO TO 35
       GO TO 36
    35 F=1.0
    36 GIR(I)=GID(I)*F*COS(PHEE)*RHOS
       GIDR(I)=(1.-SIN(BT(J)/2.))*((1.+COS(BT(J)))/2.)*DIFFH(I)*RHOS
       WS(I)=GIR(I)+GIDR(I)
    40 CONTINUE
       WSMAX(J)=WS(25)
    34 BT(J+1)=BT(J)+0.17453
    50 CONTINUE
       MAX=WSMAX(1)
       DO 60 K=1,17
       IF(WSMAX(K+1) .GE. MAX)  GO TO 41
       GO TO 60
    41 MAX=WSMAX(K+1)
       BR=BT(K+1)
    60 CONTINUE
       RETURN
       END
C
C
```

```
      SUBROUTINE   PERFOR(AK,BL,N,TMAXF,TVARF,EMCP,EGLS,VMLH,I,TAPH,TAF,
     *QTLOS,WIN,DAY,LONG,LAT,M,TP)
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C     +      THIS SUBROUTINE CALCULATES THE LOSS COEFFICIENT             +
C     +      FOR THE TOP SURFACE AS A RESULT OF CONVECTION               +
C     +      AND RADIATION BETWEEN PARALLEL PLATES . HOTTEL'S            +
C     +      EQUATION FOR SOLAR COLLECTOR PERFORMANCE                    +
C     +      IS USED FOR THESE CALCULATIONS.                             +
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      DIMENSION WD(50),WS(50),GI(50),GIR(50),GIDR(50),DIFFH(50)
      DIMENSION TAPH(50),QTLOS(50),TAF(50),WT(50),WIN(50),TA(50)
      DIMENSION  HR(50),GID(50),BETAD(50),PHID(50),PHI(50),BETA(50)
      REAL  LONG,LAT
      CALL       SUN(DAY,LONG,LAT,GID,BETAD,HR,PHID,SS,SR,M,DELTAD,PHI,
     *BETA,DIFFH)
      CALL           COLREF(BD,WT,WD,WS,DAY,LONG,LAT,M,GI,GIR,GIDR)
C
C     CALCULATE THE REFLECTANCE OF THE GLASS COVER , RO
C     CALCULATE THE TRANSMITTANCE DUE TO REFLECTION , TAUR
C     CALCULATE THE TRANSMITTANCE DUE TO ABSORPTION , TALPH
C     CALCULATE THE TOTAL TRANSMITTANCE (REFLECTION AND ABSORPTION ) , TAU
C     CALCULATE THE TRANSMITTANCE-ABSORPTANCE PRODUCT , TAPH
C
      G1=1.0
      G2=1.526
      ALPHAT=0.95
      TMAXC=(5./9.)*(TMAXF-32.)
      TVARC=(5./9.)*TVARF
      HR(1)=0.0
      DO 40 K=1,49
      HR(K+1)=HR(K)+0.5
      TETIN=ARCOS(SIN(BETA(K)))
      TETAR=ARSIN(G1*SIN(TETIN)/G2)
      RO1=(SIN(TETAR-TETIN))**2/(SIN(TETAR+TETIN))**2
      RO2=(TAN(TETAR-TETIN))**2/(TAN(TETAR+TETIN))**2
      IF(N .EQ. 1)  GO TO 1
      IF(N .EQ. 2)  GO TO 2
    1 RO=0.5*(RO1+RO2)
      TAUR=(1.0-RO)/(1.0+RO)
      TALPH=1.0/EXP(AK*BL)
      ROD=0.16
      GO TO 3
    2 TAUR=0.5*((1.0-RO1)/(1.0+3.0*RO1)+(1.0-RO2)/(1.0+3.0*RO2))
      TALPH=1.0/EXP(2.0*AK*BL)
      ROD=0.24
    3 TAU=TALPH*TAUR
      IF((HR(K)-SR) .LE. 0.1)  GO TO 9
      IF(SS-HR(K) .LE. 0.1)  GO TO 9
       IF(HR(K) .LT. SR .OR. HR(K) .GT. SS) GO TO 9
      TAPH(K)=(TAU*ALPHAT)/(1.-(1.-ALPHAT)*ROD)
      GO TO 10
    9 TAPH(K)=0.0
      QTLOS(K)=0.0
      WIN(K)=0.0
C
C     CALCULATE THE AIR TEMPERATURE IN DEGREES F . TAF
C     THE PERCENTAGE OF THE DAILY RANGE FOR AIR TEMPERATURE
C     CALCULATIONS WERE OBTAINED FROM ASHREA HANDBOOK
```

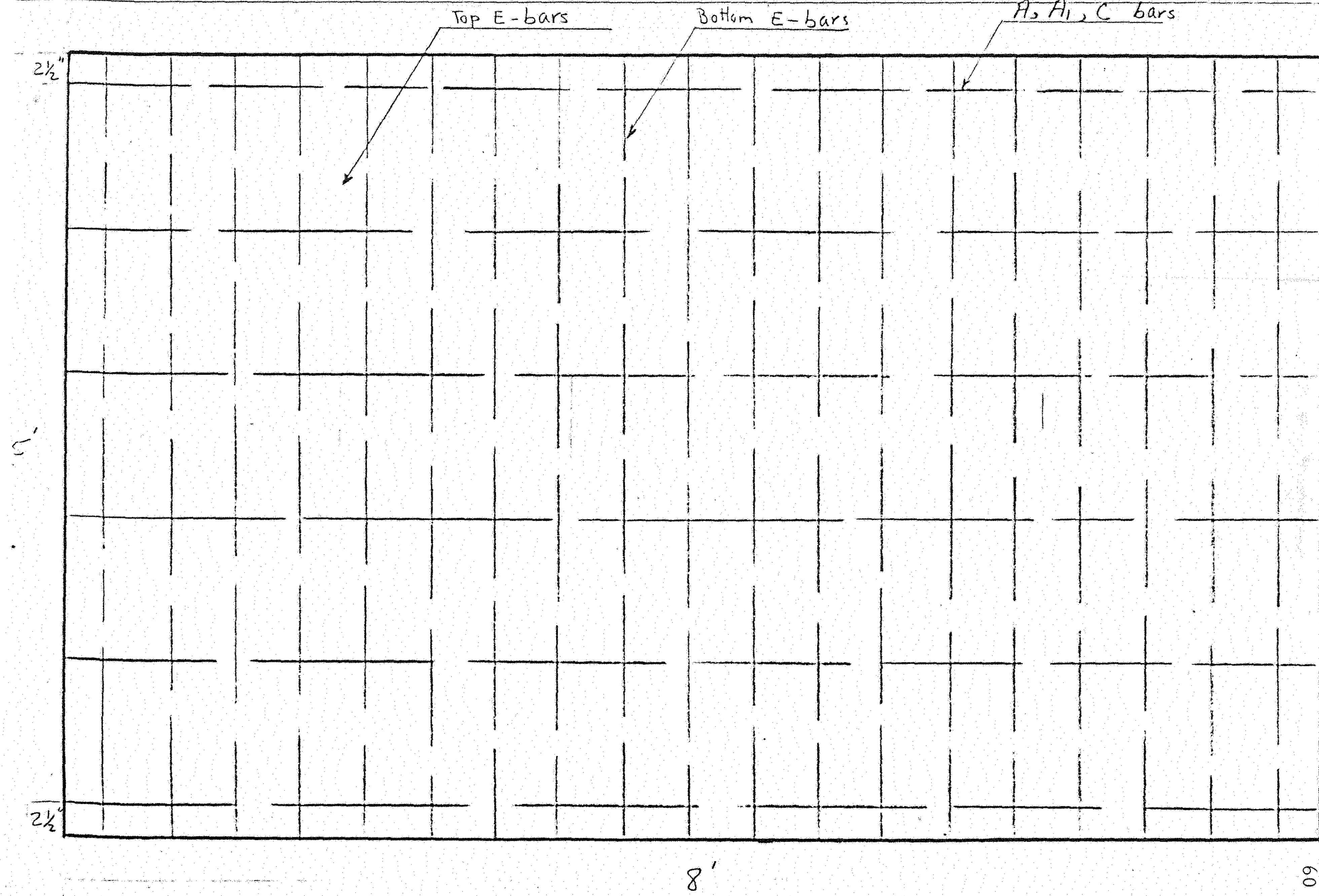
```
C
   10 TME=(3.1416/12.)*HR(K)
      VAR=56.29+29.32*COS(TME)+38.48*SIN(TME)-3.48*COS(2.*TME)-8.35*SIN(
     *2.*TME)
      TA(K)=TMAXC-((TVARC*VAR)/100.)
      TAF(K)=1.8*TA(K)+32.
   40 CONTINUE
C
C     CALCULATE THE ENERGY LOSS FROM THE TOP OF THE COLLECTOR , QTLOS
C     QTLOS IS IN UNITS OF BTU/HR-FT**2
C
      IF((HR(I)-SR) .LE. 0.1)  GO TO 30
      IF(SS-HR(I) .LE. 0.1)  GO TO 30
       IF(HR(I) .LT. SR .OR. HR(I) .GT. SS) GO TO 30
      VMS=VMLH*0.44704
      HW=5.7+3.8*VMS
      F=(1.-0.04*HW+5.E-4*HW*HW)*(1.+0.058*N)
      IF(TP .GT. TA(I))  GO TO 6
      A1=(344./(TP+273.))*((TA(I)-TP)/(N+F))**0.31
      GO TO 7
    6 A1=(344./(TP+273.))*((TP-TA(I))/(N+F))**0.31
    7 AA=1./((N/A1)+(1./HW))
      B1=(5.6693E-8)*((TP+273.)+(TA(I)+273.))*((TP+273.)**2+(TA(I)+273.)
     ***2)
      B2=1./(EMCP+0.0425*N*(1.-EMCR))
      B3=((2.*N+F-1.)/EGLS)-N
      BB=B1/(B2+B3)
      UTOP=AA+BB
      IF(TP .GT. TA(I))  GO TO 4
      QTL=UTOP*(TA(I)-TP)
      GO TO 5
    4 QTL=UTOP*(TP-TA(I))
    5 QTLOS(I)=QTL/3.152
      GO TO 8
   30 QTLOS(I)=0.0
      TAPH(I)=0.0
C
C     CALCULATE THE NET ENERGY IN BTU/HR-FT**2 , WIN
C
    8 WIN(I)=WT(I)*TAPH(I)-QTLOS(I)
      WIN(I+1)=WT(I+1)*TAPH(I+1)-QTLOS(I)
      RETURN
      END
C
C
      SUBROUTINE TRDG77 (X,N)
C
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C     +       THIS SUBROUTINE SOLVES THE SET OF SIMULTANEOUS          +
C     +       EQUATIONS WHICH RESULT FROM APPLYING THE                +
C     +       CRANK-NICOLSON METHOD .                                 +
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      DIMENSION X(50,4)
      DO 10 I=2,N
      X(I,2)=X(I,2)-X(I,1)/X(I-1,2)*X(I-1,3)
   10 X(I,4)=X(I,4)-X(I,1)/X(I-1,2)*X(I-1,4)
      NMI=N-1
```

```
      DO 20 I=1,NMI
      M=N-I
   20 X(M,4)=X(M,4)-X(M,3)/X(M+1,2)*X(M+1,4)
      DO 30 I=1,N
   30 X(I,4)=X(I,4)/X(I,2)
      RETURN
      END

$ENTRY
```

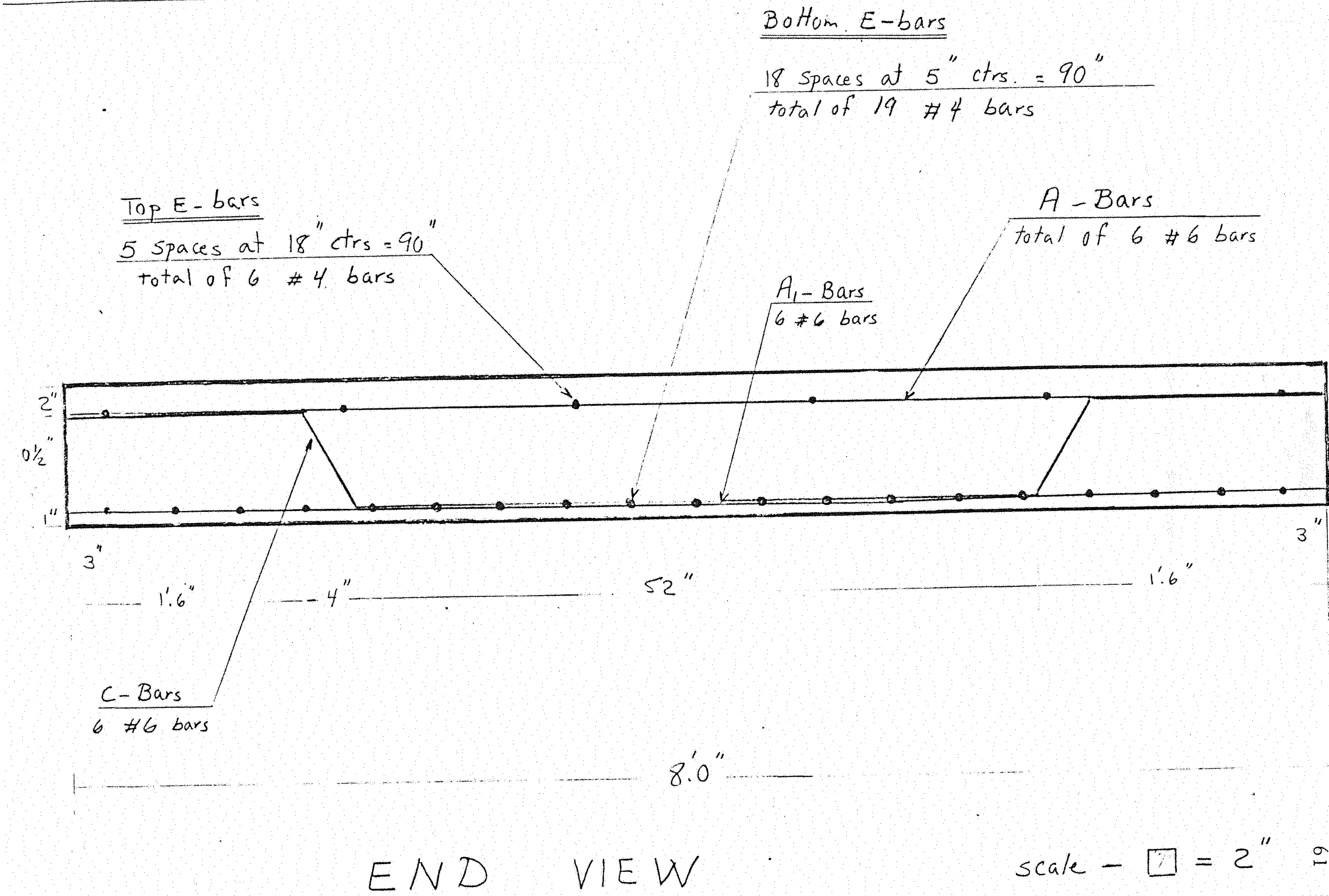
APPENDIX D

Experimental Model



TOP VIEW

Figure 1



Bottom E-bars
18 Spaces at 5" ctrs. = 90"
total of 19 #4 bars
Top E-bars
5 Spaces at 18" ctrs = 90"
total of 6 #4 bars
A - Bars
total of 6 #6 bars
A1 - Bars
6 #6 bars
C - Bars
6 #6 bars
2"
0½"
1"
3"
3"
1'6"
4"
52"
1'6"
8'0"
END VIEW
scale - □ = 2"

Figure 2

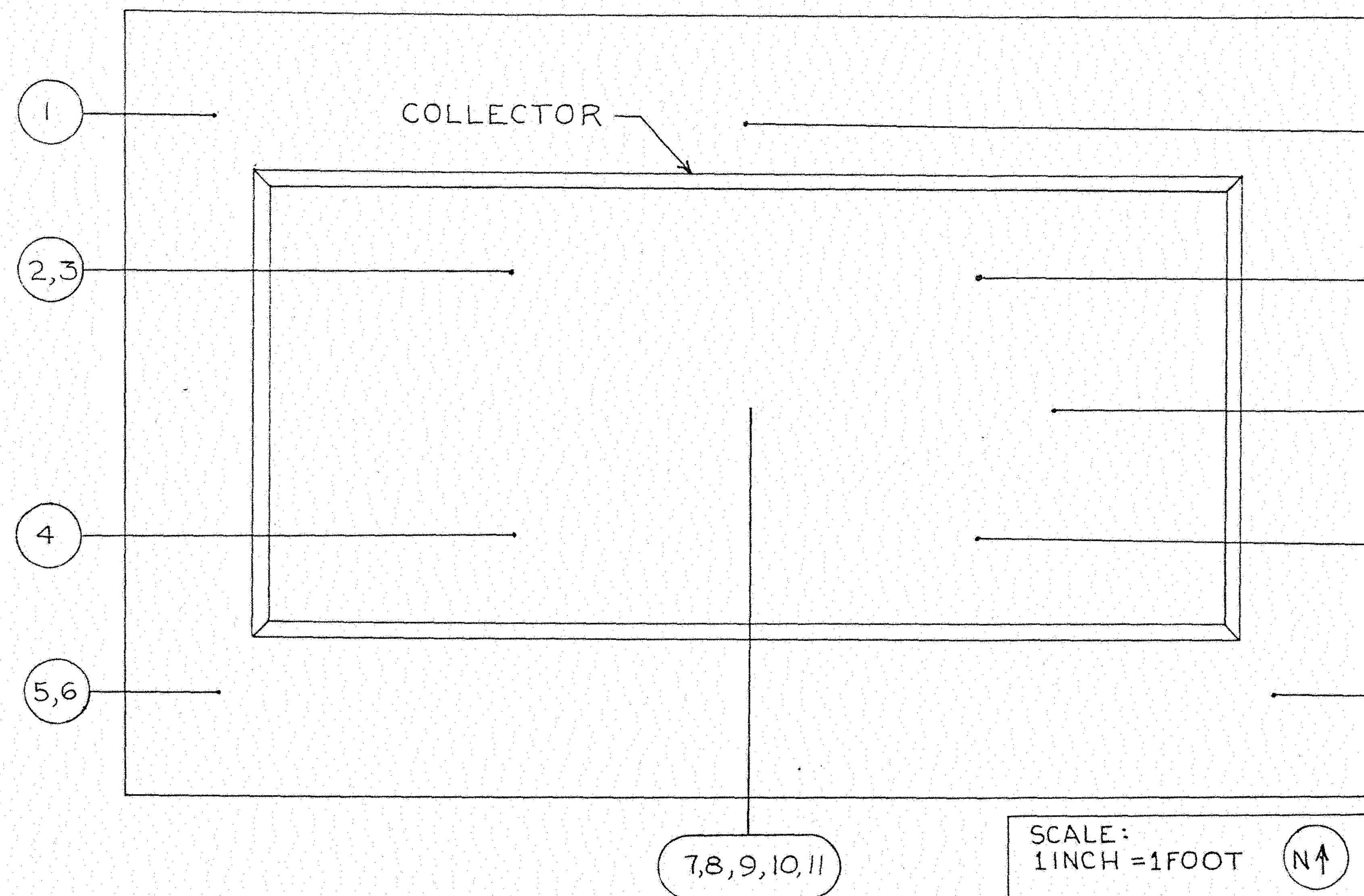


Figure 3: Thermocouple Layout for Concrete Slab

TABLE I

THERMOCOUPLE POSITIONS

Thermocouple	Distance from North edge of Slab (inches)	Distance from West edge of Slab (inches)	Depth (from top of slab) (inches)
1	8	7	2
2	20	30	2
3	20	30	1
4	40	30	2
5	52	7	2
6	52	7	1
7	30	48	2
8	30	48	1
9	30	48	4.5
10	30	48	6.5
11	30	48	8.5
12	52	89	2
13	52	89	1
14	40	66	2
15	30	72	2
16	30	72	1
17	20	66	2
18	8	48	2
19	8	48	1

APPENDIX E

Theoretical Results

TABLE I

```
NO. OF GLASS COVERS = 2
INDEX OF REFRACTION FOR AIR = 1.0
INDEX OF REFRACTION FOR GLASS = 1.526
EXTINCTION COEFFICIENT = 0.174 1/INCH
GLASS THICKNESS = 0.250 INCH
SURFACE COLOR = BLACK
EMITTANCE OF GLASS = 0.88
EMITTANCE OF PLATE = 0.90
ABSORPTANCE OF THE PLATE = 0.95
REFLECTOR REFLECTANCE = 0.95
WIND VELOCITY =  10.0 MILE/HR
MAXIMUM TEMP. = 50.00 DEGREES F
TEMP. VARIATION = 22.00 DEGREES F
```

NTH = 1 DECLINATION = -20.14 DEGREES

TITUDE = 36.07 DEGREES SUNRISE = 6.91 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 17.09 HOUR

ENING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	77.3	6.8	4.5	11.3	41.5	1.2	42
.00	174.7	30.9	10.1	41.0	88.1	2.8	90
.50	225.5	58.5	13.1	71.6	106.7	3.6	110
.00	254.9	85.1	14.8	99.9	113.1	4.0	117
.50	273.3	109.2	15.9	125.0	114.1	4.3	118
.00	285.4	129.7	16.6	146.3	112.6	4.5	117
.50	293.3	146.2	17.0	163.2	110.3	4.6	114
.00	298.4	158.3	17.3	175.6	108.1	4.7	112
.50	301.2	165.6	17.5	183.1	106.6	4.7	111
.00	302.1	168.0	17.5	185.6	106.1	4.8	110
.50	301.2	165.6	17.5	183.1	106.6	4.7	111
.00	298.4	158.3	17.3	175.6	108.1	4.7	112
.50	293.3	146.2	17.0	163.2	110.3	4.6	114
.00	285.4	129.7	16.6	146.3	112.6	4.5	117
.50	273.3	109.2	15.9	125.0	114.1	4.3	118
.00	254.9	85.1	14.8	99.9	113.1	4.0	117
.50	225.5	58.5	13.1	71.6	106.7	3.6	110
.00	174.7	30.9	10.1	41.0	88.1	2.8	90
.50	77.3	6.8	4.5	11.3	41.5	1.2	42
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

R	WT	QTLS	WIN	TAPH	TAF	ALT	AZ
.00	0.0	0.0	0.0	0.00	31.9	0.0	0.
.50	0.0	0.0	0.0	0.00	31.3	0.0	0.
.00	0.0	0.0	0.0	0.00	30.8	0.0	0.
.50	0.0	0.0	0.0	0.00	30.3	0.0	0.
.00	0.0	0.0	0.0	0.00	29.8	0.0	0.
.50	0.0	0.0	0.0	0.00	29.3	0.0	0.
.00	0.0	0.0	0.0	0.00	28.9	0.0	0.
.50	0.0	0.0	0.0	0.00	28.5	0.0	0.
.00	0.0	0.0	0.0	0.00	28.3	0.0	0.
.50	0.0	0.0	0.0	0.00	28.1	0.0	0.
.00	0.0	0.0	0.0	0.00	28.0	0.0	0.
.50	0.0	0.0	0.0	0.00	28.1	0.0	0.
.00	0.0	0.0	0.0	0.00	28.4	0.0	0.
.50	0.0	0.0	0.0	0.00	28.9	0.0	0.
.00	0.0	0.0	0.0	0.00	29.5	0.0	0.
.50	54.0	0.4	6.5	0.13	30.4	5.0	60.
.00	131.8	0.7	36.0	0.28	31.5	10.2	55.
.50	181.8	3.5	72.3	0.42	32.9	15.0	50.
.00	217.1	7.8	105.8	0.52	34.4	19.5	44.
.50	243.4	12.9	132.0	0.60	36.0	23.5	38.
.00	263.4	18.3	150.5	0.64	37.8	27.0	31.
.50	278.2	23.5	162.3	0.67	39.6	29.9	24.
.00	288.4	28.3	168.9	0.68	41.4	32.0	16.
.50	294.4	32.6	171.2	0.69	43.2	33.3	8.
.00	296.4	36.3	169.6	0.69	44.8	33.8	0.
.50	294.4	39.3	164.4	0.69	46.3	33.3	8.
.00	288.4	41.6	155.6	0.68	47.6	32.0	16.
.50	278.2	42.9	142.9	0.67	48.7	29.9	24.
.00	263.4	43.2	125.6	0.64	49.4	27.0	31.
.50	243.4	42.1	102.8	0.60	49.9	23.5	38.
.00	217.1	39.6	74.0	0.52	50.0	19.5	44.
.50	181.8	35.5	40.3	0.42	49.8	15.0	50.
.00	131.8	30.3	6.4	0.28	49.4	10.2	55.
.50	54.0	24.9	-18.1	0.13	48.7	5.0	60.
.00	0.0	0.0	0.0	0.00	47.7	0.0	0.
.50	0.0	0.0	0.0	0.00	46.6	0.0	0.
.00	0.0	0.0	0.0	0.00	45.3	0.0	0.
.50	0.0	0.0	0.0	0.00	44.0	0.0	0.
.00	0.0	0.0	0.0	0.00	42.5	0.0	0.
.50	0.0	0.0	0.0	0.00	41.1	0.0	0.
.00	0.0	0.0	0.0	0.00	39.7	0.0	0.
.50	0.0	0.0	0.0	0.00	38.4	0.0	0.
.00	0.0	0.0	0.0	0.00	37.2	0.0	0.
.50	0.0	0.0	0.0	0.00	36.1	0.0	0.
.00	0.0	0.0	0.0	0.00	35.1	0.0	0.
.50	0.0	0.0	0.0	0.00	34.1	0.0	0.
.00	0.0	0.0	0.0	0.00	33.3	0.0	0.
.50	0.0	0.0	0.0	0.00	32.6	0.0	0.
.00	0.0	0.0	0.0	0.00	31.9	0.0	0.

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 29.39 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39
T = 0.50 HOURS	33.45	30.47	29.68	29.46	29.41	29.39	29.39	29.41	29.47	29.71	30.60
T = 1.00 HOURS	41.28	33.83	30.91	29.89	29.55	29.45	29.44	29.51	29.73	30.29	31.36
T = 1.50 HOURS	51.56	39.31	33.51	30.99	29.99	29.64	29.58	29.72	30.12	30.97	32.67
T = 2.00 HOURS	62.77	46.31	37.39	32.95	30.92	30.09	29.88	30.06	30.65	31.85	33.95
T = 2.50 HOURS	73.83	54.06	42.27	35.75	32.42	30.91	30.40	30.56	31.33	32.85	35.48
T = 3.00 HOURS	84.16	62.00	47.76	39.24	34.51	32.14	31.22	31.28	32.18	34.01	37.06
T = 3.50 HOURS	93.48	69.74	53.55	43.23	37.10	33.80	32.37	32.25	33.21	35.30	38.74
T = 4.00 HOURS	101.67	77.02	59.38	47.54	40.11	35.85	33.84	33.46	34.43	36.70	40.43
T = 4.50 HOURS	108.65	83.69	65.06	51.99	43.41	38.24	35.62	34.93	35.82	38.19	42.10
T = 5.00 HOURS	114.34	89.62	70.44	56.45	46.89	40.90	37.67	36.62	37.37	39.74	43.69
T = 5.50 HOURS	118.64	94.70	75.39	60.80	50.47	43.75	39.94	38.51	39.05	41.32	45.17
T = 6.00 HOURS	121.39	98.81	79.81	64.93	54.05	46.71	42.38	40.55	40.81	42.88	46.48
T = 6.50 HOURS	122.37	101.78	83.56	68.74	57.52	49.72	44.91	42.68	42.62	44.37	47.58
T = 7.00 HOURS	121.28	103.43	86.51	72.10	60.31	52.68	47.48	44.86	44.42	45.77	48.46
T = 7.50 HOURS	117.79	103.52	88.49	74.90	63.80	55.53	50.02	47.03	46.17	47.03	49.07
T = 8.00 HOURS	111.73	101.83	89.31	77.00	66.40	58.17	52.46	49.12	47.82	48.12	49.42
T = 8.50 HOURS	103.49	98.35	88.86	78.27	68.49	60.52	54.73	51.09	49.34	49.02	49.49
T = 9.00 HOURS	94.54	93.52	87.19	78.63	69.98	62.48	56.74	52.87	50.67	49.70	49.31

Jan

T = 9.50 HOURS

87.47	88.47	84.70	78.17	70.82	63.99	58.44	54.41	51.78	50.16	48.88

T = 10.00 HOURS

86.91	85.35	82.31	77.23	71.11	65.03	59.77	55.66	52.65	50.39	48.23

T = 10.50 HOURS

84.46	83.57	80.60	76.27	71.05	65.67	60.74	56.61	53.26	50.39	47.40

```
NO. OF GLASS COVERS = 2
INDEX OF REFRACTION FOR AIR = 1.0
INDEX OF REFRACTION FOR GLASS = 1.526
EXTINCTION COEFFICIENT = 0.174 1/INCH
GLASS THICKNESS = 0.250 INCH
SURFACE COLOR = BLACK
EMITTANCE OF GLASS = 0.88
EMITTANCE OF PLATE = 0.90
ABSORPTANCE OF THE PLATE = 0.95
REFLECTOR REFLECTANCE = 0.95
WIND VELOCITY =  10.0 MILE/HR
MAXIMUM TEMP. = 63.00 DEGREES F
TEMP. VARIATION = 22.00 DEGREES F
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ITH = 2 DECLINATION = -11.23 DEGREES

ITUDE = 36.07 DEGREES SUNRISE = 6.53 HOUR

IGITUDE = 97.05 DEGREES SUNSET = 17.47 HOUR

NING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	WS
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	78.5	7.1	4.7	11.8	55.1	1.3	56.
.50	179.6	33.9	10.8	44.7	120.7	2.9	123.
.00	231.0	65.1	13.9	78.9	148.5	3.8	152.
.50	260.3	95.8	15.6	111.4	160.2	4.2	164.
.00	278.8	124.3	16.7	141.1	164.2	4.5	168.
.50	291.0	149.7	17.5	167.1	164.6	4.7	169.
.00	299.3	171.2	18.0	189.2	163.2	4.9	168.
.50	305.0	188.4	18.3	206.7	161.3	5.0	166.
.00	308.6	201.0	18.5	219.5	159.5	5.0	164.
.50	310.7	208.6	18.6	227.3	158.2	5.1	163.
.00	311.4	211.2	18.7	229.9	157.8	5.1	162.
.50	310.7	208.6	18.6	227.3	158.2	5.1	163.
.00	308.6	201.0	18.5	219.5	159.5	5.0	164.
.50	305.0	188.4	18.3	206.7	161.3	5.0	166.
.00	299.3	171.2	18.0	189.2	163.2	4.9	168.
.50	291.0	149.7	17.5	167.1	164.6	4.7	169.
.00	278.8	124.3	16.7	141.1	164.2	4.5	168.
.50	260.3	95.8	15.6	111.4	160.2	4.2	164.
.00	231.0	65.1	13.9	78.9	148.5	3.8	152.
.50	179.6	33.9	10.8	44.7	120.7	2.9	123.
.00	78.5	7.1	4.7	11.8	55.1	1.3	56.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.

HR	WT	CTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	44.9	0.0	0
.50	0.0	0.0	0.0	0.00	44.3	0.0	0
.00	0.0	0.0	0.0	0.00	43.8	0.0	0
.50	0.0	0.0	0.0	0.00	43.3	0.0	0
.00	0.0	0.0	0.0	0.00	42.8	0.0	0
.50	0.0	0.0	0.0	0.00	42.3	0.0	0
.00	0.0	0.0	0.0	0.00	41.9	0.0	0
.50	0.0	0.0	0.0	0.00	41.5	0.0	0
.00	0.0	0.0	0.0	0.00	41.3	0.0	0
.50	0.0	0.0	0.0	0.00	41.1	0.0	0
.00	0.0	0.0	0.0	0.00	41.0	0.0	0
.50	0.0	0.0	0.0	0.00	41.1	0.0	0
.00	0.0	0.0	0.0	0.00	41.4	0.0	0
.50	0.0	0.0	0.0	0.00	41.9	0.0	0
.00	68.2	0.2	8.8	0.13	42.5	5.2	72
.50	168.3	1.6	48.7	0.30	43.4	10.9	67
.00	231.3	6.2	98.3	0.45	44.5	16.4	62
.50	275.9	13.0	142.5	0.56	45.9	21.6	56
.00	309.9	20.9	175.7	0.63	47.4	26.5	50
.50	336.5	29.1	198.5	0.68	49.0	31.0	44
.00	357.3	37.0	213.2	0.70	50.8	34.9	36
.50	373.0	44.5	221.8	0.71	52.6	38.2	28
.00	384.0	51.3	225.8	0.72	54.4	40.6	19
.50	390.5	57.4	225.9	0.73	56.2	42.2	9
.00	392.7	62.8	222.6	0.73	57.8	42.7	0
.50	390.5	67.2	216.1	0.73	59.3	42.2	9
.00	384.0	70.8	206.4	0.72	60.6	40.6	19
.50	373.0	73.2	193.1	0.71	61.7	38.2	28
.00	357.3	74.4	175.8	0.70	62.4	34.9	36
.50	336.5	74.1	153.4	0.68	62.9	31.0	44
.00	309.9	72.0	124.6	0.63	63.0	26.5	50
.50	275.9	67.7	87.8	0.56	62.8	21.6	56
.00	231.3	60.9	43.5	0.45	62.4	16.4	62
.50	168.3	52.3	-1.9	0.30	61.7	10.9	67
.00	68.2	43.4	-34.5	0.13	60.7	5.2	72
.50	0.0	0.0	0.0	0.00	59.6	0.0	0
.00	0.0	0.0	0.0	0.00	58.3	0.0	0
.50	0.0	0.0	0.0	0.00	57.0	0.0	0
.00	0.0	0.0	0.0	0.00	55.5	0.0	0
.50	0.0	0.0	0.0	0.00	54.1	0.0	0
.00	0.0	0.0	0.0	0.00	52.7	0.0	0
.50	0.0	0.0	0.0	0.00	51.4	0.0	0
.00	0.0	0.0	0.0	0.00	50.2	0.0	0
.50	0.0	0.0	0.0	0.00	49.1	0.0	0
.00	0.0	0.0	0.0	0.00	48.1	0.0	0
.50	0.0	0.0	0.0	0.00	47.1	0.0	0
.00	0.0	0.0	0.0	0.00	46.3	0.0	0
.50	0.0	0.0	0.0	0.00	45.6	0.0	0
.00	0.0	0.0	0.0	0.00	44.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 41.89 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T (HOURS)											
T = 0.00 HOURS	41.89	41.89	41.89	41.89	41.89	41.89	41.89	41.89	41.89	41.89	41.89
T = 0.50 HOURS	47.47	43.38	42.29	42.00	41.92	41.90	41.89	41.90	41.94	42.09	42.63
T = 1.00 HOURS	58.12	47.97	43.98	42.57	42.11	41.96	41.93	41.97	42.12	42.51	43.35
T = 1.50 HOURS	72.02	55.41	47.50	44.07	42.70	42.20	42.07	42.14	42.42	43.07	44.40
T = 2.00 HOURS	86.89	64.79	52.75	46.73	43.94	42.78	42.39	42.44	42.86	43.81	45.56
T = 2.50 HOURS	101.33	75.06	59.26	50.48	45.65	43.82	42.99	42.93	43.47	44.71	46.94
T = 3.00 HOURS	114.73	85.46	66.53	55.11	48.70	45.40	43.95	43.67	44.27	45.78	48.44
T = 3.50 HOURS	126.86	95.56	74.12	60.36	52.10	47.52	45.33	44.71	45.30	47.02	50.07
T = 4.00 HOURS	137.66	105.10	81.75	65.99	56.00	50.13	47.11	46.07	46.56	48.42	51.77
T = 4.50 HOURS	147.13	113.94	89.21	71.81	60.28	53.17	49.28	47.75	48.05	49.97	53.50
T = 5.00 HOURS	155.25	121.98	96.35	77.66	64.79	56.54	51.79	49.72	49.77	51.64	55.22
T = 5.50 HOURS	161.98	129.16	103.05	83.41	69.44	60.15	54.59	51.96	51.68	53.38	56.87
T = 6.00 HOURS	167.26	135.38	109.23	88.96	74.12	63.94	57.61	54.40	53.73	55.17	58.40
T = 6.50 HOURS	170.99	140.56	114.78	94.21	78.73	67.81	60.79	57.00	55.88	56.95	59.78
T = 7.00 HOURS	172.98	144.59	119.61	99.08	83.20	71.69	64.05	59.70	58.08	58.67	60.95
T = 7.50 HOURS	172.96	147.29	123.61	103.46	87.44	75.51	67.33	62.44	60.28	60.30	61.89
T = 8.00 HOURS	170.52	148.42	126.61	107.25	91.35	79.17	70.57	65.15	62.42	61.79	62.57
T = 8.50 HOURS	165.13	147.67	128.41	110.30	94.83	82.60	73.68	67.78	64.46	63.11	62.99
T = 9.00 HOURS	156.40	144.68	128.77	112.44	97.77	85.72	76.59	70.27	66.35	64.23	63.13

T = 9.50 HOURS

144.72	139.35	127.50	113.51	100.02	88.40	79.24	72.55	68.05	65.13	63.01

T = 10.00 HOURS

132.07	132.23	124.62	113.40	101.47	90.56	81.53	74.58	69.52	65.80	62.64

T = 10.50 HOURS

122.16	124.88	120.68	112.21	102.07	92.11	83.39	76.29	70.73	66.23	62.05

T = 11.00 HOURS

122.77	120.67	117.05	110.44	101.95	93.05	84.77	77.63	71.64	66.42	61.27

```
NO. OF GLASS COVERS = 2
INDEX OF REFRACTION FOR AIR = 1.0
INDEX OF REFRACTION FOR GLASS = 1.526
EXTINCTION COEFFICIENT = 0.174 1/INCH
GLASS THICKNESS = 0.250 INCH
SURFACE COLOR = BLACK
EMITTANCE OF GLASS = 0.88
EMITTANCE OF PLATE = 0.90
ABSORPTANCE OF THE PLATE = 0.95
REFLECTOR REFLECTANCE = 0.95
WIND VELOCITY =  10.0 MILE/HR
MAXIMUM TEMP. = 65.00 DEGREES F
TEMP. VARIATION = 22.00 DEGREES F
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NTH = 3 DECLINATION = 0.00 DEGREES

TITUDE = 36.07 DEGREES SUNRISE = 6.00 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.00 HOUR

ENING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	85.7	9.0	6.1	15.1	74.5	1.7	76
.00	178.4	37.3	12.7	50.0	150.8	3.4	154
.50	227.1	70.2	16.1	86.4	186.5	4.4	190
.00	255.6	103.3	18.1	121.5	203.9	4.9	208
.50	273.8	134.8	19.4	154.2	212.1	5.3	217
.00	286.2	163.6	20.3	183.9	215.5	5.5	221
.50	294.8	189.1	20.9	210.0	216.3	5.7	222
.00	300.9	210.6	21.4	232.0	215.7	5.8	221
.50	305.1	227.9	21.7	249.5	214.6	5.9	220
.00	307.9	240.4	21.9	262.3	213.4	5.9	219
.50	309.5	248.0	22.0	270.0	212.6	6.0	218
.00	310.0	250.6	22.0	272.6	212.3	6.0	218
.50	309.5	248.0	22.0	270.0	212.6	6.0	218
.00	307.9	240.4	21.9	262.3	213.4	5.9	219
.50	305.1	227.9	21.7	249.5	214.6	5.9	220
.00	300.9	210.6	21.4	232.0	215.7	5.8	221
.50	294.8	189.1	20.9	210.0	216.3	5.7	222
.00	286.2	163.6	20.3	183.9	215.5	5.5	221
.50	273.8	134.8	19.4	154.2	212.1	5.3	217
.00	255.6	103.3	18.1	121.5	203.9	4.9	208
.50	227.1	70.2	16.1	86.4	186.5	4.4	190
.00	178.4	37.3	12.7	50.0	150.8	3.4	154
.50	85.7	9.0	6.1	15.1	74.5	1.7	76
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	46.9	0.0	0
.50	0.0	0.0	0.0	0.00	46.3	0.0	0
.00	0.0	0.0	0.0	0.00	45.8	0.0	0
.50	0.0	0.0	0.0	0.00	45.3	0.0	0
.00	0.0	0.0	0.0	0.00	44.8	0.0	0
.50	0.0	0.0	0.0	0.00	44.3	0.0	0
.00	0.0	0.0	0.0	0.00	43.9	0.0	0
.50	0.0	0.0	0.0	0.00	43.5	0.0	0
.00	0.0	0.0	0.0	0.00	43.3	0.0	0
.50	0.0	0.0	0.0	0.00	43.1	0.0	0
.00	0.0	0.0	0.0	0.00	43.0	0.0	0
.50	0.0	0.0	0.0	0.00	43.1	0.0	0
.00	0.0	0.0	0.0	0.00	43.4	0.0	0
.50	91.3	0.2	14.1	0.16	43.9	6.1	85
.00	204.3	2.8	65.5	0.33	44.5	12.1	81
.50	277.3	9.2	126.9	0.49	45.4	18.0	76
.00	330.3	18.5	179.6	0.60	46.5	23.8	71
.50	371.6	29.1	217.8	0.66	47.9	29.5	65
.00	405.0	40.0	243.6	0.70	49.4	34.9	59
.50	432.0	50.5	260.4	0.72	51.0	39.9	52
.00	453.5	60.5	270.7	0.73	52.8	44.4	44
.50	470.0	69.8	276.1	0.74	54.6	48.3	35
.00	481.6	78.3	277.7	0.74	56.4	51.3	24
.50	488.6	86.0	275.9	0.74	58.2	53.3	12
.00	490.9	92.8	271.0	0.74	59.8	53.9	0
.50	488.6	98.6	263.3	0.74	61.3	53.3	12
.00	481.6	103.3	252.7	0.74	62.6	51.3	24
.50	470.0	106.9	239.1	0.74	63.7	48.3	35
.00	453.5	109.1	222.1	0.73	64.4	44.4	44
.50	432.0	109.7	201.1	0.72	64.9	39.9	52
.00	405.0	108.5	175.0	0.70	65.0	34.9	59
.50	371.6	105.1	141.8	0.66	64.8	29.5	65
.00	330.3	98.8	99.3	0.60	64.4	23.8	71
.50	277.3	89.3	46.9	0.49	63.7	18.0	76
.00	204.3	77.1	-8.8	0.33	62.7	12.1	81
.50	91.3	64.5	-50.2	0.16	61.6	6.1	85
.00	0.0	0.0	0.0	0.00	60.3	0.0	0
.50	0.0	0.0	0.0	0.00	59.0	0.0	0
.00	0.0	0.0	0.0	0.00	57.5	0.0	0
.50	0.0	0.0	0.0	0.00	56.1	0.0	0
.00	0.0	0.0	0.0	0.00	54.7	0.0	0
.50	0.0	0.0	0.0	0.00	53.4	0.0	0
.00	0.0	0.0	0.0	0.00	52.2	0.0	0
.50	0.0	0.0	0.0	0.00	51.1	0.0	0
.00	0.0	0.0	0.0	0.00	50.1	0.0	0
.50	0.0	0.0	0.0	0.00	49.1	0.0	0
.00	0.0	0.0	0.0	0.00	48.3	0.0	0
.50	0.0	0.0	0.0	0.00	47.6	0.0	0
.00	0.0	0.0	0.0	0.00	46.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 43.39 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

March

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS										
43.39	43.39	43.39	43.39	43.39	43.39	43.39	43.39	43.39	43.39	43.39
T = 0.50 HOURS										
51.18	45.47	43.94	43.54	43.43	43.40	43.39	43.40	43.42	43.53	43.93
T = 1.00 HOURS										
64.84	51.55	46.22	44.32	43.68	43.48	43.43	43.45	43.56	43.85	44.48
T = 1.50 HOURS										
82.22	61.02	50.79	46.29	44.47	43.79	43.58	43.59	43.79	44.29	45.33
T = 2.00 HOURS										
100.37	72.70	57.43	49.69	46.07	44.52	43.94	43.87	44.16	44.90	46.32
T = 2.50 HOURS										
117.78	85.27	65.52	54.41	48.61	45.82	44.64	44.36	44.70	45.68	47.54
T = 3.00 HOURS										
133.84	97.89	74.43	60.15	52.03	47.76	45.77	45.14	45.46	46.66	48.91
T = 3.50 HOURS										
148.44	110.10	83.66	66.59	56.21	50.35	47.38	46.27	46.47	47.83	50.45
T = 4.00 HOURS										
161.56	121.66	92.95	73.46	60.98	53.51	49.48	47.78	47.77	49.20	52.11
T = 4.50 HOURS										
173.24	132.44	102.02	80.53	66.16	57.16	52.03	49.66	49.35	50.77	53.86
T = 5.00 HOURS										
183.51	142.38	110.75	87.64	71.63	61.20	54.98	51.89	51.21	52.52	55.65
T = 5.50 HOURS										
192.38	151.42	119.03	94.67	77.26	65.53	58.27	54.44	53.31	54.40	57.43
T = 6.00 HOURS										
199.82	159.50	126.77	101.50	82.94	70.07	61.83	57.26	55.62	56.38	59.15
T = 6.50 HOURS										
205.81	166.58	133.91	108.05	88.59	74.74	65.59	60.28	58.08	58.40	60.75
T = 7.00 HOURS										
210.26	172.59	140.37	114.25	94.12	79.44	69.48	63.44	60.63	60.42	62.20
T = 7.50 HOURS										
213.08	177.44	146.07	120.00	99.45	84.12	73.42	66.69	63.23	62.37	63.44
T = 8.00 HOURS										
214.06	181.03	150.93	125.24	104.51	88.69	77.36	69.96	65.81	64.23	64.44
T = 8.50 HOURS										
212.91	133.18	154.83	129.87	109.22	93.08	81.23	73.18	68.33	65.94	65.19
T = 9.00 HOURS										
209.15	183.63	157.62	133.79	113.49	97.22	84.95	76.31	70.73	67.48	65.67

T (HOURS)										
T = 9.50 HOURS										
202.09	181.98	159.06	136.85	117.22	101.03	88.46	79.28	72.97	68.81	65.87
T = 10.00 HOURS										
191.11	177.78	158.87	138.86	120.29	104.41	91.69	82.03	75.01	69.91	65.81
T = 10.50 HOURS										
176.41	170.79	156.76	139.61	122.54	107.27	94.56	84.52	76.81	70.78	65.50
T = 11.00 HOURS										
160.28	161.54	152.73	138.96	123.83	109.48	96.98	86.67	78.34	71.41	64.97
T = 11.50 HOURS										
147.31	151.92	147.36	137.00	124.10	110.95	98.89	88.45	79.58	71.78	64.24
T = 12.00 HOURS										
149.26	146.60	142.47	134.35	123.50	111.67	100.22	89.79	80.48	71.92	63.36

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 73.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 4 DECLINATION = 11.93 DEGREES

TITUDE = 36.07 DEGREES SUNRISE = 5.44 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.56 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	82.0	10.0	8.0	17.9	63.8	1.1	64.
.50	161.7	36.4	15.7	52.1	138.9	2.2	141
.00	207.4	67.7	20.1	87.8	193.4	2.8	196
.50	235.5	100.0	22.8	122.8	211.5	3.2	214
.00	254.2	131.4	24.7	156.1	210.5	3.4	213
.50	267.1	161.1	25.9	187.0	202.9	3.6	206
.00	276.4	188.2	26.8	215.0	191.8	3.7	195
.50	283.1	212.1	27.5	239.5	179.4	3.8	183
.00	288.0	232.3	27.9	260.2	167.3	3.9	171
.50	291.5	248.4	28.3	276.7	155.7	3.9	160
.00	293.8	260.2	28.5	288.7	148.4	4.0	152
.50	295.1	267.3	28.5	295.9	143.2	4.0	147
.00	295.6	269.7	28.7	298.4	141.4	4.0	145
.50	295.1	267.3	28.6	295.9	143.2	4.0	147
.00	293.8	260.2	28.5	288.7	148.4	4.0	152
.50	291.5	248.4	28.3	276.7	155.7	3.9	160
.00	288.0	232.3	27.9	260.2	167.3	3.9	171
.50	283.1	212.1	27.5	239.5	179.4	3.8	183
.00	276.4	188.2	26.8	215.0	191.8	3.7	195
.50	267.1	161.1	25.9	187.0	202.9	3.6	206
.00	254.2	131.4	24.7	156.1	210.5	3.4	213
.50	235.5	100.0	22.8	122.8	211.5	3.2	214
.00	207.4	67.7	20.1	87.8	193.4	2.8	196
.50	161.7	36.4	15.7	52.1	138.9	2.2	141
.00	82.0	10.0	8.0	17.9	63.8	1.1	64.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	54.9	0.0	0
.50	0.0	0.0	0.0	0.00	54.3	0.0	0
.00	0.0	0.0	0.0	0.00	53.8	0.0	0
.50	0.0	0.0	0.0	0.00	53.3	0.0	0
.00	0.0	0.0	0.0	0.00	52.8	0.0	0
.50	0.0	0.0	0.0	0.00	52.3	0.0	0
.00	0.0	0.0	0.0	0.00	51.9	0.0	0
.50	0.0	0.0	0.0	0.00	51.5	0.0	0
.00	0.0	0.0	0.0	0.00	51.3	0.0	0
.50	0.0	0.0	0.0	0.00	51.1	0.0	0
.00	0.0	0.0	0.0	0.00	51.0	0.0	0
.50	0.0	0.0	0.0	0.00	51.1	0.0	0
.00	82.8	0.1	15.1	0.18	51.4	7.0	80
.50	193.1	3.2	66.5	0.36	51.9	13.0	84
.00	284.0	10.4	135.6	0.51	52.5	19.0	88
.50	337.5	20.7	187.7	0.62	53.4	25.1	86
.00	370.0	31.6	219.1	0.68	54.5	31.1	81
.50	393.5	42.1	237.3	0.71	55.9	37.1	76
.00	410.5	51.6	246.9	0.73	57.4	42.9	70
.50	422.8	60.2	251.1	0.74	59.0	48.5	64
.00	431.5	67.9	251.8	0.74	60.8	53.8	55
.50	437.3	74.7	250.4	0.74	62.6	58.5	45
.00	441.1	80.8	247.5	0.74	64.4	62.3	33
.50	443.1	86.2	244.0	0.75	66.2	64.9	17
.00	443.8	91.2	239.5	0.75	67.8	55.9	0
.50	443.1	95.6	234.5	0.75	69.3	64.9	17
.00	441.1	99.7	228.8	0.74	70.6	62.3	33
.50	437.3	103.2	221.9	0.74	71.7	58.5	45
.00	431.5	106.3	213.4	0.74	72.4	53.8	55
.50	422.8	108.6	202.7	0.74	72.9	48.5	64
.00	410.5	110.0	188.5	0.73	73.0	42.9	70
.50	393.5	110.0	169.4	0.71	72.8	37.1	76
.00	370.0	108.1	142.7	0.68	72.4	31.1	81
.50	337.5	103.3	105.1	0.62	71.7	25.1	86
.00	284.0	94.5	51.4	0.51	70.7	19.0	88
.50	193.1	81.8	-12.1	0.36	69.6	13.0	84
3.00	82.8	68.4	-53.2	0.18	68.3	7.0	80
3.50	0.0	0.0	0.0	0.00	67.0	0.0	0
9.00	0.0	0.0	0.0	0.00	65.5	0.0	0
9.50	0.0	0.0	0.0	0.00	64.1	0.0	0
0.00	0.0	0.0	0.0	0.00	62.7	0.0	0
0.50	0.0	0.0	0.0	0.00	61.4	0.0	0
1.00	0.0	0.0	0.0	0.00	60.2	0.0	0
1.50	0.0	0.0	0.0	0.00	59.1	0.0	0
2.00	0.0	0.0	0.0	0.00	58.1	0.0	0
2.50	0.0	0.0	0.0	0.00	57.1	0.0	0
3.00	0.0	0.0	0.0	0.00	56.3	0.0	0
3.50	0.0	0.0	0.0	0.00	55.6	0.0	0
4.00	0.0	0.0	0.0	0.00	54.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 51.10 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

APRIL

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS										
51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10
T = 0.50 HOURS										
59.13	53.25	51.67	51.25	51.14	51.11	51.10	51.10	51.12	51.19	51.43
T = 1.00 HOURS										
73.62	59.62	54.04	52.06	51.40	51.19	51.14	51.14	51.21	51.40	51.83
T = 1.50 HOURS										
92.03	69.64	58.86	54.13	52.23	51.51	51.27	51.25	51.38	51.72	52.48
T = 2.00 HOURS										
109.96	81.66	65.78	57.69	53.90	52.26	51.62	51.48	51.66	52.20	53.28
T = 2.50 HOURS										
125.16	93.97	73.96	62.54	56.52	53.59	52.31	51.93	52.11	52.84	54.32
T = 3.00 HOURS										
140.45	105.81	82.65	68.28	59.99	55.57	53.44	52.66	52.78	53.69	55.53
T = 3.50 HOURS										
152.94	116.85	91.37	74.54	64.13	58.15	55.03	53.74	53.71	54.74	56.94
T = 4.00 HOURS										
163.87	127.01	99.86	81.02	68.74	61.24	57.08	55.18	54.92	56.02	58.50
T = 4.50 HOURS										
173.46	136.29	107.97	87.55	73.64	64.75	59.54	56.99	56.43	57.51	60.20
T = 5.00 HOURS										
181.93	144.75	115.65	93.99	78.71	68.57	62.36	59.13	58.21	59.20	61.98
T = 5.50 HOURS										
189.44	152.47	122.87	100.27	83.86	72.60	65.47	61.57	60.24	61.06	63.80
T = 6.00 HOURS										
195.12	159.52	129.65	106.35	89.00	76.78	68.80	64.25	62.48	63.03	65.61
T = 6.50 HOURS										
202.06	165.96	136.00	112.19	94.09	81.05	72.30	67.11	64.87	65.08	67.35
T = 7.00 HOURS										
207.28	171.82	141.94	117.78	99.09	85.34	75.90	70.11	67.36	67.13	68.97
T = 7.50 HOURS										
211.78	177.11	147.46	123.11	103.97	89.63	79.56	73.18	69.89	69.16	70.41
T = 8.00 HOURS										
215.47	181.82	152.55	128.17	108.69	93.87	83.24	75.28	72.43	71.10	71.65
T = 8.50 HOURS										
218.21	185.86	157.19	132.92	113.24	98.01	86.88	79.37	74.91	72.91	72.64
T = 9.00 HOURS										
219.73	189.11	161.30	137.33	117.57	102.04	90.45	82.39	77.30	74.56	73.37

T											
T = 9.50 HOURS	219.64	191.36	164.78	141.33	121.65	105.89	93.91	85.31	79.57	76.02	73.83
T = 10.00 HOURS	217.30	192.29	167.45	144.82	125.39	109.54	97.21	88.09	81.67	77.27	74.01
T = 10.50 HOURS	211.81	191.40	169.04	147.65	128.73	112.91	100.31	90.69	83.59	78.30	73.92
T = 11.00 HOURS	201.82	187.96	169.15	149.61	131.53	115.93	103.15	93.09	85.29	79.10	73.59
T = 11.50 HOURS	185.80	181.27	167.31	150.40	133.61	118.49	105.68	95.23	86.77	79.68	73.05
T = 12.00 HOURS	170.12	171.89	163.33	149.76	134.78	120.47	107.81	97.07	88.00	80.03	72.32
T = 12.50 HOURS	157.00	162.08	157.86	147.72	134.92	121.74	109.46	98.56	88.96	80.18	71.43
T = 13.00 HOURS	159.44	156.80	152.89	144.96	134.18	122.28	110.56	99.65	89.63	80.11	70.44
T = 13.50 HOURS	155.59	154.39	149.64	142.42	132.97	122.20	111.11	100.32	89.99	79.85	69.36

May

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 78.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

Mu

NTH = 5 DECLINATION = 20.34 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 5.08 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.92 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	54.8	5.8	6.6	12.4	30.3	0.9	31
.00	134.3	27.5	16.3	43.7	85.6	2.3	88
.50	183.5	55.7	22.2	77.9	134.1	3.1	137
.00	214.6	86.0	26.0	112.0	173.8	3.6	177
.50	235.5	116.5	28.5	145.0	207.6	4.0	211
.00	250.2	146.0	30.3	176.3	236.5	4.2	240
.50	260.8	173.7	31.6	205.2	233.7	4.4	238
.00	268.6	198.9	32.5	231.4	225.8	4.5	230
.50	274.4	221.2	33.2	254.4	216.6	4.6	221
.00	278.7	240.0	33.7	273.7	207.4	4.7	212
.50	281.8	255.0	34.1	289.1	199.3	4.7	204
.00	283.9	266.0	34.4	300.3	193.0	4.8	197
.50	285.1	272.6	34.5	307.1	189.0	4.8	193
.00	285.5	274.8	34.5	309.4	187.6	4.8	192
.50	285.1	272.6	34.5	307.1	189.0	4.8	193
.00	283.9	266.0	34.4	300.3	193.0	4.8	197
.50	281.8	255.0	34.1	289.1	199.3	4.7	204
.00	278.7	240.0	33.7	273.7	207.4	4.7	212
.50	274.4	221.2	33.2	254.4	216.6	4.6	221
.00	268.6	198.9	32.5	231.4	225.8	4.5	230
5.50	260.8	173.7	31.6	205.2	233.7	4.4	238
.00	250.2	146.0	30.3	176.3	236.5	4.2	240
.50	235.5	116.5	28.5	145.0	207.6	4.0	211
.00	214.6	86.0	26.0	112.0	173.8	3.6	177
.50	183.5	55.7	22.2	77.9	134.1	3.1	137
3.00	134.3	27.5	16.3	43.7	86.6	2.3	88
3.50	54.8	5.8	6.6	12.4	30.3	0.9	31
.00	0.0	0.0	0.0	0.0	0.0	0.0	C
.50	0.0	0.0	0.0	0.0	0.0	0.0	C
.00	0.0	0.0	0.0	0.0	0.0	0.0	C
.50	0.0	0.0	0.0	0.0	0.0	0.0	C
1.00	0.0	0.0	0.0	0.0	0.0	0.0	C
1.50	0.0	0.0	0.0	0.0	0.0	0.0	C
2.00	0.0	0.0	0.0	0.0	0.0	0.0	C
2.50	0.0	0.0	0.0	0.0	0.0	0.0	C
3.00	0.0	0.0	0.0	0.0	0.0	0.0	C
3.50	0.0	0.0	0.0	0.0	0.0	0.0	C
4.00	0.0	0.0	0.0	0.0	0.0	0.0	C

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	59.9	0.0	0
.50	0.0	0.0	0.0	0.00	59.3	0.0	0
.00	0.0	0.0	0.0	0.00	58.8	0.0	0
.50	0.0	0.0	0.0	0.00	58.3	0.0	0
.00	0.0	0.0	0.0	0.00	57.8	0.0	0
.50	0.0	0.0	0.0	0.00	57.3	0.0	0
.00	0.0	0.0	0.0	0.00	55.9	0.0	0
.50	0.0	0.0	0.0	0.00	56.5	0.0	0
.00	0.0	0.0	0.0	0.00	56.3	0.0	0
.50	0.0	0.0	0.0	0.00	56.1	0.0	0
.00	0.0	0.0	0.0	0.00	56.0	0.0	0
.50	43.7	0.0	6.8	0.16	56.1	6.1	69
.00	132.6	1.9	41.4	0.33	55.4	11.8	7
.50	215.1	6.9	97.0	0.48	56.9	17.7	77
.00	289.4	15.4	157.2	0.60	57.5	23.6	81
.50	356.5	26.8	210.6	0.67	58.4	29.6	85
.00	415.9	40.0	253.6	0.70	59.5	35.7	89
.50	443.4	52.6	268.7	0.72	60.9	41.8	85
.00	461.7	63.6	276.0	0.74	62.4	47.8	80
.50	475.6	73.4	279.0	0.74	64.0	53.7	74
.00	485.9	82.3	279.1	0.74	65.8	59.4	67
.50	493.2	90.3	277.2	0.75	67.6	54.8	57
.00	498.1	97.4	274.0	0.75	69.4	69.5	43
.50	500.9	103.9	269.7	0.75	71.2	73.0	24
.00	501.8	109.7	264.6	0.75	72.8	74.3	0
.50	500.9	115.0	258.7	0.75	74.3	73.0	24
.00	498.1	119.7	251.8	0.75	75.6	69.5	43
.50	493.2	123.8	243.7	0.75	76.7	64.8	57
.00	485.9	127.2	234.2	0.74	77.4	59.4	67
.50	475.6	129.9	222.5	0.74	77.9	53.7	74
.00	461.7	131.5	208.0	0.74	78.0	47.8	80
.50	443.4	131.8	189.5	0.72	77.8	41.8	85
.00	415.9	130.0	163.6	0.70	77.4	35.7	89
.50	356.5	123.8	113.6	0.67	76.7	29.6	85
.00	289.4	113.0	59.7	0.60	75.7	23.6	8
.50	215.1	99.6	4.3	0.48	74.6	17.7	77
.00	132.6	85.2	-41.9	0.33	73.3	11.8	7
.50	43.7	72.6	-65.7	0.16	72.0	6.1	6
.00	0.0	0.0	0.0	0.00	70.5	0.0	
.50	0.0	0.0	0.0	0.00	59.1	0.0	
.00	0.0	0.0	0.0	0.00	67.7	0.0	
.50	0.0	0.0	0.0	0.00	66.4	0.0	
.00	0.0	0.0	0.0	0.00	65.2	0.0	
.50	0.0	0.0	0.0	0.00	64.1	0.0	
.00	0.0	0.0	0.0	0.00	63.1	0.0	
.50	0.0	0.0	0.0	0.00	62.1	0.0	
.00	0.0	0.0	0.0	0.00	61.3	0.0	
.50	0.0	0.0	0.0	0.00	60.6	0.0	
.00	0.0	0.0	0.0	0.00	59.9	0.0	

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 56.03 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03
T = 0.50 HOURS	60.78	57.30	56.37	56.12	56.05	56.04	56.03	56.03	56.04	56.06	56.13
T = 1.00 HOURS	71.22	61.57	57.91	56.64	56.22	56.09	56.05	56.05	56.07	56.16	56.40
T = 1.50 HOURS	87.08	69.41	61.42	58.08	56.78	56.30	56.14	56.11	56.17	56.37	56.83
T = 2.00 HOURS	105.08	80.45	67.20	60.85	58.01	56.82	56.37	56.26	56.36	56.71	57.46
T = 2.50 HOURS	125.25	93.63	75.01	65.09	60.16	57.86	56.88	56.57	56.69	57.20	58.29
T = 3.00 HOURS	144.51	107.50	84.22	70.67	63.28	59.52	57.77	57.13	57.19	57.87	59.32
T = 3.50 HOURS	159.69	120.60	93.99	77.20	67.32	61.88	59.14	58.01	57.94	58.75	60.55
T = 4.00 HOURS	172.99	132.58	103.66	84.26	72.05	64.88	61.01	59.26	58.97	59.86	61.97
T = 4.50 HOURS	184.64	143.57	112.97	91.49	77.26	68.42	63.37	60.91	60.31	61.20	63.55
T = 5.00 HOURS	194.94	153.60	121.84	98.71	82.75	72.39	66.17	62.95	61.96	62.77	65.27
T = 5.50 HOURS	204.05	162.76	130.22	105.80	88.39	76.66	69.34	65.34	63.91	64.55	67.08
T = 6.00 HOURS	212.14	171.13	138.09	112.69	94.08	81.15	72.80	68.04	66.11	66.51	68.93
T = 6.50 HOURS	219.31	178.76	145.48	119.35	99.74	85.78	76.49	70.98	68.53	68.58	70.77
T = 7.00 HOURS	225.65	185.71	152.39	125.74	105.33	90.47	80.34	74.11	71.10	70.73	72.54
T = 7.50 HOURS	231.17	192.01	158.82	131.84	110.81	95.19	84.29	77.38	73.78	72.90	74.18
T = 8.00 HOURS	235.87	197.66	164.79	137.64	116.14	99.88	88.29	80.72	76.51	75.03	75.66
T = 8.50 HOURS	239.70	202.66	170.27	143.12	121.29	104.50	92.30	84.08	79.23	77.08	76.93
T = 9.00 HOURS	242.53	206.94	175.24	148.26	126.22	109.01	96.25	87.42	81.90	79.00	77.96

T = 9.50 HOURS

244.17	210.40	179.65	153.01	130.91	113.38	100.12	90.69	84.47	80.76	78.72

T = 10.00 HOURS

244.32	212.88	183.40	157.32	135.31	117.55	103.86	93.84	86.90	82.32	79.20

T = 10.50 HOURS

242.36	214.11	186.36	161.11	139.37	121.50	107.43	96.84	89.17	83.67	79.41

T = 11.00 HOURS

235.92	213.20	188.16	164.22	142.99	125.14	110.78	99.66	91.24	84.79	79.35

T = 11.50 HOURS

224.56	209.22	188.25	165.36	146.04	128.42	113.87	102.25	93.10	85.69	79.05

T = 12.00 HOURS

209.88	202.24	186.26	167.21	148.30	131.20	116.61	104.57	94.71	86.35	78.53

T = 12.50 HOURS

193.32	192.92	182.24	166.60	149.59	133.36	118.93	106.58	96.07	86.78	77.82

T = 13.00 HOURS

177.85	182.51	176.65	164.58	149.82	134.77	120.73	108.22	97.15	87.00	75.96

T = 13.50 HOURS

165.29	172.78	170.33	161.47	149.05	135.39	121.95	109.44	97.91	87.00	75.99

T = 14.00 HOURS

170.40	168.02	165.07	158.00	147.53	135.28	122.58	110.20	98.36	86.80	74.93

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 85.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 6 DECLINATION = 23.45 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 4.97 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 19.03 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	77.7	10.7	10.4	21.1	38.9	1.4	40
.00	143.8	33.7	19.3	53.0	85.4	2.7	88
.50	185.7	61.5	24.9	86.4	125.5	3.5	129
.00	213.3	90.9	28.6	119.5	162.4	4.0	166
.50	232.3	120.3	31.1	151.4	193.8	4.3	198
.00	245.9	148.8	32.9	181.7	221.2	4.6	225
.50	255.8	175.4	34.3	209.7	241.3	4.8	246
.00	263.3	199.8	35.3	235.0	234.6	4.9	239
.50	268.9	221.2	36.0	257.2	226.7	5.0	231
.00	273.1	239.3	36.6	275.9	218.7	5.1	223
.50	276.0	253.8	37.0	290.8	211.6	5.1	216
.00	278.1	264.3	37.3	301.6	206.0	5.2	211
.50	279.2	270.7	37.4	308.1	202.4	5.2	207
.00	279.6	272.9	37.5	310.3	201.2	5.2	206
.50	279.2	270.7	37.4	308.1	202.4	5.2	207
.00	278.1	264.3	37.3	301.6	206.0	5.2	211
.50	276.0	253.8	37.0	290.8	211.6	5.1	216
.00	273.1	239.3	36.6	275.9	218.7	5.1	223
.50	268.9	221.2	36.0	257.2	226.7	5.0	231
.00	263.3	199.8	35.3	235.0	234.6	4.9	239
.50	255.8	175.4	34.3	209.7	241.3	4.8	246
.00	245.9	148.8	32.9	181.7	221.2	4.6	225
.50	232.3	120.3	31.1	151.4	193.8	4.3	198
.00	213.3	90.9	28.6	119.5	162.4	4.0	166
.50	185.7	61.5	24.9	86.4	125.5	3.5	129
.00	143.8	33.7	19.3	53.0	85.4	2.7	88
.50	77.7	10.7	10.4	21.1	38.9	1.4	40
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
0.00	0.0	0.0	0.0	0.00	66.9	0.0	0
0.50	0.0	0.0	0.0	0.00	66.3	0.0	0
1.00	0.0	0.0	0.0	0.00	65.8	0.0	0
1.50	0.0	0.0	0.0	0.00	65.3	0.0	0
2.00	0.0	0.0	0.0	0.00	64.8	0.0	0
2.50	0.0	0.0	0.0	0.00	64.3	0.0	0
3.00	0.0	0.0	0.0	0.00	63.9	0.0	0
3.50	0.0	0.0	0.0	0.00	63.5	0.0	0
4.00	0.0	0.0	0.0	0.00	63.3	0.0	0
4.50	0.0	0.0	0.0	0.00	63.1	0.0	0
5.00	0.0	0.0	0.0	0.00	63.0	0.0	0
5.50	61.5	0.0	12.9	0.21	63.1	7.9	66
6.00	141.1	2.6	50.5	0.38	63.4	13.5	70
6.50	216.3	8.2	104.3	0.52	63.8	19.3	74
7.00	285.8	17.0	159.9	0.62	64.5	25.2	78
7.50	349.6	28.3	208.8	0.68	65.4	31.2	82
8.00	407.5	41.1	248.5	0.71	66.5	37.2	86
8.50	455.8	54.6	277.2	0.73	67.9	43.3	89
9.00	474.6	66.8	283.0	0.74	69.4	49.3	84
9.50	488.9	77.2	285.5	0.74	71.0	55.3	79
10.00	499.7	86.6	285.3	0.74	72.8	61.2	72
10.50	507.5	95.1	283.3	0.75	74.6	66.8	63
11.00	512.8	102.6	279.8	0.75	76.4	71.9	49
11.50	515.8	109.5	275.3	0.75	78.2	75.8	29
12.00	516.8	115.6	269.9	0.75	79.8	77.4	0
12.50	515.8	121.1	263.5	0.75	81.3	75.8	29
13.00	512.8	126.1	256.4	0.75	82.6	71.9	49
13.50	507.5	130.3	248.0	0.75	83.7	66.8	63
14.00	499.7	133.9	238.1	0.74	84.4	61.2	72
14.50	488.9	136.6	226.2	0.74	84.9	55.3	79
15.00	474.6	138.3	211.6	0.74	85.0	49.3	84
15.50	455.8	138.6	193.2	0.73	84.8	43.3	89
16.00	407.5	135.3	154.2	0.71	84.4	37.2	86
16.50	349.6	127.7	109.3	0.68	83.7	31.2	82
17.00	285.8	117.0	59.9	0.62	82.7	25.2	78
17.50	216.3	103.8	8.6	0.52	81.6	19.3	74
18.00	141.1	89.6	-36.5	0.38	80.3	13.5	70
18.50	61.5	76.6	-63.7	0.21	79.0	7.9	66
19.00	0.0	0.0	0.0	0.00	77.5	0.0	0
19.50	0.0	0.0	0.0	0.00	76.1	0.0	0
20.00	0.0	0.0	0.0	0.00	74.7	0.0	0
20.50	0.0	0.0	0.0	0.00	73.4	0.0	0
21.00	0.0	0.0	0.0	0.00	72.2	0.0	0
21.50	0.0	0.0	0.0	0.00	71.1	0.0	0
22.00	0.0	0.0	0.0	0.00	70.1	0.0	0
22.50	0.0	0.0	0.0	0.00	69.1	0.0	0
23.00	0.0	0.0	0.0	0.00	68.3	0.0	0
23.50	0.0	0.0	0.0	0.00	67.6	0.0	0
24.00	0.0	0.0	0.0	0.00	66.9	0.0	0

Jun

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 63.02 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T											
T = 0.00 HOURS	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02
T = 0.50 HOURS	69.28	64.70	63.47	63.14	63.06	63.03	63.03	63.03	63.03	63.05	63.13
T = 1.00 HOURS	80.31	69.59	65.30	63.77	63.26	63.10	63.05	63.05	63.07	63.16	63.40
T = 1.50 HOURS	95.08	77.70	69.12	65.40	63.90	63.34	63.15	63.11	63.17	63.37	63.83
T = 2.00 HOURS	114.39	88.65	75.02	68.32	65.25	63.93	63.41	63.27	63.37	63.71	64.46
T = 2.50 HOURS	133.66	101.46	82.76	72.63	67.47	65.02	63.96	63.61	63.70	64.20	65.29
T = 3.00 HOURS	152.64	115.23	91.88	78.19	70.65	66.74	64.89	64.19	64.22	64.88	66.32
T = 3.50 HOURS	169.06	128.83	101.75	84.74	74.70	69.13	66.29	65.10	64.99	65.77	67.56
T = 4.00 HOURS	182.61	141.28	111.69	91.91	79.49	72.17	68.19	66.38	66.03	66.89	68.98
T = 4.50 HOURS	194.57	152.53	121.26	99.30	84.79	75.76	70.59	68.05	67.39	68.24	70.57
T = 5.00 HOURS	205.07	162.81	130.33	105.69	90.39	79.80	73.43	70.12	69.06	69.83	72.29
T = 5.50 HOURS	214.36	172.17	138.90	113.94	96.15	84.16	76.65	72.54	71.03	71.62	74.10
T = 6.00 HOURS	222.60	180.70	146.95	120.99	101.96	88.73	80.18	75.28	73.26	73.58	75.95
T = 6.50 HOURS	229.89	188.48	154.49	127.78	107.74	93.45	83.93	78.27	75.70	75.68	77.79
T = 7.00 HOURS	236.30	195.55	161.53	134.30	113.44	98.24	87.85	81.45	78.31	77.84	79.57
T = 7.50 HOURS	241.87	201.94	168.08	140.52	119.03	103.05	91.88	84.75	81.02	80.03	81.22
T = 8.00 HOURS	245.59	207.67	174.14	145.43	124.46	107.83	95.95	88.16	83.78	82.18	82.71
T = 8.50 HOURS	250.41	212.71	179.70	152.00	129.70	112.53	100.02	91.57	86.54	84.25	83.98
T = 9.00 HOURS	253.22	217.02	184.73	157.21	134.71	117.12	104.05	94.95	89.25	86.19	85.01

T = 9.50 HOURS	254.85	220.50	189.19	162.03	139.48	121.56	107.98	98.28	91.85	87.97	85.78
T = 10.00 HOURS	255.03	223.02	192.99	165.40	143.94	125.80	111.78	101.48	94.32	89.56	85.27
T = 10.50 HOURS	251.74	223.91	195.89	170.22	148.05	129.79	115.40	104.53	96.62	90.93	85.48
T = 11.00 HOURS	244.13	222.29	197.42	173.26	151.69	133.49	118.80	107.39	98.73	92.07	85.43
T = 11.50 HOURS	233.15	217.97	197.19	175.25	154.69	136.77	121.92	110.01	100.61	92.98	86.14
T = 12.00 HOURS	219.10	211.13	195.08	175.96	156.88	139.54	124.67	112.36	102.25	93.65	85.62
T = 12.50 HOURS	203.17	202.12	191.13	175.30	158.12	141.66	126.99	114.39	103.63	94.10	84.91
T = 13.00 HOURS	187.72	191.92	185.66	173.31	158.33	143.06	128.78	116.03	104.71	94.33	84.06
T = 13.50 HOURS	175.46	182.06	179.38	170.24	157.57	143.67	130.00	117.24	105.48	94.33	83.08
T = 14.00 HOURS	179.59	177.12	174.04	165.76	155.06	143.56	130.62	118.01	105.93	94.13	82.02
T = 14.50 HOURS	176.11	175.11	170.69	163.76	154.25	142.91	130.70	118.32	106.05	93.73	80.92

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 90.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

INTH = 7 DECLINATION = 20.24 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 5.09 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.91 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	
0.00	0.0	0.0	0.0	0.0	0.0	0.0	
0.50	0.0	0.0	0.0	0.0	0.0	0.0	
.00	0.0	0.0	0.0	0.0	0.0	0.0	
.50	0.0	0.0	0.0	0.0	0.0	0.0	
2.00	0.0	0.0	0.0	0.0	0.0	0.0	
2.50	0.0	0.0	0.0	0.0	0.0	0.0	
3.00	0.0	0.0	0.0	0.0	0.0	0.0	
3.50	0.0	0.0	0.0	0.0	0.0	0.0	
4.00	0.0	0.0	0.0	0.0	0.0	0.0	
4.50	0.0	0.0	0.0	0.0	0.0	0.0	
5.00	0.0	0.0	0.0	0.0	0.0	0.0	
5.50	47.6	5.0	6.5	11.5	25.4	0.9	2
6.00	124.5	25.4	16.9	42.3	80.5	2.4	8
6.50	173.6	52.5	23.6	76.2	127.1	3.3	13
7.00	205.0	82.0	27.9	109.9	155.3	3.9	17
7.50	226.2	111.7	30.8	142.5	199.7	4.3	20
8.00	241.2	140.6	32.8	173.4	228.3	4.6	23
8.50	252.0	167.7	34.3	202.0	225.5	4.8	23
9.00	260.1	192.4	35.4	227.8	218.1	4.9	22
9.50	266.0	214.3	36.2	250.4	209.5	5.0	21
0.00	270.4	232.7	36.8	269.5	200.7	5.1	20
0.50	273.6	247.5	37.2	284.7	193.0	5.2	19
1.00	275.8	258.2	37.5	295.7	185.9	5.2	19
1.50	277.0	264.7	37.7	302.4	183.0	5.2	18
2.00	277.4	266.9	37.7	304.6	181.7	5.2	18
2.50	277.0	264.7	37.7	302.4	183.0	5.2	18
3.00	275.8	258.2	37.5	295.7	186.9	5.2	19
3.50	273.6	247.5	37.2	284.7	193.0	5.2	19
4.00	270.4	232.7	36.8	269.5	200.7	5.1	20
4.50	266.0	214.3	36.2	250.4	209.5	5.0	21
5.00	260.1	192.4	35.4	227.8	218.1	4.9	22
5.50	252.0	167.7	34.3	202.0	225.5	4.8	23
6.00	241.2	140.6	32.8	173.4	228.3	4.6	23
6.50	226.2	111.7	30.8	142.5	199.7	4.3	20
7.00	205.0	82.0	27.9	109.9	165.3	3.9	17
7.50	173.6	52.5	23.6	76.2	127.1	3.3	13
8.00	124.5	25.4	16.9	42.3	80.5	2.4	8
8.50	47.6	5.0	6.5	11.5	26.4	0.9	2
9.00	0.0	0.0	0.0	0.0	0.0	0.0	
9.50	0.0	0.0	0.0	0.0	0.0	0.0	
0.00	0.0	0.0	0.0	0.0	0.0	0.0	
0.50	0.0	0.0	0.0	0.0	0.0	0.0	
1.00	0.0	0.0	0.0	0.0	0.0	0.0	
1.50	0.0	0.0	0.0	0.0	0.0	0.0	
2.00	0.0	0.0	0.0	0.0	0.0	0.0	
2.50	0.0	0.0	0.0	0.0	0.0	0.0	
3.00	0.0	0.0	0.0	0.0	0.0	0.0	
3.50	0.0	0.0	0.0	0.0	0.0	0.0	
4.00	0.0	0.0	0.0	0.0	0.0	0.0	

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	71.9	0.0	0.
.50	0.0	0.0	0.0	0.00	71.3	0.0	0.
.00	0.0	0.0	0.0	0.00	70.8	0.0	0.
.50	0.0	0.0	0.0	0.00	70.3	0.0	0.
.00	0.0	0.0	0.0	0.00	69.8	0.0	0.
.50	0.0	0.0	0.0	0.00	69.3	0.0	0
.00	0.0	0.0	0.0	0.00	68.9	0.0	0.
.50	0.0	0.0	0.0	0.00	68.5	0.0	0.
.00	0.0	0.0	0.0	0.00	68.3	0.0	0.
.50	0.0	0.0	0.0	0.00	68.1	0.0	0.
.00	0.0	0.0	0.0	0.00	68.0	0.0	0.
.50	38.8	0.0	6.0	0.15	68.1	6.0	69.
.00	125.1	1.8	38.8	0.32	68.4	11.8	73.
.50	206.5	6.7	92.8	0.48	68.9	17.6	77.
.00	280.1	15.3	151.6	0.60	69.5	23.6	81.
.50	346.5	26.6	204.0	0.67	70.4	29.6	85.
.00	406.3	39.8	246.2	0.70	71.5	35.7	89.
.50	432.2	52.4	260.8	0.72	72.9	41.7	85.
.00	450.8	63.3	268.2	0.74	74.4	47.7	80.
.50	464.9	73.1	271.3	0.74	76.0	53.6	74.
.00	475.4	82.0	271.6	0.74	77.8	59.4	67.
.50	482.8	89.9	269.8	0.75	79.6	64.7	57.
.00	487.8	97.0	266.7	0.75	81.4	69.4	43.
.50	490.6	103.4	262.5	0.75	83.2	72.9	24.
.00	491.5	109.2	257.5	0.75	84.8	74.2	0.
.50	490.6	114.4	251.6	0.75	86.3	72.9	24.
.00	487.8	119.0	244.7	0.75	87.6	69.4	43.
.50	482.8	123.0	236.7	0.75	88.7	64.7	57.
.00	475.4	126.4	227.2	0.74	89.4	59.4	67.
.50	464.9	128.9	215.6	0.74	89.9	53.6	74.
.00	450.8	130.4	201.1	0.74	90.0	47.7	80.
.50	432.2	130.5	182.6	0.72	89.8	41.7	85.
.00	406.3	128.7	157.3	0.70	89.4	35.7	89.
.50	346.5	122.4	108.2	0.67	88.7	29.6	85.
.00	280.1	111.5	55.4	0.60	87.7	23.6	81.
.50	206.5	98.1	1.4	0.48	86.6	17.6	77
.00	125.1	83.7	-43.1	0.32	85.3	11.8	73
.50	38.8	71.3	-65.3	0.15	84.0	6.0	69
.00	0.0	0.0	0.0	0.00	82.5	0.0	0
.50	0.0	0.0	0.0	0.00	81.1	0.0	0
.00	0.0	0.0	0.0	0.00	79.7	0.0	0
.50	0.0	0.0	0.0	0.00	78.4	0.0	0
.00	0.0	0.0	0.0	0.00	77.2	0.0	0
.50	0.0	0.0	0.0	0.00	76.1	0.0	0
.00	0.0	0.0	0.0	0.00	75.1	0.0	0
.50	0.0	0.0	0.0	0.00	74.1	0.0	0
.00	0.0	0.0	0.0	0.00	73.3	0.0	0
.50	0.0	0.0	0.0	0.00	72.6	0.0	0
.00	0.0	0.0	0.0	0.00	71.9	0.0	0

```
HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.=  10.01 BTU/HR-F-FT**2

INITIAL TEMP. =  68.03 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB =  10.50 INCHES


TIME INTERVAL =  0.50 HR

DISTANCE INTERVAL =  1.05 INCHES
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SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS										
58.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03
T = 0.50 HOURS										
72.45	69.21	68.35	68.11	68.05	68.04	68.03	68.03	68.04	68.06	68.13
T = 1.00 HOURS										
82.45	73.26	69.80	68.60	68.21	68.09	68.05	68.05	68.07	68.16	68.40
T = 1.50 HOURS										
97.81	80.81	73.16	69.98	68.74	68.28	68.13	68.11	68.17	68.37	68.83
T = 2.00 HOURS										
116.30	91.50	78.73	72.64	69.92	68.79	68.36	68.25	68.36	68.71	69.46
T = 2.50 HOURS										
135.97	104.32	86.30	76.73	71.98	69.78	68.84	68.56	68.68	69.20	70.29
T = 3.00 HOURS										
153.75	117.82	95.25	82.14	75.01	71.39	69.71	69.10	69.18	69.87	71.32
T = 3.50 HOURS										
158.55	130.58	104.75	88.48	78.92	73.66	71.03	69.96	69.92	70.74	72.55
T = 4.00 HOURS										
181.55	142.25	114.16	95.34	83.51	76.58	72.84	71.18	70.93	71.84	73.96
T = 4.50 HOURS										
192.93	152.97	123.23	102.37	88.58	80.02	75.14	72.79	72.25	73.17	75.55
T = 5.00 HOURS										
202.99	162.76	131.87	109.40	93.92	83.87	77.87	74.78	73.87	74.73	77.26
T = 5.50 HOURS										
211.89	171.70	140.04	116.31	99.40	88.03	80.95	77.12	75.78	76.49	79.06
T = 6.00 HOURS										
219.78	179.86	147.72	123.03	104.94	92.41	84.33	79.75	77.95	78.42	80.91
T = 6.50 HOURS										
225.77	187.30	154.92	129.51	110.47	96.92	87.93	82.63	80.32	80.48	82.74
T = 7.00 HOURS										
232.92	194.07	161.65	135.74	115.92	101.50	91.68	85.70	82.85	82.60	84.50
T = 7.50 HOURS										
238.28	200.19	167.92	141.69	121.26	106.10	95.55	88.89	85.48	84.74	86.14
T = 8.00 HOURS										
242.82	205.69	173.73	147.34	125.45	110.68	99.46	92.16	88.16	86.85	87.61
T = 8.50 HOURS										
245.49	210.52	179.06	152.68	131.47	115.19	103.37	95.46	90.83	88.87	88.87
T = 9.00 HOURS										
249.16	214.65	183.88	157.67	136.28	119.59	107.24	98.72	93.45	90.76	89.89

T = 9.50 HOURS										
250.65	217.96	188.14	152.29	140.85	123.85	111.02	101.92	95.97	92.49	90.54
T = 10.00 HOURS										
250.66	220.30	191.75	166.47	145.13	127.92	114.67	105.01	98.36	94.02	91.12
T = 10.50 HOURS										
243.62	221.40	194.58	170.13	149.07	131.76	118.16	107.94	100.58	95.34	91.32
T = 11.00 HOURS										
242.21	220.42	196.27	173.12	152.58	135.31	121.42	110.69	102.60	96.44	91.25
T = 11.50 HOURS										
230.97	216.43	196.28	175.16	155.52	138.49	124.43	113.22	104.41	97.30	90.94
T = 12.00 HOURS										
215.54	209.51	194.26	175.94	157.69	141.18	127.09	115.48	105.98	97.94	90.41
T = 12.50 HOURS										
200.33	200.35	190.27	175.29	158.92	143.26	129.34	117.43	107.30	98.35	89.70
T = 13.00 HOURS										
185.34	190.18	184.77	173.27	159.10	144.61	131.08	119.01	108.33	98.54	88.83
T = 13.50 HOURS										
174.23	180.73	178.59	170.20	158.31	145.18	132.25	120.18	109.06	98.52	87.85
T = 14.00 HOURS										
173.46	176.19	173.48	166.80	156.81	145.05	132.83	120.90	109.47	98.29	85.78

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 92.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 8 DECLINATION = 11.40 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 5.46 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.54 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	62.4	7.3	7.5	14.9	49.1	1.1	50
.50	140.7	30.9	17.2	48.1	121.9	2.4	124
.00	187.8	60.4	22.9	83.3	175.6	3.2	179
.50	217.4	91.2	26.5	117.8	193.5	3.7	197
.00	237.1	121.6	28.9	150.5	194.4	4.0	198
.50	250.9	150.2	30.5	180.8	188.3	4.3	192
.00	260.8	176.5	31.8	208.3	178.5	4.4	182
.50	268.0	199.7	32.7	232.4	167.2	4.5	171
.00	273.2	219.3	33.3	252.6	155.9	4.6	160
.50	277.0	235.0	33.8	268.8	145.9	4.7	150
.00	279.5	246.4	34.1	280.5	138.0	4.7	142
.50	280.9	253.4	34.3	287.6	133.1	4.8	137
.00	281.4	255.7	34.3	290.0	131.4	4.8	136
.50	280.9	253.4	34.3	287.6	133.1	4.8	137
.00	279.5	246.4	34.1	280.5	138.0	4.7	142
.50	277.0	235.0	33.8	268.8	145.9	4.7	150
.00	273.2	219.3	33.3	252.6	155.9	4.6	160
.50	268.0	199.7	32.7	232.4	167.2	4.5	171
.00	260.8	176.5	31.8	208.3	178.5	4.4	182
.50	250.9	150.2	30.6	180.8	188.3	4.3	192
.00	237.1	121.6	28.9	150.5	194.4	4.0	198
.50	217.4	91.2	26.5	117.8	193.5	3.7	197
.00	187.8	60.4	22.9	83.3	176.6	3.2	179
.50	140.7	30.9	17.2	48.1	121.9	2.4	124
.00	62.4	7.3	7.5	14.9	49.1	1.1	50
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	A_T	A
.00	0.0	0.0	0.0	0.00	73.9	0.0	0
.50	0.0	0.0	0.0	0.00	73.3	0.0	0.
.00	0.0	0.0	0.0	0.00	72.8	0.0	0.
.50	0.0	0.0	0.0	0.00	72.3	0.0	0
.00	0.0	0.0	0.0	0.00	71.8	0.0	0.
.50	0.0	0.0	0.0	0.00	71.3	0.0	0.
.00	0.0	0.0	0.0	0.00	70.9	0.0	0.
.50	0.0	0.0	0.0	0.00	70.5	0.0	0.
.00	0.0	0.0	0.0	0.00	70.3	0.0	0.
.50	0.0	0.0	0.0	0.00	70.1	0.0	0.
.00	0.0	0.0	0.0	0.00	70.0	0.0	0.
.50	0.0	0.0	0.0	0.00	70.1	0.0	0.
.00	65.0	0.1	11.2	0.17	70.4	6.7	80.
.50	172.3	2.8	57.9	0.35	70.9	12.7	85.
.00	263.1	9.7	123.8	0.51	71.5	18.8	89.
.50	315.0	19.7	173.6	0.61	72.4	24.8	86.
.00	348.9	30.4	205.3	0.68	73.5	30.8	81.
.50	373.4	40.7	223.9	0.71	74.9	36.8	76.
.00	391.2	50.3	234.0	0.73	76.4	42.6	70.
.50	404.1	58.8	238.5	0.74	78.0	48.2	63.
.00	413.1	66.4	239.6	0.74	79.8	53.4	55.
.50	419.3	73.2	238.5	0.74	81.6	58.0	45.
.00	423.3	79.2	235.9	0.74	83.4	61.9	32.
.50	425.5	84.6	232.4	0.75	85.2	64.4	17.
.00	426.2	89.4	228.2	0.75	86.8	65.3	0.
.50	425.5	93.7	223.3	0.75	88.3	64.4	17.
.00	423.3	97.6	217.5	0.74	89.6	61.9	32.
.50	419.3	101.1	210.6	0.74	90.7	58.0	45.
.00	413.1	103.9	202.1	0.74	91.4	53.4	55.
.50	404.1	106.1	191.3	0.74	91.9	48.2	63.
.00	391.2	107.2	177.0	0.73	92.0	42.6	70.
.50	373.4	107.0	157.7	0.71	91.8	36.8	76.
.00	348.9	104.7	131.0	0.68	91.4	30.8	81.
.50	315.0	99.5	93.7	0.61	90.7	24.8	86
.00	263.1	90.7	42.8	0.51	89.7	18.8	89.
.50	172.3	78.1	-17.3	0.35	88.6	12.7	85.
.00	65.0	65.1	-53.8	0.17	87.3	5.7	80.
.50	0.0	0.0	0.0	0.00	85.0	0.0	0.
.00	0.0	0.0	0.0	0.00	84.5	0.0	0
.50	0.0	0.0	0.0	0.00	83.1	0.0	0
.00	0.0	0.0	0.0	0.00	81.7	0.0	0
.50	0.0	0.0	0.0	0.00	80.4	0.0	0.
.00	0.0	0.0	0.0	0.00	79.2	0.0	0
.50	0.0	0.0	0.0	0.00	78.1	0.0	0.
.00	0.0	0.0	0.0	0.00	77.1	0.0	0
.50	0.0	0.0	0.0	0.00	76.1	0.0	0
.00	0.0	0.0	0.0	0.00	75.3	0.0	0
.50	0.0	0.0	0.0	0.00	74.6	0.0	0
.00	0.0	0.0	0.0	0.00	73.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 70.10 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T (HOURS)											
T = 0.00 HOURS	70.10	70.10	70.10	70.10	70.10	70.10	70.10	70.10	70.10	70.10	70.10
T = 0.50 HOURS	75.92	71.93	70.59	70.23	70.14	70.11	70.11	70.11	70.13	70.19	70.43
T = 1.00 HOURS	90.26	77.61	72.68	70.95	70.37	70.19	70.14	70.15	70.21	70.40	70.83
T = 1.50 HOURS	107.49	86.87	77.06	72.80	71.10	70.47	70.26	70.25	70.38	70.72	71.48
T = 2.00 HOURS	124.50	98.13	83.47	76.06	72.62	71.14	70.58	70.47	70.66	71.20	72.29
T = 2.50 HOURS	140.06	109.79	91.14	80.56	75.03	72.36	71.22	70.89	71.10	71.84	73.31
T = 3.00 HOURS	153.84	121.10	99.35	85.95	78.27	74.19	72.26	71.58	71.75	72.67	74.53
T = 3.50 HOURS	165.90	131.68	107.64	91.85	82.15	76.60	73.74	72.60	72.64	73.71	75.93
T = 4.00 HOURS	176.46	141.44	115.75	98.01	86.49	79.51	75.67	73.97	73.81	74.97	77.49
T = 4.50 HOURS	185.73	150.36	123.51	104.22	91.14	82.83	78.00	75.69	75.26	76.44	79.18
T = 5.00 HOURS	193.90	158.50	130.86	110.37	95.97	86.44	80.67	77.73	76.99	78.09	80.95
T = 5.50 HOURS	201.12	165.92	137.79	116.37	100.87	90.28	83.63	80.06	78.95	79.91	82.76
T = 6.00 HOURS	207.54	172.68	144.29	122.18	105.78	94.27	86.81	82.62	81.11	81.84	84.56
T = 6.50 HOURS	213.21	178.85	150.37	127.77	110.64	98.34	90.15	85.37	83.42	83.84	86.23
T = 7.00 HOURS	213.18	184.45	156.05	133.12	115.42	102.46	93.61	88.25	85.83	85.86	87.89
T = 7.50 HOURS	222.42	189.49	161.32	138.22	120.09	106.56	97.12	91.21	88.29	87.83	89.32
T = 8.00 HOURS	225.86	193.94	166.18	143.05	124.61	110.62	100.65	94.20	90.74	89.72	90.54
T = 8.50 HOURS	223.33	197.73	170.58	147.58	128.96	114.59	104.14	97.17	93.14	91.49	91.52
T = 9.00 HOURS	229.58	200.73	174.45	151.77	133.10	118.44	107.57	100.08	95.46	93.09	92.24

T = 9.50 HOURS										
229.21	202.73	177.70	155.56	136.98	122.13	110.88	102.89	97.64	94.50	92.68
T = 10.00 HOURS										
225.59	203.41	180.13	158.83	140.53	125.61	114.05	105.56	99.66	95.71	92.85
T = 10.50 HOURS										
220.87	202.27	181.49	161.46	143.68	128.82	117.01	108.05	101.50	96.69	92.75
T = 11.00 HOURS										
210.96	198.68	181.41	163.22	146.29	131.68	119.72	110.34	103.13	97.45	92.41
T = 11.50 HOURS										
195.43	192.06	179.45	163.84	148.21	134.09	122.12	112.38	104.54	97.98	91.35
T = 12.00 HOURS										
180.63	183.00	175.50	163.10	149.24	135.92	124.13	114.12	105.69	98.30	91.10
T = 12.50 HOURS										
168.61	173.74	170.23	161.06	149.29	137.08	125.66	115.52	106.58	98.40	90.21
T = 13.00 HOURS										
171.33	168.92	165.53	158.39	148.52	137.53	126.66	116.52	107.18	98.29	89.20
T = 13.50 HOURS										
167.87	166.81	162.52	155.97	147.33	137.41	127.15	117.12	107.48	98.00	88.12

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 81.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 9 DECLINATION = -0.61 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 6.03 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 17.97 HOUR

ENING ANGLE = 90.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	61.4	6.1	5.5	11.7	53.1	0.8	53
.00	152.6	31.0	14.0	45.0	119.8	2.0	121
.50	203.5	61.7	18.7	80.4	142.8	2.6	145
.00	233.9	93.1	21.5	114.6	144.5	3.0	147
.50	253.6	123.2	23.3	146.5	135.7	3.2	138
.00	266.9	150.9	24.5	175.4	121.8	3.4	125
.50	276.2	175.4	25.4	200.8	106.0	3.5	109
.00	282.8	196.2	26.0	222.2	90.5	3.6	94
.50	287.4	212.8	26.4	239.3	76.8	3.7	80
.00	290.4	224.9	26.7	251.7	66.1	3.7	69
.50	292.2	232.3	26.9	259.2	59.3	3.7	63
.00	292.7	234.8	26.9	261.7	57.0	3.7	60
.50	292.2	232.3	26.9	259.2	59.3	3.7	63
.00	290.4	224.9	26.7	251.7	66.1	3.7	69
.50	287.4	212.8	26.4	239.3	76.8	3.7	80
.00	282.8	196.2	26.0	222.2	90.5	3.6	94
.50	276.2	175.4	25.4	200.8	106.0	3.5	109
.00	266.9	150.9	24.5	175.4	121.8	3.4	125
.50	253.6	123.2	23.3	146.5	135.7	3.2	138
.00	233.9	93.1	21.5	114.6	144.5	3.0	147
.50	203.5	61.7	18.7	80.4	142.8	2.6	145
.00	152.6	31.0	14.0	45.0	119.8	2.0	121
.50	61.4	6.1	5.5	11.7	53.1	0.8	53
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	62.9	0.0	0
.50	0.0	0.0	0.0	0.00	62.3	0.0	0
.00	0.0	0.0	0.0	0.00	51.8	0.0	0
.50	0.0	0.0	0.0	0.00	61.3	0.0	0
.00	0.0	0.0	0.0	0.00	60.8	0.0	0
.50	0.0	0.0	0.0	0.00	60.3	0.0	0
.00	0.0	0.0	0.0	0.00	59.9	0.0	0
.50	0.0	0.0	0.0	0.00	59.5	0.0	0
.00	0.0	0.0	0.0	0.00	59.3	0.0	0
.50	0.0	0.0	0.0	0.00	59.1	0.0	0
.00	0.0	0.0	0.0	0.00	59.0	0.0	0
.50	0.0	0.0	0.0	0.00	59.1	0.0	0
.00	0.0	0.0	0.0	0.00	59.4	0.0	0
.50	65.6	0.2	9.4	0.15	59.9	5.7	85
.00	165.7	2.1	51.8	0.32	60.5	11.7	80
.50	225.8	7.3	101.6	0.48	61.4	17.6	75
.00	262.1	14.5	141.2	0.59	62.5	23.4	70
.50	285.4	22.2	166.4	0.66	63.9	29.1	65
.00	300.7	29.5	180.3	0.70	65.4	34.4	59
.50	310.4	36.0	186.9	0.72	67.0	39.4	52
.00	316.3	41.7	189.0	0.73	68.8	43.9	44
.50	319.7	46.5	188.6	0.74	70.6	47.8	34
.00	321.4	50.7	186.7	0.74	72.4	50.8	24
.50	322.2	54.4	184.1	0.74	74.2	52.7	12
.00	322.4	57.7	181.1	0.74	75.8	53.3	0
.50	322.2	60.7	177.8	0.74	77.3	52.7	12
.00	321.4	63.5	173.9	0.74	78.6	50.8	24
.50	319.7	66.0	169.1	0.74	79.7	47.8	34
.00	316.3	68.2	162.5	0.73	80.4	43.9	44
.50	310.4	69.8	153.1	0.72	80.9	39.4	52
.00	300.7	70.5	139.3	0.70	81.0	34.4	59
.50	285.4	69.8	118.8	0.66	80.8	29.1	65
.00	262.1	67.1	88.5	0.59	80.4	23.4	70
.50	225.8	61.6	47.3	0.48	79.7	17.6	75
.00	165.7	53.5	0.4	0.32	78.7	11.7	80
.50	65.6	44.6	-35.0	0.15	77.6	5.7	85
.00	0.0	0.0	0.0	0.00	76.3	0.0	0
.50	0.0	0.0	0.0	0.00	75.0	0.0	0
.00	0.0	0.0	0.0	0.00	73.5	0.0	0
.50	0.0	0.0	0.0	0.00	72.1	0.0	0
.00	0.0	0.0	0.0	0.00	70.7	0.0	0
.50	0.0	0.0	0.0	0.00	69.4	0.0	0
.00	0.0	0.0	0.0	0.00	68.2	0.0	0
.50	0.0	0.0	0.0	0.00	67.1	0.0	0
.00	0.0	0.0	0.0	0.00	66.1	0.0	0
.50	0.0	0.0	0.0	0.00	65.1	0.0	0
.00	0.0	0.0	0.0	0.00	64.3	0.0	0
.50	0.0	0.0	0.0	0.00	63.6	0.0	0
.00	0.0	0.0	0.0	0.00	62.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 59.41 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T											
T = 0.00 HOURS	59.41	59.41	59.41	59.41	59.41	59.41	59.41	59.41	59.41	59.41	59.41
T = 0.50 HOURS	65.40	61.01	59.84	59.52	59.44	59.42	59.41	59.42	59.44	59.55	59.92
T = 1.00 HOURS	75.45	65.83	61.62	60.13	59.64	59.48	59.45	59.47	59.57	59.86	60.49
T = 1.50 HOURS	90.13	73.37	65.26	61.70	60.26	59.73	59.57	59.60	59.81	60.30	61.33
T = 2.00 HOURS	103.78	82.41	70.46	64.38	61.53	60.31	59.87	59.85	60.16	60.91	62.33
T = 2.50 HOURS	115.16	91.76	76.65	68.04	63.52	61.34	60.45	60.29	60.68	61.68	63.54
T = 3.00 HOURS	125.95	100.75	83.23	72.39	66.16	62.87	61.37	60.97	61.39	62.63	64.91
T = 3.50 HOURS	135.25	109.07	89.84	77.14	69.32	64.88	62.67	61.94	62.33	63.77	65.44
T = 4.00 HOURS	144.28	116.65	96.23	82.06	72.84	67.29	64.33	63.21	63.50	65.09	68.08
T = 4.50 HOURS	151.26	123.52	102.30	86.99	76.59	70.02	66.32	64.76	64.91	66.57	69.81
T = 5.00 HOURS	157.39	129.74	108.02	91.84	80.46	72.99	68.59	66.59	66.53	68.20	71.56
T = 5.50 HOURS	162.85	135.41	113.39	96.56	84.38	76.13	71.09	68.64	68.34	69.93	73.30
T = 6.00 HOURS	167.73	140.60	118.43	101.12	88.30	79.38	73.75	70.87	70.29	71.72	74.97
T = 6.50 HOURS	172.09	145.35	123.15	105.51	92.18	82.69	76.54	73.23	72.34	73.53	76.51
T = 7.00 HOURS	175.90	149.68	127.56	109.72	95.99	86.03	79.41	75.68	74.43	75.29	77.88
T = 7.50 HOURS	179.02	153.54	131.67	113.73	99.71	89.35	82.31	78.17	76.53	76.97	79.04
T = 8.00 HOURS	181.25	156.84	135.41	117.52	103.31	92.63	85.20	80.65	78.58	78.53	79.96
T = 8.50 HOURS	182.20	159.39	138.70	121.04	106.76	95.83	88.05	83.10	80.55	79.93	80.62
T = 9.00 HOURS	181.29	160.89	141.38	124.21	110.00	98.91	90.82	85.46	82.41	81.14	81.00

Sept

T = 9.50 HOURS
177.70 160.90 143.22 125.89 112.95 101.81 93.47 87.70 84.12 82.16 81.11

T = 10.00 HOURS
170.59 158.85 143.88 128.89 115.52 104.47 95.95 89.80 85.66 82.96 80.96

T = 10.50 HOURS
159.85 154.33 143.02 129.99 117.54 106.80 98.19 91.70 87.00 83.55 80.57

T = 11.00 HOURS
147.45 147.70 140.50 129.98 118.86 108.68 100.14 93.36 88.13 83.92 79.96

T = 11.50 HOURS
137.61 140.58 136.79 128.89 119.39 110.02 101.70 94.75 89.03 84.07 79.17

T = 12.00 HOURS
133.58 136.57 133.30 127.18 119.22 110.79 102.84 95.81 89.66 84.02 78.23

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 77.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 10 DECLINATION = -12.10 DEGREES

TITUDE = 35.07 DEGREES SUNRISE = 6.57 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 17.43 HOUR

ENING ANGLE = 30.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	52.6	4.3	3.8	8.1	34.6	0.8	35
.50	154.6	27.7	11.3	39.0	92.6	2.2	94
.00	209.8	57.0	15.3	72.3	113.2	3.0	116
.50	241.7	86.4	17.6	104.1	116.6	3.5	120
.00	261.8	114.0	19.1	133.1	112.1	3.8	115
.50	275.1	138.5	20.1	158.6	104.1	4.0	108
.00	284.2	159.5	20.7	180.2	95.2	4.1	99
.50	290.4	176.2	21.2	197.4	86.9	4.2	91
.00	294.4	188.4	21.5	209.9	80.2	4.3	84
.50	296.6	195.8	21.7	217.5	75.9	4.3	80
.00	297.4	198.3	21.7	220.0	74.5	4.3	78
.50	296.6	195.8	21.7	217.5	75.9	4.3	80
.00	294.4	188.4	21.5	209.9	80.2	4.3	84
.50	290.4	176.2	21.2	197.4	85.9	4.2	91
.00	284.2	159.5	20.7	180.2	95.2	4.1	99
.50	275.1	138.5	20.1	158.6	104.1	4.0	108
.00	261.8	114.0	19.1	133.1	112.1	3.8	115
.50	241.7	86.4	17.6	104.1	115.6	3.5	120
.00	209.8	57.0	15.3	72.3	113.2	3.0	116
.50	154.6	27.7	11.3	39.0	92.6	2.2	94
.00	52.6	4.3	3.8	8.1	34.6	0.8	35
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	58.9	0.0	0
.50	0.0	0.0	0.0	0.00	58.3	0.0	0
.00	0.0	0.0	0.0	0.00	57.8	0.0	0
.50	0.0	0.0	0.0	0.00	57.3	0.0	0
.00	0.0	0.0	0.0	0.00	56.8	0.0	0
.50	0.0	0.0	0.0	0.00	56.3	0.0	0
.00	0.0	0.0	0.0	0.00	55.9	0.0	0
.50	0.0	0.0	0.0	0.00	55.5	0.0	0
.00	0.0	0.0	0.0	0.00	55.3	0.0	0
.50	0.0	0.0	0.0	0.00	55.1	0.0	0
.00	0.0	0.0	0.0	0.00	55.0	0.0	0
.50	0.0	0.0	0.0	0.00	55.1	0.0	0
.00	0.0	0.0	0.0	0.00	55.4	0.0	0
.50	0.0	0.0	0.0	0.00	55.9	0.0	0
.00	43.5	0.2	4.8	0.12	56.5	4.7	71
.50	133.8	1.0	36.7	0.28	57.4	10.3	66
.00	188.6	4.6	77.7	0.44	58.5	15.8	61
.50	224.2	9.9	113.8	0.55	59.9	21.0	56
.00	249.0	16.0	139.9	0.63	61.4	25.8	50
.50	266.7	22.2	156.7	0.67	63.0	30.2	43
.00	279.5	27.9	166.7	0.70	64.8	34.1	36
.50	288.5	33.1	172.0	0.71	66.6	37.4	28
.00	294.4	37.7	174.0	0.72	68.4	39.8	19
.50	297.7	41.8	173.6	0.72	70.2	41.3	9
.00	298.8	45.4	171.2	0.72	71.8	41.8	0
.50	297.7	48.4	167.0	0.72	73.3	41.3	9
.00	294.4	50.9	160.9	0.72	74.6	39.8	19
.50	288.5	52.8	152.4	0.71	75.7	37.4	28
.00	279.5	53.9	140.7	0.70	76.4	34.1	36
.50	266.7	54.1	124.8	0.67	76.9	30.2	43
.00	249.0	53.0	103.0	0.63	77.0	25.8	50
.50	224.2	50.1	73.7	0.55	76.8	21.0	56
.00	188.6	45.2	37.1	0.44	76.4	15.8	61
.50	133.8	38.7	-0.9	0.28	75.7	10.3	66
.00	43.5	32.0	-26.9	0.12	74.7	4.7	71
.50	0.0	0.0	0.0	0.00	73.6	0.0	0
.00	0.0	0.0	0.0	0.00	72.3	0.0	0
.50	0.0	0.0	0.0	0.00	71.0	0.0	0
.00	0.0	0.0	0.0	0.00	69.5	0.0	0
.50	0.0	0.0	0.0	0.00	68.1	0.0	0
.00	0.0	0.0	0.0	0.00	66.7	0.0	0
.50	0.0	0.0	0.0	0.00	65.4	0.0	0
.00	0.0	0.0	0.0	0.00	64.2	0.0	0
.50	0.0	0.0	0.0	0.00	63.1	0.0	0
.00	0.0	0.0	0.0	0.00	62.1	0.0	0
.50	0.0	0.0	0.0	0.00	61.1	0.0	0
.00	0.0	0.0	0.0	0.00	60.3	0.0	0
.50	0.0	0.0	0.0	0.00	59.6	0.0	0
.00	0.0	0.0	0.0	0.00	58.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 55.93 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS	55.93	55.93	55.93	55.93	55.93	55.93	55.93	55.93	55.93	55.93	55.93
T = 0.50 HOURS	59.95	57.01	56.22	56.01	55.96	55.94	55.94	55.95	55.98	56.12	56.63
T = 1.00 HOURS	63.46	60.54	57.50	56.44	56.10	55.99	55.97	56.01	56.15	56.53	57.37
T = 1.50 HOURS	79.68	65.48	60.27	57.60	56.55	56.18	56.09	56.17	56.45	57.09	58.40
T = 2.00 HOURS	91.58	73.99	64.44	59.70	57.53	56.63	56.35	56.44	56.88	57.83	59.57
T = 2.50 HOURS	102.94	82.15	69.63	62.68	59.12	57.46	56.86	56.89	57.47	58.72	60.94
T = 3.00 HOURS	113.27	90.30	75.37	66.36	61.31	58.74	57.66	57.56	58.23	59.77	62.44
T = 3.50 HOURS	122.45	98.10	81.32	70.50	64.01	60.45	58.80	58.47	59.20	60.98	64.05
T = 4.00 HOURS	130.55	105.39	87.23	74.91	67.10	62.55	60.28	59.66	60.36	62.34	65.75
T = 4.50 HOURS	137.63	112.09	92.96	79.44	70.47	64.98	62.08	61.12	61.74	63.83	67.46
T = 5.00 HOURS	143.76	118.19	98.42	83.97	74.02	67.68	64.15	62.81	63.29	65.41	69.16
T = 5.50 HOURS	148.97	123.68	103.56	88.41	77.66	70.57	66.45	64.72	65.00	67.06	70.78
T = 6.00 HOURS	153.24	128.53	108.33	92.72	81.32	73.59	68.92	65.80	66.82	68.72	72.28
T = 6.50 HOURS	155.49	132.69	112.69	96.82	84.95	76.68	71.51	68.99	68.72	70.36	73.61
T = 7.00 HOURS	158.55	136.08	116.57	100.67	88.49	79.78	74.18	71.26	70.63	71.93	74.74
T = 7.50 HOURS	159.13	138.53	119.87	104.20	91.88	82.85	76.86	73.55	72.53	73.38	75.63
T = 8.00 HOURS	157.79	139.81	122.46	107.31	95.05	85.82	79.51	75.82	74.36	74.70	76.26
T = 8.50 HOURS	153.98	139.60	124.15	109.90	97.92	88.64	82.07	78.01	76.09	75.83	76.62
T = 9.00 HOURS	147.26	137.52	124.70	111.79	100.38	91.21	84.48	80.08	77.67	76.77	76.71

T											
T = 9.50 HOURS	137.92	133.44	123.89	112.83	102.32	93.47	86.69	81.98	79.09	77.50	76.54
T = 10.00 HOURS	127.81	127.84	121.75	112.90	103.63	95.31	88.61	83.67	80.29	78.01	75.13
T = 10.50 HOURS	120.14	122.11	118.73	112.09	104.24	95.66	90.18	85.09	81.26	78.29	75.49
T = 11.00 HOURS	120.46	118.82	115.95	110.80	104.27	97.51	91.37	86.20	81.98	78.35	74.68

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 62.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 11 DECLINATION = -20.64 DEGREES

TITUDE = 36.07 DEGREES SUNRISE = 6.93 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 17.07 HOUR

ENING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	62.9	5.2	4.0	9.1	33.3	1.1	34
.00	161.7	27.6	10.2	37.8	80.2	2.8	83
.50	214.8	54.3	13.5	67.9	99.8	3.7	103
.00	245.5	80.4	15.5	95.8	105.9	4.2	111
.50	264.8	104.0	16.7	120.6	108.3	4.5	112
.00	277.4	124.2	17.5	141.7	107.1	4.8	111
.50	285.8	140.4	18.0	158.4	104.9	4.9	109
.00	291.1	152.3	18.3	170.6	102.9	5.0	107
.50	294.1	159.5	18.5	178.0	101.4	5.0	106
.00	295.0	161.9	18.6	180.5	100.9	5.1	106
.50	294.1	159.5	18.5	178.0	101.4	5.0	106
.00	291.1	152.3	18.3	170.6	102.9	5.0	107
.50	285.8	140.4	18.0	158.4	104.9	4.9	109
.00	277.4	124.2	17.5	141.7	107.1	4.8	111
.50	264.8	104.0	16.7	120.6	108.3	4.5	112
.00	245.5	80.4	15.5	95.8	105.9	4.2	111
.50	214.8	54.3	13.5	67.9	99.8	3.7	103
.00	161.7	27.6	10.2	37.8	80.2	2.8	83
.50	62.9	5.2	4.0	9.1	33.3	1.1	34
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	43.9	0.0	0
.50	0.0	0.0	0.0	0.00	43.3	0.0	0
.00	0.0	0.0	0.0	0.00	42.8	0.0	0
.50	0.0	0.0	0.0	0.00	42.3	0.0	0
.00	0.0	0.0	0.0	0.00	41.8	0.0	0
.50	0.0	0.0	0.0	0.00	41.3	0.0	0
.00	0.0	0.0	0.0	0.00	40.9	0.0	0
.50	0.0	0.0	0.0	0.00	40.5	0.0	0
.00	0.0	0.0	0.0	0.00	40.3	0.0	0
.50	0.0	0.0	0.0	0.00	40.1	0.0	0
.00	0.0	0.0	0.0	0.00	40.0	0.0	0
.50	0.0	0.0	0.0	0.00	40.1	0.0	0
.00	0.0	0.0	0.0	0.00	40.4	0.0	0
.50	0.0	0.0	0.0	0.00	40.9	0.0	0
.00	0.0	0.0	0.0	0.00	41.5	0.0	0
.50	43.4	0.4	4.8	0.12	42.4	4.7	60
.00	120.8	0.5	31.8	0.27	43.5	9.8	55
.50	171.3	3.1	66.5	0.41	44.9	14.7	50
.00	206.9	7.2	99.4	0.52	46.4	19.1	44
.50	233.4	12.2	125.3	0.59	48.0	23.1	38
.00	253.5	17.5	143.7	0.64	49.8	26.6	31
.50	268.3	22.6	155.6	0.66	51.6	29.4	24
.00	278.5	27.3	162.2	0.68	53.4	31.5	16
.50	284.5	31.6	164.5	0.69	55.2	32.9	8
.00	286.5	35.2	163.0	0.69	55.8	33.3	0
.50	284.5	38.1	157.9	0.69	58.3	32.9	8
.00	278.5	40.3	149.2	0.68	59.6	31.5	16
.50	268.3	41.5	136.6	0.66	60.7	29.4	24
.00	253.5	41.7	119.4	0.64	61.4	26.6	31
.50	233.4	40.6	96.9	0.59	51.9	23.1	38
.00	206.9	37.9	68.6	0.52	62.0	19.1	44
.50	171.3	33.8	35.9	0.41	61.8	14.7	50
.00	120.8	28.6	3.7	0.27	61.4	9.8	55
.50	43.4	23.5	-18.3	0.12	60.7	4.7	60
.00	0.0	0.0	0.0	0.00	59.7	0.0	0
.50	0.0	0.0	0.0	0.00	58.6	0.0	0
.00	0.0	0.0	0.0	0.00	57.3	0.0	0
.50	0.0	0.0	0.0	0.00	56.0	0.0	0
.00	0.0	0.0	0.0	0.00	54.5	0.0	0
.50	0.0	0.0	0.0	0.00	53.1	0.0	0
.00	0.0	0.0	0.0	0.00	51.7	0.0	0
.50	0.0	0.0	0.0	0.00	50.4	0.0	0
.00	0.0	0.0	0.0	0.00	49.2	0.0	0
.50	0.0	0.0	0.0	0.00	48.1	0.0	0
.00	0.0	0.0	0.0	0.00	47.1	0.0	0
.50	0.0	0.0	0.0	0.00	46.1	0.0	0
.00	0.0	0.0	0.0	0.00	45.3	0.0	0
.50	0.0	0.0	0.0	0.00	44.6	0.0	0
.00	0.0	0.0	0.0	0.00	43.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 41.41 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T (HOURS)											
T = 0.00 HOURS	41.41	41.41	41.41	41.41	41.41	41.41	41.41	41.41	41.41	41.41	41.41
T = 0.50 HOURS	44.90	42.35	41.66	41.48	41.43	41.42	41.42	41.44	41.50	41.73	42.59
T = 1.00 HOURS	52.16	45.37	42.76	41.85	41.56	41.47	41.47	41.53	41.75	42.30	43.37
T = 1.50 HOURS	61.91	50.49	45.14	42.85	41.96	41.64	41.60	41.74	42.14	42.98	44.67
T = 2.00 HOURS	72.67	57.13	48.79	44.67	42.81	42.06	41.88	42.07	42.66	43.86	45.95
T = 2.50 HOURS	83.37	64.56	53.42	47.31	44.21	42.82	42.38	42.56	43.34	44.86	47.49
T = 3.00 HOURS	93.38	72.21	58.68	50.62	45.18	43.98	43.16	43.26	44.17	46.01	49.06
T = 3.50 HOURS	102.44	79.68	64.24	54.44	48.65	45.56	44.25	44.19	45.19	47.29	50.74
T = 4.00 HOURS	110.39	86.73	69.85	58.57	51.52	47.52	45.66	45.37	46.39	48.68	52.42
T = 4.50 HOURS	117.16	93.19	75.33	62.85	54.69	49.81	47.37	46.79	47.75	50.16	54.09
T = 5.00 HOURS	122.66	98.92	80.52	67.15	58.04	52.36	49.35	48.44	49.27	51.70	55.68
T = 5.50 HOURS	125.78	103.82	85.31	71.34	61.49	55.11	51.54	50.27	50.92	53.25	57.15
T = 6.00 HOURS	129.37	107.75	89.56	75.32	64.93	57.97	53.90	52.25	52.64	54.79	58.45
T = 6.50 HOURS	130.21	110.57	93.16	78.98	68.28	60.87	56.35	54.32	54.41	56.26	59.55
T = 7.00 HOURS	129.01	112.08	95.96	82.21	71.45	63.73	58.84	56.44	56.17	57.64	60.42
T = 7.50 HOURS	125.45	112.06	97.81	84.89	74.33	66.48	61.30	58.55	57.87	58.87	61.03
T = 8.00 HOURS	119.43	110.31	98.53	86.87	76.82	69.02	63.66	60.58	59.48	59.94	61.36
T = 8.50 HOURS	111.40	106.85	98.02	88.04	78.80	71.28	65.84	62.48	60.95	60.81	61.43
T = 9.00 HOURS	102.88	102.16	96.35	88.34	80.21	73.16	67.78	64.20	62.24	61.47	61.24

T = 9.50 HOURS

95.33	97.37	93.94	87.87	80.99	74.60	69.41	65.69	63.31	61.90	60.81

T = 10.00 HOURS

95.92	94.46	91.67	85.96	81.25	75.59	70.69	65.89	64.15	62.10	60.15

T = 10.50 HOURS

93.65	92.83	90.08	85.05	81.20	76.19	71.61	67.79	64.72	62.08	59.31

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = BLACK

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.90

ABSORPTANCE OF THE PLATE = 0.95

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 54.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

ONTH = 12 DECLINATION = -23.44 DEGREES

ATITUDE = 35.07 DEGREES SUNRISE = 7.03 HOUR

ONGITUDE = 97.05 DEGREES SUNSET = 16.97 HOUR

PENING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
2.00	0.0	0.0	0.0	0.0	0.0	0.0	0
2.50	0.0	0.0	0.0	0.0	0.0	0.0	0
3.00	0.0	0.0	0.0	0.0	0.0	0.0	0
3.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	22.3	1.1	1.3	2.4	10.8	0.3	11
.00	138.2	18.9	7.9	26.8	62.2	2.1	64
.50	203.4	44.2	11.6	55.8	84.9	3.2	88
.00	239.7	69.5	13.7	83.2	92.8	3.7	96
.50	261.8	92.7	14.9	107.6	94.2	4.1	98
.00	276.1	112.6	15.7	128.4	92.8	4.3	97
.50	285.4	128.7	16.3	144.9	90.5	4.4	94
.00	291.2	140.4	16.6	157.0	88.2	4.5	92
.50	294.5	147.5	16.8	164.3	85.6	4.6	91
.00	295.5	149.9	16.8	166.8	85.0	4.6	90
.50	294.5	147.5	16.8	164.3	85.6	4.6	91
.00	291.2	140.4	16.6	157.0	88.2	4.5	92
.50	285.4	128.7	16.3	144.9	90.5	4.4	94
.00	276.1	112.6	15.7	128.4	92.8	4.3	97
.50	261.8	92.7	14.9	107.6	94.2	4.1	98
.00	239.7	69.5	13.7	83.2	92.8	3.7	96
.50	203.4	44.2	11.6	55.8	84.9	3.2	88
.00	138.2	18.9	7.9	26.8	62.2	2.1	64
.50	22.3	1.1	1.3	2.4	10.8	0.3	11
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

IR	WT	QTLS	WIN	TAPH	TAF	ALT	AZ
00	0.0	0.0	0.0	0.00	35.9	0.0	0.
50	0.0	0.0	0.0	0.00	35.3	0.0	0.
00	0.0	0.0	0.0	0.00	34.8	0.0	0.
50	0.0	0.0	0.0	0.00	34.3	0.0	0.
00	0.0	0.0	0.0	0.00	33.8	0.0	0.
50	0.0	0.0	0.0	0.00	33.3	0.0	0.
00	0.0	0.0	0.0	0.00	32.9	0.0	0.
50	0.0	0.0	0.0	0.00	32.5	0.0	0.
00	0.0	0.0	0.0	0.00	32.3	0.0	0.
50	0.0	0.0	0.0	0.00	32.1	0.0	0.
00	0.0	0.0	0.0	0.00	32.0	0.0	0.
50	0.0	0.0	0.0	0.00	32.1	0.0	0.
00	0.0	0.0	0.0	0.00	32.4	0.0	0.
50	0.0	0.0	0.0	0.00	32.9	0.0	0.
00	0.0	0.0	0.0	0.00	33.5	0.0	0.
50	13.5	0.3	0.6	0.07	34.4	2.8	58.
00	91.1	0.0	19.0	0.21	35.5	7.8	53.
50	143.8	1.5	48.5	0.35	36.9	12.5	48.
00	179.7	4.5	78.9	0.46	38.4	15.9	42.
50	205.9	8.4	104.4	0.55	40.0	20.7	36.
00	225.5	12.7	123.3	0.60	41.8	24.1	30.
50	239.8	17.0	136.0	0.64	43.6	26.8	23.
00	249.7	21.0	143.4	0.66	45.4	28.8	15.
50	255.5	24.7	146.3	0.67	47.2	30.1	8.
00	257.4	27.7	145.4	0.67	48.8	30.5	0.
50	255.5	30.2	140.8	0.67	50.3	30.1	8.
00	249.7	32.0	132.5	0.66	51.6	28.8	15.
50	239.8	32.9	120.1	0.64	52.7	26.8	23.
00	225.5	32.8	103.3	0.60	53.4	24.1	30.
50	205.9	31.5	81.3	0.55	53.9	20.7	36.
00	179.7	29.0	54.4	0.46	54.0	15.9	42.
50	143.8	25.3	24.7	0.35	53.8	12.5	48.
00	91.1	21.0	-2.0	0.21	53.4	7.8	53.
50	13.5	17.1	-16.2	0.07	52.7	2.8	58.
00	0.0	0.0	0.0	0.00	51.7	0.0	0.
50	0.0	0.0	0.0	0.00	50.6	0.0	0.
00	0.0	0.0	0.0	0.00	49.3	0.0	0.
50	0.0	0.0	0.0	0.00	48.0	0.0	0.
00	0.0	0.0	0.0	0.00	46.5	0.0	0.
50	0.0	0.0	0.0	0.00	45.1	0.0	0.
00	0.0	0.0	0.0	0.00	43.7	0.0	0.
50	0.0	0.0	0.0	0.00	42.4	0.0	0.
00	0.0	0.0	0.0	0.00	41.2	0.0	0.
50	0.0	0.0	0.0	0.00	40.1	0.0	0.
00	0.0	0.0	0.0	0.00	39.1	0.0	0.
50	0.0	0.0	0.0	0.00	38.1	0.0	0.
00	0.0	0.0	0.0	0.00	37.3	0.0	0.
50	0.0	0.0	0.0	0.00	36.6	0.0	0.
00	0.0	0.0	0.0	0.00	35.9	0.0	0.

```
HEAT CAPACITY = 0.24 BTU/LBM-F
DENSITY = 145.00 L3M/FT**3
THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F
HEAT TRANSFER CJEFF.=  10.01 BTU/HR-F-FT**2
INITIAL TEMP. =  33.57 F
NO. OF INTERIJR NODES = 10
DEPTH OF SLAB =  10.50 INCHES


TIME INTERVAL =  0.50 HR
DISTANCE INTERVAL =  1.05 INCHES
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SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T											
T = 0.00 HOURS	33.57	33.57	33.57	33.57	33.57	33.57	33.57	33.57	33.57	33.57	33.57
T = 0.50 HOURS	35.40	34.06	33.70	33.61	33.58	33.58	33.58	33.59	33.64	33.84	34.57
T = 1.00 HOURS	40.72	36.05	34.39	33.83	33.65	33.61	33.61	33.68	33.87	34.38	35.42
T = 1.50 HOURS	48.73	39.99	36.10	34.52	33.92	33.73	33.72	33.86	34.24	35.05	35.67
T = 2.00 HOURS	58.11	45.48	38.96	35.88	34.54	34.03	33.94	34.16	34.75	35.91	37.98
T = 2.50 HOURS	67.76	51.91	42.81	37.99	35.63	34.62	34.35	34.51	35.40	36.90	39.49
T = 3.00 HOURS	75.97	58.72	47.34	40.75	37.23	35.55	35.00	35.24	36.20	38.04	41.07
T = 3.50 HOURS	85.39	65.49	52.25	44.03	39.30	36.87	35.93	36.07	37.16	39.29	42.74
T = 4.00 HOURS	92.80	71.93	57.27	47.65	41.77	38.54	37.15	37.13	38.29	40.65	44.41
T = 4.50 HOURS	99.11	77.85	62.22	51.45	44.54	40.53	38.66	38.42	39.57	42.09	46.07
T = 5.00 HOURS	104.19	83.11	66.93	55.30	47.52	42.78	40.41	39.91	41.00	43.57	47.64
T = 5.50 HOURS	107.94	87.58	71.27	59.08	50.60	45.22	42.37	41.58	42.53	45.07	49.10
T = 6.00 HOURS	110.18	91.13	75.11	62.67	53.69	47.79	44.49	43.38	44.14	46.54	50.38
T = 6.50 HOURS	110.70	93.58	78.33	65.96	56.70	50.40	46.71	45.28	45.79	47.94	51.46
T = 7.00 HOURS	109.23	94.76	80.79	68.84	59.55	52.98	48.97	47.22	47.42	49.25	52.31
T = 7.50 HOURS	105.55	94.47	82.32	71.19	62.12	55.46	51.21	49.15	49.01	50.41	52.89
T = 8.00 HOURS	99.73	92.59	82.79	72.89	64.32	57.75	53.34	51.01	50.49	51.40	53.21
T = 8.50 HOURS	92.45	89.28	82.15	73.83	66.05	59.76	55.32	52.75	51.84	52.20	53.26
T = 9.00 HOURS	85.39	85.14	80.56	74.00	67.25	61.42	57.06	54.31	53.01	52.79	53.05

T = 9.50 HOURS

80.45	81.22	78.48	73.55	67.92	62.69	58.51	55.64	53.97	53.16	52.59

T = 10.00 HOURS

80.06	78.90	76.61	72.79	68.14	63.56	59.65	55.71	54.70	53.30	51.92

TABLE II

Theoretical maximum temperature at 2.10 inches depth and optimized opening angle

MONTH	TEMP. (°F)	ANGLE °
January *	89.3	70.0
January (Natural Surface)	81.8	70.0
February	128.8	70.0
February (Natural Surface)	118.1	70.0
March	159.1	70.0
March (Natural Surface)	145.1	70.0
April	169.2	90.0
April (N = 1)**	143.6	90.0
April (Natural Surface)	155.2	90.0
May	188.3	90.0
May (Natural Surface)	172.8	90.0
June	197.4	90.0
June (Natural Surface)	181.6	90.0
July	196.3	90.0
July (Natural Surface)	181.4	90.0
August	181.5	90.0
August (Natural Surface)	168.4	90.0
September	143.9	90.0
September (N = 1)	137.8	90.0
September (Natural Surface)	133.7	90.0
October	124.7	80.0
November	98.5	70.0
December	82.8	70.0

* If surface color not indicated assume black surface

** N is the number of glass covers, if not indicated, N = 2

APPENDIX F

Effect of surface blackening

Effect of number of glazing material

TABLE I

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = NATURAL CONCRETE

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.78

ABSORPTANCE OF THE PLATE = 0.78

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 50.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

H = 1 DECLINATION = -20.14 DEGREES

TUDE = 36.07 DEGREES SUNRISE = 6.91 HOUR

ITUDE = 97.65 DEGREES SUNSET = 17.09 HOUR

TING ANGLE = 70.0 DEGREES LOCATION = STILLWATER

IDN	ID	IDIF	WD	IDR	IDIFR	WS
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
77.3	6.8	4.5	11.3	41.5	1.2	42.
174.7	30.9	10.1	41.0	88.1	2.8	90.
225.5	58.5	13.1	71.6	106.7	3.6	110.
254.9	85.1	14.8	99.9	113.1	4.0	117.
273.3	109.2	15.9	125.0	114.1	4.3	118.
285.4	129.7	16.6	146.3	112.6	4.5	117.
293.3	146.2	17.0	163.2	110.3	4.6	114.
298.4	158.3	17.3	175.6	108.1	4.7	112.
301.2	165.6	17.5	183.1	106.6	4.7	111.
302.1	168.0	17.5	185.6	106.1	4.8	110.
301.2	165.6	17.5	183.1	106.6	4.7	111.
298.4	158.3	17.3	175.6	108.1	4.7	112.
293.3	146.2	17.0	163.2	110.3	4.6	114.
285.4	129.7	16.6	146.3	112.6	4.5	117.
273.3	109.2	15.9	125.0	114.1	4.3	118.
254.9	85.1	14.8	99.9	113.1	4.0	117.
225.5	58.5	13.1	71.6	106.7	3.6	110.
174.7	30.9	10.1	41.0	88.1	2.8	90.
77.3	6.8	4.5	11.3	41.5	1.2	42.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.
0.0	0.0	0.0	0.0	0.0	0.0	0.

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	31.9	0.0	0.
.50	0.0	0.0	0.0	0.00	31.3	0.0	0.
.00	0.0	0.0	0.0	0.00	30.8	0.0	0.
.50	0.0	0.0	0.0	0.00	30.3	0.0	0.
.00	0.0	0.0	0.0	0.00	29.8	0.0	0.
.50	0.0	0.0	0.0	0.00	29.3	0.0	0.
.00	0.0	0.0	0.0	0.00	28.9	0.0	0.
.50	0.0	0.0	0.0	0.00	28.5	0.0	0.
.00	0.0	0.0	0.0	0.00	28.3	0.0	0.
.50	0.0	0.0	0.0	0.00	28.1	0.0	0.
.00	0.0	0.0	0.0	0.00	28.0	0.0	0.
.50	0.0	0.0	0.0	0.00	28.1	0.0	0.
.00	0.0	0.0	0.0	0.00	28.4	0.0	0.
.50	0.0	0.0	0.0	0.00	28.9	0.0	0.
.00	0.0	0.0	0.0	0.00	29.5	0.0	0.
.50	54.0	0.3	5.5	0.11	30.4	5.0	60.
.00	131.8	0.4	31.0	0.24	31.5	10.2	55.
.50	181.8	2.6	62.3	0.36	32.9	15.0	50.
.00	217.1	6.0	91.3	0.45	34.4	19.5	44.
.50	243.4	10.1	114.0	0.51	36.0	23.5	38.
.00	263.4	14.3	130.2	0.55	37.8	27.0	31.
.50	278.2	18.4	140.7	0.57	39.6	29.9	24.
.00	288.4	22.2	146.7	0.59	41.4	32.0	16.
.50	294.4	25.5	149.0	0.59	43.2	33.3	8.
.00	296.4	28.4	147.9	0.59	44.8	33.8	0.
.50	294.4	30.8	143.7	0.59	46.3	33.3	8
.00	288.4	32.6	136.3	0.59	47.6	32.0	16.
.50	278.2	33.6	125.5	0.57	48.7	29.9	24
.00	263.4	33.9	110.6	0.55	49.4	27.0	31
.50	243.4	33.1	91.0	0.51	49.9	23.5	38
.00	217.1	31.2	66.1	0.45	50.0	19.5	44
.50	181.8	28.0	36.9	0.36	49.8	15.0	50.
.00	131.8	23.9	7.5	0.24	49.4	10.2	55.
.50	54.0	19.6	-13.8	0.11	48.7	5.0	60
.00	0.0	0.0	0.0	0.00	47.7	0.0	0.
.50	0.0	0.0	0.0	0.00	46.6	0.0	0.
.00	0.0	0.0	0.0	0.00	45.3	0.0	0
.50	0.0	0.0	0.0	0.00	44.0	0.0	0.
.00	0.0	0.0	0.0	0.00	42.5	0.0	0
.50	0.0	0.0	0.0	0.00	41.1	0.0	0.
.00	0.0	0.0	0.0	0.00	39.7	0.0	0
.50	0.0	0.0	0.0	0.00	38.4	0.0	0
.00	0.0	0.0	0.0	0.00	37.2	0.0	0
.50	0.0	0.0	0.0	0.00	36.1	0.0	0
.00	0.0	0.0	0.0	0.00	35.1	0.0	0
.50	0.0	0.0	0.0	0.00	34.1	0.0	0
.00	0.0	0.0	0.0	0.00	33.3	0.0	0
.50	0.0	0.0	0.0	0.00	32.6	0.0	0
.00	0.0	0.0	0.0	0.00	31.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 29.39 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39	29.39
T = 0.50 HOURS	32.86	30.32	29.64	29.45	29.40	29.39	29.39	29.41	29.47	29.71	30.60
T = 1.00 HOURS	39.60	33.20	30.70	29.81	29.52	29.44	29.44	29.51	29.73	30.29	31.36
T = 1.50 HOURS	48.45	37.92	32.92	30.76	29.91	29.61	29.57	29.71	30.12	30.97	32.67
T = 2.00 HOURS	58.13	43.94	36.27	32.45	30.71	30.01	29.84	30.04	30.64	31.85	33.95
T = 2.50 HOURS	67.70	50.64	40.48	34.87	32.01	30.72	30.33	30.53	31.32	32.85	35.48
T = 3.00 HOURS	76.67	57.52	45.23	37.88	33.82	31.81	31.07	31.22	32.15	34.00	37.06
T = 3.50 HOURS	84.80	64.24	50.25	41.34	36.07	33.27	32.10	32.12	33.15	35.27	38.74
T = 4.00 HOURS	91.98	70.58	55.31	45.08	38.69	35.07	33.43	33.25	34.33	36.66	40.41
T = 4.50 HOURS	98.12	76.42	60.26	48.96	41.57	37.18	35.03	34.61	35.66	38.12	42.08
T = 5.00 HOURS	103.17	81.63	64.97	52.86	44.63	39.53	36.87	36.17	37.13	39.63	43.56
T = 5.50 HOURS	107.02	86.12	69.32	56.67	47.78	42.05	38.91	37.91	38.72	41.16	45.12
T = 6.00 HOURS	109.54	89.77	73.22	60.31	50.93	44.68	41.10	39.78	40.38	42.66	46.42
T = 6.50 HOURS	110.53	92.46	76.56	63.68	54.01	47.36	43.39	41.73	42.07	44.09	47.50
T = 7.00 HOURS	109.73	94.01	79.20	66.67	56.93	50.01	45.71	43.72	43.74	45.42	48.36
T = 7.50 HOURS	106.85	94.20	81.02	69.19	59.61	52.56	48.00	45.70	45.36	46.60	48.95
T = 8.00 HOURS	101.74	92.86	81.84	71.10	61.95	54.94	50.20	47.61	46.88	47.62	49.27
T = 8.50 HOURS	94.73	89.97	81.56	72.30	63.85	57.06	52.25	49.40	48.27	48.44	49.33
T = 9.00 HOURS	87.07	85.90	80.22	72.72	65.23	58.86	54.09	51.02	49.48	49.05	49.12

T = 9.50 HOURS

81.91	81.62	78.16	72.42	66.06	60.25	55.64	52.42	50.48	49.44	48.67

T = 10.00 HOURS

80.26	78.90	76.16	71.70	66.40	61.24	56.87	53.56	51.26	49.60	48.01

T = 10.50 HOURS

78.10	77.30	74.71	70.92	66.43	61.87	57.77	54.42	51.78	49.55	47.16

NO. OF GLASS COVERS = 2

INDEX OF REFRACTION FOR AIR = 1.0

INDEX OF REFRACTION FOR GLASS = 1.526

EXTINCTION COEFFICIENT = 0.174 1/INCH

GLASS THICKNESS = 0.250 INCH

SURFACE COLOR = NATURAL CONCRETE

EMITTANCE OF GLASS = 0.88

EMITTANCE OF PLATE = 0.78

ABSORPTANCE OF THE PLATE = 0.78

REFLECTOR REFLECTANCE = 0.95

WIND VELOCITY = 10.0 MILE/HR

MAXIMUM TEMP. = 85.00 DEGREES F

TEMP. VARIATION = 22.00 DEGREES F

NTH = 6 | DECLINATION = 23.45 DEGREES

TITUDE = 36.07 DEGREES | SUNRISE = 4.97 HOUR

NGITUDE = 97.05 DEGREES | SUNSET = 19.03 HOUR

ENING ANGLE = 90.0 DEGREES | LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	77.7	10.7	10.4	21.1	38.9	1.4	40
.00	143.8	33.7	19.3	53.0	85.4	2.7	88
.50	185.7	61.5	24.9	86.4	126.5	3.5	129
.00	213.3	90.9	28.6	119.5	162.4	4.0	166
.50	232.3	120.3	31.1	151.4	193.8	4.3	198
.00	245.9	148.8	32.9	181.7	221.2	4.6	225
.50	255.8	175.4	34.3	209.7	241.3	4.8	246
.00	263.3	199.8	35.3	235.0	234.6	4.9	239
.50	268.9	221.2	36.0	257.2	226.7	5.0	231
.00	273.1	239.3	36.5	275.9	218.7	5.1	223
.50	276.0	253.8	37.0	290.8	211.6	5.1	216
.00	278.1	264.3	37.3	301.6	206.0	5.2	211
.50	279.2	270.7	37.4	308.1	202.4	5.2	207
.00	279.6	272.9	37.5	310.3	201.2	5.2	206
.50	279.2	270.7	37.4	308.1	202.4	5.2	207
.00	278.1	264.3	37.3	301.6	206.0	5.2	211
.50	276.0	253.8	37.0	290.8	211.6	5.1	216
.00	273.1	239.3	36.5	275.9	218.7	5.1	223
.50	268.9	221.2	36.0	257.2	226.7	5.0	231
.00	263.3	199.8	35.3	235.0	234.6	4.9	239
.50	255.8	175.4	34.3	209.7	241.3	4.8	246
.00	245.9	148.8	32.9	181.7	221.2	4.6	225
.50	232.3	120.3	31.1	151.4	193.8	4.3	198
.00	213.3	90.9	28.6	119.5	162.4	4.0	166
.50	185.7	61.5	24.9	86.4	126.5	3.5	129
.00	143.8	33.7	19.3	53.0	85.4	2.7	88
.50	77.7	10.7	10.4	21.1	38.9	1.4	40
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	A
.00	0.0	0.0	0.0	0.00	55.9	0.0	0
.50	0.0	0.0	0.0	0.00	66.3	0.0	0
.00	0.0	0.0	0.0	0.00	55.8	0.0	0
.50	0.0	0.0	0.0	0.00	65.3	0.0	0
.00	0.0	0.0	0.0	0.00	64.8	0.0	0
.50	0.0	0.0	0.0	0.00	54.3	0.0	0
.00	0.0	0.0	0.0	0.00	63.9	0.0	0
.50	0.0	0.0	0.0	0.00	63.5	0.0	0
.00	0.0	0.0	0.0	0.00	63.3	0.0	0
.50	0.0	0.0	0.0	0.00	63.1	0.0	0
.00	0.0	0.0	0.0	0.00	63.0	0.0	0
.50	61.5	0.0	11.0	0.18	63.1	7.9	66
.00	141.1	2.1	43.4	0.32	63.4	13.5	70
.50	216.3	6.6	89.7	0.45	63.8	19.3	74
.00	285.8	13.7	137.8	0.53	64.5	25.2	78
.50	349.6	22.8	180.2	0.58	65.4	31.2	82
.00	407.5	33.0	215.0	0.61	66.5	37.2	86
.50	455.8	43.8	240.4	0.62	67.9	43.3	89
.00	474.6	53.5	246.2	0.63	69.4	49.3	84
.50	488.9	61.7	249.0	0.64	71.0	55.3	79
.00	499.7	69.1	249.4	0.64	72.8	61.2	72
.50	507.5	75.7	248.3	0.64	74.6	66.8	63
.00	512.8	81.7	245.8	0.64	75.4	71.9	49
.50	515.8	87.1	242.5	0.64	78.2	75.8	29
.00	515.8	91.9	238.3	0.64	79.8	77.4	0
.50	515.8	96.3	233.2	0.64	81.3	75.8	29
.00	512.8	100.3	227.3	0.64	82.6	71.9	49
.50	507.5	103.7	220.3	0.64	83.7	66.8	63
.00	499.7	106.7	211.9	0.64	84.4	61.2	72
.50	488.9	109.0	201.7	0.64	84.9	55.3	79
.00	474.6	110.5	189.1	0.63	85.0	49.3	84
.50	455.8	111.0	173.1	0.62	84.8	43.3	89
.00	407.5	108.8	139.2	0.61	84.4	37.2	86
.50	349.6	103.1	99.9	0.58	83.7	31.2	82
.00	285.8	95.0	56.5	0.53	82.7	25.2	78
.50	216.3	84.8	11.5	0.45	81.6	19.3	74
.00	141.1	73.7	-28.2	0.32	80.3	13.5	70
.50	61.5	63.4	-52.4	0.18	79.0	7.9	66
.00	0.0	0.0	0.0	0.00	77.5	0.0	0
.50	0.0	0.0	0.0	0.00	75.1	0.0	0
.00	0.0	0.0	0.0	0.00	74.7	0.0	0
.50	0.0	0.0	0.0	0.00	73.4	0.0	0
.00	0.0	0.0	0.0	0.00	72.2	0.0	0
.50	0.0	0.0	0.0	0.00	71.1	0.0	0
.00	0.0	0.0	0.0	0.00	70.1	0.0	0
.50	0.0	0.0	0.0	0.00	69.1	0.0	0
.00	0.0	0.0	0.0	0.00	68.3	0.0	0
.50	0.0	0.0	0.0	0.00	67.6	0.0	0
.00	0.0	0.0	0.0	0.00	66.9	0.0	0

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CUNDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER CJEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 63.02 F

NO. OF INTERIUR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T = 0.00 HOURS	53.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02	63.02
T = 0.50 HOURS	58.38	64.46	63.41	63.13	63.05	63.03	63.03	63.03	63.03	63.05	63.13
T = 1.00 HOURS	77.85	68.66	64.98	63.67	63.23	63.09	63.05	63.04	63.07	63.16	63.40
T = 1.50 HOURS	91.42	75.62	68.25	65.06	63.78	63.30	63.13	63.11	63.17	63.37	63.83
T = 2.00 HOURS	107.21	85.05	73.33	67.57	64.93	63.80	63.37	63.26	63.36	63.71	64.46
T = 2.50 HOURS	123.88	96.10	80.00	71.28	66.85	64.75	63.84	63.56	63.68	64.20	65.29
T = 3.00 HOURS	140.35	108.03	87.87	76.08	69.58	66.23	64.66	64.09	64.18	64.87	66.32
T = 3.50 HOURS	154.70	119.84	96.42	81.74	73.09	68.30	65.88	64.90	64.90	65.74	67.55
T = 4.00 HOURS	155.62	130.70	105.05	87.95	77.23	70.94	67.55	65.05	65.88	66.82	68.96
T = 4.50 HOURS	177.18	140.56	113.40	94.38	81.83	74.07	69.65	67.56	67.14	68.13	70.54
T = 5.00 HOURS	185.52	149.61	121.34	100.82	86.71	77.59	72.16	69.41	68.69	69.65	72.24
T = 5.50 HOURS	194.83	157.89	128.87	107.17	91.75	81.40	75.00	71.58	70.50	71.36	74.03
T = 6.00 HOURS	202.24	165.48	135.97	113.36	96.84	85.42	78.11	74.04	72.56	73.23	75.85
T = 6.50 HOURS	208.84	172.43	142.65	119.35	101.93	89.58	81.44	76.73	74.81	75.22	77.66
T = 7.00 HOURS	214.69	178.77	148.92	125.12	106.97	93.82	84.93	79.60	77.20	77.27	79.41
T = 7.50 HOURS	219.81	184.55	154.77	130.64	111.91	98.08	88.52	82.59	79.70	79.33	81.02
T = 8.00 HOURS	224.19	189.75	160.21	135.91	116.74	102.34	92.16	85.65	82.23	81.36	82.47
T = 8.50 HOURS	227.79	194.36	165.23	140.90	121.42	106.54	95.82	88.74	84.76	83.29	83.71
T = 9.00 HOURS	230.50	198.33	169.79	145.59	125.92	110.65	99.44	91.81	87.24	85.10	84.70

T = 9.50 HOURS	232.18	201.59	173.86	149.94	130.20	114.63	102.98	94.82	89.62	86.75	85.43
T = 10.00 HOURS	232.59	204.00	177.36	153.92	134.24	118.46	106.41	97.72	91.87	88.20	85.88
T = 10.50 HOURS	229.97	205.00	180.08	157.41	137.96	122.07	109.68	100.48	93.96	89.44	86.06
T = 11.00 HOURS	223.58	203.81	181.61	160.24	141.29	125.42	112.76	103.07	95.86	90.46	85.97
T = 11.50 HOURS	214.21	200.25	181.61	162.14	144.06	128.42	115.59	105.44	97.56	91.26	85.64
T = 12.00 HOURS	202.11	194.47	179.95	162.93	146.11	130.96	118.10	107.57	99.02	91.83	85.09
T = 12.50 HOURS	188.33	186.77	176.67	162.52	147.34	132.94	120.22	109.40	100.24	92.18	84.36
T = 13.00 HOURS	174.92	177.99	172.05	160.93	147.67	134.27	121.87	110.88	101.19	92.32	83.48
T = 13.50 HOURS	164.22	169.47	166.70	158.39	147.13	134.92	123.02	111.99	101.86	92.25	82.48
T = 14.00 HOURS	157.27	165.07	162.10	155.46	145.92	134.92	123.63	112.68	102.23	91.99	81.40
T = 14.50 HOURS	164.11	163.16	159.15	152.90	144.43	134.43	123.75	112.98	102.30	91.55	80.28

TABLE II

NO. OF GLASS COVERS = 1
INDEX OF REFRACTION FOR AIR = 1.0
INDEX OF REFRACTION FOR GLASS = 1.526
EXTINCTION COEFFICIENT = 0.174 1/INCH
GLASS THICKNESS = 0.250 INCH
SURFACE COLOR = BLACK
EMITTANCE OF GLASS = 0.88
EMITTANCE OF PLATE = 0.90
ABSORPTANCE OF THE PLATE = 0.95
REFLECTOR REFLECTANCE = 0.95
WIND VELOCITY = 10.0 MILE/HR
MAXIMUM TEMP. = 73.00 DEGREES F
TEMP. VARIATION = 22.00 DEGREES F

NTH = 4 DECLINATION = 11.93 DEGREES

TITUDE = 36.07 DEGREES SUNRISE = 5.44 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.56 HOUR

ENING ANGLE = 100.0 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	WS
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	82.0	10.0	8.0	17.9	58.4	0.7	59.
.50	161.7	36.4	15.7	52.1	126.7	1.4	128.
.00	207.4	67.7	20.1	87.8	176.3	1.8	178.
.50	235.5	100.0	22.8	122.8	185.5	2.1	187.
.00	254.2	131.4	24.7	156.1	173.4	2.3	175.
.50	267.1	161.1	25.9	187.0	154.5	2.4	156.
.00	276.4	188.2	26.8	215.0	132.4	2.5	134.
.50	283.1	212.1	27.5	239.5	109.7	2.5	112.
.00	288.0	232.3	27.9	260.2	88.4	2.6	91.
.50	291.5	248.4	28.3	276.7	70.0	2.6	72.
.00	293.8	260.2	28.5	288.7	55.9	2.6	58.
.50	295.1	267.3	28.6	295.9	47.0	2.6	49.
.00	295.6	269.7	28.7	298.4	43.9	2.6	46.
.50	295.1	267.3	28.6	295.9	47.0	2.6	49.
.00	293.8	260.2	28.5	288.7	55.9	2.6	58.
.50	291.5	248.4	28.3	276.7	70.0	2.6	72.
.00	288.0	232.3	27.9	260.2	88.4	2.6	91.
.50	283.1	212.1	27.5	239.5	109.7	2.5	112.
.00	276.4	188.2	26.8	215.0	132.4	2.5	134.
.50	267.1	161.1	25.9	187.0	154.5	2.4	156.
.00	254.2	131.4	24.7	156.1	173.4	2.3	175.
.50	235.5	100.0	22.8	122.8	185.5	2.1	187.
.00	207.4	67.7	20.1	87.8	176.3	1.8	178.
.50	161.7	36.4	15.7	52.1	126.7	1.4	128.
.00	82.0	10.0	8.0	17.9	58.4	0.7	59.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.
.50	0.0	0.0	0.0	0.0	0.0	0.0	0.
.00	0.0	0.0	0.0	0.0	0.0	0.0	0.

R	WT	GTLS	WIN	TAPH	TAF	ALT	AZ
00	0.0	0.0	0.0	0.00	54.9	0.0	0.
50	0.0	0.0	0.0	0.00	54.3	0.0	0.
00	0.0	0.0	0.0	0.00	53.8	0.0	0.
50	0.0	0.0	0.0	0.00	53.3	0.0	0.
00	0.0	0.0	0.0	0.00	52.8	0.0	0.
50	0.0	0.0	0.0	0.00	52.3	0.0	0.
00	0.0	0.0	0.0	0.00	51.9	0.0	0.
50	0.0	0.0	0.0	0.00	51.5	0.0	0.
00	0.0	0.0	0.0	0.00	51.3	0.0	0.
50	0.0	0.0	0.0	0.00	51.1	0.0	0.
00	0.0	0.0	0.0	0.00	51.0	0.0	0.
50	0.0	0.0	0.0	0.00	51.1	0.0	0.
00	77.1	0.2	22.6	0.30	51.4	7.0	80.
50	180.2	8.4	79.8	0.49	51.9	13.0	84.
00	265.9	23.9	142.6	0.63	52.5	19.0	88.
50	310.4	42.9	178.8	0.71	53.4	25.1	86.
00	331.7	60.1	194.8	0.77	54.5	31.1	81.
50	343.9	74.8	200.4	0.80	55.9	37.1	76.
00	349.9	86.7	199.7	0.82	57.4	42.9	70.
50	351.8	96.1	195.5	0.83	59.0	48.5	64.
00	351.2	103.5	189.6	0.83	60.8	53.8	55.
50	349.3	109.3	183.2	0.84	62.6	58.5	45.
00	347.2	113.9	177.3	0.84	64.4	62.3	33.
50	345.6	117.9	172.2	0.84	66.2	64.9	17.
00	345.0	121.5	168.2	0.84	67.8	65.9	0.
50	345.6	125.1	165.0	0.84	69.3	64.9	17.
00	347.2	128.7	162.5	0.84	70.6	62.3	33.
50	349.3	132.6	160.0	0.84	71.7	58.5	45.
00	351.2	136.4	156.7	0.83	72.4	53.8	55.
50	351.8	139.8	151.8	0.83	72.9	48.5	64.
00	349.9	142.5	143.9	0.82	73.0	42.9	70.
50	343.9	143.6	131.6	0.80	72.8	37.1	76.
00	331.7	142.2	112.7	0.77	72.4	31.1	81.
50	310.4	137.0	84.7	0.71	71.7	25.1	86.
00	265.9	125.8	40.7	0.63	70.7	19.0	88.
50	180.2	107.0	-18.8	0.49	69.6	13.0	84.
00	77.1	85.6	-62.8	0.30	68.3	7.0	80.
50	0.0	0.0	0.0	0.00	67.0	0.0	0.
00	0.0	0.0	0.0	0.00	65.5	0.0	0.
50	0.0	0.0	0.0	0.00	64.1	0.0	0.
00	0.0	0.0	0.0	0.00	62.7	0.0	0.
50	0.0	0.0	0.0	0.00	61.4	0.0	0.
00	0.0	0.0	0.0	0.00	60.2	0.0	0.
50	0.0	0.0	0.0	0.00	59.1	0.0	0.
00	0.0	0.0	0.0	0.00	58.1	0.0	0.
50	0.0	0.0	0.0	0.00	57.1	0.0	0.
00	0.0	0.0	0.0	0.00	56.3	0.0	0.
50	0.0	0.0	0.0	0.00	55.6	0.0	0.
00	0.0	0.0	0.0	0.00	54.9	0.0	0.

Apr.

HEAT CAPACITY = 0.24 BTU/LBM-F

DENSITY = 145.00 LBM/FT**3

THERMAL CONDUCTIVITY = 0.53 BTU/HR-FT-F

HEAT TRANSFER COEFF.= 10.01 BTU/HR-F-FT**2

INITIAL TEMP. = 51.10 F

NO. OF INTERIOR NODES = 10

DEPTH OF SLAB = 10.50 INCHES

TIME INTERVAL = 0.50 HR

DISTANCE INTERVAL = 1.05 INCHES

Apr.

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T											
T = 0.00 HOURS	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10	51.10
T = 0.50 HOURS	61.59	53.91	51.85	51.30	51.15	51.11	51.10	51.10	51.12	51.19	51.43
T = 1.00 HOURS	77.16	61.33	54.71	52.30	51.48	51.22	51.14	51.14	51.21	51.40	51.83
T = 1.50 HOURS	94.40	71.56	59.96	54.65	52.44	51.59	51.30	51.26	51.38	51.72	52.48
T = 2.00 HOURS	109.16	82.58	66.78	58.36	54.25	52.42	51.70	51.51	51.67	52.20	53.29
T = 2.50 HOURS	121.40	92.89	74.22	63.04	56.91	53.83	52.44	51.99	52.14	52.85	54.32
T = 3.00 HOURS	131.37	102.14	81.56	68.23	60.22	55.79	53.59	52.75	52.82	53.70	55.54
T = 3.50 HOURS	139.42	110.23	88.54	73.57	63.96	58.23	55.15	53.83	53.76	54.77	56.95
T = 4.00 HOURS	145.96	117.22	94.97	78.85	67.92	61.03	57.08	55.24	54.97	56.05	58.51
T = 4.50 HOURS	151.34	123.27	100.81	83.92	71.97	64.07	59.32	56.96	56.44	57.53	60.21
T = 5.00 HOURS	155.90	128.54	106.11	88.72	76.00	67.27	61.81	58.93	58.15	59.20	61.98
T = 5.50 HOURS	159.91	133.22	110.93	93.25	79.95	70.56	64.47	61.12	60.06	61.00	63.79
T = 6.00 HOURS	163.59	137.45	115.35	97.51	83.80	73.87	67.26	63.48	62.12	62.89	65.57
T = 6.50 HOURS	167.07	141.37	119.46	101.53	87.52	77.17	70.12	65.94	64.28	64.81	67.28
T = 7.00 HOURS	170.43	145.07	123.33	105.36	91.13	80.44	73.01	68.47	66.49	66.72	68.85
T = 7.50 HOURS	173.64	148.60	127.02	109.03	94.62	83.67	75.90	71.02	68.70	68.57	70.25
T = 8.00 HOURS	176.60	151.95	130.53	112.55	98.02	86.83	78.77	73.56	70.87	70.31	71.43
T = 8.50 HOURS	179.11	155.03	133.86	115.93	101.31	89.92	81.59	76.04	72.95	71.90	72.36
T = 9.00 HOURS	180.87	157.70	136.95	119.15	104.48	92.93	84.34	78.45	74.93	73.32	73.02

T = 9.50 HOURS
181.44 159.73 139.68 122.16 107.52 95.83 86.99 80.75 76.76 74.53 73.40

T = 10.00 HOURS
180.21 160.81 141.89 124.86 110.36 98.60 89.53 82.93 78.44 75.53 73.51

T = 10.50 HOURS
176.41 160.46 143.31 127.13 112.94 101.19 91.92 84.95 79.93 76.31 73.35

T = 11.00 HOURS
168.60 157.98 143.58 128.75 115.15 103.53 94.12 86.80 81.23 76.87 72.95

T = 11.50 HOURS
155.48 152.45 142.15 129.42 116.81 105.54 96.08 88.44 82.33 77.21 72.34

T = 12.00 HOURS
139.77 144.02 138.68 128.84 117.72 107.08 97.72 89.84 83.21 77.36 71.55

T = 12.50 HOURS
127.24 134.84 133.66 126.95 117.73 108.04 98.97 90.94 83.86 77.31 70.61

T = 13.00 HOURS
132.78 130.73 129.22 124.39 116.93 108.35 99.76 91.71 84.26 77.07 69.56

T = 13.50 HOURS-
130.24 129.75 126.76 122.17 115.76 108.13 100.08 92.12 84.39 76.66 68.44

APPENDIX G

Experimental Results

TABLE I

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: July 13, 1976 (Natural Surface) REFLECTOR ANGLE: 100°

Clear to partly cloudy.

THERMOCOUPLE	TIME 1:00	1:30	2:00	2:30	3:00	3:40	4:10
1	110.2	113.8	115.6	116.9	118.0	117.7	116.2
2	122.9	121.6	130.6	133.2	136.0	139.1	139.0
3	133.6	138.8	141.2	144.3	146.6	148.4	146.3
4	120.4	129.7	132.5	135.7	137.7	137.9	136.8
5	101.6	106.9	110.1	111.9	113.5	114.8	113.9
6	104.1	110.2	113.2	114.7	116.0	116.2	114.6
7	136.2	142.1	149.8	154.5	155.2	155.7	154.3
8	145.9	149.7	158.0	162.8	162.9	161.5	158.5
9	109.7	114.2	118.4	122.1	125.4	129.0	131.4
10	103.6	107.1	110.5	113.3	116.4	120.0	122.8
11	99.8	102.7	105.0	107.8	110.1	113.3	116.0
12	109.6	112.6	114.8	116.4	117.4	118.2	118.1
13	113.0	116.2	118.1	119.5	120.3	120.1	119.5
14	126.7	134.3	144.3	144.1	148.4	148.5	146.0
15	128.1	136.8	144.9	149.7	151.1	151.9	151.4
16	137.7	149.3	157.3	162.5	162.7	159.5	161.0
17	125.7	129.5	132.5	134.6	137.3	138.2	138.0
18	111.8	114.7	116.8	118.1	119.8	120.1	119.5
19	118.6	121.9	122.8	124.3	125.3	124.1	122.8
Ambient Temp.	95	97	97	97	99	96	97
Intensity (BTU/hr-ft^2)	339	339	335	335	325	316	266

*All temperatures are given in degrees Fahrenheit.

TABLE III

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: July 20 (Black Surface) REFLECTOR ANGLE: 100°

Partly cloudy.

THERMOCOUPLE	TIME 1:00	1:30	2:00	2:30	3:00	3:30
1	117.6	122.6	123.4	128.2	127.7	127.5
2	128.9	134.1	136.2	140.7	143.0	144.3
3	138.7	144.7	147.2	152.6	153.5	154.8
4	126.0	132.8	135.7	142.5	144.4	144.3
5	111.7	116.9	119.3	122.5	122.7	123.8
6	116.3	121.5	124.3	127.3	126.0	127.5
7	140.3	145.6	148.9	156.6	157.7	160.5
8	148.2	152.8	156.2	164.1	164.5	168.5
9	113.5	117.6	121.0	124.4	128.1	130.5
10	106.6	110.1	113.1	116.2	119.0	121.4
11	101.9	104.9	107.5	110.1	112.2	114.7
12	116.8	120.9	123.3	127.1	126.5	127.7
13	112.3	126.2	129.7	133.2	131.7	132.0
14	127.1	135.1	139.9	146.6	147.2	151.7
15	129.5	139.5	145.4	154.1	154.2	156.0
16	139.4	154.5	165.7	171.7	166.8	166.0
17	135.6	140.4	143.5	148.1	149.4	150.5
18	119.9	124.0	125.1	129.1	128.8	130.0
19	129.2	132.6	133.6	137.5	136.0	135.3
Ambient Temp.	93.8	94.6	94.5	96.0	99.5	96.9
Intensity (BTU/hr-ft^2)	323	345	323	319	319	302

*All temperatures are given in degrees Fahrenheit.

TABLE IV

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: July 26 (Black Surface) REFLECTOR ANGLE: 100°

Clear to hazy.

THERMOCOUPLE	TIME 1:30	2:00	2:30	3:00	3:30	4:00
1	126.5	130.7	133.0	134.5	134.9	134.3
2	139.7	145.7	149.1	152.3	154.3	156.3
3	152.2	157.5	160.6	163.7	165.2	167.3
4	137.6	145.6	151.2	153.9	154.8	154.3
5	121.6	127.9	129.2	130.4	131.6	132.6
6	127.6	133.9	133.6	134.4	135.2	136.0
7	153.5	158.5	163.0	166.2	171.2	172.7
8	162.6	166.0	169.7	172.7	178.6	180.6
9	122.4	128.1	131.8	135.1	138.7	141.5
10	114.1	119.0	122.6	125.5	128.7	131.5
11	108.5	112.6	115.8	118.4	121.3	123.8
12	124.6	132.7	133.8	135.0	136.2	136.8
13	131.5	140.4	139.9	140.3	141.0	141.1
14	139.0	146.7	154.5	156.0	159.7	161.7
15	149.0	155.1	161.3	164.0	167.6	169.7
16	162.9	168.1	175.6	177.6	184.4	182.4
17	147.0	153.4	156.7	159.6	162.0	162.4
18	129.2	132.8	135.5	137.1	138.5	139.3
19	138.4	140.9	144.1	144.8	145.7	146.0
Ambient Temp.	96	99	99.5	100	100	102
Intensity (BTU/hr-ft^2)	314	302	292	284	280	249

*All temperatures are given in degrees Fahrenheit.

NTH = 7 DECLINATION = 20.24 DEGREES

TABLE V

TITUDE = 36.07 DEGREES SUNRISE = 5.09 HOUR

NGITUDE = 97.05 DEGREES SUNSET = 18.91 HOUR

ENING ANGLE = 99.9 DEGREES LOCATION = STILLWATER

HR	IDN	ID	IDIF	WD	IDR	IDIFR	W
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	47.6	5.0	6.5	11.5	22.2	0.6	22
.00	124.5	25.4	16.9	42.3	57.6	1.6	69
.50	173.6	52.5	23.6	76.2	107.3	2.2	109
.00	205.0	82.0	27.9	109.9	141.3	2.6	143
.50	225.2	111.7	30.8	142.5	170.7	2.8	173
.00	241.2	140.6	32.8	173.4	196.5	3.0	199
.50	252.0	167.7	34.3	202.0	184.4	3.2	187
.00	260.1	192.4	35.4	227.8	157.7	3.3	170
.50	266.0	214.3	36.2	250.4	150.3	3.3	153
.00	270.4	232.7	36.8	269.5	133.8	3.4	137
.50	273.6	247.5	37.2	284.7	119.6	3.4	123
.00	275.8	258.2	37.5	295.7	108.6	3.5	112
.50	277.0	264.7	37.7	302.4	101.7	3.5	105
.00	277.4	266.9	37.7	304.6	99.3	3.5	102
.50	277.0	264.7	37.7	302.4	101.7	3.5	105
.00	275.8	258.2	37.5	295.7	108.6	3.5	112
.50	273.6	247.5	37.2	284.7	119.6	3.4	123
.00	270.4	232.7	36.8	269.5	133.8	3.4	137
.50	266.0	214.3	36.2	250.4	150.3	3.3	153
.00	260.1	192.4	35.4	227.8	157.7	3.3	170
.50	252.0	167.7	34.3	202.0	184.4	3.2	187
.00	241.2	140.6	32.8	173.4	196.5	3.0	199
.50	225.2	111.7	30.8	142.5	170.7	2.8	173
.00	205.0	82.0	27.9	109.9	141.3	2.6	143
.50	173.6	52.5	23.6	76.2	107.3	2.2	109
.00	124.5	25.4	16.9	42.3	67.6	1.6	69
.50	47.6	5.0	6.5	11.5	22.2	0.6	22
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0
.50	0.0	0.0	0.0	0.0	0.0	0.0	0
.00	0.0	0.0	0.0	0.0	0.0	0.0	0

HR	WT	QTLS	WIN	TAPH	TAF	ALT	AZ
.00	0.0	0.0	0.0	0.00	71.9	0.0	0.
.50	0.0	0.0	0.0	0.00	71.3	0.0	0.
.00	0.0	0.0	0.0	0.00	70.8	0.0	0.
.50	0.0	0.0	0.0	0.00	70.3	0.0	0.
.00	0.0	0.0	0.0	0.00	69.8	0.0	0.
.50	0.0	0.0	0.0	0.00	69.3	0.0	0.
.00	0.0	0.0	0.0	0.00	68.9	0.0	0.
.50	0.0	0.0	0.0	0.00	68.5	0.0	0.
.00	0.0	0.0	0.0	0.00	68.3	0.0	0.
.50	0.0	0.0	0.0	0.00	68.1	0.0	0.
.00	0.0	0.0	0.0	0.00	68.0	0.0	0.
.50	34.2	0.0	5.3	0.15	68.1	5.0	69.
.00	111.5	1.6	34.6	0.32	68.4	11.8	73.
.50	185.7	5.9	83.5	0.48	68.9	17.6	77.
.00	253.7	13.5	137.7	0.60	69.5	23.6	81.
.50	316.1	23.7	186.6	0.67	70.4	29.6	85.
.00	372.8	35.6	226.9	0.70	71.5	35.7	89.
.50	389.5	46.5	235.7	0.72	72.9	41.7	85.
.00	398.7	55.4	237.8	0.74	74.4	47.7	80.
.50	404.0	62.9	236.4	0.74	76.0	53.6	74.
.00	406.7	69.4	233.1	0.74	77.8	59.4	67.
.50	407.6	74.9	228.9	0.75	79.6	64.7	57.
.00	407.7	79.7	224.4	0.75	81.4	69.4	43.
.50	407.5	84.0	220.0	0.75	83.2	72.9	24.
.00	407.4	88.0	216.0	0.75	84.8	74.2	0.
.50	407.5	91.7	212.3	0.75	86.3	72.9	24.
.00	407.7	95.3	208.8	0.75	87.6	69.4	43.
.50	407.6	98.8	205.0	0.75	88.7	64.7	57.
.00	406.7	102.1	200.4	0.74	89.4	59.4	67.
.50	404.0	105.1	194.3	0.74	89.9	53.6	74.
.00	398.7	107.5	185.7	0.74	90.0	47.7	80.
.50	389.5	109.1	173.1	0.72	89.8	41.7	85.
.00	372.8	109.0	153.4	0.70	89.4	35.7	89.
.50	316.1	104.6	105.7	0.67	88.7	29.6	85.
.00	253.7	95.6	55.6	0.60	87.7	23.6	81.
.50	185.7	84.2	5.2	0.48	86.6	17.6	77.
.00	111.5	72.0	-35.8	0.32	85.3	11.8	73.
.50	34.2	61.5	-56.2	0.15	84.0	6.0	69.
.00	0.0	0.0	0.0	0.00	82.5	0.0	0.
.50	0.0	0.0	0.0	0.00	81.1	0.0	0.
.00	0.0	0.0	0.0	0.00	79.7	0.0	0.
.50	0.0	0.0	0.0	0.00	78.4	0.0	0.
.00	0.0	0.0	0.0	0.00	77.2	0.0	0.
.50	0.0	0.0	0.0	0.00	76.1	0.0	0.
.00	0.0	0.0	0.0	0.00	75.1	0.0	0.
.50	0.0	0.0	0.0	0.00	74.1	0.0	0.
.00	0.0	0.0	0.0	0.00	73.3	0.0	0.
.50	0.0	0.0	0.0	0.00	72.6	0.0	0.
.00	0.0	0.0	0.0	0.00	71.9	0.0	0.

SOLUTION TO HEAT FLOW PROBLEM BY CRANK-NICOLSON METHOD

T (HOURS)											
T = 0.00 HOURS	53.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03	68.03
T = 0.50 HOURS	71.96	69.08	68.31	68.11	68.05	68.04	68.03	68.03	68.04	68.06	68.13
T = 1.00 HOURS	80.96	72.71	69.61	68.54	68.19	68.08	68.05	68.05	68.07	68.16	68.40
T = 1.50 HOURS	94.92	79.53	72.64	69.78	68.66	68.26	68.12	68.10	68.17	68.37	68.83
T = 2.00 HOURS	111.88	89.28	77.69	72.18	69.73	68.71	68.33	68.24	68.36	68.71	69.45
T = 2.50 HOURS	130.13	101.08	84.61	75.91	71.60	69.61	68.77	68.53	68.67	69.19	70.29
T = 3.00 HOURS	145.16	113.43	92.82	80.85	74.36	71.08	69.56	69.04	69.16	69.86	71.32
T = 3.50 HOURS	158.73	124.78	101.42	86.63	77.93	73.16	70.78	69.84	69.86	70.72	72.54
T = 4.00 HOURS	159.38	134.82	109.76	92.80	82.10	75.81	72.45	70.98	70.84	71.80	73.95
T = 4.50 HOURS	173.41	143.79	117.61	99.03	86.65	78.94	74.55	72.48	72.09	73.10	75.53
T = 5.00 HOURS	186.19	151.79	124.94	105.14	91.38	82.40	77.04	74.33	73.63	74.62	77.23
T = 5.50 HOURS	193.00	158.97	131.74	111.06	96.18	86.11	79.83	76.49	75.44	76.33	79.02
T = 6.00 HOURS	199.07	165.47	138.06	115.73	100.96	89.96	82.86	78.90	77.48	78.20	80.84
T = 6.50 HOURS	204.58	171.41	143.95	122.16	105.69	93.90	86.07	81.53	79.70	80.17	82.65
T = 7.00 HOURS	209.65	176.91	149.46	127.35	110.32	97.87	89.40	84.31	82.05	82.20	84.38
T = 7.50 HOURS	214.35	182.03	154.65	132.32	114.85	101.84	92.80	87.18	84.48	84.23	85.99
T = 8.00 HOURS	218.69	186.82	159.56	137.08	119.26	105.78	96.23	90.11	86.93	86.21	87.43
T = 8.50 HOURS	222.61	191.27	164.20	141.64	123.54	109.67	99.65	93.04	89.36	88.09	88.65
T = 9.00 HOURS	225.97	195.34	168.56	145.00	127.70	113.48	103.04	95.95	91.73	89.84	89.63

T = 9.50 HOURS

223.54	193.92	172.60	150.14	131.70	117.20	106.35	98.78	94.00	91.42	90.34

T = 10.00 HOURS

229.98	201.83	176.23	154.02	135.54	120.79	109.57	101.51	96.13	92.81	90.77

T = 10.50 HOURS

229.63	203.78	179.30	157.55	139.15	124.23	112.66	104.12	98.10	93.98	90.93

T = 11.00 HOURS

224.59	203.76	181.42	160.58	142.46	127.46	115.59	106.57	99.90	94.94	90.82

T = 11.50 HOURS

214.74	200.70	181.96	162.79	145.31	130.42	118.32	108.83	101.50	95.67	90.47

T = 12.00 HOURS

201.79	194.75	180.51	163.82	147.50	132.98	120.77	110.87	102.89	96.19	89.91

T = 12.50 HOURS

187.19	185.67	177.19	163.51	148.82	134.99	122.87	112.65	104.05	96.51	89.15

T = 13.00 HOURS

173.73	177.63	172.43	161.91	149.19	136.35	124.52	114.10	104.97	96.61	88.27

T = 13.50 HOURS

153.78	169.24	167.03	159.32	148.65	137.01	125.66	115.19	105.61	96.53	87.27

T = 14.00 HOURS

167.16	165.13	162.52	156.41	147.44	137.00	126.27	115.88	105.96	96.26	85.19

TABLE VI

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: November 19, 1976 REFLECTOR ANGLE: No Reflector

THERMOCOUPLE	TIME 12:00	1:00	2:00
1	94.8	88.7	94.4
2	88.6	84.4	91.3
3	83.4	79.3	86.8
4	94.6	91.7	98.1
5	88.7	83.3	88.0
6	86.0	80.8	86.2
7	86.4	82.4	88.7
8	83.0	79.2	86.0
9	96.6	94.4	99.9
10	99.2	97.4	103.2
11	100.8	99.2	105.0
12	85.1	79.6	84.8
13	81.4	76.1	82.0
14	91.8	89.1	95.6
15	86.9	83.8	89.9
16	81.9	78.9	85.8
17	85.4	82.1	88.5
18	98.9	96.8	102.6
19	96.7	94.7	100.9
Ambient Temp.			
Intensity (BTU/hr-ft^2)	150.1	145.9	122.2

*All temperatures are given in degrees Fahrenheit.

TABLE VII

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: November 20, 1976 (Black Surface) REFLECTOR ANGLE: No Reflector

THERMOCOUPLE	TIME 11:00	12:00	1:00
1	83.2	88.5	86.5
2	70.4	79.5	79.3
3	66.4	74.5	74.2
4	75.3	85.3	85.9
5	76.8	82.7	80.2
6	75.6	80.7	77.8
7	68.9	76.5	75.5
8	66.2	73.5	72.5
9	76.4	87.2	87.4
10	78.2	90.2	90.5
11	79.7	91.9	92.1
12	73.2	79.1	75.5
13	69.9	75.3	71.8
14	72.2	82.2	81.4
15	68.7	77.1	75.6
16	64.7	72.0	71.1
17	68.1	75.3	74.6
18	82.6	91.0	91.2
19	81.4	89.5	89.6
Ambient Temp.		54	
Intensity (BTU/hr-ft^2)	136.2	152.8	161.2

*All temperatures are given in degrees Fahrenheit.

TABLE VIII

TEMPERATURE AND INTENSITY MEASUREMENTS*

DATE: December 28, 1976 (Black Surface) REFLECTOR ANGLE: 70°

NOTE: Insulation on north side of collector had been moved.

THERMOCOUPLE	TIME 2:30	3:00	3:30
1	69.2	67.2	64.9
2	83.3	85.0	84.0
3	92.6	94.0	90.6
4	88.4	88.7	84.6
5	69.0	68.5	67.5
6	68.7	68.2	67.0
7	94.6	93.6	93.0
8	98.8	97.1	96.2
9	73.5	74.9	76.6
10	66.1	67.6	69.6
11	59.9	61.6	63.6
12	83.0	82.5	76.5
13	89.7	86.7	77.2
14	90.0	88.2	86.5
15	91.7	92.4	91.2
16	99.8	98.6	95.5
17	90.2	93.2	91.2
18	71.9	71.6	70.0
19	76.1	75.7	72.1
Ambient Temp.	41	45.0	45.4
Intensity (BTU/hr-ft^2)	152.8	133.4	

*All temperatures are given in degrees Fahrenheit.