ACCURATE MODELING OF INSTANTANEOUS SOLAR RADIATION

by

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DEDICATION

I would like to dedicate this thesis to Dr. Charles K. Alexander, Jr., whose generous guidance throughout this paper has been of great value.

This thesis is also dedicated to Hashim Nasser whose friendship I shall always cherish.

ABSTRACT

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The need for alternative energy sources is becoming more and more apparent as time goes by. The world's resources of fossil fuel are rapidly decreasing, and scientists are looking for alternate routes to solve the energy problems faced by most nations on earth. One such route is the utilization of Solar Energy which is abundant in enormous quantities. For example, the amount falling on Lake Erie can supply the needs for the entire nation.[6] Solar Engineers have been trying to bring Solar Energy into the picture as an alternative source of energy for many years now, because of its promise in providing efficient and economical systems. However, the design of an efficient and economical system depends on the accuracy of predicting the amount of radiation received during the period in which the system is expected to operate. Unfortunately it is very difficult to model incoming radiation because of constant changes in atmospheric conditions. The best that could be done, thus far, is to use previous radiation data averaged over a number of years for a specific locality, and through statistical analyzis predict future insolation.

Such a technique was presented by Liu and Jordan[1] in 1960. It turns out, however, that this kind of approach is not very useful for predicting the performance of a solar system because it is an averaging technique and solar systems do not operate on an average basis. Thus, the need for a model that predicts instantaneous radiation that is not averaged over the entire day (which in turn is averaged over the entire month) is yet to be satisfied. Alexander and Taft[2] have derived such a model using Liu and Jordan's technique along with Meinel's development of Laue's observations.[4]

This paper outlines a computer program which models and tests Alexander and Taft's technique and outputs instantaneous insolation data for 10 different locations around the country. Using this technique, modifications to Laue's curves were proposed for the different locations under study. The program can be used to predict instantaneous solar insolation for any location in the world where monthly average total radiation data are available.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the efficient advisement of Dr. Charles K. Alexander, Jr., and Dr. Gus Mavrigian. I would like to thank both of them as well as Mrs. Anna Mae Serrecchio for taking the time to type this paper.

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LIST OF SYMBOLS

b	Tilt angle of collector relative to the horizontal
$\bar{C}$	Correction factor
CDIF	Magnitude of diffuse radiation on a clear day
CDIR	Magnitude of direct radiation on a clear day.
$\overline{CDIR}$	Value of CDIR Corrected by $1/\bar{C}$.
E	Irradiance after transmittance through the atmosphere.
E_0	Irradiance outside the atmosphere.
H	Angle of rotation of the earth after solar noon.
HDIF	Monthly Average Daily Diffuse Radiation, also ($\bar{D}$).
HDIR	Monthly Average Dail Direct Radiation.
$\bar{H}$	Monthly Average Daily Total Radiation.
H_0	Extraterrestrial Radiation.
HS	Experimental number of hours of sunshine.
I_{0h}	Instantaneous radiation intensity.
I_{sc}	Solar constant (I_{sc}=1353 W/m^2).
$\bar{K}_T$	$\bar{H}/H_0$
L	Latitude (North positive).
m	Air mass
P	Azimuth angle
r_d	I_{0h}/H_0.
SS	Hours from sunrise to sunset.
t_{sr}	Sunrise time
t_{ss}	Sunset time
XLENG	Calculated number of hours of sunshine.

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CHAPTER I

SOLAR ENERGY AVAILABILITY

1.1 INTRODUCTION

The energy that is received from the sun on the surface of the earth depends upon the physical and chemical characteristics of the sun and the effects of the earth's atmospheric attenuation. This chapter will analyze these points and provide the basic building block for the rest of this paper.

1.2 ABOUT THE SUN

In general, the sun can be visualized as a black body operating at 5760°K. It is a sphere of fusion reactions with estimated interior temperatures reaching 40×10^6 °K. The sun has a radius of 6.95×10^5 Km and an average distance of 1.5×10^8 Km from the earth. The energy received on a unit area, perpendicular to the incident rays, per unit time, in space, has been found to be 1353 W/m^2 or 429.2 BTU/ft^2-hr. This value is referred to as the NASA/ASTM standard value of the solar constant, and is within an estimated error of $\pm$ 1.5%.

In practice, only radiation between 0.3 and 3μm is considered for terrestrial applications. Radiation outside this range is neglected because of strong absorption by O_2 and N_2 for wavelengths less than 0.3μm, and by CO_2 and H_2O for wavelengths greater than 3μm. Hence, knowledge of the spectral distribution of radiation is instrumental for the estimation of insolation. The spectral irradiance curve given in Figure 1.1 shows the extraterrestrial solar spectrum for the range of 0.2 - 2.6μm.

1.3 ATMOSPHERIC ATTENUATION

The radiation received on the surface of the earth is made up of two components:

A. Direct Radiation (I_D): Solar radiation whose direction has not been altered by atmospheric scattering and reflection.

B. Diffuse Radiation (I_d): Solar radiation whose direction has been deflected due to reflection and scattering by the atmosphere.

Obviously the total radiation received (I_T) is the algebraic sum of I_D and I_d.

The earth moves along an elliptical orbit thus causing the sun-earth distance to vary on a seasonal basis. Hence, the insolation received at the surface of the earth depends upon the variation of the distance between the sun and earth. Moreover, the atmosphere contains air molecules, H_2O vapor, dust, O_2, O_3, and CO_2, all of which absorb and scatter radiation. Therefore, the solar radiation received on the surface of the earth varies according to:

1. Variations in sun-earth distance.
2. Variations of scattering and absorption by atmospheric effects.

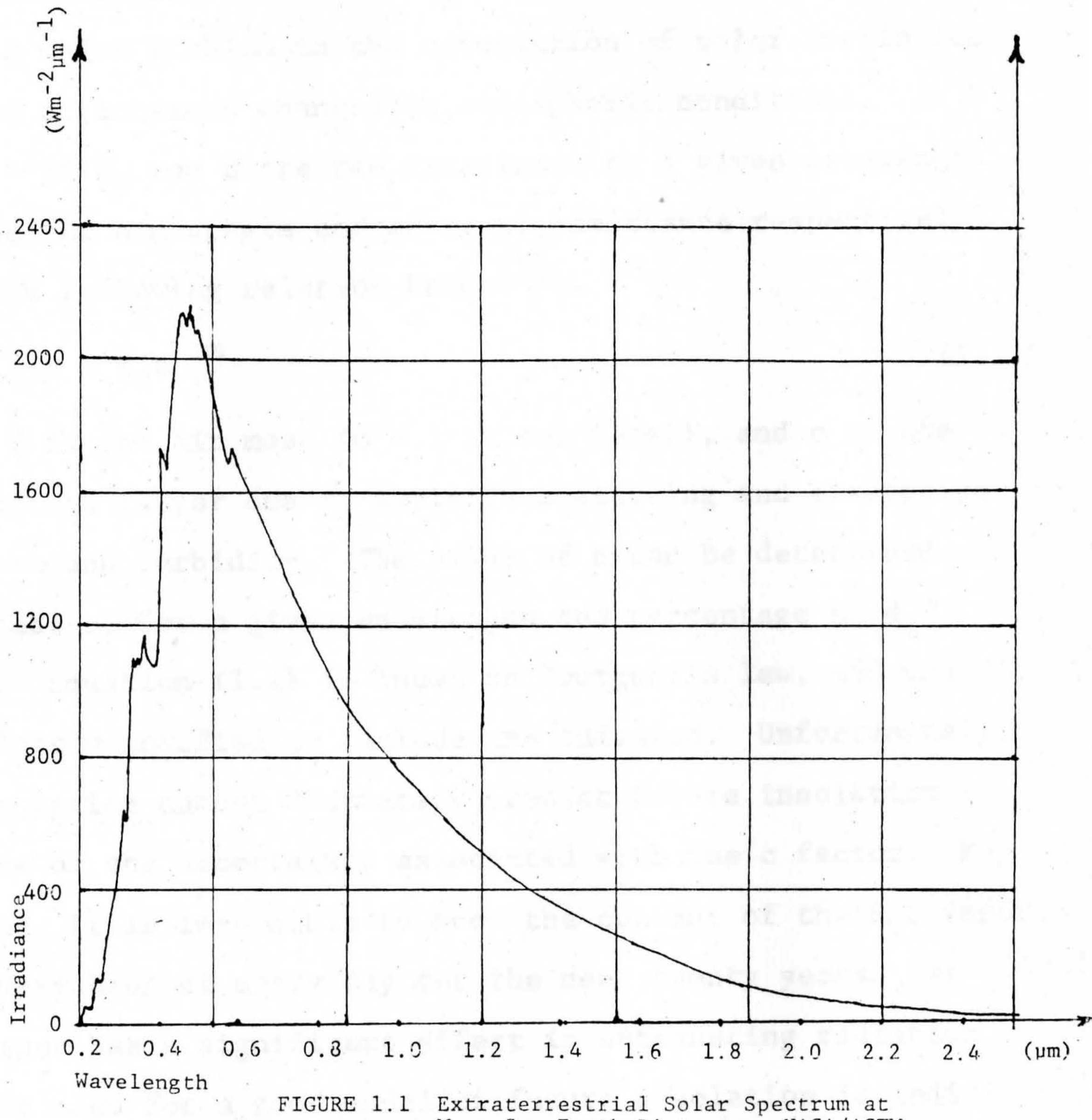

FIGURE 1.1 Extraterrestrial Solar Spectrum at Mean Sun-Earth Distance. NASA/ASTM Standard Curve. Solar Constant = 1353 W/m^2.

Variations in sun-earth distance contribute only a uniform ± 3% change in extraterrestrial radiation, but, variations due to dust particles, H_2O vapor, and air molecules cause a major problem in the calculation of solar insolation because of constant changes in atmospheric conditions.

If E_0 and E are the irradiance at a given wavelength outside the atmosphere and after transmittance respectively, then the following relation holds[3]:

$$E = E_0 e^{-cm} \tag{1.1}$$

where m is the air mass (m = 1 at sea level), and c is the attenuation factor due to Rayleigh scattering and absorption by ozone and turbidity. The value of c can be determined from tables, for a given wavelength and percentage of H_2O vapor. Equation (1.1) is known as Bourguer's law, and has to be slightly modified to include the infrared. Unfortunately, this equation cannot accurately predict future insolation because of the uncertainty associated with the c factor. For example, it is impossible to know the content of the H_2O vapor, for every hour of every day for the next twenty years. Yet H_2O vapor has a significant effect in attenuating radiation and the need for a good model of future insolation is indispensable in the design of solar collectors. This has been the subject of many studies, the most important of which are presented in detail in later chapters.

1.4 FUNDAMENTAL EQUATIONS

It is very important to know the position of the sun relative to a collector. For example, one needs to know the exact direction of incident radiation for every hour of the day in order to design for the optimal tilt and spacing of collectors of a solar plant, where shading effects can cause some problems.

At any time of day the position of the sun relative to a collector can be described by the following angles,

H: angle of rotation of the earth after solar noon ($H = 15 \times$ hours after solar noon).

b: tilt angle of the collector relative to the horizontal.

p: azimuth angle (rotation of collector from due south).

L: latitute (north positive).

δ: seasonal declination angle.

$$\delta = 23.45 \sin \left(360. \frac{d+284}{365}\right)$$

where d is the day of the year.

The angle of incidence (i) of direct solar radiation relative to the collector surface normal is given by,

$$\begin{aligned} \cos(i) = [&\cos(p) \sin(L) \sin(b) \cos(\delta) \cos(H) \\ &+ \cos(L) \cos(b) \cos(\delta) \cos(H) \\ &+ \sin(p) \sin(b) \cos(\delta) \sin(H) \\ &+ \sin(L) \sin(\delta) \cos(b) \\ &- \cos(p) \cos(L) \sin(b) \sin(\delta)] \end{aligned} \quad (1.2)$$

If b = 0, then the angle of incidence reduces to the zenith angle which is given by,

$$\cos(z) = \sin(L)\sin(\delta) + \cos(L)\cos(\delta)\cos(H) \tag{1.3}$$

It is also useful to calculate the length of day (as shown in Chapter four) which is given by,

$$SS = (2 \times H)/15 \tag{1.4}$$

where SS is the number of hours from sunrise to sunset. Equation (1.3) can be solved for H by substituting z = 90°. Hence,

$$\cos(z) = 0.$$

and

$$\cos(H) = -\tan(L)\tan(\delta) \tag{1.5}$$

Equations (1.2) - (1.5) constitute the basic building blocks from which the analysis presented in this paper is going to develop. For example, knowing the zenith angle (z), the direct radiation on a clear day can be found from Figure 1.2 or the diffuse radiation from Figure 1.3. These are known as Meinel's development of Laue's observations and will be used in Chapters three and four. The graphs are based on measurements in urban, desert and standard areas.

1.5 MEASUREMENTS.

In 1.3, it was pointed out that it is practically impossible to predict the exact value of future insolation because of unpredictable weather changes. In practice, however, one can rely on measured data for a specified number of past years and use them to predict the future performance of a system. This technique is presented in detail in the next chapter. The two most widely used instruments for the measurement of solar radiation are:

1. Pyranometer: Measures the total direct and diffuse radiation.
2. Pyroheliometer: Measures direct radiation.

Most of the solar radiation instruments used in the U.S.A. are manufactured by Eppley Laboratory. These instruments either generate or modify an electric current which is proportional to the amount of heat change in the element. For example, the Eppley pyranometer, which is made up of black and white concentric rings, influences a change in the current (through its thermocouple) by the effect of temperature differences between the absorbing black and reflecting white rings. This change in current is proportional to the heat absorbed. Meteorological instruments are calibrated in langleys which is the international unit of solar energy and is equivalent to 1 calorie per square centimeter. However, solar engineers usually prefer the unit of BTU per square foot per hour or Watts per square meter. Throughout this paper the unit of Watts per square meter is adopted unless otherwise specified.

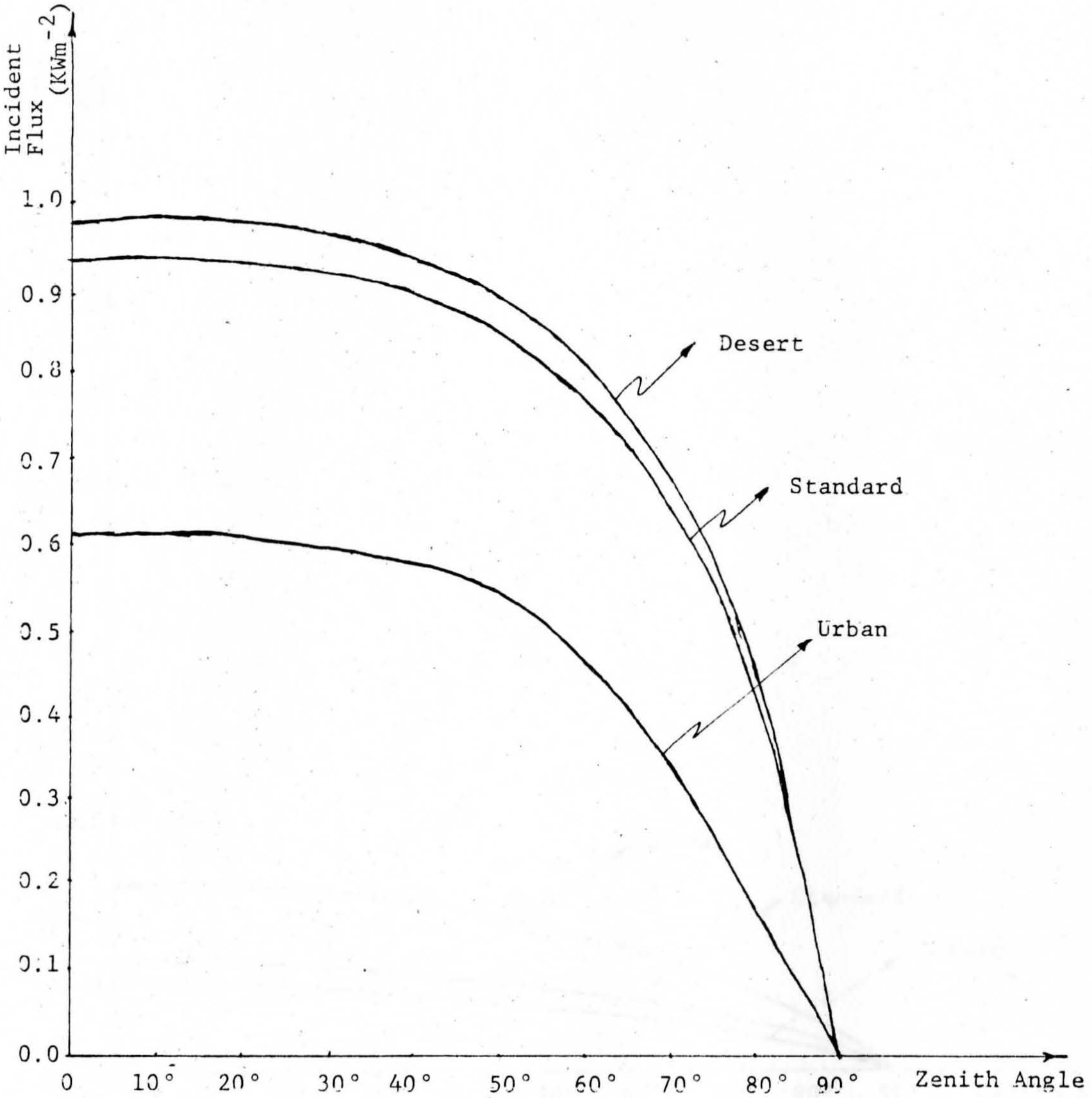

FIGURE 1.2 Curves Showing Direct Radiation as a Function of Zenith Angle on Clear Days, for Urban, Desert and Standard Areas, (Meinel)[4].

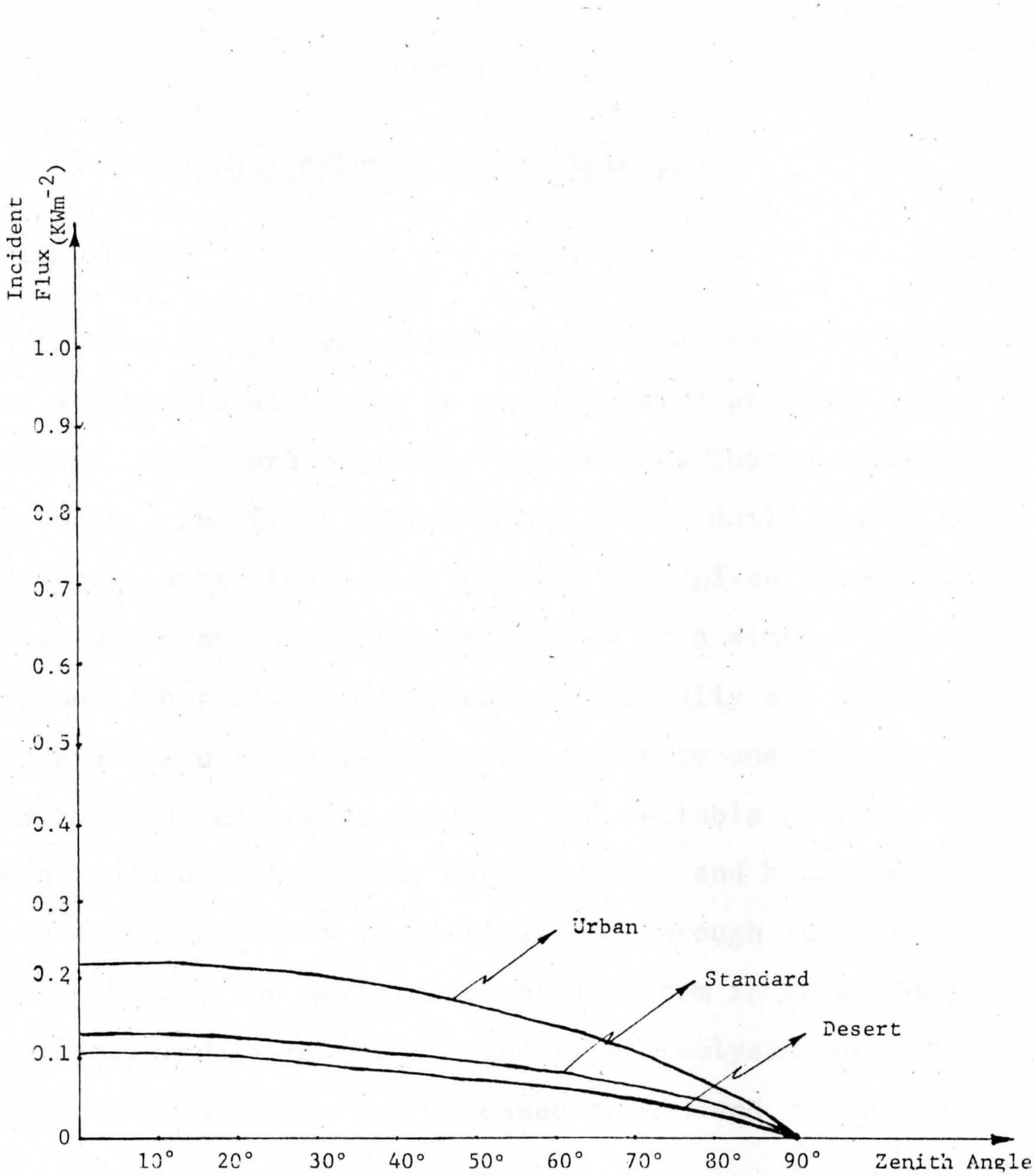

FIGURE 1.3 Curves Showing Diffuse Radiation as a Function of Zenith Angle on Clear Days, for Urban, Desert and Standard Areas, (Meinel)[4].

CHAPTER II

MONTHLY AVERAGE SOLAR RADIATION

2.1 INTRODUCTION

In Chapter I, it was suggested that future solar insolation for a given locality can be modeled using previous measured values. There are basically two methods that utilize this approach. The first method makes use of daily and/or hourly average data, for a specific day in a given locality, to predict daily and/or hourly insolation on a similar day. This method is not widely accepted because daily and hourly average data are not available in the quantity and quality demanded by solar engineers for good and reliable designs. The second method uses monthly average daily and hourly radiation data for a number of localities, and through statistical analysis, predicts the performance of a system in other localities on similar days. This chapter is an analysis and critique of such a technique and is based on Liu and Jordan's paper.[1]

2.2 THE APPROACH

The major contribution of Liu and Jordan's observations is embodied in the established relationship between direct and diffuse radiation for monthly average days. This relationship was derived from experimental data that have been averaged over a number of years. This was done for different locations (of different climates). Comparison revealed that the data for all locations tested follow similar paths. Therefore, it was concluded that the relationship derived must hold for any location, since the test locations vary in climate from one extreme to the other. It is important, however, to note that this relationship is between the ratio of the monthly average daily diffuse radiation to the monthly average daily total radiation as a function of what is termed the cloudiness index $\bar{K}_T$, where

$$\bar{K}_T = \bar{H}/H_0 \qquad (2.1)$$

and

$\bar{H}$ = monthly average daily total radiation,

H_0 = extraterrestrial daily insolation.

The extraterrestrial daily insolation is given by Equation (2.2)

$$H_0 = 24.r.I_{sc}.[(\cos (L).\cos (\delta).\sin (H) + H.\sin (L).\sin (\delta)] \qquad (2.2)$$

where

I_{sc} = solar constant (I_{sc} = 1353 W/m^2)

and r is the ratio of intensity of radiation at normal incidence outside the atmosphere to the solar constant.

The value of $\bar{K}_T$ can be obtained from tables or calculated from Equation (2.1) if $\bar{H}$ is known. The relationship between the monthly average daily total and diffuse radiation is given in Figure (2.1). The plot is a curve fit for experimental data taken in Blue Hill, Massachusetts, Nice, France, Helsingfors, Finland, and Kew Obervatory in London. The monthly average direct radiation can be easily obtained by noting the difference between the total and diffuse radiation.

Using a similar technique to the one outlined previously, Liu and Jordan have also found a general relationship between hourly diffuse radiation and daily diffuse radiation as a function of the number of hours from sunrise to sunset, and between daily total radiation and hourly total radiation as a function of sunrise-sunset hours. These are given in Figure (2.2) and (2.3) respectively, for 1/2 to 6 1/2 hours after solar noon. These curves were also tested with an expression for the instantaneous radiation intensity (I_{0h}) and excellent agreement was shown to exist between the theoretical and experimental observations. The ratio of hourly diffuse radiation to daily diffuse radiation is given by,

$$r_d = \frac{I_{0h}}{H_0} \qquad (2.3)$$

where

$$I_{0h} = r.I_{sc}.(\cos(L).\cos(\delta).\cos(H) + \sin(L).\sin(\delta)) \qquad (2.4)$$

2.3 ACCURACY OF LIU AND JORDAN'S METHOD

The previous section has revealed that once $\overline{H}$ is known, one can find the monthly average daily diffuse radiation, the hourly diffuse radiation, and hourly total radiation. These values, however, are monthly averages and assume a certain percentage of cloudiness for every day of the month. Thus, unlike the values obtained from Laue's observations which are only good for clear days, the values from Liu and Jordan's

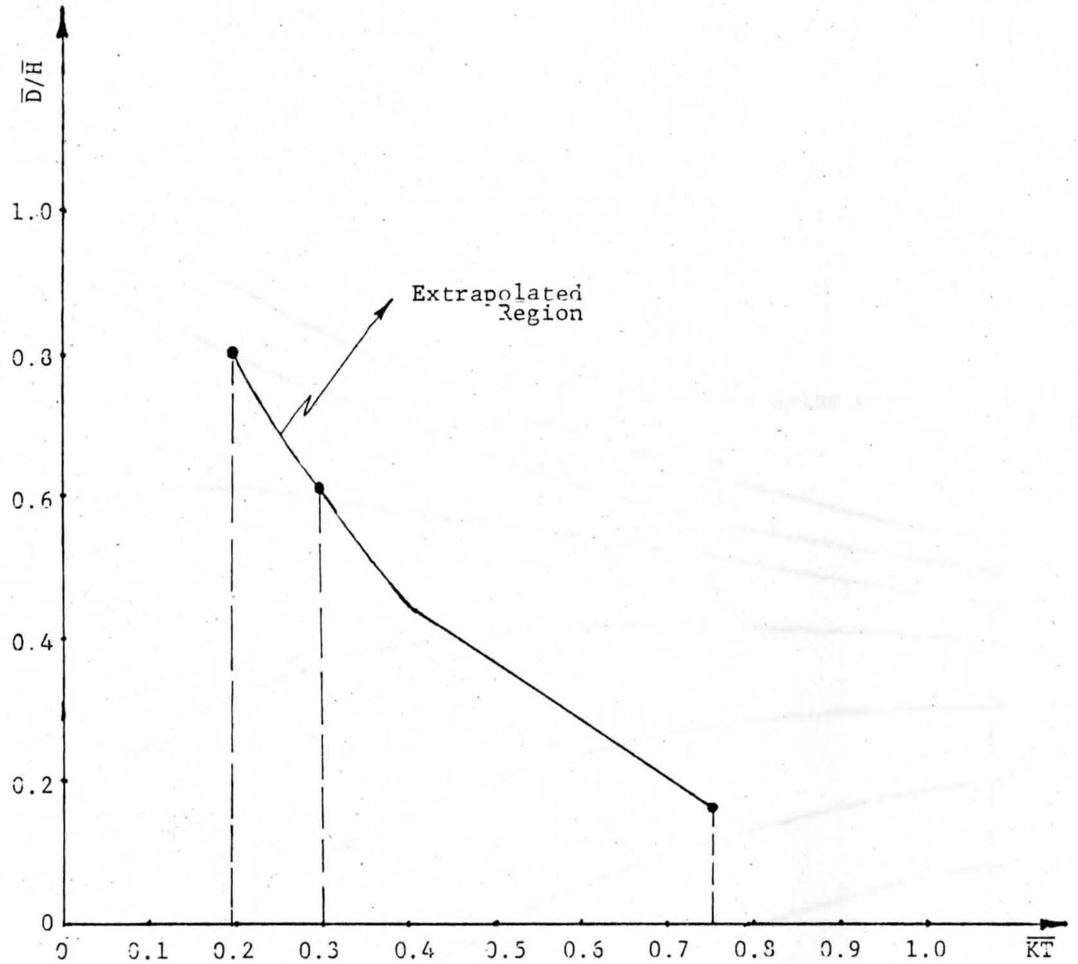

FIGURE 2.1 Ratio of the Monthly Average Daily Diffuse Radiation to the Monthly Average Daily Total Radiation as a Function of $\bar{K}_T$, (Liu and Jordan)[1].

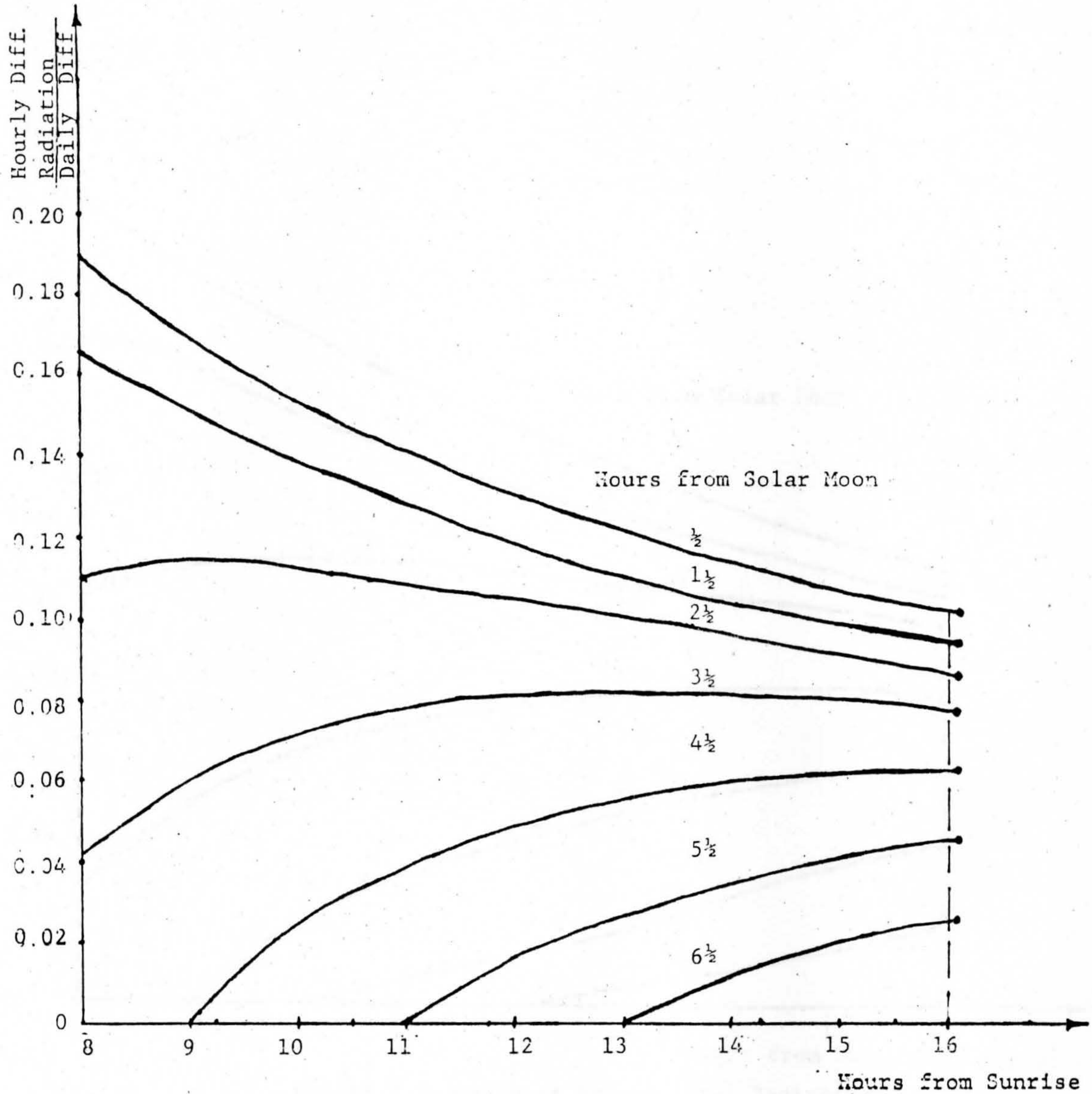

FIGURE 2.2 Ratio of Hourly Diffuse Radiation to the Daily Diffuse Radiation as a Function of Hours from Sunrise to Sunset, (Liu and Jordan)[1].

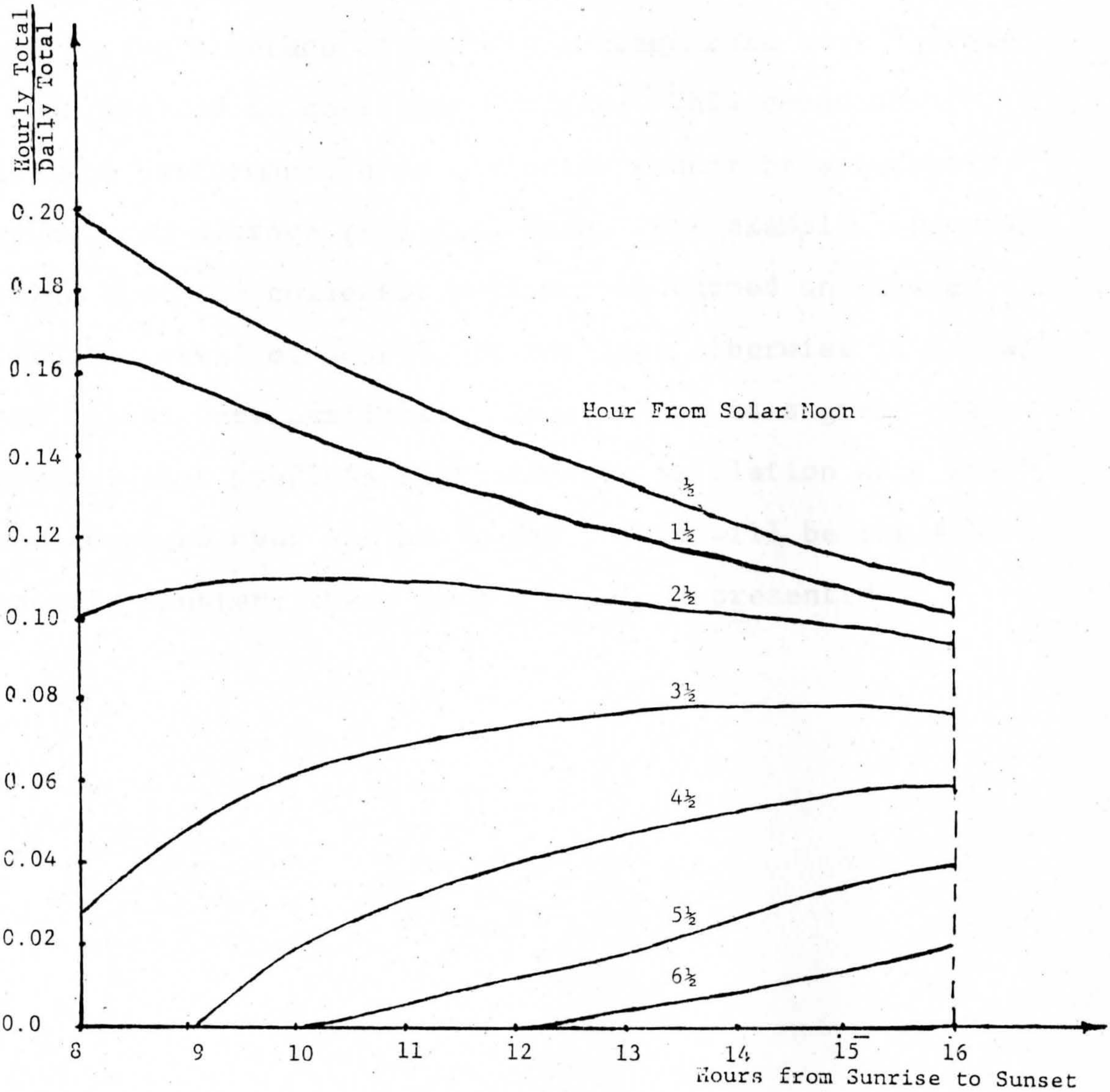

FIGURE 2.3 Ratio of Hourly Total Radiation to Daily Total Radiation as a Function of Hours from Sunrise to Sunset, (Liu and Jordan)[1].

observations are on the average good for any day of the year (although they are never absolutely correct). Unfortunately, Liu and Jordan's method of monthly average data have a drawback when applied to collector designs. This comes about because the performance of a collector cannot be accurately predicted from average radiation data. For example, one might determine that the collector will not be turned on between a specified interval of hours, yet conclude otherwise if instantaneous values were available. Thus, there is a great need for a model that predicts instantaneous insolation data which are not averaged over the whole day. This will be the subject of the next chapter, where such a model is presented.

CHAPTER 3

INSTANTANEOUS INSOLATION

3.1 INTRODUCTION

The two methods presented thus far are not practical for solar design purposes. Laue's observations are only good for clear days and Liu and Jordan's method of statistical analysis does not offer a great deal of promise in that it is an averaging technique, and in general solar systems do not operate on an average basis. The model presented in this chapter combines Laue's observations with Liu and Jordan's method in a way that produces a peaking effect rather than an average one. The model is based on Alexander and Taft's paper.[2]

3.2 THE MODEL

During a monthly average day there is a certain number of hours of sunshine which is different from the number of hours from sunrise to sunset in that the former represents the sunshine hours useful for design purposes. Thus, it is assumed that the direct radiation occurs during an interval of time equal to the number of hours of sunshine.

On a clear day, the magnitudes of direct radiation (CDIR) and diffuse radiation (CDIF) can be read from Figures 1.2 and 1.3 respectively. Both CDIR and CDIF are functions of the zenith angle and can be written as,

$$CDIR(t) = f[z(t)] \tag{3.1}$$

$$CDIF(t) = g[z(t)] \tag{3.2}$$

On a monthly average day, the values of direct (HDIR) and diffuse (HDIF) radiation are related to 3.1 and 3.2 by,

$$\int_{t_{sr}}^{t_{ss}} CDIR(t) \cdot \cos(i) \cdot dt \geq HDIR \tag{3.3}$$

$$\int_{t_{sr}}^{t_{ss}} CDIF(t) \cdot dt \leq HDIF \tag{3.4}$$

where

t_{sr} = sunrise time

t_{ss} = sunset time

Now let the number of hours of sunshine on a particular day vary from t_1 to t_2. For a clear day, t_1, and t_2 will coincide with t_{sr} and t_{ss} respectively. However, due to the unpredictable changes in atmospheric conditions, one has to work on a monthly average day basis. Thus, Alexander and Taft proposed to start with CDIR(t) and sweep across the curve until the area reached is equal to the monthly average value predicted by Liu and Jordan. If t_1 was the starting point and t_2 the ending point, then (t_2-t_1) is equal to the number of hours of sunshine. Now that a value for t_2 has been established, one can find the direct radiation at any instant during the interval of (t_2-t_1) by simply reading the corresponding value from CDIR(t). In general, it is best to fix t_1 at solar noon and vary t_2 towards t_{sr} until HDIR is satisfied. However, if

HDIR is not satisfied before t_{sr}, then t_1 is set at t_{sr} and t_2 is varied from solar noon towards t_{ss}. This is shown schematically in Figure 3.1.

If the same procedure is used for the diffuse radiation, then - in general - HDIF will never be satisfied since its absolute value is greater than the area under CDIF(t) from t_{sr} to t_{ss}. Thus CDIF(t) has to be modified by a factor of K which can be derived from Figure 3.1.

$$HDIF = K \cdot \int_{t_{sr}}^{t_1} CDIF(t) \cdot dt + K \cdot \int_{t_2}^{t_{ss}} CDIF(t) \cdot dt + \int_{t_1}^{t_2} CDIF(t) \cdot dt$$

Hence

$$K = \frac{HDIF - C}{A + B} \tag{3.5}$$

where

$$C = \int_{t_1}^{t_2} CDIF(t) \cdot dt$$

$$A = \int_{t_{sr}}^{t_1} CDIF(t) \cdot dt$$

$$B = \int_{t_2}^{t_{ss}} CDIF(t) \cdot dt$$

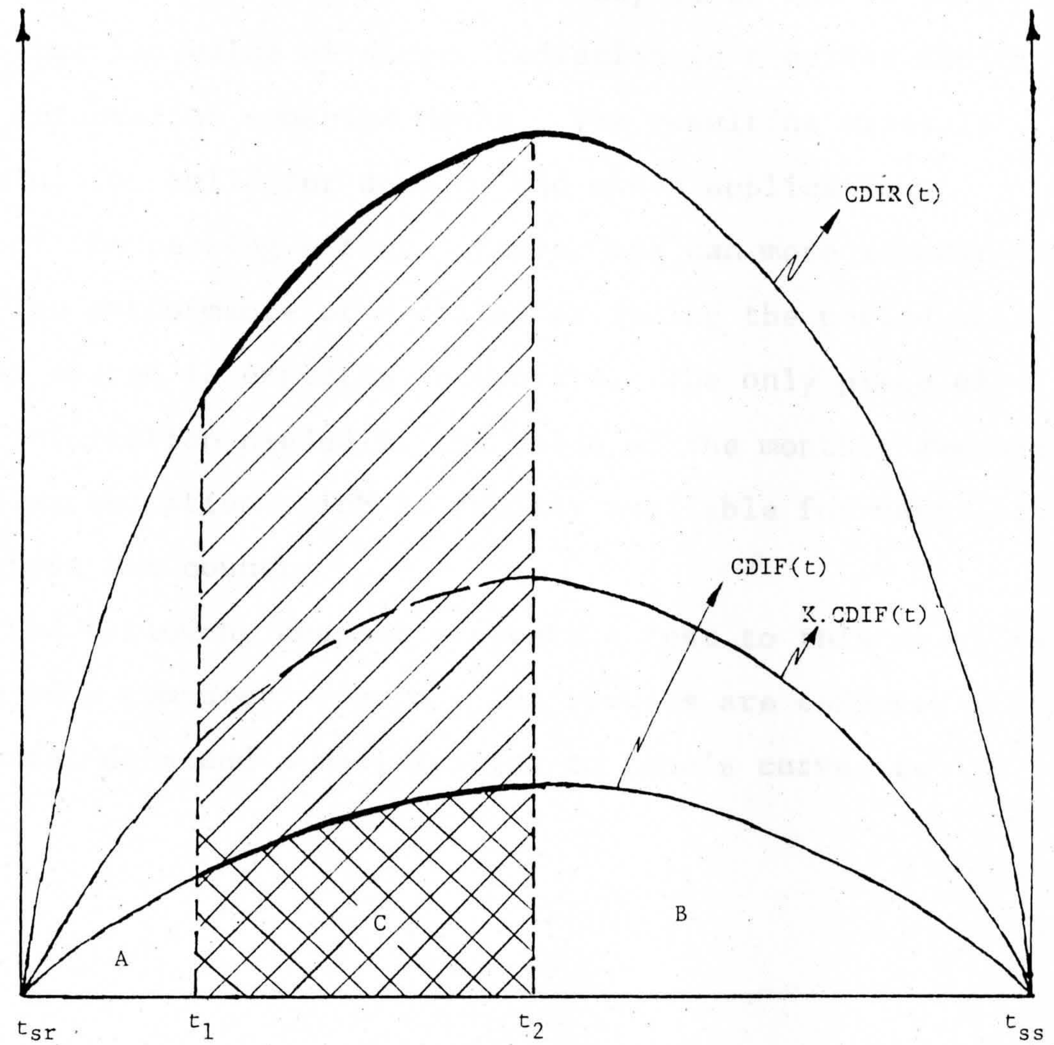

FIGURE 3.1 Absolute Value of Direct Radiation and Diffuse Radiation as a Function of the Time of day, (Alexander and Taft)[2].

3.3 CONCLUSION

This method is different from any other one in that it assumes that the value of direct radiation is received during a fixed interval of sunshine hours. The resulting model is very useful for collector designs and other applications because of the peaking effect. Hence, one can more accurately predict the performance of a collector during the period which the solar system is expected to operate. The only piece of outside information needed is the value of the monthly average daily solar radiation which is readily available for many locations across the country.

The following chapter presents a test to this model in the form of a computer program. The results are compared with experimental data and a modification to Laue's curves is proposed.

CHAPTER 4

THE MODEL

4.1 INTRODUCTION

This chapter presents a computer program that models and tests the methods described in the previous chapters. The program was developed using a structured programming technique which is outlined in Section 4.2. Alexander and Taft's method is emphasized because of its better accuracy in predicting solar collector performance as well as concentrator designs. Instantaneous radiation for 10 different localities in the United States have been calculated, and the results are shown in Section 4.4. The localities are:

1. Atlanta, Georgia
2. Boston, Massachussetts
3. Cleveland, Ohio
4. Columbus, Ohio
5. Los Angeles, California
6. Nashville, Tennessee
7. Pittsburg, Pennsylvania
8. Seattle, Washington
9. St. Louis, Missouri
10. Wichita, Kansas

An in-depth analysis of the data is also presented and some modifications to Laue's curves is proposed.

4.2 STRUCTURED PROGRAMMING

The most important feature of structured programming is the minimization of complexity, through organization. The system is partitioned into distinct hierarchical structures called levels of abstraction. Each structure or level represents a module that performs a specific job. Every module is designed idependently. The final system is composed of these independent modules connected together through well defined interfaces. Thus, the two most important points to consider are the maximization of relationships within each module and the minimization of relationships among modules. The strength of a system is represented by the degree of isolation of a single function to each module. This is referred to as module strength. Moreover, the degree of minimizing data relationships among modules is a measure of module coupling. Hence one has to strive for high module strength and loose module coupling.

In general, the program should have as many statements as required for maximum clarity and simplicity. After the design process has been achieved the system should be thoroughly tested. Basically, there are four types of testing to which one can resort.[7]

1. Bottom up: The following steps should be followed.
   a. The program is tested from bottom to top.
   b. The first modules to be tested are the ones that call none of the other modules.

c. Test those modules that directly call the modules described in step (b).

d. This process is repeated until the top is reached.

2. Top-down: The following steps should be followed.

a. The program is tested from top to bottom.

b. The only module to be tested in isolation is the first module.

c. All the modules that are directly called by the first module are then merged and tested.

d. Repeat the process until all the modules have been combined and tested.

3. Sandwich testing: This is a combination of bottom-up and top-down testing. The objective is to start at both ends and meet at a specified point of coincidence in the middle of the program.

4. Big-Bang: Each module is unit tested in isolation. Then all of the modules are merged and tested as a whole.

The program outlined in this chapter has been tested using the Big-Bang method because each module was designed to be completely independent of any other module, and hence the Big-Bang method was the easiest to adopt. The program uses FORTRAN language where the respective modules take the form of independent subroutines that are called by the main program. These subroutines are studied in detail in the section that follows.

4.3 ABOUT THE PROGRAM

A complete listing of the program is provided in Appendix B. It is composed of three major subroutines, and two minor subroutines. The major ones are involved with the actual development of the model, while the other two subroutines are involved with communicating information that simplify the process of understanding the input and output data. The following is an in depth look at the respective modules.

I. Subroutine Jord: This module calculates the hourly total, direct and diffuse radiation using Liu and Jordan's observations (See Chapter 2). The inputs to this module are the values of $\bar{H}$ and $\overline{KT}$. With these known, one can use Figure (2.1) to calculate the value of monthly average diffuse radiation. Now the hourly diffuse and total radiation can be obtained from Figures (2.2) and (2.3) respectively. The only problem is to be able to incorporate these figures into the computer program. This was done using a regression technique so that the experimental data points can be curve fitted. This technique assumes a polynomial fit of the form;

$$y = K_0x^n + K_1x^{n-1} + K_2x^{n-2} + \text{-----} + K_nx^0 \qquad (4.1)$$

where K_i is a constant and n can be adjusted to satisfy the curve requirement for a best fit. Once the K_i's are found, the problem is solved and a curve fit is established. It turns out that these K_i's are easily found by using elementary calculus (for a detailed analysis, see Appendix A). Via this technique the following curve fits were found:

A. From Figure (2.1).

$$y = 1.35 - 3.25\,x + 2.5\,x^2 \qquad 0 \le x \le .4 \qquad (4.2)$$

$$y = 0.77 - 0.8\,x \qquad x \ge .4 \qquad (4.3)$$

where

$$y = \frac{D}{\bar{H}} = \frac{\text{Monthly Average Daily Diffuse Radiation}}{\text{Monthly Average Daily Total Radiation}}$$

$$x = K_T = \frac{\bar{H}}{H_0}$$

B From Figure (2.2)

HR: ½ $u = 0.3981709 - (.034119)V + (9.80952 \times 10^{-4})V^2$

HR: 1½ $u = 0.314407 - (.0244047)V + (6.88225 \times 10^{-4})V^2$

HR: 2½ $u = 0.0869 + (6.4 \times 10^{-3})V - (4 \times 10^{-4})V^2$

HR: 3½ $u = - 0.172504 + (0.0385416)V - (1.4583 \times 10^{-3})V^2$

HR: 4½ $u = - 0.320007 + (0.0528333)V - (1.8333 \times 10^{-3})V^2$

HR: 5½ $u = - 0.44 + (0.062)V - (2 \times 10^{-3})V^2$

HR: 6½ $u = - 0.455017 + (0.056666)V - 1.6666 \times 10^{-3})V^2$

where

$$u = \frac{\text{Hourly Diffuse Radiation}}{\text{Daily Diffuse Radiation}}$$

V = Hours from sunrise to sunset.

HR = Hours after solar noon.

C. From Figure (2.3).

HR: ½ $w = 0.351749 - (0.02407)V + (5.5352 \times 10^{-4})V^2$

HR: 1½ $w = 0.2783838 - (0.0172258)V + (3.9072 \times 10^{-4})V^2$

HR: 2½ $w = 0.0614835 + (8.90109 \times 10^{-3})V - (4.3956 \times 10^{-4})V^2$

HR: 3½ $w = - 0.1527705 + (0.0338461)V - (1.23076 \times 10^{-3})V^2$

HR: 4½ $w = - 0.2 + (0.032)V - (10^{-3})V_2$

HR: 5½ $w = - 0.0253896 + (7.14285 \times 10^{-5})V + (2.46753 \times 10^{-4})V^2$

HR: 6½ $w = - 0.0200665 - (9.2857 \times 10^{-4})V + (2.09523 \times 10^{-4})V^2$

where $w = \frac{\text{Hourly Total Radiation}}{\text{Daily Total Radiation}}$

Hourly diffuse, direct and total radiation are given in section 4.4 for ten localities in the United States, for an average day during each month of the year.

II. Subroutine LLJ: This module calculates the number of hours of sunshine during an average day and compares the results with experimental data based on Weather Bureau records from black-bulb type sunshine recorders, during the period of 1931-1960.[9] The number of hours of sunshine were found according to the method described in Chapter 3. Hence, this module tests Alexander and Taft's method by comparing hours of sunshine data. Sunshine data for three different types of localities namely, Desert, Standard, and Urban are presented Using the regression analysis (See Appendix A), Laue's observations for these types of localities were fitted into the following curves:

A. Desert:

$$CDIR(z) = [959.8844 + 1.203539z - 0.170716z^2 + 0.454363 \times 10^{-2}z^3 - 0.456588 \times 10^{-4}z^4] \quad (4.4)$$

$$CDIF(z) = [85.0517 - 0.912085z + 0.041425z^2 - 0.750411 \times 10^{-3} + 0.3182 \times 10^{-5}z^4] \quad (4.5)$$

B. Standard:

$$CDIR(z) = [929.4566 + 0.49859z - 0.140152z^2 + 0.395109 \times 10^{-2}z^3 - 0.414178 \times 10^{-4}z^4] \quad (4.6)$$

$$CDIF(z) = [96.45 - 0.613444z + 0.03077z^2 - 0.648918 \times 10^{-3}z^3 + 0.278249 \times 10^{-5}z^4] \quad (4.7)$$

C. Urban:

$$CDIR(z) = [612.66 - 1.382752z + 0.06817z^2 - 0.176841 \times 10^{-2}z^3 + 0.374235 \times 10^{-5}z^4] \quad (4.8)$$

$$CDIF(z) = [215.6253 + 0.069213z - 0.012605z^2 - 0.187604 \times 10^{-3}z^3 + 0.23314 \times 10^{-6}z^4] \quad (4.9)$$

Thus, if the locality is of type A, B, or C one should expect the results to be in close agreement with the experimental data. However, this is not always the case because of two major reasons:

1. Laue's Observations: The three types of localities were characterized as being strictly desert, standard or urban. However, the experimental data might have been obtained in areas that cannot be characterized by any of these three types of localities. Instead one might find that the atmospheric conditions dictate a type of area which is somewhere between desert and standard or standard and urban. Indeed, the data obtained via the computer program (See Section 4.4) show that this kind of result is possible and probable. It is also important to point out that this does not imply defects in the proposed model, but reveals the limitations imposed by Laue's curves which have to be modified to include more types of localities. Section 4.4 proposes such a modification for ten different localities in the United States.

2. Total Versus Direct and Diffuse radiation: The model used in the program utilizes the curve developed by Liu and Jordan (2.1) to calculate the montly average direct and diffuse radiation from the value of $\bar{K}_T$. This curve is an average

one and thus it never predicts perfect values of direct and diffuse radiation. Therefore, one should expect a slight difference between the experimental and theoretical data because the assumption is that the measured data are correct, and hence, Laue's curves are modified accordingly.

Subroutine LLJ also generates values for the daily direct and diffuse radiation on clear days, and the number of hours from sunrise to sunset. Day 15 of each month is taken as the reference day for which all values were calculated.

III. Subroutine CALC: This module generates values of instantaneous radiation in the form of hourly data. Once the number of hours of sunshine on a given day in a given locality is fixed, one can look up the hourly radiation during that period by simply reading off the corresponding values from the output of this module. At this point, it would serve as a good reminder to mention that all the values obtained are for horizontal surfaces where b=0, and i=z. One can easily modify the output to include radiation on a quarter hourly basis by changing the index of summation, since the curves utilized are continuous functions of time rather than discrete functions. The hourly basis was chosen for simplicity and convenience.

IV. Subroutine DATA: This prints the respective input to the program. The inputs are:

a. $\overline{H}$

b. DAY

c. L

d. $\overline{KT}$

e. HS

There are 12 values for each input that correspond to the 15th day of each month of the year.

V. Subroutine DEF: This subroutine defines the various variables of the system.

Each subroutine contains a testing routine which makes sure that the inputs are not out of range and that the module is behaving according to the specifications of the system. For a complete listing of the program, see Appendix B.

4.4 THE OUTPUT

This section is a presentation of the output of the program. Tables 4.1 - 4.10 represent the hourly radiation for the ten localities listed in section 4.1. The data are given in sets of three. The first set are values for the hourly total, direct and diffuse radiation for the fifteenth day of January. The second set are values for the fifteenth day of February and so forth.

Tables 4.11 and 4.12 give the calculated number of hours of sunshine for the fifteenth day of each month, for the ten different localities. These are compared with the experimental data from Weather Bureau Records.[9] Since the calculated number of hours of sunshine are linearly dependent on the value of CDIR from sunrise to sunset, then one can apply a correction factor to CDIR so that the measured and calculated values coincide. Let $\overline{CDIR}$ be the new value of CDIR corrected by a factor $\bar{C}$.

Then $$\bar{C} = \frac{HS}{XLENG}$$

and $$\overline{CDIR} = \frac{1}{\bar{C}} \cdot CDIR$$

when HS = experimental number of sunshine hours

XLENG = calculated number of sunshine hours.

The value of $\bar{C}$ is given in Tables 4.13 and 4.14. Figures 1.2 - 1.3 give Laue's curves which have to be modified by the correction factor. For some locations, the model predicted a drop in the number of sunshine hours for March, whereas the experimental data did not predict such a drop. However, this drop can be justified according to the following argument. It was noticed that for each location where the drop occurred, the experimental value of $\bar{K}_T$ also dropped during the same month. This means that during this month, the ratio of monthly average total radiation to extraterrestrial radiation has decreased. Thus, one should expect more cloud concentration and higher winds which dictate the predicted decrease in the number of hours of sunshine. The preceding argument is based on the assumption that the value of $\bar{K}_T$ has been more accurately measured than the value of sunshine hours, since the former is generally more reliable because of the difficulty encountered when measuring sunshine hours.

Now that a value for the number of hours of sunshine has been established, the instantaneous radiation can be found during this interval from the hourly radiation as given in Table 4.15.

4.5 CONCLUSION

The program outlined in this chapter can be easily modified to include any location in the world where $\bar{H}$ data are available. The program can also be modified to handle radiation on an inclined surface, by setting a value to the tilt angle (b) and calculating the value of the incidence angle – which is no longer equal to the zenith angle. Hence, this program predicts instantaneous radiation during any day of the year for any location where $\bar{H}$ data are available.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	439.877	384.056	282.002	165.998	53.483	0.252	0.00
HOURLY DIRECT	288.251	247.881	173.415	100.153	28.757	0.252	0.00
HOURLY DIFFU.	151.626	136.175	108.587	65.844	24.726	0.000	0.00
HOURLY TOTAL	517.002	456.069	350.976	227.566	94.686	13.314	0.00
HOURLY DIRECT	340.660	295.631	217.373	137.878	50.257	13.314	0.00
HOURLY DIFFU.	176.342	160.439	133.603	89.688	44.429	0.000	0.00
HOURLY TOTAL	634.820	568.040	461.333	328.981	167.549	42.687	0.00
HOURLY DIRECT	434.350	382.527	299.536	209.007	94.801	23.089	0.00
HOURLY DIFFU.	200.470	185.513	161.796	119.574	72.748	19.598	0.00
HOURLY TOTAL	753.228	684.277	580.804	443.118	258.581	91.065	14.31
HOURLY DIRECT	532.695	476.836	394.088	294.807	157.077	43.427	14.31
HOURLY DIFFU.	220.533	207.440	186.716	148.310	101.504	47.638	0.00
HOURLY TOTAL	780.647	718.427	626.580	496.120	315.924	137.374	41.52
HOURLY DIRECT	551.273	500.058	427.743	332.550	196.367	68.894	24.05
HOURLY DIFFU.	229.373	218.369	198.837	163.570	119.558	68.479	17.46
HOURLY TOTAL	782.628	725.115	638.818	512.254	339.470	163.223	57.80
HOURLY DIRECT	551.575	503.963	437.498	344.954	214.056	86.339	29.91
HOURLY DIFFU.	231.052	221.152	201.321	167.300	125.413	76.883	27.89
HOURLY TOTAL	769.012	710.759	624.090	498.403	325.633	151.010	50.82
HOURLY DIRECT	542.429	494.290	426.910	335.040	204.218	78.255	27.04
HOURLY DIFFU.	226.583	216.468	197.180	163.362	121.414	72.755	23.78
HOURLY TOTAL	755.045	690.582	595.269	464.041	284.050	112.128	27.18
HOURLY DIRECT	533.760	481.067	405.188	309.875	174.501	54.234	20.08
HOURLY DIFFU.	221.285	209.515	190.081	154.166	109.549	57.894	7.09
HOURLY TOTAL	667.266	601.496	499.948	369.785	202.532	61.433	1.06
HOURLY DIRECT	461.997	409.974	329.930	238.886	117.674	29.027	1.06
HOURLY DIFFU.	205.269	191.522	170.018	130.899	84.858	32.407	0.00
HOURLY TOTAL	614.299	545.488	431.052	293.424	135.900	27.005	0.00
HOURLY DIRECT	437.429	383.273	292.773	195.736	81.902	21.469	0.00
HOURLY DIFFU.	176.870	162.215	138.279	97.687	53.997	5.536	0.00
HOURLY TOTAL	499.025	437.561	327.876	201.593	73.541	5.255	0.00
HOURLY DIRECT	346.323	299.673	215.818	130.455	42.907	5.255	0.00
HOURLY DIFFU.	152.703	137.887	112.058	71.137	30.633	0.000	0.00
HOURLY TOTAL	394.222	343.292	248.786	142.155	41.599	0.000	0.00
HOURLY DIRECT	252.019	216.010	148.540	83.242	21.761	0.000	0.00
HOURLY DIFFU.	142.204	127.282	100.246	58.913	19.839	0.000	0.00

TABLE 4.1 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Atlanta, Georgia

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	284.938	246.269	171.408	88.576	16.722	0.000	0.000
HOURLY DIRECT	168.251	142.842	93.038	47.141	8.521	0.000	0.000
HOURLY DIFFU.	116.688	103.427	78.370	41.435	8.201	0.000	0.000
HOURLY TOTAL	373.638	327.503	245.012	150.139	54.281	3.622	0.000
HOURLY DIRECT	225.989	194.238	136.872	81.731	25.109	3.622	0.000
HOURLY DIFFU.	147.649	133.265	108.140	68.408	29.172	0.000	0.000
HOURLY TOTAL	496.224	443.513	358.815	254.261	127.865	31.571	0.000
HOURLY DIRECT	317.678	278.509	215.349	148.575	64.547	15.839	0.000
HOURLY DIFFU.	178.546	165.009	143.466	105.686	63.318	15.732	0.000
HOURLY TOTAL	553.521	505.166	433.420	335.721	202.496	77.150	16.801
HOURLY DIRECT	347.070	310.095	256.814	193.352	102.459	26.043	13.502
HOURLY DIFFU.	206.452	195.071	176.605	142.368	100.037	51.107	3.299
HOURLY TOTAL	657.699	611.111	540.205	434.923	292.941	146.870	54.802
HOURLY DIRECT	433.982	396.536	345.171	272.430	170.004	69.653	23.842
HOURLY DIFFU.	223.717	214.574	195.033	162.493	122.937	77.217	30.959
HOURLY TOTAL	665.492	624.139	555.576	450.549	319.505	183.515	78.109
HOURLY DIRECT	436.400	403.152	357.034	285.034	191.194	97.479	34.605
HOURLY DIFFU.	229.092	220.987	198.542	165.515	128.311	86.036	43.503
HOURLY TOTAL	671.918	628.038	558.056	451.858	314.543	171.942	70.151
HOURLY DIRECT	451.706	416.016	366.526	291.989	191.580	91.253	32.195
HOURLY DIFFU.	220.212	212.023	191.531	159.869	122.964	80.689	37.956
HOURLY TOTAL	617.038	568.434	496.608	394.072	252.498	111.497	34.656
HOURLY DIRECT	408.590	369.817	315.711	244.979	143.070	48.103	17.332
HOURLY DIFFU.	208.448	198.617	180.897	149.092	109.428	63.394	17.324
HOURLY TOTAL	547.593	494.425	412.889	307.574	170.882	53.606	2.781
HOURLY DIRECT	359.274	318.409	256.116	185.996	91.067	21.484	2.781
HOURLY DIFFU.	188.319	176.016	156.773	121.579	79.814	32.122	0.000
HOURLY TOTAL	426.724	377.422	293.626	194.315	84.682	13.998	0.000
HOURLY DIRECT	272.084	236.274	174.938	112.911	42.377	13.998	0.000
HOURLY DIFFU.	154.640	141.148	118.688	81.404	42.305	0.000	0.000
HOURLY TOTAL	286.891	249.404	179.171	100.293	27.271	0.000	0.000
HOURLY DIRECT	168.144	143.349	96.335	52.655	12.535	0.000	0.000
HOURLY DIFFU.	118.747	106.054	82.836	47.639	14.737	0.000	0.000
HOURLY TOTAL	249.595	214.950	146.527	71.457	8.968	0.000	0.000
HOURLY DIRECT	144.972	122.653	77.984	37.356	5.153	0.000	0.000
HOURLY DIFFU.	104.623	92.297	68.543	34.100	3.816	0.000	0.000

TABLE 4.2 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Boston, Massachussetts.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	252.420	212.444	153.140	90.654	14.853	0.000	0.000
HOURLY DIRECT	137.816	116.692	75.504	39.779	7.425	0.000	0.000
HOURLY DIFFU.	114.604	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	339.115	296.605	222.725	137.541	50.759	3.036	0.000
HOURLY DIRECT	192.091	154.664	115.240	69.023	20.991	3.036	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	523.198	472.155	392.172	271.032	136.521	33.045	0.000
HOURLY DIRECT	345.373	303.634	235.594	162.043	71.474	17.557	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	575.099	524.552	449.467	347.524	209.764	73.770	14.600
HOURLY DIRECT	364.307	325.964	249.792	202.932	107.494	37.529	14.161
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	732.968	680.216	600.464	492.457	322.957	150.006	58.073
HOURLY DIRECT	516.253	472.539	411.555	325.419	204.350	95.319	29.697
HOURLY DIFFU.	216.714	207.677	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	750.915	703.166	625.484	506.042	356.474	209.140	83.615
HOURLY DIRECT	532.055	492.224	435.459	348.421	233.894	113.319	43.770
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	751.485	701.405	622.616	503.611	347.921	196.214	74.502
HOURLY DIRECT	533.434	491.645	432.775	345.151	226.396	107.306	38.424
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	719.124	661.272	577.352	457.240	291.340	126.872	38.453
HOURLY DIRECT	513.066	465.684	399.707	310.252	193.960	65.242	22.622
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

HOURLY TOTAL	604.229	545.450	455.231	338.816	187.903	58.600	2.707
HOURLY DIRECT	418.414	371.813	300.640	219.039	109.393	27.302	2.707
HOURLY DIFFU.	185.815	173.637	154.591	119.779	78.510	31.298	0.000
HOURLY TOTAL	470.337	414.205	324.457	215.524	84.704	14.077	0.000
HOURLY DIRECT	313.800	273.233	204.023	132.594	51.241	14.077	0.000
HOURLY DIFFU.	156.537	140.967	120.434	82.927	33.462	0.000	0.000
HOURLY TOTAL	277.427	241.439	174.426	89.344	29.232	0.000	0.000
HOURLY DIRECT	164.524	132.307	80.515	49.424	12.033	0.000	0.000
HOURLY DIFFU.	112.903	109.132	94.911	40.920	14.199	0.000	0.000
HOURLY TOTAL	239.029	206.140	141.401	70.750	10.720	0.000	0.000
HOURLY DIRECT	131.796	111.365	70.741	34.566	5.390	0.000	0.000
HOURLY DIFFU.	107.233	94.775	70.650	36.184	5.330	0.000	0.000

TABLE 4.3 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Cleveland, Ohio.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.
HOURLY TOTAL	259.890	225.242	159.200	85.621	19.768	0.000	0.00
HOURLY DIRECT	142.126	120.482	78.639	41.199	8.458	0.000	0.00
HOURLY DIFFU.	117.765	104.760	80.561	44.421	11.310	0.000	0.00
HOURLY TOTAL	369.929	324.817	244.948	152.588	57.598	5.151	0.00
HOURLY DIRECT	218.528	187.865	132.994	80.531	25.402	5.151	0.00
HOURLY DIFFU.	151.401	136.952	111.954	72.057	32.195	0.000	0.00
HOURLY TOTAL	500.640	447.604	362.506	257.326	129.860	32.344	0.000
HOURLY DIRECT	316.878	277.713	214.668	148.222	64.276	15.667	0.000
HOURLY DIFFU.	183.762	169.891	147.838	109.104	65.585	16.678	0.000
HOURLY TOTAL	601.288	548.069	468.901	361.780	216.303	80.696	16.332
HOURLY DIRECT	390.193	343.853	288.796	217.140	115.364	30.216	14.957
HOURLY DIFFU.	211.094	199.217	180.104	144.640	100.940	50.480	1.375
HOURLY TOTAL	688.608	638.150	562.365	451.106	299.337	144.408	51.372
HOURLY DIRECT	465.065	424.149	367.572	289.191	177.868	69.792	24.066
HOURLY DIFFU.	223.543	214.001	194.793	161.915	121.469	74.616	27.306
HOURLY TOTAL	761.198	711.522	632.258	511.956	356.476	195.005	79.613
HOURLY DIRECT	539.899	498.448	439.791	351.306	232.896	113.885	41.410
HOURLY DIFFU.	221.298	213.074	192.467	160.650	123.579	81.120	38.203
HOURLY TOTAL	745.175	694.369	615.532	497.154	340.241	177.832	69.459
HOURLY DIRECT	523.894	481.723	422.724	336.274	217.501	99.017	35.113
HOURLY DIFFU.	221.281	212.646	192.809	160.880	122.740	78.614	34.346
HOURLY TOTAL	699.500	643.129	559.974	442.421	280.065	120.008	35.262
HOURLY DIRECT	488.969	442.864	377.681	292.745	171.105	58.292	20.632
HOURLY DIFFU.	210.530	200.266	132.292	149.676	108.960	61.716	14.630
HOURLY TOTAL	679.388	613.150	511.385	380.218	210.429	65.416	2.795
HOURLY DIRECT	495.176	441.055	358.240	261.684	132.875	34.631	2.795
HOURLY DIFFU.	184.213	172.096	153.145	118.535	77.553	30.786	0.000
HOURLY TOTAL	509.801	451.390	352.705	235.288	104.358	18.245	0.000
HOURLY DIRECT	351.453	306.666	230.541	150.793	59.650	17.408	0.000
HOURLY DIFFU.	158.348	144.724	122.164	84.495	44.708	0.837	0.000
HOURLY TOTAL	347.502	302.803	220.162	126.750	38.046	0.000	0.000
HOURLY DIRECT	217.057	185.948	127.843	72.064	19.088	0.000	0.000
HOURLY DIFFU.	130.446	116.855	92.319	54.687	18.958	0.000	0.000
HOURLY TOTAL	271.557	234.573	162.753	83.393	14.985	0.000	0.000
HOURLY DIRECT	158.213	134.183	86.916	43.653	7.608	0.000	0.000
HOURLY DIFFU.	113.344	100.390	75.837	39.740	7.376	0.000	0.000

TABLE 4.4 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Columbus, Ohio.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	496.813	433.676	318.114	186.831	59.779	0.053	0.000
HOURLY DIRECT	351.445	303.157	214.136	123.932	36.342	0.053	0.000
HOURLY DIFFU.	145.368	130.519	103.978	62.899	23.437	0.000	0.000
HOURLY TOTAL	626.658	552.729	425.127	275.354	114.291	15.922	0.000
HOURLY DIRECT	459.109	400.315	298.270	190.289	72.259	15.922	0.000
HOURLY DIFFU.	167.549	152.414	126.858	85.065	42.032	0.000	0.000
HOURLY TOTAL	772.604	691.314	561.406	400.294	203.816	51.895	0.000
HOURLY DIRECT	590.675	522.962	414.585	291.439	137.826	34.145	0.000
HOURLY DIFFU.	181.930	168.352	146.820	108.855	65.990	17.750	0.000
HOURLY TOTAL	805.770	732.076	621.519	474.338	276.992	97.711	15.493
HOURLY DIRECT	599.159	537.714	446.551	335.313	181.789	52.943	15.493
HOURLY DIFFU.	206.611	194.362	174.969	139.024	95.203	44.767	0.000
HOURLY TOTAL	839.900	773.108	674.494	534.285	340.633	148.557	45.148
HOURLY DIRECT	623.750	567.293	487.078	380.053	227.810	83.792	28.398
HOURLY DIFFU.	216.150	205.814	187.415	154.232	112.823	64.765	16.749
HOURLY TOTAL	870.488	806.718	710.932	570.297	378.470	182.637	64.996
HOURLY DIRECT	658.145	603.436	525.898	416.491	263.076	111.740	39.032
HOURLY DIFFU.	212.342	203.281	185.034	153.807	115.394	70.896	25.964
HOURLY TOTAL	926.594	856.598	752.392	601.109	393.261	182.990	61.902
HOURLY DIRECT	728.159	666.988	579.682	457.975	286.793	119.050	40.777
HOURLY DIFFU.	198.435	189.611	172.710	143.134	106.468	63.940	21.125
HOURLY TOTAL	885.469	809.989	698.407	544.666	333.726	132.047	32.222
HOURLY DIRECT	690.426	625.296	530.823	408.694	237.036	80.838	25.759
HOURLY DIFFU.	195.043	184.693	167.583	135.971	96.690	51.209	6.463
HOURLY TOTAL	816.166	735.744	611.590	452.428	247.868	75.238	1.354
HOURLY DIRECT	636.404	568.015	462.683	337.765	173.517	46.811	1.354
HOURLY DIFFU.	179.762	167.729	148.907	114.663	74.352	28.426	0.000
HOURLY TOTAL	646.003	573.594	453.122	308.279	142.616	28.248	0.000
HOURLY DIRECT	474.211	416.051	318.862	213.484	90.278	22.995	0.000
HOURLY DIFFU.	171.792	157.542	134.260	94.794	52.338	5.253	0.000
HOURLY TOTAL	552.272	484.164	362.504	222.508	80.806	5.583	0.000
HOURLY DIRECT	407.831	353.765	256.611	155.404	52.050	5.583	0.000
HOURLY DIFFU.	144.442	130.399	105.893	67.104	28.756	0.000	0.000
HOURLY TOTAL	482.961	420.471	304.366	173.447	50.290	0.000	0.000
HOURLY DIRECT	348.428	300.090	209.659	117.946	31.797	0.000	0.000
HOURLY DIFFU.	134.533	120.382	94.707	55.501	18.493	0.000	0.000

TABLE 4.5 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Los Angeles, California

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	320.093	278.672	201.703	114.918	33.295	0.000	0.000
HOURLY DIRECT	183.051	156.048	105.241	58.402	14.480	0.000	0.000
HOURLY DIFFU.	137.042	122.623	96.462	56.516	18.815	0.000	0.000
HOURLY TOTAL	441.410	388.683	296.815	189.594	76.156	9.294	0.000
HOURLY DIRECT	274.298	236.981	171.369	106.694	36.580	9.294	0.000
HOURLY DIFFU.	167.112	151.702	125.447	82.899	39.576	0.000	0.000
HOURLY TOTAL	554.895	496.364	402.685	286.652	145.477	36.742	0.000
HOURLY DIRECT	359.375	315.498	245.079	169.999	74.978	18.159	0.000
HOURLY DIFFU.	195.519	180.866	157.606	116.653	70.498	18.583	0.000
HOURLY TOTAL	695.876	632.993	538.973	413.055	243.362	87.674	15.391
HOURLY DIRECT	476.937	426.786	353.029	264.703	141.034	38.387	15.391
HOURLY DIFFU.	218.939	206.206	185.944	148.352	102.327	49.288	0.000
HOURLY TOTAL	744.559	687.067	601.862	479.228	310.183	140.482	45.577
HOURLY DIRECT	519.984	472.788	406.662	317.888	190.980	70.178	24.361
HOURLY DIFFU.	224.575	214.279	195.200	161.340	119.203	70.304	21.216
HOURLY TOTAL	787.861	732.470	647.878	521.979	352.710	178.318	67.179
HOURLY DIRECT	566.093	519.682	454.548	360.843	230.587	101.259	35.727
HOURLY DIFFU.	221.768	212.788	193.330	161.136	122.123	77.059	31.452
HOURLY TOTAL	778.615	721.914	636.570	511.005	340.032	165.221	59.327
HOURLY DIRECT	554.316	507.112	441.088	348.437	217.874	89.860	31.240
HOURLY DIFFU.	224.299	214.802	195.481	162.568	122.158	75.361	28.086
HOURLY TOTAL	735.845	674.385	583.694	457.538	283.822	115.715	30.501
HOURLY DIRECT	520.045	469.686	397.687	305.897	175.004	56.532	20.401
HOURLY DIFFU.	215.800	204.700	186.007	151.641	108.818	59.183	10.100
HOURLY TOTAL	691.544	623.668	519.072	384.715	211.571	64.796	1.773
HOURLY DIRECT	493.934	439.201	355.160	258.254	129.293	32.886	1.773
HOURLY DIFFU.	197.609	184.467	163.912	126.461	82.278	31.909	0.000
HOURLY TOTAL	577.057	511.842	402.724	272.046	123.968	23.512	0.000
HOURLY DIRECT	406.536	355.661	270.085	179.092	73.418	19.890	0.000
HOURLY DIFFU.	170.521	156.181	132.639	92.954	50.550	3.622	0.000
HOURLY TOTAL	414.160	362.267	268.377	161.076	54.973	1.980	0.000
HOURLY DIRECT	268.612	231.245	163.024	95.873	28.869	1.980	0.000
HOURLY DIFFU.	145.547	131.022	105.353	65.204	26.103	0.000	0.000
HOURLY TOTAL	321.351	278.958	198.884	109.298	27.670	0.000	0.000
HOURLY DIRECT	190.510	162.321	108.442	58.283	13.161	0.000	0.000
HOURLY DIFFU.	130.840	116.637	90.442	51.016	14.509	0.000	0.000

TABLE 4.6 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Nashville, Tennessee.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	319.966	277.208	195.540	104.635	23.608	0.000	0.000
HOURLY DIRECT	194.170	165.357	109.690	57.549	11.951	0.000	0.000
HOURLY DIFFU.	125.795	111.851	85.850	47.087	11.657	0.000	0.000
HOURLY TOTAL	399.081	350.333	263.916	164.056	61.591	5.332	0.000
HOURLY DIRECT	244.582	210.619	149.813	90.780	29.041	5.332	0.000
HOURLY DIFFU.	154.499	139.714	114.103	73.276	32.549	0.000	0.000
HOURLY TOTAL	545.160	487.388	394.672	280.094	141.285	35.150	0.000
HOURLY DIRECT	360.981	317.120	246.522	170.786	75.607	18.499	0.000
HOURLY DIFFU.	184.179	170.268	148.149	109.308	65.678	16.651	0.000
HOURLY TOTAL	612.504	558.385	477.907	368.923	220.832	82.615	16.892
HOURLY DIRECT	401.923	359.622	298.177	224.510	119.958	32.023	15.257
HOURLY DIFFU.	210.581	198.764	179.730	144.412	100.873	50.592	1.635
HOURLY TOTAL	686.863	636.752	561.376	450.548	299.559	145.251	52.015
HOURLY DIRECT	463.818	423.173	366.996	288.918	178.164	70.453	24.285
HOURLY DIFFU.	223.045	213.578	194.380	161.630	121.395	74.798	27.730
HOURLY TOTAL	756.373	707.323	628.702	509.214	355.422	195.676	80.350
HOURLY DIRECT	536.345	495.417	437.410	349.555	232.472	114.734	41.849
HOURLY DIFFU.	220.028	211.906	191.292	159.658	122.949	80.942	38.500
HOURLY TOTAL	751.308	700.368	621.069	501.819	344.206	180.968	71.113
HOURLY DIRECT	533.644	491.143	431.442	343.575	223.342	103.127	36.824
HOURLY DIFFU.	217.664	209.225	189.626	158.244	120.864	77.841	34.289
HOURLY TOTAL	706.554	649.784	566.026	447.469	283.717	122.057	36.145
HOURLY DIRECT	499.028	452.332	386.277	299.804	176.102	60.916	21.349
HOURLY DIFFU.	207.526	197.452	179.749	147.664	107.615	61.141	14.796
HOURLY TOTAL	654.109	590.370	492.468	366.246	202.799	63.120	2.774
HOURLY DIRECT	467.230	415.773	337.079	245.943	124.054	31.804	2.774
HOURLY DIFFU.	186.879	174.597	155.389	120.303	78.745	31.316	0.000
HOURLY TOTAL	525.101	464.871	363.031	241.925	107.059	18.585	0.000
HOURLY DIRECT	369.703	322.868	243.225	159.151	63.362	17.965	0.000
HOURLY DIFFU.	155.397	142.002	119.807	82.775	43.697	0.620	0.000
HOURLY TOTAL	360.261	313.824	227.819	130.690	38.761	0.000	0.000
HOURLY DIRECT	230.360	197.503	136.058	76.538	20.244	0.000	0.000
HOURLY DIFFU.	129.900	116.321	91.761	54.151	18.517	0.000	0.000
HOURLY TOTAL	292.996	252.991	175.132	89.181	15.429	0.000	0.000
HOURLY DIRECT	177.280	150.554	97.919	48.982	8.331	0.000	0.000
HOURLY DIFFU.	115.716	102.437	77.214	40.199	7.097	0.000	0.000

TABLE 4.7 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Pittsburgh, Pennsylvania

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	167.092	143.367	95.592	43.577	2.101	0.000	0.000
HOURLY DIRECT	83.924	70.360	42.522	19.379	1.959	0.000	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	263.522	220.937	149.310	98.404	31.939	0.000	0.000
HOURLY DIRECT	143.139	121.908	92.424	46.693	12.979	0.000	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	449.120	401.144	323.627	229.265	113.724	27.431	0.000
HOURLY DIRECT	297.490	251.353	194.123	133.323	57.351	14.309	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	592.415	542.450	449.649	366.467	226.027	90.254	22.120
HOURLY DIRECT	401.472	361.476	304.327	232.915	130.594	30.541	15.419
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	675.638	632.120	562.016	455.323	319.629	176.627	72.970
HOURLY DIRECT	463.934	429.176	379.041	301.797	200.259	99.450	35.390
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	667.458	631.451	562.117	454.799	339.434	221.455	103.049
HOURLY DIRECT	449.079	420.922	374.210	301.490	217.952	136.906	53.301
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	739.843	697.119	621.091	503.656	366.655	225.570	101.016
HOURLY DIRECT	533.061	437.213	443.290	356.150	251.069	146.121	57.255
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	672.608	622.846	542.339	430.329	290.243	133.455	49.519
HOURLY DIRECT	479.059	437.665	379.730	290.292	185.663	74.530	25.914
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	523.696	473.394	396.622	296.009	166.596	53.493	3.993
HOURLY DIRECT	351.249	312.021	252.569	184.639	92.256	22.536	3.999
HOURLY DIFFU.	172.437	161.372	144.053	112.270	74.341	30.957	0.000
HOURLY TOTAL	344.110	303.493	233.343	151.967	62.624	9.493	0.000
HOURLY DIRECT	208.951	180.553	131.066	92.509	29.709	3.493	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	217.524	197.949	139.606	67.200	12.376	0.000	0.000
HOURLY DIRECT	120.195	101.714	65.366	32.962	5.796	0.000	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	141.152	120.400	79.209	32.431	0.000	0.000	0.000
HOURLY DIRECT	69.264	56.972	33.196	13.364	0.000	0.000	0.000
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 4.8 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Seattle, Washington.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	351.342	305.082	217.846	120.174	30.890	0.000	0.000
HOURLY DIRECT	218.887	186.961	126.118	68.226	15.847	0.000	0.000
HOURLY DIFFU.	132.455	118.121	91.729	51.948	15.043	0.000	0.000
HOURLY TOTAL	457.030	401.778	304.616	191.825	74.418	7.724	0.000
HOURLY DIRECT	297.256	257.034	185.707	114.414	38.802	7.724	0.000
HOURLY DIFFU.	159.773	144.743	118.909	77.411	35.616	0.000	0.000
HOURLY TOTAL	585.280	523.389	424.191	301.473	152.503	38.210	0.000
HOURLY DIRECT	396.122	348.468	271.886	188.932	84.699	20.699	0.000
HOURLY DIFFU.	189.157	174.922	152.305	112.540	67.804	17.510	0.000
HOURLY TOTAL	661.591	602.515	514.455	395.821	235.206	86.473	16.546
HOURLY DIRECT	448.604	401.682	333.079	250.554	134.320	36.791	16.546
HOURLY DIFFU.	212.987	200.833	181.376	145.267	100.886	49.682	0.000
HOURLY TOTAL	753.902	697.401	613.115	490.385	322.030	151.281	51.890
HOURLY DIRECT	531.622	484.899	419.577	329.853	202.344	78.961	27.297
HOURLY DIFFU.	222.280	212.502	193.537	160.532	119.685	72.320	24.593
HOURLY TOTAL	784.182	731.331	648.763	524.403	360.565	190.774	75.447
HOURLY DIRECT	562.665	518.344	455.819	363.373	237.427	111.218	40.004
HOURLY DIFFU.	221.517	212.987	192.944	161.030	123.138	79.556	35.443
HOURLY TOTAL	789.496	734.116	649.448	523.350	353.973	179.400	67.777
HOURLY DIRECT	573.039	526.399	460.750	366.058	234.702	104.039	36.858
HOURLY DIFFU.	216.457	207.717	188.698	157.292	119.271	75.360	30.918
HOURLY TOTAL	738.717	678.268	589.123	463.958	291.221	122.210	34.398
HOURLY DIRECT	527.299	477.395	406.390	314.349	182.951	61.889	21.717
HOURLY DIFFU.	211.418	200.073	182.733	149.608	108.270	60.320	12.681
HOURLY TOTAL	674.639	608.677	507.208	376.612	207.877	64.218	2.332
HOURLY DIRECT	486.791	433.243	351.188	256.015	129.160	33.272	2.332
HOURLY DIFFU.	187.849	175.434	156.019	120.597	78.717	30.946	0.000
HOURLY TOTAL	547.138	484.810	379.939	254.821	114.346	20.718	0.000
HOURLY DIRECT	385.333	336.793	254.670	167.689	67.694	18.769	0.000
HOURLY DIFFU.	161.806	148.017	125.269	87.132	46.653	1.949	0.000
HOURLY TOTAL	402.855	351.602	257.705	151.085	48.077	0.000	0.000
HOURLY DIRECT	266.935	229.590	160.578	92.439	26.359	0.000	0.000
HOURLY DIFFU.	135.920	122.011	97.127	58.646	21.718	0.000	0.000
HOURLY TOTAL	313.440	271.316	190.465	100.667	21.409	0.000	0.000
HOURLY DIRECT	190.067	161.745	106.753	55.346	10.979	0.000	0.000
HOURLY DIFFU.	123.372	109.571	83.712	45.321	10.431	0.000	0.000

TABLE 4.9 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: St. Louis, Missouri.

HALF HOURLY RADIATION FROM LIU AND JORDAN

	HR 0.5	HR 1.5	HR 2.5	HR 3.5	HR 4.5	HR 5.5	HR 6.5
HOURLY TOTAL	439.795	392.328	274.665	153.748	41.808	0.000	0.000
HOURLY DIRECT	307.180	263.889	182.155	100.546	25.349	0.000	0.000
HOURLY DIFFU.	132.614	[illegible]	92.510	[illegible]	16.459	0.000	0.000
HOURLY TOTAL	528.969	465.357	353.953	224.322	99.407	0.906	0.000
HOURLY DIRECT	367.643	319.075	233.426	145.329	51.448	0.906	0.000
HOURLY DIFFU.	161.326	[illegible]	[illegible]	[illegible]	36.959	0.000	0.000
HOURLY TOTAL	645.470	577.290	469.081	332.904	168.645	42.405	0.000
HOURLY DIRECT	455.730	401.803	315.229	219.876	100.454	24.633	0.000
HOURLY DIFFU.	189.740	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.000
HOURLY TOTAL	728.205	662.834	565.265	434.144	257.023	93.652	17.274
HOURLY DIRECT	520.273	466.868	389.402	292.751	159.107	45.896	17.274
HOURLY DIFFU.	207.931	195.966	175.863	141.413	97.916	47.755	0.000
HOURLY TOTAL	779.429	720.229	632.206	504.696	329.317	152.225	50.998
HOURLY DIRECT	561.223	511.800	442.344	347.435	212.539	92.396	28.305
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	830.500	773.456	685.303	553.206	377.461	195.731	75.820
HOURLY DIRECT	614.653	566.106	497.196	396.290	257.921	119.281	42.995
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	815.358	757.196	668.943	538.199	361.409	179.784	66.465
HOURLY DIRECT	604.090	554.638	484.767	384.813	245.554	107.334	37.916
HOURLY DIFFU.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	799.739	733.696	636.290	500.087	312.272	129.386	35.413
HOURLY DIRECT	600.084	544.136	463.926	359.228	210.709	73.390	24.597
HOURLY DIFFU.	[illegible]	[illegible]	172.363	[illegible]	[illegible]	[illegible]	[illegible]
HOURLY TOTAL	721.965	651.255	542.398	402.415	221.759	68.246	2.209
HOURLY DIRECT	536.697	478.266	388.611	283.642	144.343	37.992	2.209
HOURLY DIFFU.	185.267	172.989	153.787	118.773	77.416	30.254	0.000
HOURLY TOTAL	609.809	540.586	424.401	285.553	129.023	23.865	0.000
HOURLY DIRECT	451.927	396.079	301.913	200.069	82.932	21.319	0.000
HOURLY DIFFU.	[illegible]	144.507	[illegible]	[illegible]	[illegible]	[illegible]	0.000
HOURLY TOTAL	471.938	412.298	303.639	179.907	59.125	0.921	0.000
HOURLY DIRECT	337.492	291.459	207.011	120.910	36.475	0.921	0.000
HOURLY DIFFU.	134.446	[illegible]	[illegible]	[illegible]	[illegible]	0.000	0.000
HOURLY TOTAL	399.763	346.475	244.919	131.763	30.464	0.000	0.000
HOURLY DIRECT	272.740	233.476	158.010	93.826	18.238	0.000	0.000
HOURLY DIFFU.	127.023	113.000	[illegible]	[illegible]	12.225	0.000	0.000

TABLE 4.10 Monthly Average Hourly Radiation for 0.5 - 6.5 Hours after Solar Noon. Location: Wichita, Kansas.

MONTH	ATLANTA	BOSTON	CLEVELAND	COLUMBUS	LOS ANGELES
1	5.75	4.87	2.50	2.50	6.75
2	5.88	5.25	2.75	3.50	7.38
3	6.64	6.10	6.10	4.50	8.39
4	7.41	4.25	4.50	5.25	8.17
5	7.86	7.44	8.15	7.60	8.62
6	8.08	7.00	8.47	8.40	9.10
7	7.76	7.65	8.35	8.29	9.77
8	7.65	6.00	7.86	7.58	9.15
9	6.90	6.45	6.94	7.69	8.65
10	6.87	5.73	6.00	6.52	7.37
11	6.41	3.25	2.75	5.18	7.16
12	5.41	4.73	2.75	4.25	6.90

TABLE 4.11 Number of Hours of Sunshine for an Average Day in each Month Using Laue's Standard Curve.

MONTH	NASHVILLE	PITTSBURGH	SEATTLE	ST. LOUIS	WICHITA
1	3.00	5.21	1.75	5.30	6.59
2	4.75	5.45	2.50	5.76	6.78
3	6.13	6.36	6.07	6.62	7.12
4	7.21	6.78	7.19	7.00	7.73
5	7.70	7.61	8.19	8.04	8.25
6	8.46	8.42	8.35	8.57	9.02
7	8.12	8.31	9.20	8.47	8.67
8	7.72	7.84	8.32	7.78	8.50
9	7.41	7.44	6.74	7.43	7.92
10	6.58	6.76	3.75	6.54	7.31
11	5.57	5.42	2.75	5.74	6.78
12	4.00	5.08	1.50	5.18	6.23

TABLE 4.12 Number of Hours of Sunshine for an Average Day in each Month Using Laue's Standard Curve.

MONTH	ATLANTA	BOSTON	CLEVELAND	COLUMBUS	LOS ANGELES
1	0.89	1.01	1.05	1.49	1.10
2	0.93	1.06	1.34	1.25	0.97
3	1.09	1.15	0.91	1.31	1.08
4	1.19	1.74	1.54	1.36	1.07
5	1.30	1.17	1.11	1.18	1.12
6	1.25	1.34	1.18	1.17	1.09
7	1.21	1.30	1.29	1.29	1.20
8	1.24	1.55	1.22	1.27	1.22
9	1.19	1.19	1.12	1.08	1.13
10	1.16	1.20	1.03	1.07	1.18
11	0.97	1.56	1.20	0.84	1.15
12	0.98	1.04	0.93	0.79	1.06

TABLE 4.13 Correction Factor, $\bar{C}$, for Five Locations around the United States, During an Average Day of Each Month.

MONTH	NASHVILLE	PITTSBURGH	SEATTLE	ST. LOUIS	WICHITA
1	1.36	0.56	1.40	0.86	0.94
2	0.99	0.69	1.32	0.88	0.91
3	1.06	0.85	0.84	1.01	1.08
4	1.11	0.98	0.93	1.11	1.09
5	1.23	1.04	1.00	1.17	1.17
6	1.21	1.02	0.93	1.26	1.18
7	1.19	1.13	1.10	1.27	1.34
8	1.20	1.06	0.99	1.23	1.26
9	1.12	1.04	0.97	1.14	1.16
10	1.13	0.88	1.08	1.13	1.11
11	1.00	0.70	0.93	0.96	1.01
12	1.05	0.49	1.37	0.80	0.97

TABLE 4.14 Correction Factor $\overline{C}$, for Five Locations around the United States, During an Average Day of Each Month.

THIS MODULE CALCULATES THE HOURLY ZENITH ANGLES
AND DIRECT INSOLATION USING LAUES CURVE

ZENITH	DIR	HOR	DIF
90.0000	2.0227	0.0000	-0.0246
79.1748	423.8157	79.5983	28.0380
69.5604	646.1458	225.6466	49.3979
61.7566	753.8823	356.7512	63.5518
56.5395	800.4932	441.3613	71.2782
54.6674	813.4585	470.4414	73.7066
56.4775	800.9509	442.3367	71.3615
61.6431	755.0833	358.6362	63.7349
69.4096	648.7598	228.1592	49.7001
78.9986	429.0103	81.8695	28.4639
89.8070	11.5354	0.0389	0.5020
90.0000	2.0227	0.0000	-0.0246
78.2940	449.3203	91.1629	30.1556
67.4729	680.2942	260.6348	53.4811
58.1020	788.2617	416.5242	69.1124
51.0345	834.0935	524.5222	77.9056
47.3429	850.1196	576.0488	81.4950
47.8284	848.2502	569.4761	81.0610
52.3734	827.1204	504.9685	76.4363
60.0506	771.0054	384.9131	66.2338
69.8121	641.7322	221.4626	48.8915
80.8734	371.2732	58.8899	23.8736
89.9999	2.0264	0.0000	-0.0244
77.5837	469.0530	100.8527	31.8412
65.5568	708.0085	292.9678	57.0404
54.3532	815.4675	475.2437	74.0963
44.7257	859.1602	610.4194	83.6422
37.9842	876.4990	690.8394	87.7734
35.8472	880.8430	713.9949	88.7029
39.0897	874.0862	678.4307	87.2250
46.5863	852.9070	586.1707	82.1489
56.6367	799.7710	439.8308	71.1472
68.0641	671.0581	250.6870	52.3462
80.2033	392.5430	66.7923	25.5290
89.9999	2.0264	0.0000	-0.0244
77.5868	468.9685	100.8100	31.8338
65.0765	714.4470	301.0740	57.9039
52.7515	825.0232	499.3643	76.0048
41.0597	869.4297	655.5723	86.1266
30.9598	889.7532	762.9890	90.2511
24.6697	900.4414	818.2373	91.3310
25.2926	899.3889	813.1711	91.2578
32.4279	887.1782	748.8374	89.8630
42.8543	864.5896	633.4072	84.9572
54.7347	813.0222	469.4097	73.6224
67.1135	685.7476	266.6924	54.1625
79.6254	410.3176	73.8918	26.9437
[illegible]	2.0264	0.0000	-0.0244

FIGURE 4.15 Page 1 of 3

78.1476	453.4451	93.1353	30.5045
65.8663	703.7542	287.7419	56.4779
53.3758	821.4314	490.0364	75.2765
40.9144	869.7910	657.2917	86.2131
28.9077	893.2739	781.9712	90.6973
18.6417	910.6409	862.8650	91.8396
14.7189	917.0872	886.9919	92.1484
21.0921	906.5000	845.7676	91.6618
32.0782	887.7974	752.2522	89.9611
44.2760	860.5552	616.1445	83.9791
56.7745	798.7395	437.6584	70.9607
69.2292	651.8552	231.1681	50.0598
81.4171	353.4868	52.7550	22.5193
89.9999	2.0264	0.0000	-0.0244
78.5934	440.7817	87.1741	29.4393
66.6165	693.0908	275.0762	55.0943
54.2841	815.9031	476.2966	74.1814
41.7821	867.5881	646.9465	85.6834
29.3545	892.5127	777.9170	90.6090
17.6470	912.3064	869.3752	91.9106
10.2121	923.6897	909.0569	92.7336
15.6082	915.6609	881.8948	92.0691
26.9664	896.5625	799.0813	91.0297
39.3307	873.5425	675.6855	87.0990
51.8419	829.9709	512.7844	77.0304
64.2222	725.4231	315.4734	59.4108
76.2839	503.3042	119.3392	34.8740
87.8222	104.7661	3.9812	5.8735
89.9999	2.0264	0.0000	-0.0244
78.4213	445.7048	89.4593	29.8513
66.3215	697.3433	280.0557	55.6417
53.9154	818.1914	481.8979	74.6311
41.4035	868.5632	651.4841	85.9185
29.0848	892.9724	780.3699	90.6629
17.8183	912.0205	868.2722	91.8982
11.7243	921.6221	902.3938	92.4942
17.5660	912.4414	869.8943	91.9165
28.7785	893.4937	783.1360	90.7220
41.0856	869.3650	655.2649	86.1111
53.5972	820.1174	486.7056	75.0135
66.0086	701.7703	285.3398	56.2175
78.1186	454.2620	93.5269	30.5737
89.7136	16.1106	0.0805	0.7568
89.9999	2.0264	0.0000	-0.0244
77.8245	462.4441	97.5324	31.2718
65.3682	710.5605	296.1516	57.3808
52.8712	824.3472	497.5835	75.8668
40.6552	870.4275	660.3447	86.3652
29.3869	892.4575	777.6216	90.6024
20.9367	906.7634	846.8950	91.6737
19.5545	909.1025	856.6687	91.7750
26.3885	897.5386	804.0156	91.1140
37.1006	878.3413	700.5454	88.1781

FIGURE 4.15 Page 2 of 3

49.1298	842.9006	551.5503	79.8413
61.5838	755.7075	359.6208	63.8303
74.0788	556.2019	152.5747	39.8586
86.3645	168.1121	10.6601	9.7617
89.9999	2.0264	0.0000	-0.0244
77.4878	471.6594	102.1839	32.0673
65.1169	713.9136	300.3916	57.8315
53.2411	822.2207	492.0579	75.4354
42.4738	865.7478	638.5635	85.2381
34.0352	884.2732	732.7920	89.3649
30.0527	891.3179	771.4939	90.4614
32.2543	887.4861	750.5359	89.9121
39.6089	872.9065	672.4998	86.9508
49.8436	839.7434	541.5305	79.1369
61.4694	756.9048	361.5190	64.0138
73.7358	563.8701	157.9221	40.6151
86.2353	173.5234	11.3934	10.1039
89.9999	2.0264	0.0000	-0.0244
77.8626	460.8369	96.7368	31.1343
66.4224	695.8987	278.3538	55.4550
56.1324	803.4629	447.7507	71.8218
47.8518	848.1584	569.1572	81.0397
42.8143	864.8125	634.3926	85.0113
42.2219	866.4270	641.6304	85.4027
46.2483	854.1042	590.6423	82.4322
53.8529	818.5740	482.8450	74.7066
63.7393	731.3657	323.5981	60.2465
74.9674	535.6482	138.9300	37.8745
86.9579	142.8328	7.5802	8.1852
89.9999	2.0264	0.0000	-0.0244
78.7792	435.4146	84.7278	28.9929
68.6403	661.7307	241.0172	51.2237
60.1762	769.8113	382.8535	66.0414
54.2072	816.3853	477.4675	74.2758
51.6238	831.1082	515.9702	77.2700
52.9306	824.0098	496.6982	75.7979
57.8616	790.2322	420.3765	69.4539
65.5941	707.4998	292.3379	56.9729
75.2516	528.8596	134.6344	37.2330
86.1638	176.5044	11.8089	10.2930
89.9999	2.0264	0.0000	-0.0244
79.4366	416.0110	76.2650	27.4031
70.1582	635.5542	215.7231	48.1902
62.7635	742.8159	339.9607	61.8984
57.9955	789.1389	418.2324	69.2641
56.5328	800.5430	441.4673	71.2872
58.6260	783.8491	408.0898	68.3578
63.9231	729.1255	320.5068	59.9298
71.7089	606.2800	190.2781	44.9787
81.2574	358.7593	54.5299	22.9178

TABLE 4.15 Hourly Data incompassing the zenith angle, direct radiation on a vertical surface, direct radiation on a horizontal surface, and diffuse radiation, for clear days, for January - December. Location: Atlanta, Georgia.

APPENDIX A

REGRESSION ANALYSIS

REGRESSION ANALYSIS

The term regression is used to imply working backwards. Herein, given the results of a study in the form of data points, one would work backwards in order to generalize the result by fitting the data points by an optimal curve.

Assume that a set of experimental data points can be approximated by a polynomial fit of the form,

$$y = K_0x^n + K_1x^{n-1} + \text{--------}K_nx^0 \qquad (A.1)$$

Now let $\hat{y}_i$ be the exact value of the i^{th} ordinate data point. The idea is to minimize the difference between the exact value and the approximate one. If I is taken to be the polynomial fit, then

$$I = \sum_{i=1}^{K} |\hat{y}_i - y| \qquad (A.2)$$

where K = number of data points.

Thus

$$I = \sum_{i=1}^{K} |\hat{y}_i - (K_0x_i^n + K_1x_i^{n-1} + \text{-----}\ K_nx_i^0)| \qquad (A.3)$$

The absolute value indicates that the data point could be below or above the approximate fit. However, it is very hard to handle absolute quantities when minimizing a function. Therefore, it is best to square both sides of Equation (A.3) and get rid of the absolute value.

$$P = I^2 = \sum_{i=1}^{K} [\hat{y}_i - (K_0x_i^n + K_1x_i^{n-1} + \text{-----}\ K_n)]^2 \qquad (A.4)$$

Now the task is reduced to that of minimizing P using elementary calculus, since the only unknowns are the K's.

Example: For simplicity let n = 2, and k = 10

$$P = \sum_{i=1}^{10} [y_i - (K_0 x_i^2 + K_1 x_i + K_2)]^2$$

$$\frac{\partial P}{\partial K_0} = 0 \quad ; \quad K_0 . \sum_{i=1}^{10} x_i^4 + K_1 . \sum_{i=1}^{10} x_i^3 + K_2 . \sum_{i=1}^{10} x_i^2 = \sum_{i=1}^{10} y_i . x_i^2$$

$$\frac{\partial P}{\partial K_1} = 0 \quad ; \quad K_0 . \sum_{i=1}^{10} x_i^3 + K_1 . \sum_{i=1}^{10} x_i^2 + K_2 . \sum_{i=1}^{10} x_i = \sum_{i=1}^{10} y_i . x_i$$

$$\frac{\partial P}{\partial K_2} = 0 \quad ; \quad K_0 . \sum_{i=1}^{10} x_i^2 + K_1 . \sum_{i=1}^{10} x_i + K_2 .(10) = \sum_{i=1}^{10} y_i$$

The x_i's and y_i's are known, and the problem is solved by solving the three equation simultaneously. This technique is sometimes referred to as the "least square" technique and can be programmed on the computer.

APPENDIX B

The following is a listing of a computer program that generates instantaneous radiation using two different techniques for any location where $\overline{H}$ data are available.

```
$JOB
           DIMENSION HBAR(48),DAY(48)
           REAL L(48),KT(48),HS(48)
           CALL DEF(NOTH)
           DO 40 I=1,12
     40    READ(5,500)HBAR(I),DAY(I),L(I),KT(I),HS(I)
           CALL DATA(HBAR,DAY,L,KT,HS)
           CALL LLJ(HBAR,DAY,L,KT,HS)
           CALL JORD(HBAR,KT,DAY,L)
           CALL CALC(DAY,L)
    500    FORMAT(2F10.2,F10.4,2F10.2)
           STOP
           END

           SUBROUTINE LLJ(HBAR,DAY,L,KT,HS)
           REAL L(48),KT(48),HS(48)
           DIMENSION HBAR(48),DAY(48)
           TWO(T)=COS(L(I))*COS(DEL)*COS(T)
           THREE(T)=ONE+TWO(T)
           XZEN(T)=ARCOS(THREE(T))
           ZEN(T)=XZEN(T)*180./PI
           STA1(T)=((-0.41478E-4)*(ZEN(T)**4))+((0.39511E-2)*(ZEN(T)**3))
           STA2(T)=((-0.140152)*(ZEN(T)**2))+((0.49859)*(ZEN(T)))
           STA3(T)=((0.278249E-5)*(ZEN(T)**4))-((0.648918E-3)*(ZEN(T)**3))
           STA4(T)=((0.03077)*(ZEN(T)**2))-((0.613444)*(ZEN(T)))
           DIRS(T)=STA1(T)+STA2(T)+929.4566
           HORS(T)=DIRS(T)*THREE(T)
           DIFS(T)=STA3(T)+STA4(T)+96.45
           DES1(T)=((-0.456588E-4)*(ZEN(T)**4))+((0.454363E-2)*(ZEN(T)**3))
           DES2(T)=((-0.170761)*(ZEN(T)**2))+((1.203539)*(ZEN(T)))
           DES3(T)=((0.3182E-5)*(ZEN(T)**4))-((0.750421E-3)*(ZEN(T)**3))
           DES4(T)=((0.041425)*(ZEN(T)**2))-((0.912085)*(ZEN(T)))
           DIRD(T)=DES1(T)+DES2(T)+959.8844
           HORD(T)=DIRD(T)*THREE(T)
           DIFD(T)=DES3(T)+DES4(T)+85.0517
           URB1(T)=((0.37423E-5)*(ZEN(T)**4))-((0.17684E-2)*(ZEN(T)**3))
           URB2(T)=((0.06817)*(ZEN(T)**2))-((1.38275)*(ZEN(T)))
           URB3(T)=((0.23314E-6)*(ZEN(T)**4))-((0.1876E-3)*(ZEN(T)**3))
           URB4(T)=((-0.0126)*(ZEN(T)**2))+((0.06921)*(ZEN(T)))
           DIRU(T)=URB1(T)+URB2(T)+612.66
           HORU(T)=DIRU(T)*THREE(T)
           DIFU(T)=URB3(T)+URB4(T)+215.6253
           WRITE(6,200)
           WRITE(6,300)
    200    FORMAT(////20X,'ACTUAL SUNSHINE HOURS AND DIRECT AND DIFFUSE
          1 RADIATION')
    300    FORMAT(//20X,'SLENG',10X,'ULENG',11X,'QUO1',11X,'QUO2',11X,'DIF',
          113X,'SS')
           DO 3 I=1,12
           PI=3.14159
           ANGLE=2.*PI*((DAY(I)+284.)/365.)
           DEL=23.45*SIN(ANGLE)*PI/180.
           ONE=SIN(L(I))*SIN(DEL)
           B=TAN(DEL)
           C=TAN(L(I))
           TIME=ARCOS(-B*C)
           X=TIME*180./(PI*15.)
           SS=2.*X
           SS2=SS**2
           HDIR=HBAR(I)-(HBAR(I)*(0.77-(0.8*KT(I))))
```

```
      FIND=1.35-(3.25*KT(I))+(2.5*(KT(I)**2))
      IF(KT(I) .LE. 4E-1) HDIR=HBAR(I)-(FIND*HBAR(I))
      HDIF=HBAR(I)-HDIR
      T1=0.
      T2=TIME
      T3=-TIME
      T4=0.
      DELTA=0.25*PI/180.
      HAVE=0.
      TDIR=0.
      TSAVE=-TIME
   10 TRISE=TSAVE
      TSAVE=TSAVE+(DELTA*15.)
      TVAR=TSAVE
      FUNCT=HORS(TRISE)+HORS(TVAR)
      TDIR=FUNCT*DELTA*180./(2.*PI)+TDIR
      IF(TVAR.LT.T2) GO TO 10
   20 TOLD=T1
      T1=T1-(DELTA*15.)
      TNEW=T1
      ESCOR=HORS(TNEW)+HORS(TOLD)
      HAVE=HAVE+(ESCOR*DELTA*180./(2.*PI))
      IF(HAVE .GE. HDIR) GO TO 40
      IF(HAVE .LT. HDIR .AND. T1 .GT. T3) GO TO 20
   30 TOLD=T4
      T4=T4+(DELTA*15.)
      TNEW=T4
      ESCOR=HORS(TNEW)+HORS(TOLD)
      HAVE=HAVE+(ESCOR*DELTA*180./(2.*PI))
      IF(HAVE .LT. HDIR) GO TO 30
   40 SLENG=ABS(TNEW)*180./(15.*PI)
      TEST=0.
      IF(TNEW .GT. TEST) SLENG=((TIME+TNEW)*180./(PI*15.))
      TSCAT=TDIR-HDIR
      TDIF=TSCAT/2.
      T1=0.
      T2=TIME
      T3=-TIME
      T4=0.
      HAVE=0.
      TDIR=0.
      TSAVE=-TIME
   50 TRISE=TSAVE
      TSAVE=TSAVE+(DELTA*15.)
      TVAR=TSAVE
      FUNCT=HORU(TRISE)+HORU(TVAR)
      TDIR=FUNCT*DELTA*180./(2.*PI)+TDIR
      IF(TVAR.LT.T2) GO TO 50
   60 TOLD=T1
      T1=T1-(DELTA*15.)
      TNEW=T1
      ESCOR=HORU(TNEW)+HORU(TOLD)
      HAVE=HAVE+(ESCOR*DELTA*180./(2.*PI))
      IF(HAVE .GE. HDIR) GO TO 80
      IF(HAVE .LT. HDIR .AND. T1 .GT. T3) GO TO 60
   70 TOLD=T4
      T4=T4+(DELTA*15.)
      TNEW=T4
      ESCOR=HORU(TNEW)+HORU(TOLD)
      HAVE=HAVE+(ESCOR*DELTA*180./(2.*PI))
```

```
          IF(HAVE .LT. HDIR) GO TO 70
   80     ULENG=ABS(TNEW)*180./(15.*PI)
          IF(TNEW .GT. TEST) ULENG=((TIME+TNEW)*180./(PI*15.))
          QUO1=HS(I)/SLENG
          QUO2=HS(I)/ULENG
          DIF=QUO1-QUO2
          PRINT 400,SLENG,ULENG,QUO1,QUO2,DIF,SS
  400     FORMAT(10X,6F15.4)
    3     CONTINUE
          RETURN
          END
          SUBROUTINE JORD(HBAR,KT,DAY,L)
          REAL KT(48),L(48)
          DIMENSION HBAR(48),DAY(48)
    3     WRITE(6,500)
          WRITE(6,600)
          DO 50 I=1,12
          PI=3.14159
          ANGLE=2.*PI*((DAY(I)+284.)/365.)
          DEL=23.45*SIN(ANGLE)*PI/180.
          B=TAN(DEL)
          C=TAN(L(I))
          TIME=ARCOS(-B*C)
          X=TIME*180./(PI*15.)
          SS=2.*X
          SS2=SS**2
          FIND=1.35-(3.25*KT(I))+(2.5*(KT(I)**2))
          IF(KT(I) .LE. 4E-1) DDR=FIND*HBAR(I)
          DDR=HBAR(I)*(0.77-(0.8*KT(I)))
          DHAF=DDR*(0.39817-(0.03412*SS)+((9.80952E-4)*SS2))
          DHAF1=DDR*(0.3144-(0.0244*SS)+((6.88225E-4)*SS2))
          DHAF2=DDR*(0.0869+((6.4E-3)*SS)-((4E-4)*SS2))
          DHAF3=DDR*(-0.1725+(0.03854*SS)-((1.4583E-3)*SS2))
          DHAF4=DDR*(-0.32+(0.05283*SS)-((1.8333E-3)*SS2))
          DHAF5=DDR*(-0.44+(0.062*SS)-((2E-3)*SS2))
          DHAF6=(DDR)*(-0.45501+(0.05666*SS)-((1.66666E-3)*SS2))
          THAF=HBAR(I)*(0.35175-(0.02407*SS)+((5.5352E-4)*SS2))
          THAF1=HBAR(I)*(0.27838-(0.01722*SS)+((3.9072E-4)*SS2))
          THAF2=HBAR(I)*(0.06148+((8.90109E-3)*SS)-((4.3956E-4)*SS2))
          THAF3=HBAR(I)*(-0.15277+(0.03384*SS)-((1.23076E-3)*SS2))
          THAF4=HBAR(I)*(-0.2+(0.032*SS)-((1E-3)*SS2))
          THAF5=HBAR(I)*(-0.02538+((7.14285E-5)*SS)+((2.46753E-4)*SS2))
          THAF6=HBAR(I)*(-0.02006-((9.2857E-4)*SS)+((2.09523E-4)*SS2))
          TEST=0.
          IF(THAF6.LT.TEST) THAF6=0.
          IF(DHAF6.LT.TEST) DHAF6=0.
          IF(THAF5.LT.TEST) THAF5=0.
          IF(DHAF5.LT.TEST) DHAF5=0.
          IF(THAF4.LT.TEST) THAF4=0.
          IF(DHAF4.LT.TEST) DHAF4=0.
          DIR=THAF-DHAF
          DIR1=THAF1-DHAF1
          DIR2=THAF2-DHAF2
          DIR3=THAF3-DHAF3
          DIR4=THAF4-DHAF4
          DIR5=THAF5-DHAF5
          DIR6=THAF6-DHAF6
          PRINT 800,THAF,THAF1,THAF2,THAF3,THAF4,THAF5,THAF6
          PRINT 900,DIR,DIR1,DIR2,DIR3,DIR4,DIR5,DIR6
```

```
50    PRINT 700,DHAF,DHAF1,DHAF2,DHAF3,DHAF4,DHAF5,DHAF6
500   FORMAT(////20X,'HALF HOURLY RADIATION FROM LIU AND JORDAN')
600   FORMAT(18X,'HR 0.5',3X,'HR 1.5',3X,'HR 2.5',3X,'HR 3.5',3X,
     1'HR 4.5',3X,'HR 5.5',3X,'HR 6.5')
700   FORMAT(1X,'HOURLY DIFFU.',1X,7F9.3)
800   FORMAT(1X,'HOURLY TOTAL',2X,7F9.3)
900   FORMAT(1X,'HOURLY DIRECT',1X,7F9.3)
      RETURN
      END

      SUBROUTINE DATA(HBAR,DAY,L,KT,HS)
      REAL L(48),KT(48),HS(48)
      DIMENSION HBAR(48),DAY(48)
      WRITE(6,40)
      WRITE(6,100)
40    FORMAT(////20X,'THIS MODULE PRINTS THE RESPECTIVE DATA POINTS')
      DO 41 I=1,12
      WRITE(6,200) HBAR(I),DAY(I),L(I),KT(I),HS(I)
41    CONTINUE
100   FORMAT(34X,'HBAR',17X,'DAY',19X,'L',19X,'KT',19X,'HS')
200   FORMAT(20X,5F20.4)
      RETURN
      END

      SUBROUTINE CALC(DAY,L)
      REAL L(48)
      DIMENSION DAY(48)
      WRITE(6,97)
      WRITE(6,98)
      WRITE(6,99)
97    FORMAT(////20X,'THIS MODULE CALCULATES THE HOURLY ZENITH ANGLE:
98    FORMAT(20X,'AND DIRECT INSOLATION USING LAUES CURVE')
99    FORMAT(28X,'ZENITH',9X,'DIR',11X,'HOR')
      PI=3.14159
      DO 101 I=1,12
      ANGLE=2.*PI*((DAY(I)+284.)/365.)
      DEL=23.45*SIN(ANGLE)*PI/180.
      A=TAN(DEL)
      B=TAN(L(I))
      H1=-A*B
      H2=-ARCOS(H1)
      H3=-H2
      ONE=SIN(L(I))*SIN(DEL)
100   TWO=COS(L(I))*COS(DEL)*COS(H2)
      THREE=ONE+TWO
      Z=ARCOS(THREE)*180./PI
      STA1=((-0.41417E-4)*(Z**4))+((0.3951E-2)*(Z**3))
      STA2=((-0.14015)*(Z**2))+(0.49859*Z)
      STA3=((0.27824E-5)*(Z**4))-((0.64891E-3)*(Z**3))
      STA4=((0.03077)*(Z**2))-(0.61344*Z)
      DIRS=STA1+STA2+929.4566
      HORS=DIRS*THREE
      DIFS=STA3+STA4+96.45
      DES1=((-0.45658E-4)*(Z**4))+((0.45436E-2)*(Z**3))
      DES2=((-0.17076)*(Z**2))+(1.20353*Z)
      DES3=((0.3182E-5)*(Z**4))-((0.75042E-3)*(Z**3))
      DES4=((0.04142)*(Z**2))-(0.91208*Z)
      DIRD=DES1+DES2+959.8844
      HORD=DIRD*THREE
      DIFD=DES3+DES4+85.0517
```

```
          URB1=((0.37423E-5)*(Z**4))-((0.17684E-2)*(Z**3))
          URB2=((0.06817)*(Z**2))-(1.38275*Z)
          URB3=((0.23314E-6)*(Z**4))-((0.1876E-3)*(Z**3))
          URB4=((-0.0126)*(Z**2))+(0.06921*Z)
          DIRU=URB1+URB2+612.66
          HORU=DIRU*THREE
          DIFU=URB3+URB4+215.6253
          PRINT 102,Z,DIRS,HORS,DIFS
  102     FORMAT(20X,4F15.4)
          DELTA=15*PI/180.
          H2=H2+DELTA
          IF(H2.LT.H3) GO TO 100
  101     CONTINUE
          RETURN
          END

          SUBROUTINE DEF(NOTH)
          WRITE(6,500)
          WRITE(6,501)
          WRITE(6,502)
          WRITE(6,503)
          WRITE(6,504)
          WRITE(6,505)
          WRITE(6,506)
          WRITE(6,507)
          WRITE(6,508)
  500     FORMAT(////20X,'HBAR=MONTHLY AVERAGE DAILY TOTAL RADIATION')
  501     FORMAT(20X,'HDIR=MONTHLY AVERAGE DAILY DIRECT RADIATION')
  502     FORMAT(20X,'HDIF=MONTHLY AVERAGE DAILY DIFFUSE RADIATION')
  503     FORMAT(20X,'L=LATITUDE-POSITIVE NORTH-')
  504     FORMAT(20X,'KT=HBAR/EXTRATERRESTRIAL RADIATION')
  505     FORMAT(20X,'TDIR=TOTAL AREA OF DIRECT ON A CLEAR DAY')
  506     FORMAT(20X,'SS=HOURS FROM SUNRISE TO SUNSET')
  507     FORMAT(20X,'XLENG=NUMBER OF HOURS OF SUNSHINE')
  508     FORMAT(20X,'HS=EXPERIMENTAL NUMBER OF SUNSHINE HOURS')
          RETURN
          END

      $ENTRY
```

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