A DESIGN METHOD FOR PASSIVE SUNSPACE SYSTEMS

by

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A DESIGN METHOD FOR PASSIVE SUNSPACE SYSTEMS

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In this thesis, a design method for passive sunspace systems is presented. An analytical method, based on monthly-average meteorological data, is developed to predict the net monthly energy delivery from the sunspace, by simplification of the TRNSYS sunspace model. TRNSYS is a modular transient system analysis program from the University of Wisconsin-Madison Solar Energy Laboratory.

The building auxiliary heat is evaluated using the unutilizability concept and the empirical correlation developed for collector-storage-walls. This design method is an extension of the unutilizability method of Monsen, which was developed for collector-storage walls.

Results from the unutilizability method for sunspaces agree closely with detailed TRNSYS simulation results as well as with the results from another correlation method, the Solar Load Ratio (Los Alamos National Laboratory).

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Finally this work would not have been accomplished without the love and understanding of Emmanuel and my parents.

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NOMENCLATURE

This list contains most of the symbols used in the text. Some are defined locally if used infrequently.

A_G	total area of the sunspace glazings
A_W	area of the sunspace wall
C	conductances in the thermal networks
C_p	specific heat
Cap	capacitance of the house
$(DD)_b$	heating degree-days at base temperature T_b
F	view factor
$\hat{F}$	radiation exchange factor (F-hat)
F_i	solar fraction for an infinite thermal capacity house
F_z	solar fraction for a zero thermal capacity house
$\dot{g}$	monthly-average daily internal generation rate
G_c	critical radiation level
GJ	giga-joules
G_T	instantaneous solar radiation incident on a tilted surface
$\bar{G}_T$	monthly-average daily radiation incident on a tilted surface
$\bar{H}$	monthly-average daily radiation incident on a horizontal surface
k	thermal conductivity of common wall
$\bar{K}_T$	monthly-average clearness index

L	total heating load
L_a	heating load if the sunspace is replaced by an adiabatic wall
L_w	heating load through the sunspace
N	number of days in a month
NLC	net load coefficient
Q_{aux}	auxiliary energy
$Q_{aux,i}$	auxiliary energy for an infinite thermal capacity house
$Q_{aux,z}$	auxiliary energy for a zero thermal capacity house
Q_{DUMP}	energy dunped from a zero thermal capacity house
Q_{IN}	net energy flow through the sunspace common wall
Q_S	gross energy flow through a sunspace
R	resistances in the thermal networks
S	combined absorbed solar radiation on the wall and the floor of the sunspace
S_b	building thermal storage capacity
$\bar{S}_F$	absorbed solar radiation on the floor
SLR	solar load ratio
SSF	solar savings fraction
S_w	storage capacity of the wall
$\bar{S}_w$	absorbed solar radiation on the wall
t	thickness of the common wall
T_a	ambient temperature
T_b	temperature on which the heating degree-days are based
T_{low}	low thermostat set point temperature

T_r room temperature

T_w outside wall temperature

$(UA)_{ns}$ thermal conductance of the house if the sunspace is replaced by an adiabatic wall

Y storage dump ratio

$\bar{\phi}$ monthly-average daily unutilizability

$(\tau\alpha)$ transmittance-absorptance product of the collector

$(\overline{\tau\alpha})$ monthly-average transmittance-absorptance product of the collector

Superscripts

$-$ monthly average value

$+$ only positive values are considered

CHAPTER 1: INTRODUCTION

1.1 Background

Passive solar heating systems, particularly attached sunspaces, have seen a growth in interest in the past few years. The reasons for this are many.

First of all Passive Solar Heating such as direct gain systems, collector-storage (or Trombe) wall systems, thermal storage roofs, and attached sunspaces systems can decrease the consumption of energy required to heat a house when properly designed. Passive solar systems gives also a different sense of comfort with radiant heating in increasing the mean radiant temperature. Comfort radiant heating is defined by two environmental temperatures: the mean radiant temperature and the ambient air temperature (1). The mean radiant temperature is defined as the average temperature we feel as a result of radiant energy emanating from all surfaces of a room (2). The same comfort sensation is obtained from different combinations of mean radiant and room temperatures as shown in Table 1.1. By raising the mean radiant temperature, passive solar systems provide a better comfort sensation. Furthermore, the sunspace allows one to grow plants and vegetables indoors and many people enjoy having a bright and sunny extra room.

The key point is really how to design passive solar heating systems in order to save energy while keeping a reasonable initial investment. The characteristic of a passive solar house is that the

Table 1.1. Comfort Sensation with Different Combinations of Temperatures*

Mean Radiant Temperature (°F)	Air Temp (°F)	Comfort Sensation (°F)
85	49	70
80	56	70
75	64	70
70	70	70
65	77	70
60	84	70
55	91	70

*Anderson, B., and Wells, M., Passive Solar Energy, Brick House Publishing Co., Andover, MA (1981), p. 23.

house itself both collects and stores solar energy. In a well designed passive solar house, there should be a link between the energy storage capacity and the amount of energy collected. Problems occur when not enough storage capacity is available. This may cause overheating as well as a poor utilization of the solar energy. If not enough storage is provided for the collected solar energy through the sunspace glazings, this energy is wasted and cannot be reused at a later time. A good balance between collection and storage has to be found with the help of a quick and simple design method.

1.2 The Attached Passive Solar Sunspace: Description

The term solar sunspace refers to a space where light and heating requirements are largely provided by the sun. In the particular case of a greenhouse, vegetables and plants are grown using mainly light and heat from solar radiation.

By passive solar sunspace one implies the function of passive solar heating system. In a passive solar heating system, energy is collected at one zone, transported and stored at another, and is delivered again at a different one. In this process no mechanical means are needed to transport solar energy from collector to storage and from storage to where it is needed (3).

The attached passive solar sunspace performs exactly as described above: solar radiation is transmitted and collected through the glazings, stored in the common wall and then delivered to the adjoining room by conduction and natural convection.

If well designed, an attached sunspace should deliver more heat to the house during the day than the house returns at night. A sunspace also reduces heat loss from the house to the environment in acting like a buffer zone (4).

Large glazing areas in the sunspace have the drawback of significant night losses. However, moveable night insulation may be added. Additional thermal mass such as water containers can be added to improve heat storage. Builders provide a great variety of configurations and materials to satisfy different needs and climates.

1.3 Previous Work

Simulation and correlation techniques are two main design tools for the analysis of passive or active solar buildings.

Besides these two techniques, "rules of thumb" can help in an early design stage. In Reference (5), many recommendations are found for greenhouse constructions. For example, advice is given to select the appropriate thickness of the wall between the sunspace and the house. Table 1.2 summarizes theses recommendations. However, these "rules of thumb" are certainly limited and do not provide the effects on performances for different systems by varying design parameters or the location, as simulations and correlations do.

Simulations require hourly weather data over a year or at least over a heating season, and can represent the thermal performance of passive solar energy systems with very good accuracy. Because detailed simulations usually require access to a main frame computing

Table 1.2. Recommended Thickness for the Common Wall*

Material	Recommended Thickness (cm)
Adobe	20.3-30.5
Brick (common)	25.4-35.5
Concrete (dense)	30.5-46.0
Water	20.3 or more (or 0.454 m^3 for each one m^2 of south facing glass)

*Mazria, E., The Passive Solar Energy Book: A Complete Guide to Solar Home, Greenhouse, and Building Design, Rodale Press, Emmaus, PA (1979).

system, the cost of a simulation study could be significant. Other simulations programs can operate on microcomputers but execute too slowly for an annual calculation. The need for detailed weather data and extensive computing facilities represent major drawbacks for simulations. Correlation techniques are a good alternative method.

Correlations techniques, characterized as inexpensive and easy-to-use design tool, have a completely different approach in that they provide estimates of long term performance (e.g., a month). Important design parameters and weather data are identified and using detailed simulations, they are empirically correlated with the monthly fraction of the heating load supplied by solar energy.

Many simulation programs have been developed for passive solar buildings. They vary in their complexity, level of detail and precision. Many of these programs are reviewed in References (6) and (7). Table 1.3 lists some major passive energy simulation programs available. Dirienzo and McGowan (8) (University of Massachusetts) developed a simulation program for sunspaces but it does not allow studies of a wide variety of sunspaces. Assumptions about the common wall and the glazings are made excluding a number of possible configurations. PASOLE is an example of another simulation program. It is a more general simulation program and was developed at Los Alamos Scientific Laboratory (9). It has been used to derive the Solar Load Ratio Method, a design method for sunspaces. TRNSYS is another general simulation program (10). It is a modular simulation program from the University of Wisconsin-Madison. It includes three passive

Table 1.3. Available Passive Simulation Programs

CALPAS3	Berkeley Solar Group (27)
PASOLE	Los Alamos National Laboratory (LANL) (9)
TRNSYS	University of Wisconsin-Madison (10)
DEROB	University of Texas at Austin (28)
SUNCAT	National Center for Appropriate Technology (29)
UNNAMED	University of Massachusetts (8)
SERI-RES	The Solar Energy Research Institute (33)
ENERPASS	Enermodal Engineering Ltd., Waterloo, Ontario (Version 1.1) (34)

components: direct gain window, collector-storage wall and the attached sunspace. The sunspace model was first developed by Schwedler (11). This model had two-dimensional heat transfer networks for the floor and the wall. Parsons revised this first model by reducing it to a one dimensional network for the floor and the wall (12). He added the option of a thermal storage device inside the sunspace. He also included the transmission characteristics for the glazings. TRNSYS simulation results will be the reference for the correlation presented in Chapter 3.

Among correlation methods, one well accepted simplified method is the Solar Load Ratio (SLR) method developed by the Los Alamos Scientific Laboratory (LASL) for the three types of passive components (13). Chapter 2 describes this method with more detail. In this method the Solar Saving Fraction (SSF) is correlated to the Solar Load Ratio (SLR). These two parameters are defined as:*

$$SLR = \frac{\text{solar energy absorbed}}{\text{net heating load}} \qquad (1.3.1)$$

$$SSF = 1 - \frac{\text{auxiliary heat}}{\text{net reference load}} \qquad (1.3.2)$$

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*The calculation for the SLR coefficient is given by:

$$SLR = (S/DD) - LCR_S \times H)/LCR$$

where DD is the monthly value of DDays
$LCR = NLC/A_p$ (A_p is the projected area of the collector)
S = solar radiation absorbed through the glazing of the sunspace
LCR_S and H are coefficients specific for each sunspace configuration.

The auxiliary energy required by the house for a month is defined as:

$$Q_{aux} = NLC \cdot DD(1 - SSF) \quad (1.3.3)$$

The NLC (Net Load Coefficient) is the UA (loss coefficient) of the building not including the solar component. DD is the degree-days for the month.

An important drawback in this design method is that the correlation was developed for a certain number of reference design systems (14 for the sunspace) and a precise set of parameters. If a change is done in the configuration of the sunspace, for example, the number of glazings or the night insulation R-value, sensitivity plots have to be used to account for these changes in the reference design. Another disadvantage is that the heat storage capacity of the building is not directly included as a variable.

The other general design method is the unutilizability method developed by Monsen, et al. (14) for direct gain windows and collector-storage walls. This method is based on the solar radiation utilizability (a statistic of solar radiation data) to quantify the amount of solar energy which is above any given radiation level. Two theoretical limits to the system performance are derived analytically: zero and infinite building energy storage capacity. The system performance of an actual building with a finite energy storage capacity is found by an empirical relation from these limits defined above.

Parsons developed a design method for sunspaces using monthly-average data. Having problems with the utilizability approach for sunspaces, he based his method on reduced temperature degree-day calculations. The major problem was to define a unique monthly average daily utilizability for two different surfaces absorbing solar radiation: the floor and the wall of the sunspace. This design method treats solar energy delivery in the same fashion as other building internal gains. A reduced base temperature for the month is calculated:

$$T_b = T_r - \frac{\dot{g}}{(UA)_{ns}} \tag{1.3.4}$$

where $\dot{g}$ represents the internal gains terms including the monthly average sunspace energy, Q_{IN}, and $(UA)_{ns}$ is the non-solar building loss coefficient. Then the monthly auxiliary heating requirement is calculated using the balance temperature degree-days:

$$Q_{aux} = (UA)_{ns}(DD)_b \tag{1.3.5}$$

The monthly average sunspace energy, Q_{IN}, is calculated from the TRNSYS thermal network simplified using monthly-average weather data. Effects of changing the sunspace design can be evaluated in this method. However, the important limitation is that it does not include the effect of building capacitance.

1.4 Objectives

The purpose of this research is to develop the unutilizability method for the attached sunspace solar component.

A simplified thermal network for the sunspace using monthly average weather data is studied and the results are compared with detailed TRNSYS simulations. With this simplified network, the unutilizability method is developed from TRNSYS simulation results.

This design method should be simple, accurate and general. Possibilities of investigating the effect of any change in the sunspace geometry, nature of materials and type of utilization should be allowed by this design method.

CHAPTER 2: DESIGN TOOLS FOR SUNSPACE HEATING SYSTEMS

2.1 Introduction

In this chapter a simulation model and a correlation method for sunspaces are described. The simulation model presented here is the sunspace TRNSYS model (10). This model is coupled to the TRNSYS Room and Building model and gives as the output the auxiliary energy requirement for a house with an attached sunspace. The correlation method presented is the SLR method for the sunspace (14). This method was already mentioned in Section 1.3. Advantages and drawbacks for both methods are discussed. The ideal final step for any of these methods is to be able to check them by one way or another. Test results of actual sunspace systems being not available, an alternative approach is to compare results from different well recognized methods. Comparisons between the results of these two methods are presented.

2.2 Simulation Model of the Sunspace in TRNSYS

This model is presented here in a qualitative manner; for more details see the TRNSYS Users Manual (10), Parsons (12) and Schwedler (11).

2.2.1 The Geometry and the Thermal Network

The TRNSYS sunspace model calculates heat flows and temperature using hourly weather data with a specific set of geometrical parameters and thermal characteristics.

The geometry of the component is shown in Figure 2.1 and is defined by different parameters which allow a great number of various configurations.

The sunspace thermal network is shown on Figure 2.2. C_1 and C_3 represent the conductive conductances through the wall and the floor. The number of wall and floor nodes can be varied from two to ten. C_9, C_{10} and C_{11} are the radiative conductances inside the sunspace. C_6, C_7 and C_8 are the convective conductances inside the sunspace. C_5 combines radiation, convection to the ambient and conduction through the glazings. It could also take into account additional night insulation. The infiltration rate is represented by C_{12}. C_{13} is either coupled to the outside (ventilation to the ambient), coupled to the room (ventilation to the building) or is nonexistent. Table 2.1 gives the equations which define the different conductances.

2.2.2 Solar Radiation

The TRNSYS solar radiation processor calculates the incident radiation on both tilted glazings for the beam and diffuse parts as well as the angles of incidence for the beam radiation. Radiation incident on the end walls of the sunspace is not considered. For a sunspace having a zero azimuth angle, the amount of radiation incident on one end wall is nearly equal to the radiation passing through the other end wall. Table 2.2 gives results from the SLR method for two types of sunspaces: one has opaque end walls and the other one has glazed end walls. The geometry of these two sunspaces is given

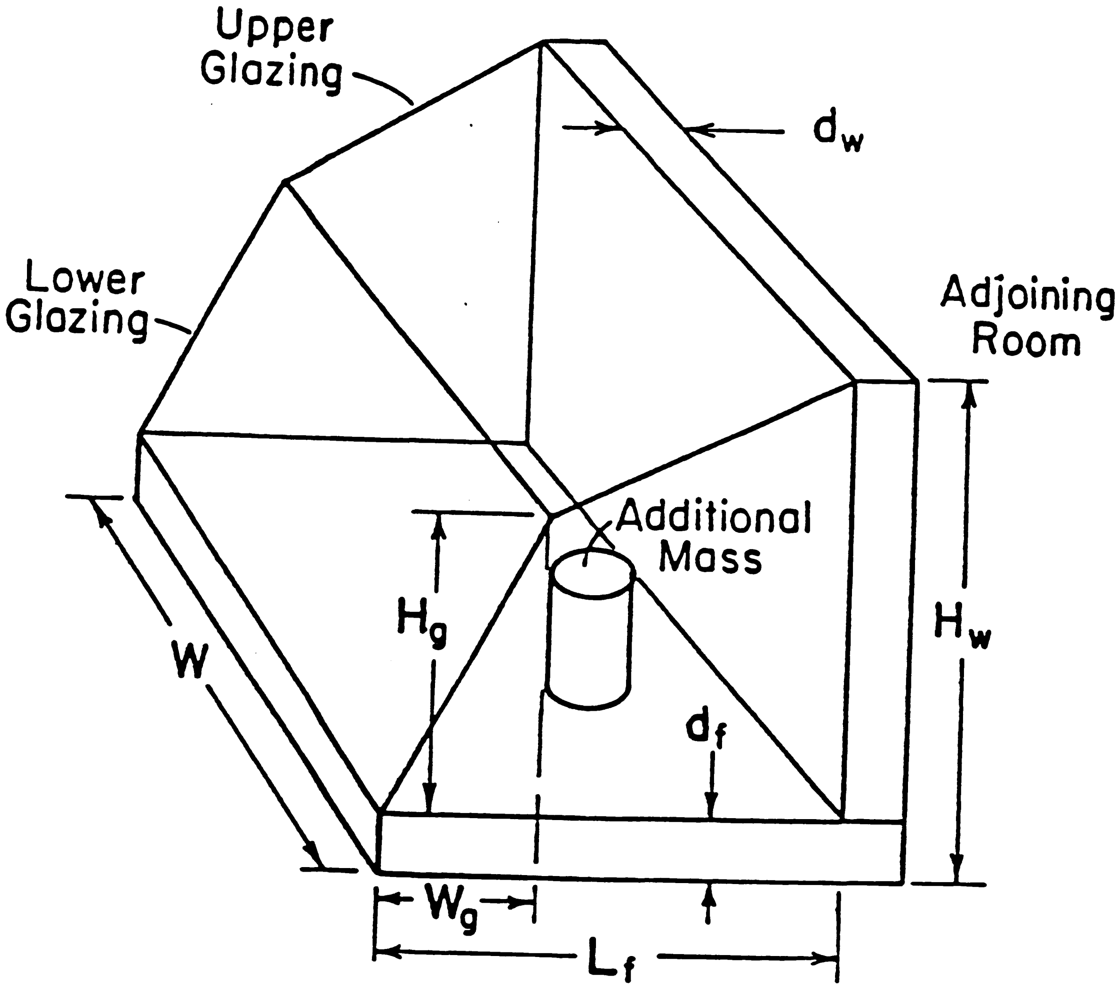


Figure 2.1. TRNSYS sunspace geometry.

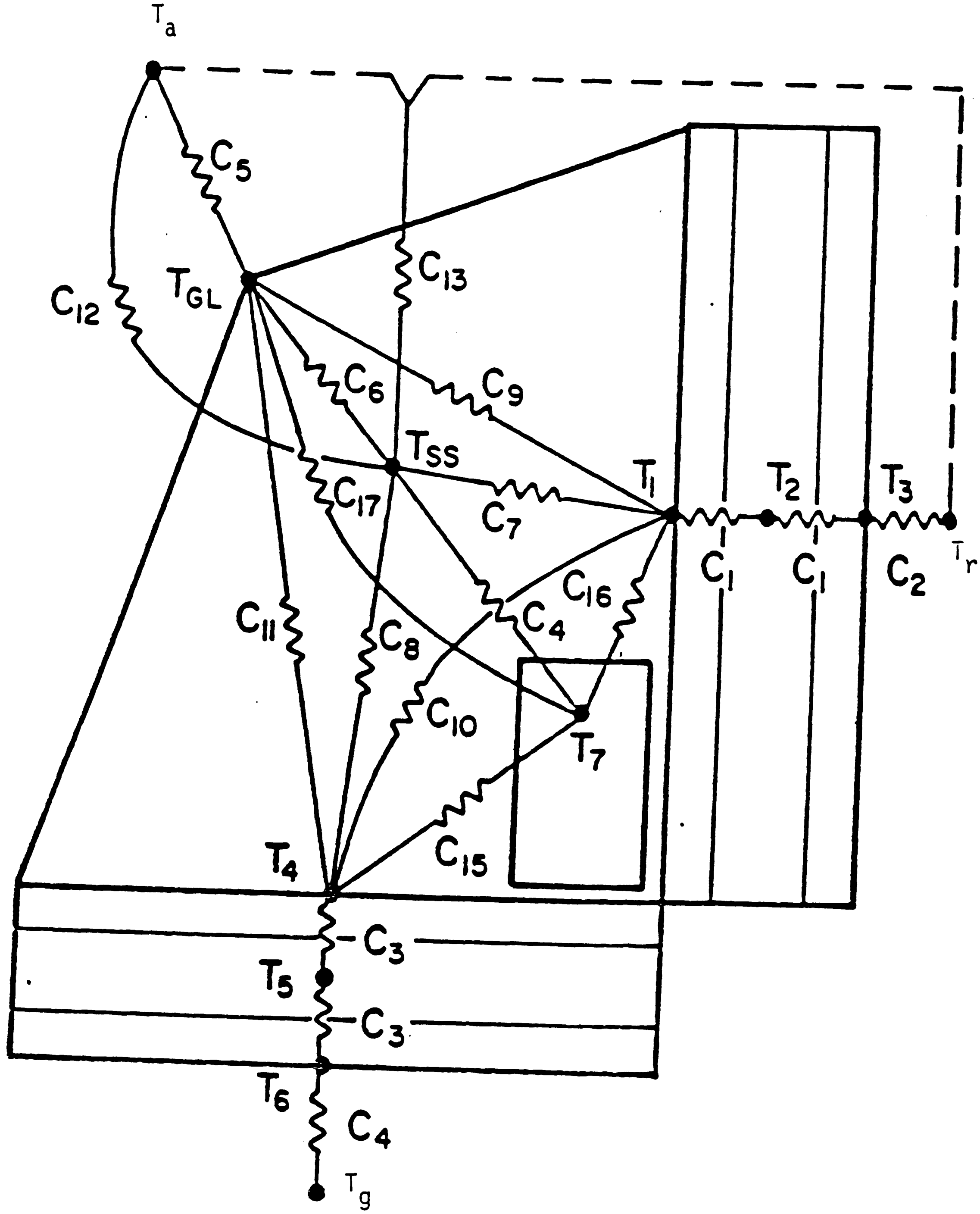


Figure 2.2. TRNSYS sunspace thermal network.

Table 2.1. Equations for the Conductances in TRNSYS Network

Conduction

$C_1 = \frac{WK \times AWL}{DXW}$

AWL = area of the wall

WK = conductivity in KJ/hr-m-°C

DXW = thickness of a space node

$C_3 = \frac{FK * AFL}{DXF}$

AFL = area of the floor

FK = conductivity in KJ/hr-m-°C

DXF = thickness of a space node

Convection

$C_6 = h_{cg} * AGL$

$C_7 = h_{cw} * AWL$

$C_8 = h_{cf} * AFL$

h_{cf} = convection coefficient from floor to sunspace air (KJ/hr-m^2-°C)

h_{cw} = convection coefficient from wall to sunspace air (KJ/hr-m^2-°C)

h_{cg} = convection coefficient between glass and sunspace air (KJ/hr-m^2-°C)

AGL = area of the glazings

Radiation

$C_9 = (EIR(1) * EIR(3) * FHAT(1,3) * T) * AWL * (TWA^2 + TGLIA^2) * (TWA + TGLIA)$

$C_{10} = (EIR(1) * (EIR(2) * FHAT(1,2) * T) * AWL * (TWA^2 + TFA^2) * (TWA + TFA)$

$C_{11} = (EIR(2) * (EIR(3) * FHAT(2,3) * T) * AFL * (TFA^2 + TGLIA^2) * (TFA + TGLIA)$

EIR(I) = emittance of surface I (1 = wall, 2 = floor, 3 = glazing)

$\sigma = 5.67 \times 10^{-8}$ W/m^2-K^4

TWA = temperature of the wall (°K)

TGLIA = temperature of the glazings (°K)

TFA = temperature of floor (°K)

The $\hat{F}$ equations are defined in Section 2.2.2

Infliltration

C_{12} = Rate * ρC_p * VOL   VOL = volume of the sunspace air

Ventilation

C_{13} = M * C_p M = mass of ventilation (kg/hr)

Table 2.2. Effect of End Walls on the Annual Auxiliary Energy

Location:	Madison, WI
UA of the building:	158 W/°C
Projected area of the glazing:	25 m^2

	Q_{aux}
End walls opaque (B_1):	42.82 GJ
End walls glazed (B_3):	43.98 GJ

in Figure 2.3 and the thermal characteristics are given in Table 2.3. Neglecting radiation on the glazed end walls will slightly underpredict the auxiliary energy required by a house.

In the sunspace component, using glazing optical properties and radiation incidence angle, the amount of transmitted radiation is then calculated. For the diffuse fraction an angle of incidence of sixty degrees is used (15).

Assuming that the diffuse radiation has a uniform intensity in all directions, its transmitted part through the glazings is distributed to the sunspace floor, wall, mass containers by multiplying by crossed string view factors. Hottel's crossed string method, used here, ignores the end wall effects (16). The projection of the beam radiation through a north-south vertical is defined by:

$$\delta = \tan^{-1} (-\tan \theta_z \cos \gamma_z) \qquad (2.2.1)$$

where θ_z is the solar zenith angle and γ_z is the solar azimuth angle.

Transmitted beam radiation is distributed by projecting solar angles on the floor and wall and calculating the fraction of the radiation transmitted through each of the glazings that is incident on each surface.

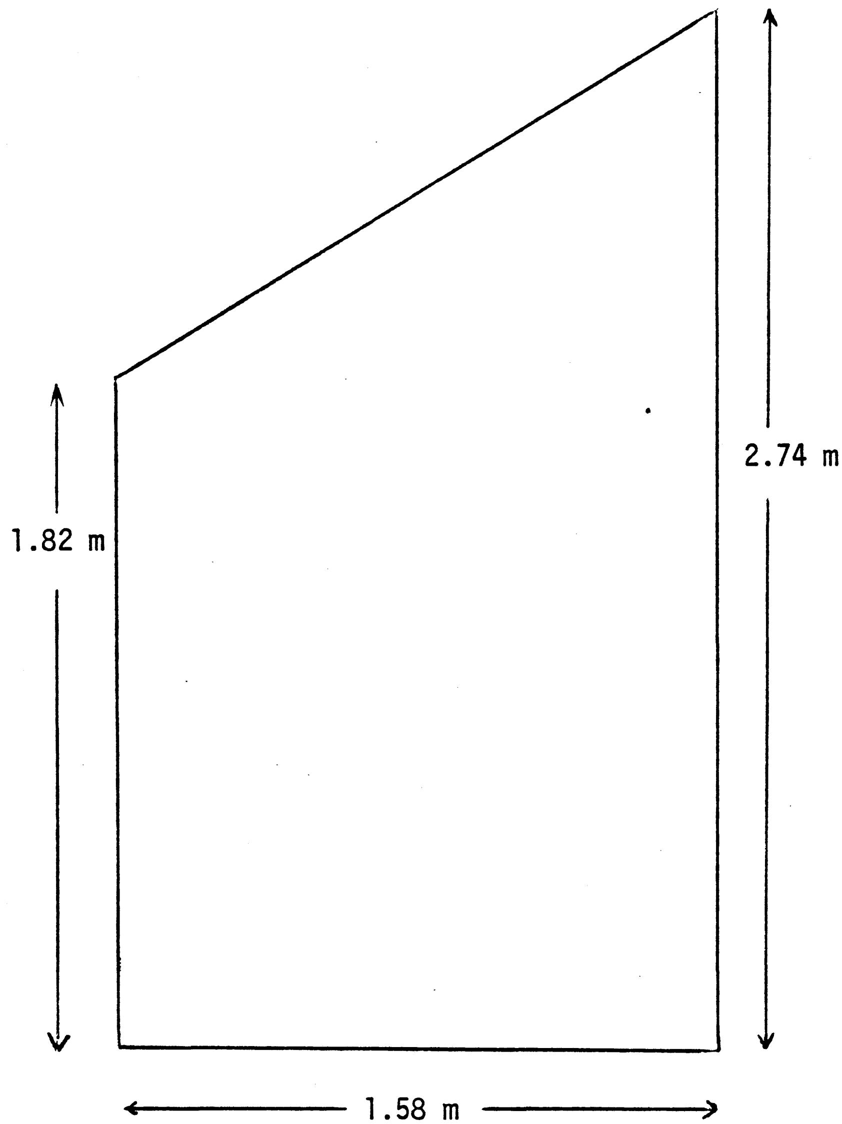


Figure 2.3. Geometry and glazing properties for the sunspace.

sunspace width = 9.14 m
infrared emittance of the glazing = 0.9
infrared emittance of the floor and wall = 0.9
solar absorbtivity of the floor and wall = 0.8
R-value of a single glazing = 0.22 m^2-°C
extinction coefficient of the glazing times thickness of the glazing = 0.0625
refractive index of the glazing = 1.526
no night insulation
fraction glazing opaque to solar radiation = 0.2

Table 2.3. Thermal Characteristics of the Sunspace for the Study of the Effect of End Walls

- Conductivity of the wall:	1.73 W/m°C
- Thickness of the wall:	0.305 m
- Conductivity of the floor:	0.865 W/m°C
- ρC_p wall:	612.5 KJ/m^2-°C
- Infiltration rate:	0.5 air change/hour
- Low set temperature of the house:	18.33°C
- Double glazing	

The incident solar radiation on node i is computed as:

$$Q_{s,i}(i) = \{BU_i\tau_{b,u}I_{b,u}A_{g\ell,u} + BL_i\tau_{b,\ell}I_{b,\ell}A_{g\ell,\ell} + \tau_d[DU_iI_{d,u}A_{g\ell,u} + DL_iI_{d,\ell}A_{g\ell,\ell}]\}\ (1 - f_{op}) \tag{2.2.2}$$

BU_i and DU_i are the fractions of beam and diffuse radiation from the upper glazing incident on node i, while BL_i and DL_i refer to fractions from the lower glazing. $I_{b,u}$ and $I_{b,\ell}$ are the beam radiation intensities incident on the upper and lower glazings. $A_{g\ell,u}$ and $A_{g\ell,\ell}$ are the areas of the upper and lower glazings.

Having calculated the incident solar radiation on the wall, floor and extra mass, the solar radiation absorbed is derived from this equation:

$$Q_{s,a}(i) = \alpha_i[Q_{s,i}(i) + \sum_j \rho_j Q_{s,i}(j)\ \hat{F}_{ji}] \tag{2.2.3}$$

where α_i is the solar absorptance of node i. $Q_{s,i}(i)$ is the incident solar on node i. ρ_j is the solar reflectance of node j. $\hat{F}_{ij}$ accounts for the multiple radiation reflections and is defined as the radiation leaving node i that is incident on node j, including all possible reflections, divided by the total radiation leaving node i (17).

$$\hat{F}_{ij} = [\delta_{ij} - \rho_j F_{ij}]^{-1} \tag{2.2.4}$$

where F_{ij} is the view factor from node i to node j. δ_{ij} is the Kronecker delta function where δ_{ij} equals one if i equals j and δ_{ij} equals 0 if i does not equal j.

2.2.3 Temperature and Heat Flow Calculations

The behavior of the sunspace temperature node is described by the differential equation:

$$(mC_p)_i \frac{dT_i}{dt} = \sum_j C_{ij}(T_j - T_i) + Q_{s,a}(i) \qquad (2.2.5)$$

where $(mC_p)_i$ is the mass-specific heat product of node i. C_{ij} is the conductance between node i and j. $Q_{s,a}(i)$ is the absorbed solar radiation at node i as defined in Equation (2.2.3).

The TRNSYS model neglects the storage capacity of the glazing and air.

Parsons used this sunspace component to simulate a large variety of sunspaces systems. Effects of venting between the sunspace and the building, maintenance of sunspace temperature and the effect of the sunspace on building cooling loads were studied.

Errors in the TRNSYS code were discovered in the definition of areas for the lower and upper glazing. Another error was found in the fraction of beam and diffuse radiation from the lower and upper glazing. The corrected computer code of the TRNSYS sunspace component is found in Appendix B.4 as well as the list of the parameters, inputs and outputs.

2.2.4 Study on the Variation of the Temperature of the Sunspace

As a sunspace allows to grow plants and vegetables, extreme variation of its temperature is an important factor to consider. Growing plants, particularly vegetables, may require additional auxiliary heating for the sunspace in order to maintain a minimum temperature for an optimal growth. Overheating may also be a problem as the temperature should not ideally exceed 30°C. With TRNSYS simulations of single and double glazed sunspaces performed in Madison, WI, and Albuquerque, NM, sunspaces air temperature distributions were plotted for the month of January in Figures 2.4a and 2.4b. A third case was studied: night insulation with a single glazing. No limitation on the sunspace temperature was done (no auxiliary heating or ventilation). These simulations were done with the geometrical configuration of Figure 2.3 for the sunspace. Other characteristics are given on Table 2.4. These two climates were selected because they are representative of extreme weather types in the United States.

For Madison, with a single glazing sunspace, temperatures around freezing point happen during 40 hours which is 5.4% of the total number of hours in the month. The distribution maximum occurs around 12.5°C. With a double glazing the temperature distribution shifts to higher values. In particular, in the lower range of temperatures the sunspace temperature will never drop below 5°C. Night insulation has the most significant effect on the temperature distribution: the temperature of the sunspace will never drop below 10°C and will be most of the time around 20°C.

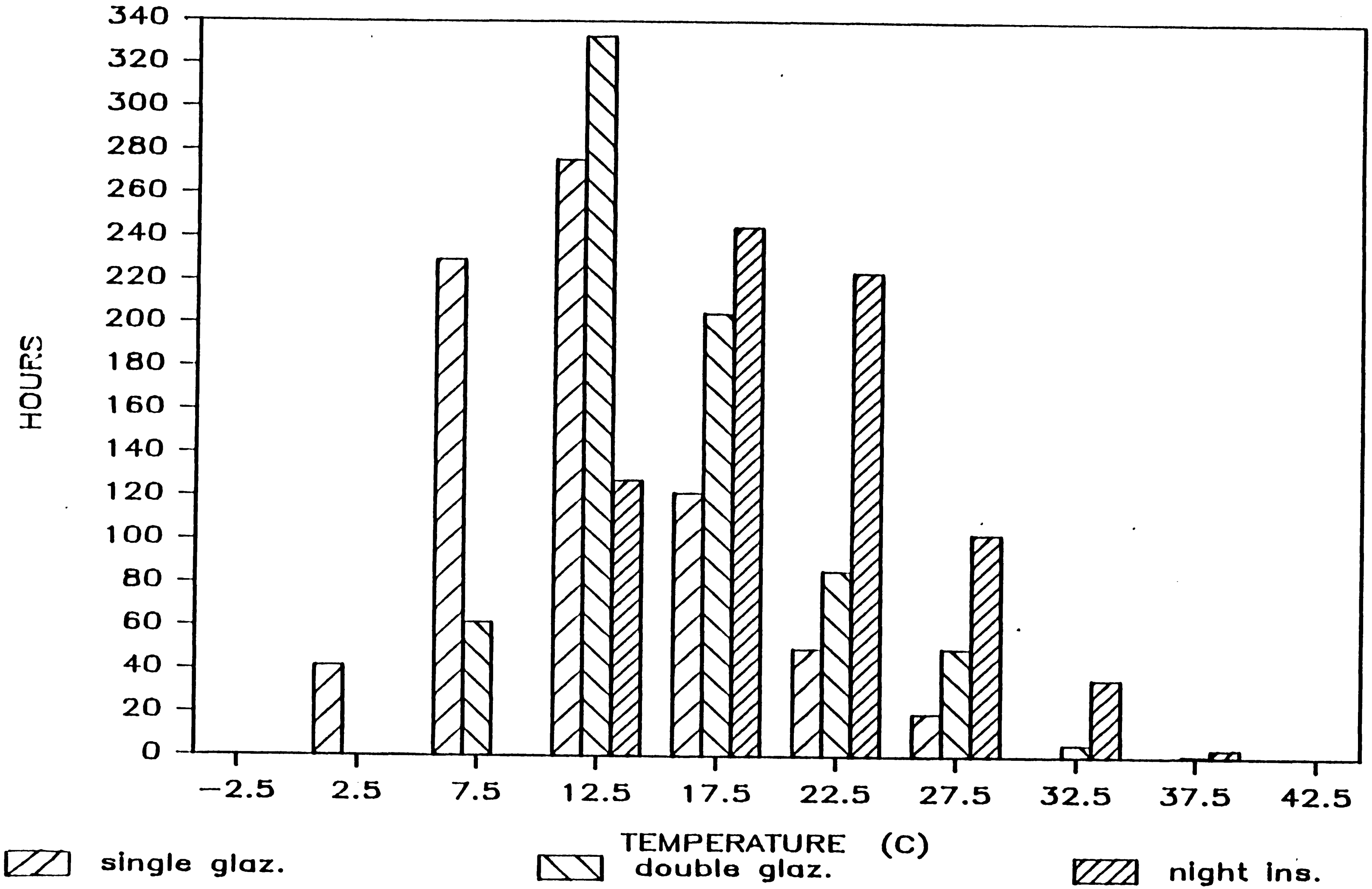


Figure 2.4a. Sunspace air temperature; Madison, WI.

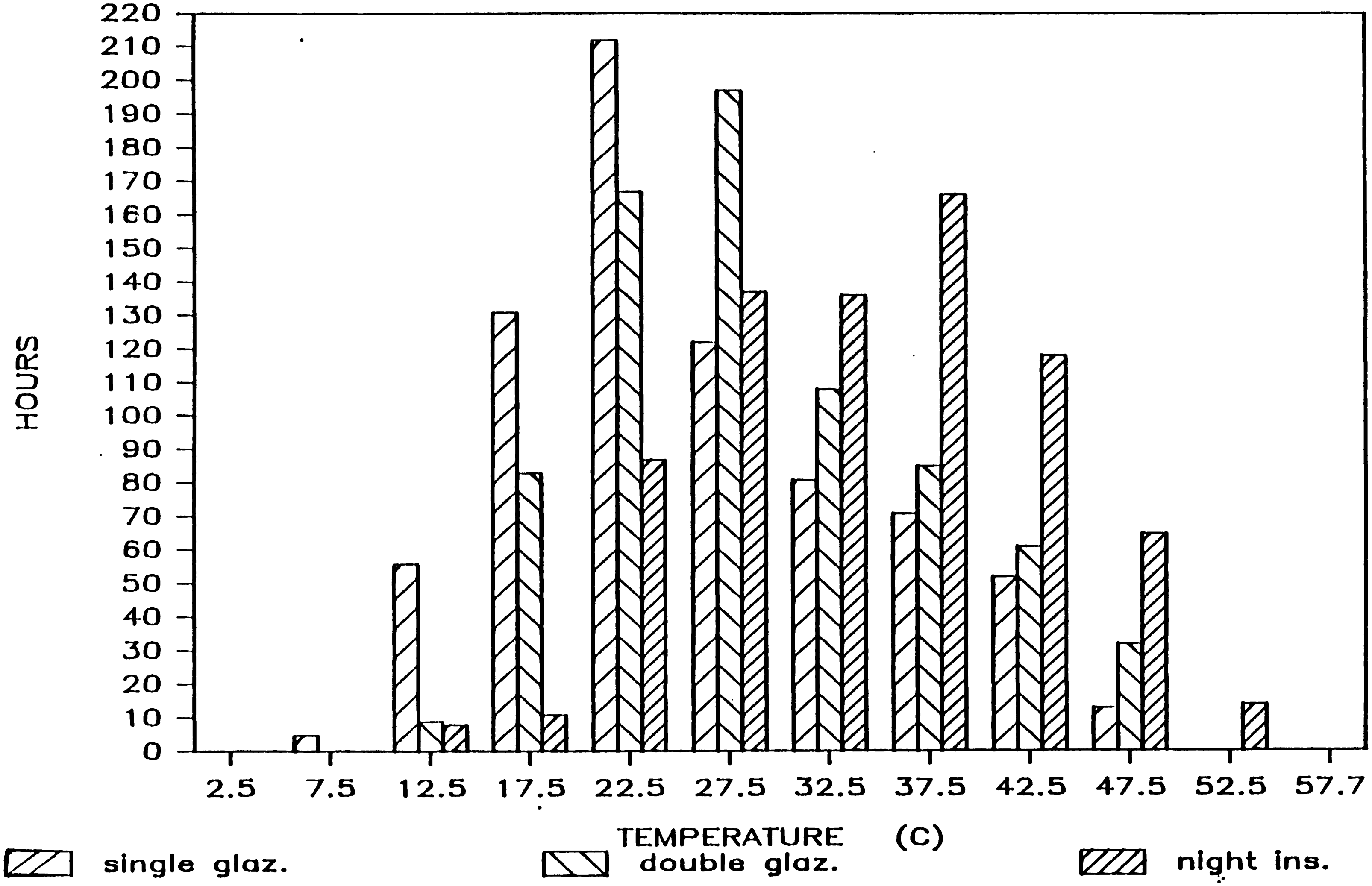


Figure 2.4b. Sunspace air temperature, Albuquerque, NM.

Table 2.4. Thermal Characteristics of the Sunspace for the Study on the Variation of the Temperature Inside the Sunspace

- No ventilation to the house	
- Low set temperature of the house =	18.33°C
- Conductivity of the wall =	1.73 W/m°C
- Thickness of the wall =	0.305 m
- Conductivity of the floor =	0.865 W/m°C
- ρC_p wall =	2009 KJ/m^2-°C
- ρC_p floor =	2009 KJ/m^2-°C
- 1 air change per hour for the sunspace	
- South orientation	

For Albuquerque the effect of double glazings and night insulation is similar. The range of temperatures although is different. The temperature will never drop below 5°C (even for the single glazing) and will go as high as 55°C (with night insulation). Night insulation for this type of climate is not needed and causes problems of overheating.

A desirable temperature range for cool-season crops is around 4.4-15.5°C. An occasional drop to 0°C or increase to 35°C will not hurt most of these crops (3). Even for Madison with a single glazed sunspace, the temperature distribution is in agreement with this optimal range for cool-season crops. Extreme temperatures (0°C and 35°C) will only occur for a small number of hours. A sunspace acts like a buffer zone. Although the monthly average temperature for Madison in January is -8°C, the sunspace will stay around freezing temperature 5% of the time. With the results of this study, limitation on the sunspace temperature will not be considered in the simulations presented further. In case a higher minimum temperature is required, additional auxiliary energy will have to be supplied and will significantly increase the total auxiliary energy. See Parsons for more details (12).

2.2.5 Net Effect of a Sunspace on the Auxiliary Energy

Figure 2.5 shows the difference in auxiliary energy using TRNSYS simulations between a house with a sunspace or without a sunspace for Madison, WI. The UA value for the house without the sunspace (174 W/°C instead of 158 W/°C) is slightly higher accounting for the

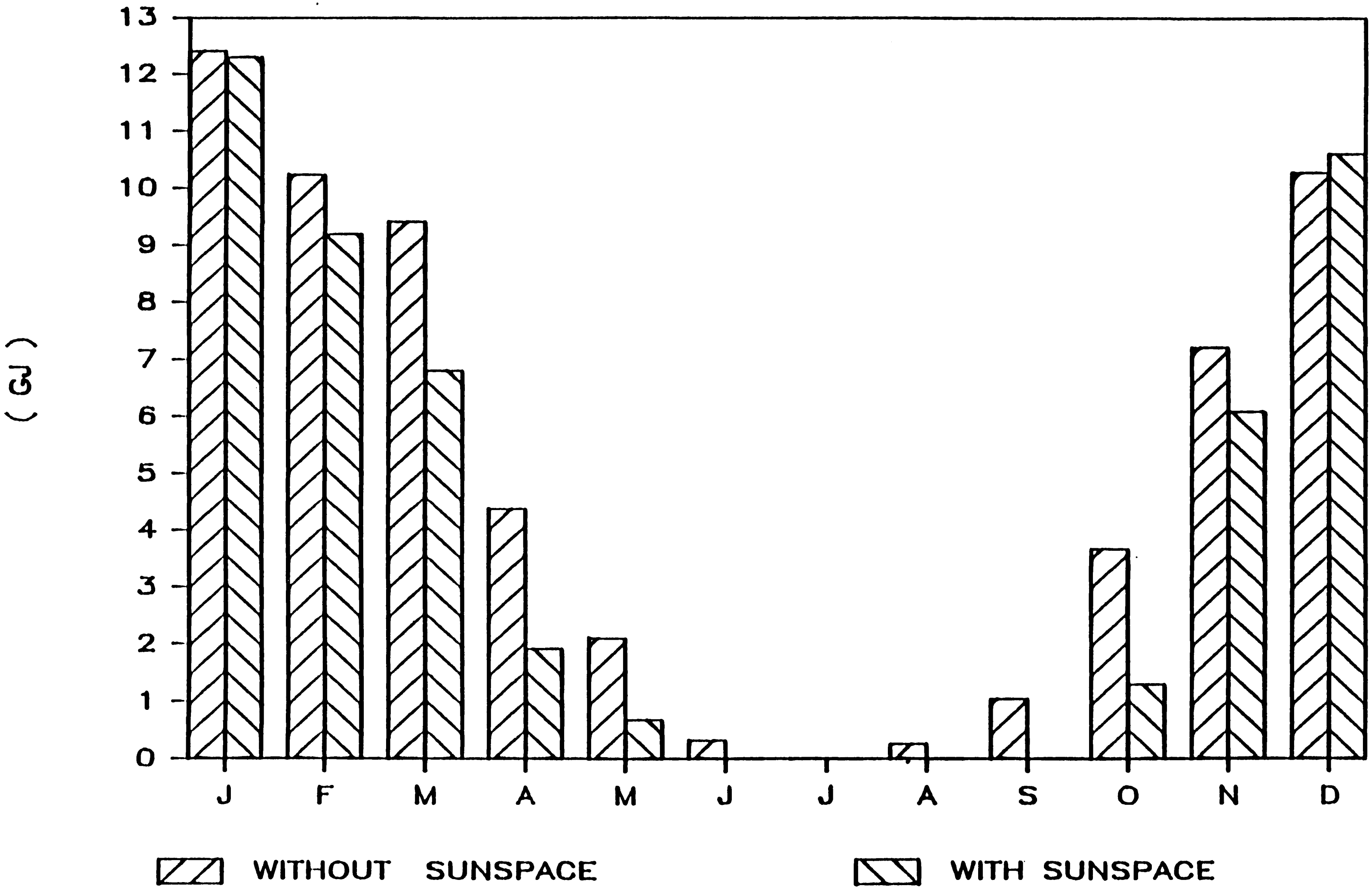


Figure 2.5. Monthly building auxiliary heat for a house with and without a sunspace, Madison, WI.

losses from the wall that replaces the sunspace. The house capacitance is the same for both cases: 25000 KJ/C. The sunspace configuration is given in Figure 2.3 and the other parameters are given in Table 2.4. The sunspace has a double glazing. No limitation on the sunspace temperature was done. One can easily deduce from the graph that spring and fall are the best seasons for an efficient use of the sunspace. In some months the sunspace can however increase the auxiliary energy needed by the house by increasing the losses. On this graph it is the case for the month of December. This graph shows that even for a severe climate like Madison, a sunspace if well designed, can contribute in the reduction of the auxiliary energy needed by a house. For the house without the sunspace the annual auxiliary energy requirement is 61.46 GJ. The house with the sunspace requires 45.19 GJ which represents a net gain of 16.27 GJ or a 26.5% reduction in the annual auxiliary energy.

2.3 Correlation Method: The SLR Method

The correlation method presented here is the Solar Load Ratio method which was developed for passive solar components, including sunspaces, by the Los Alamos Scientific Laboratory (13).

This design method has major advantages over a simulation program. No hourly detailed weather data are required; monthly average weather data have to be provided and only 12 calculations are needed for the prediction of the annual auxiliary energy.

Although this method is rather simple, it presents some drawbacks. As mentioned in Section 1.3 this method was developed for 14 reference design systems. Table 2.5 gives some of the reference design characteristics common to all references. Thus it is seen that these reference characteristics are quite restrictive in the choice of possible systems which can be studied. As long as the system being analyzed is one of the 14 reference systems the method is very simple to use. However, sensitivity plots are needed to study systems which differ from the reference systems. These plots are presented for six different locations making interpolation between climate types necessary.

2.4 Comparison of TRNSYS and SLR Results and Conclusions

In order to compare the methods, the sunspace geometry and thermal characteristics used in TRNSYS simulations have to match one of the 14 reference design system in the SLR method. The sunspace type which was selected for the comparison is a type B: the lower glazing is vertical and the upper glazing has a 30° slope. The geometry of this type of sunspace is given in Figure 2.3. The common wall is a masonry type and there is no night insulation (type B_3).

Both models were run for 3 different locations (Madison, WI; Columbia, MO; and Seattle, WA) and 2 different non-solar loss coefficients (158, 400 W/°C). Results are plotted on Figure 2.6. There is a good agreement between the two methods for these particular reference design. A value of 25000 KJ/°C was assumed for the capacitance

Table 2.5. Reference Design Characteristics for the SLR Method

Thermal Storage Capacity (per square foot of common wall)	
Masonry wall	612.5 KJ/m^2-°C
Water container (insulated wall cases)	1274 KJ/m^2-°C
Floor	306.25 KJ/m^2-°C
Wall (Masonry)	
Thickness	30.5 cm
Thermal conductivity	1.73 W/m-°C
Density	2403 kg/m^3
Glazing	
Double glazing	
Conductance of night-insulation	0.63 W/m^2-°C
Control Range	
Fixed allowable room temperature swing	18.3°C to 23.9°C
Fixed allowable sunspace temperature swing	7.2°C to 35.°C
Infiltration rate	0.5 air change/hour

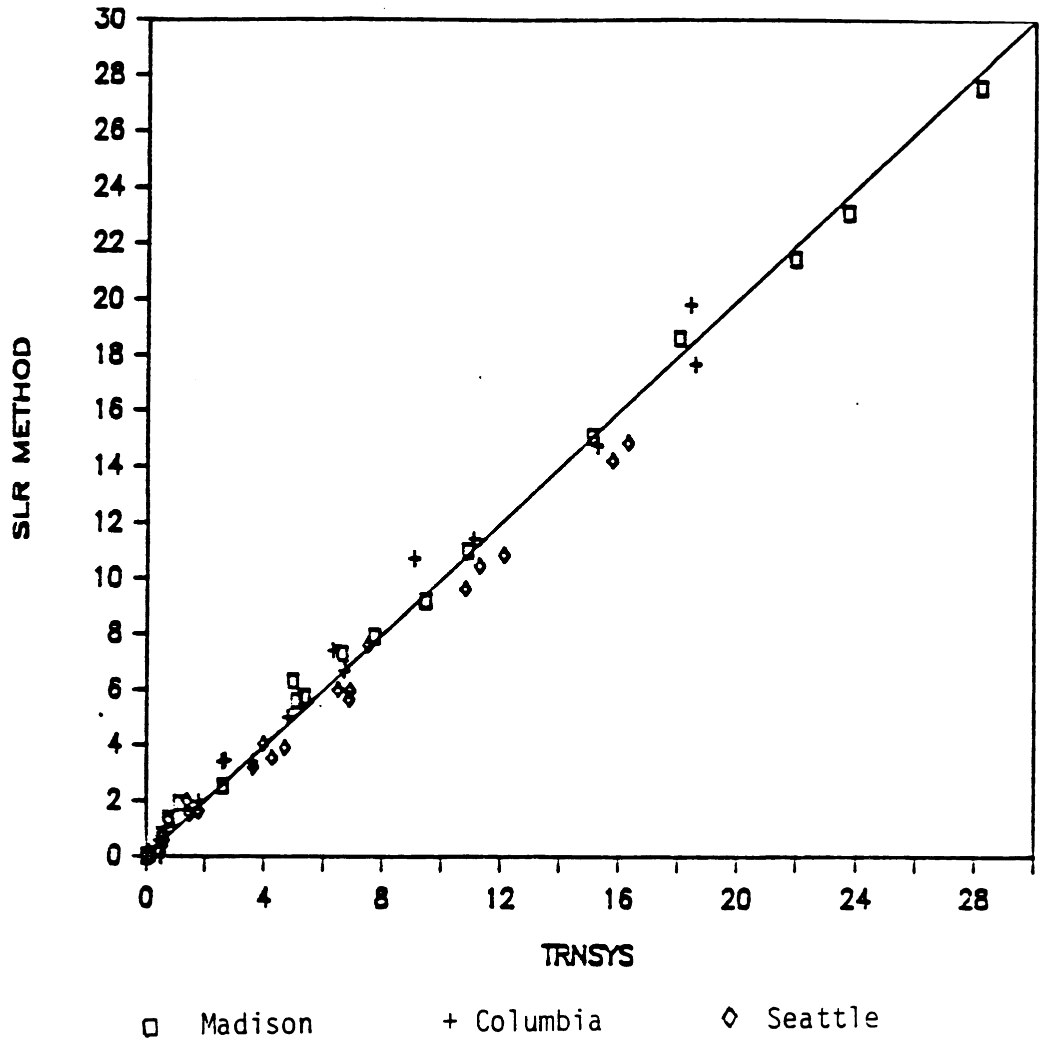


Figure 2.6. Comparison of Monthly Auxiliary Energy between TRNSYS and the SLR Method.

of the building in the TRNSYS simulation. An additional auxiliary heating system was added for the sunspace in the TRNSYS simulation to maintain a low set temperature of 7.2°C. The ventilation flow rate was set to 500 kg/hr in TRNSYS.

The two methods show a good agreement and provide a good reference for the correlation developed in Chapter 3.

The program of the SLR method is listed in Appendix B.3.

CHAPTER 3: A DESIGN METHOD FOR SUNSPACES

3.1 Introduction

In this chapter the sunspace model developed by Parsons (12), which is used in TRNSYS, is simplified by making three assumptions about the thermal characteristics. An analytical method to evaluate Q_{IN}, the amount of energy which flows through the common wall to the house, is presented. Simplifications and assumptions made in the TRNSYS model are checked.

Theoretical limits to a sunspace system performance are derived from this simplified method. The two limiting cases for auxiliary energy needed by the house are infinite and zero thermal capacity of the building.

In order to determine the auxiliary energy needed by a zero thermal capacity house, the amount of energy dumped had to be calculated using the unutilizability factor.

Finally, to evaluate the auxiliary energy needed by a finite thermal capacity house, the monthly solar fraction is correlated with dimensionless parameters using TRNSYS simulation results.

3.2 The Simplified Thermal Network

Three assumptions about the thermal characteristics of a sunspace, when averaged over a month, allow the TRNSYS sunspace network (Figure 2.2) to be reduced to a simple resistance network. Two of them were already checked by Parsons in the simplification he did for the sunspace network in his design method.

The first one is that ventilation to the building from the sunspace has little effect on the building auxiliary heating requirements. Although it has a non-negligible effect in the increase of energy flow through the wall, this increase of energy does not occur at the right time. Ventilation simply increases the effect of the conduction process during the same period of time, during the day, but has no positive effect at night. This is seen in Table 3.1 which gives TRNSYS annual results for Q_{IN}, the energy passing through the wall, and Q_{aux}, the auxiliary energy needed by the house, for a vented and an unvented sunspace. Detailed venting studies were done by Parsons, and showed that neglecting ventilation was a good approximation for relatively thin common walls made of thermally conductive materials such as masonry. On Figures 3.1a and 3.1b are plotted Q_{aux} for a vented sunspace versus an unvented sunspace for two different types of wall. Neglecting ventilation will slightly underpredict or overpredict the auxiliary energy of vented sunspace systems depending on the location. In both cases the difference between vented and unvented systems is negligible.

The second assumption made by Parsons is that the net internal energy change of the sunspace wall and floor over the month is small compared to the other sunspace energy quantities in the following energy balance:

Table 3.1. Annual Results for the Ventilation Study

Location	Madison, WI
Mass flow rate of ventilation flow stream	500 kg/hr

1. Masonry wall type

Thickness = 0.305 m

ρC_p = 2009 KJ/m^3-°C

Conductivity = 1.73 W/m°C

	Q_{IN}	Q_{aux}
no ventilation	28.59 GJ	45.13 GJ
ventilation	37.54 GJ	45.87 GJ

2. Frame wall type

Thickness = 0.15 m

ρC_p = 800 KJ/m^3-°C

Conductivity = 0.55 W/m°C

	Q_{IN}	Q_{aux}
no ventilation	24.20 GJ	46.86 GJ
ventilation	35.18 GJ	47.31 GJ

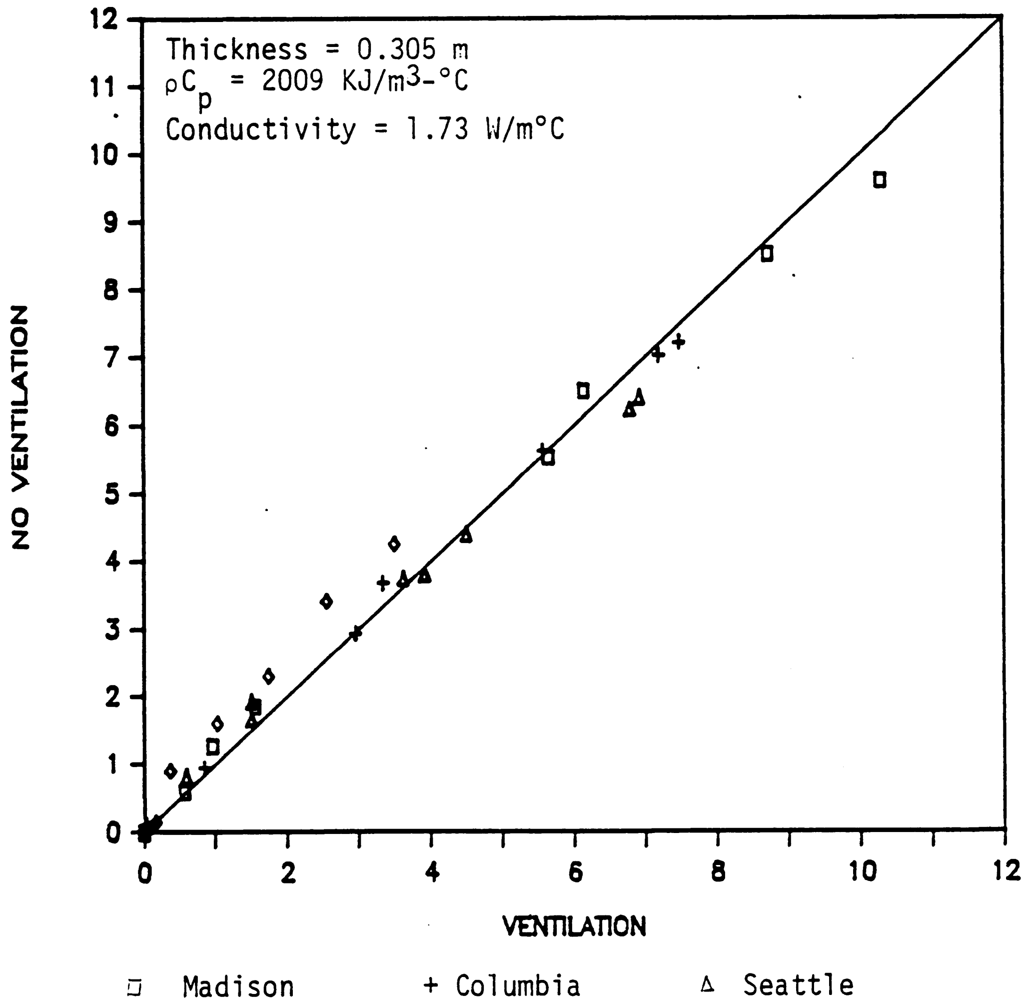


Figure 3.1a. Effect of venting thick, masonry wall on monthly auxiliary energy (GJ).

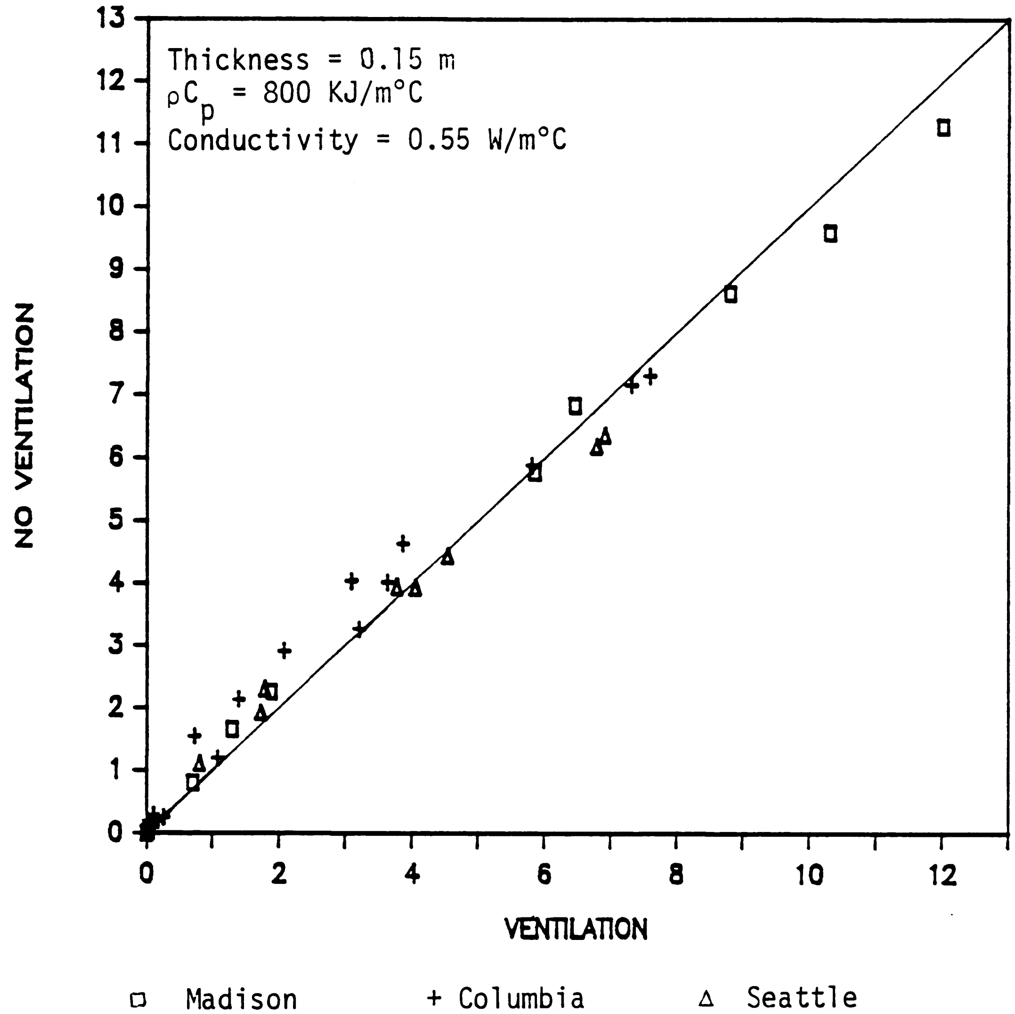


Figure 3.1b. Effect of venting thin insulated wall on monthly auxiliary energy (GJ).

$$Q_S + Q_{LOSSES} + Q_{IN} + Q_U + Q_{GND} = 0 \qquad (3.2.1)$$

where: Q_S is the absorbed solar radiation,

Q_{LOSSES} is the heat loss to ambient,

Q_{IN} is the sunspace delivery to the room,

Q_U is the change in internal energy of the sunspace, and

Q_{GND} is the heat loss through the ground.

This allows the simplification of the heat flow path through the wall and floor from Figure 2.2, by assuming that the monthly average wall and floor temperature profiles are linear. The monthly average heat transfer from the floor surface to the ground and from the sunspace wall surface to the building are characterized by a single conductance. Table 3.2 compares several monthly energy quantities for an unvented sunspace with a 0.315 m thick masonry common wall. It shows that the sunspace energy stored is negligible compared to the other energies quantities.

The third assumption which can be added to the two previous ones is to neglect the losses through the floor. This assumption is valid even for a high floor conductivity and for a low floor insulation value. Table 3.2 shows TRNSYS monthly integrated values for two sets of floor thermal characteristics. Even in the second case, the losses through the ground are quite negligible. This third assumption leads to the thermal network shown in Figure 3.2. The room, ground and ambient temperatures are monthly average values, denoted by the bar.

Table 3.2. Monthly Results for the Study of the Sunspace Floor Losses (GJ)

1. Thicknesses of the floor = 0.1525 m

   Conductivity of the floor = 1.73 W/m°C

   Floor insulation = 1.584 m^2-°C/W

	Absorbed Solar Radiation	Loss to Ambient	Sunspace Delivery	Sunspace Stored	Loss to Ground
November	5.223	4.302	0.960	-0.084	0.046
December	4.074	4.310	-0.288	0.034	0.019
January	5.785	5.691	0.01	0.061	0.023
February	6.518	5.599	0.793	0.086	0.039
March	8.882	6.711	2.060	0.040	0.071

2. Thickness of the floor = 0.10 m

   Conductivity of the floor = 2.22 W/m°C

   Floor insulation = 0.36 m^2-°C/W

	Absorbed Solar Radiation	Loss to Ambient	Sunspace Delivery	Sunspace Stored	Loss to Ground
November	5.223	4.297	0.956	-0.082	0.054
December	4.074	4.309	-0.290	0.0334	0.022
January	5.785	5.689	0.009	0.061	0.026
February	6.518	5.596	0.791	0.085	0.046
March	8.882	6.704	2.055	0.039	0.084

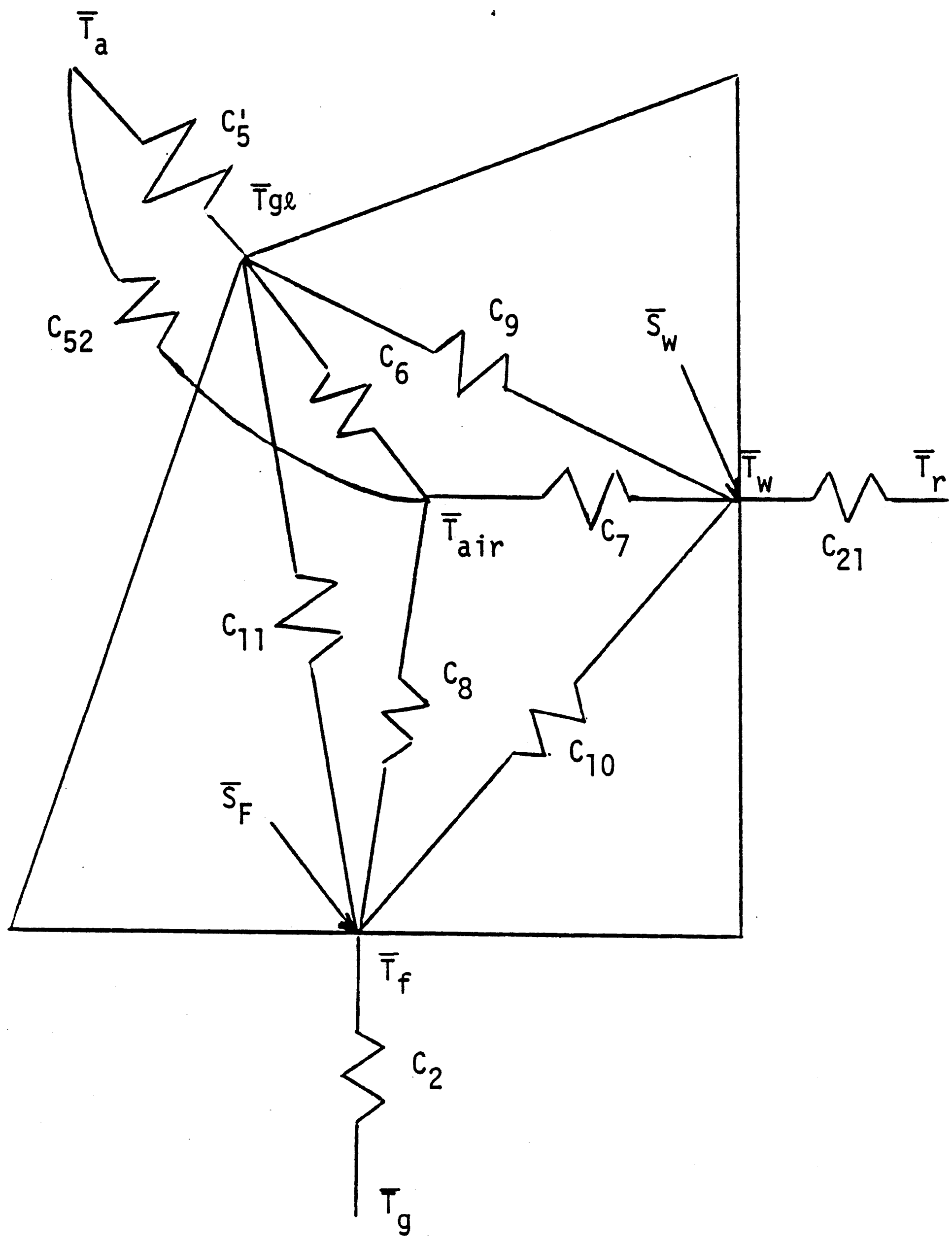


Figure 3.2. Simplified sunspace thermal network (1).

The absorbed solar radiation on the wall and floor have to be calculated now on a monthly basis.

3.3 Monthly Average Absorbed Solar Radiation

The monthly-average absorbed solar radiation for the wall and the sunspace floor was determined by Parsons using a similar approach to Klein (18) in determining the monthly average transmittance-absorptance product of solar collectors.

The idea is to calculate the absorbed solar radiation for a single day of the month (15), and multiply it by the number of days in the month to obtain the monthly-average absorbed solar radiation. Using $\overline{H}$, the monthly average daily horizontal radiation, the incident diffuse radiation is calculated on a daily basis with Erbs correlation (30):

$$\overline{H}_d/\overline{H} = 1.317 - 3.023\ \overline{K}_T + 3.372\ \overline{K}_T^2 - 1.769\ \overline{K}_T^3 \qquad (3.3.1)$$

K_T is the monthly average daily clearness index (15).

The diffuse and ground-reflected radiation incident on a glazing surface at a tilt β is then calculated:

$$\overline{H}_{d,t} = \overline{H}_d\ \left(\frac{1 + \cos\beta}{2}\right) + \rho_g \overline{H}\ \left(\frac{1 - \cos\beta}{2}\right) \qquad (3.3.2)$$

where ρ_g is the ground reflectance.

Using $\bar{H}$ and $\bar{H}_d$, the average hourly beam radiation on a tilted surface, is calculated:

$$I_{b,t} = R_b \left(r_t\bar{H} - r_d\bar{H}_d\right) \tag{3.3.3}$$

where R_b is the ratio of beam radiation on the tilted surface to that on the horizontal (15), r_t is the hourly-to-daily total radiation ratio and r_d is the hourly-to-daily diffuse radiation ratio from Collares-Pereira and Rabl (31). Using the glazing transmittance from the TRNSYS subroutine TALF (10), and apportioning the energy transmitted to the wall and floor by geometric calculations, the total monthly average daily incident radiation on the wall and floor is calculated. For further details concerning the calculation, see Parsons (12).

The design method presented in Section 3.4 calculates the monthly absorbed solar radiation using this method. The Fortran subroutine, RAD, from Parsons, to calculate the monthly average daily incident radiation for the sunspace surface -- given the month, average daily horizontal radiation intensity, ground reflectance and sunspace geometry -- is included in Appendix B.2.

The procedure of the calculation for the solar radiation absorbed is then exactly the same as in Section 2.2.2. Absorbed radiation calculated by this monthly average daily method is compared with monthly integrated TRNSYS values in Figure 3.3. The results cover a full year with the geometry of Figure 2.3 using TMY weather data (19) for Madison, WI, Albuquerque, NM, and Seattle, WA.

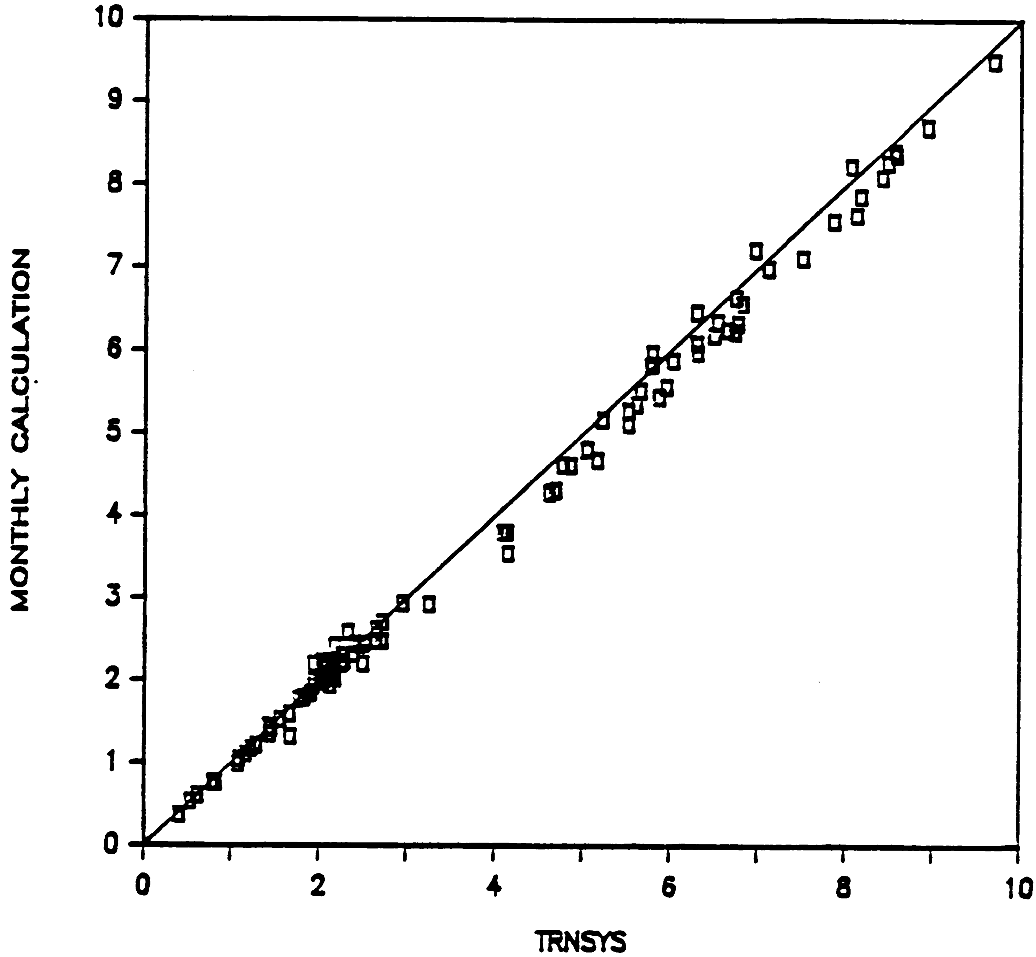


Figure 3.3. Comparison of monthly values for the absorbed radiation on the wall and the floor for Madison, WI, Albuquerque, NM and Seattle, WA (GJ).

The monthly calculation shows good agreement with TRNSYS results. Subroutine TWBAR from Parsons (Appendix B.2), which calculates this absorbed solar radiation on the wall and the floor, is included in the design method described further.

3.4 Monthly-Average Wall Temperature and Energy Delivery

Having calculated the monthly absorbed solar radiation on the wall and floor, the thermal network from Figure 3.2 can be simplified a second time.

Combining conductances from the network in Figure 3.2, using a "Y,Δ transformation", the network shown below is obtained (31):

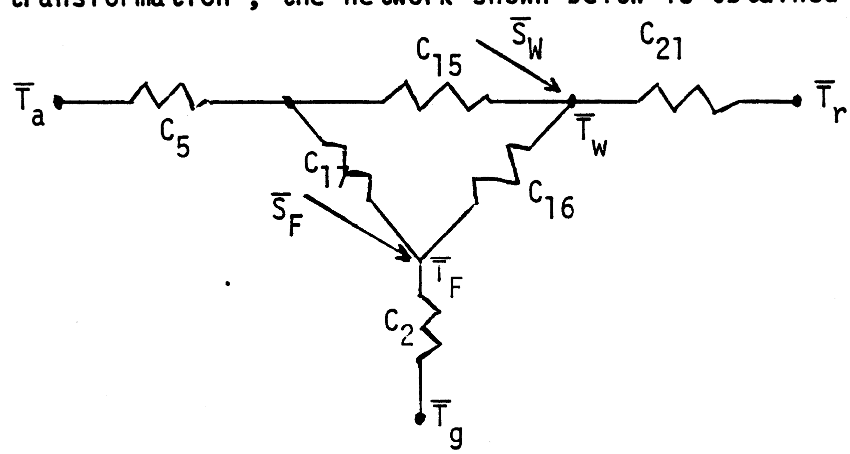


Figure 3.4. Transformation (1) of the sunspace thermal network

where:

$$C_5 = C_5' + C_{52} \quad (3.4.1)$$
$$R_{12} = (R_7 \times R_6 + R_7 \times R_8 + R_8 \times R_6)/R_8 \quad (3.4.2)$$
$$R_{13} = (R_7 \times R_6 + R_7 \times R_8 + R_8 \times R_6)/R_6 \quad (3.4.3)$$
$$R_{14} = (R_7 \times R_6 + R_7 \times R_8 + R_8 \times R_6)/R_7 \quad (3.4.4)$$
$$R_{15} = (R_9 \times R_{12})/(R_9 + R_{12}) \quad (3.4.5)$$
$$R_{16} = (R_{10} \times R_{13})/(R_{10} + R_{13}) \quad (3.4.6)$$
$$R_{17} = (R_{11} \times R_{14})/(R_{11} + R_{14}) \quad (3.4.7)$$

Another "Y,Δ Transformation" leads to:

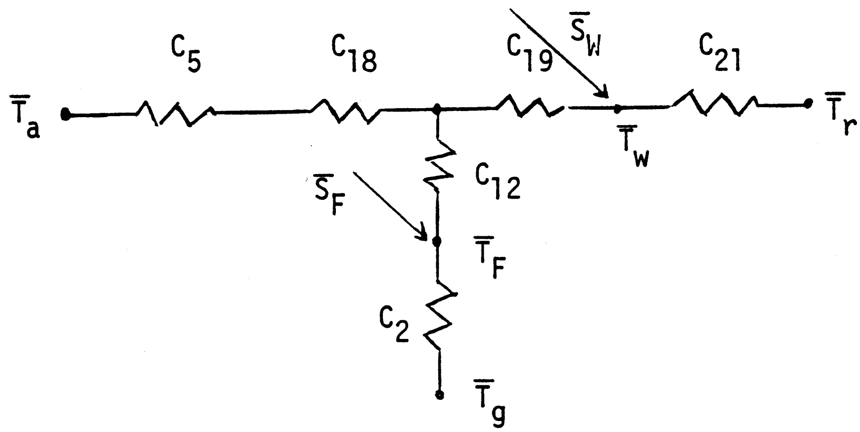


Figure 3.5. Transformation (2) of the sunspace thermal network.

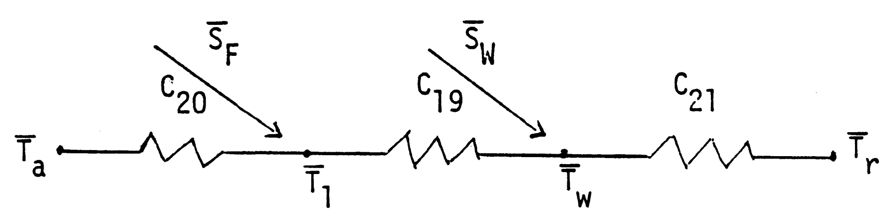
where:

$$C_{18} = (R_{15} + R_{16} + R_{17})/R(_{15} \times R_{17}) \quad (3.4.8)$$

$$C_{12} = (R_{15} + R_{16} + R_{17})/(R_{16} \times R_{17}) \quad (3.4.9)$$

$$C_{19} = (R_{15} + R_{16} + R_{17})/(R_{15} \times R_{16}) \quad (3.4.10)$$

Using the assumption that losses through the ground can be neglected, C_2 can be assumed to be equal to 0. This simplification gives the network below:



where $C_{20} = C_5 + C_{18}$

Figure 3.6. Transformation (3) of the sunspace thermal network.

It also leads to these two energy balances:

$$(\bar{T}_a - \bar{T}_1)C_{20} + (\bar{T}_w - \bar{T}_1)C_{19} + \bar{S}_F = 0 \qquad (3.4.11)$$

$$\bar{S}_w + (\bar{T}_1 - \bar{T}_w)C_{19} + (\bar{T}_r - \bar{T}_w)C_{21} = 0 \qquad (3.4.12)$$

Arranging these equations yields the following matrix equation:

$$\begin{bmatrix} -(C_{20} + C_{19}) & C_{19} \\ C_{19} & -(C_{19} + C_{21}) \end{bmatrix} \begin{bmatrix} \bar{T}_1 \\ \bar{T}_w \end{bmatrix} = \begin{bmatrix} -\bar{T}_a C_{20} - \bar{S}_F \\ -\bar{T}_r C_{21} - \bar{S}_w \end{bmatrix} \qquad (3.4.13)$$

Solving for T_w yields:

$$\bar{T}_w = \frac{\bar{S}_w + C_{22}\bar{S}_F + C_A\bar{T}_a + C_B\bar{T}_r}{(C_A + C_B)} \qquad (3.4.14)$$

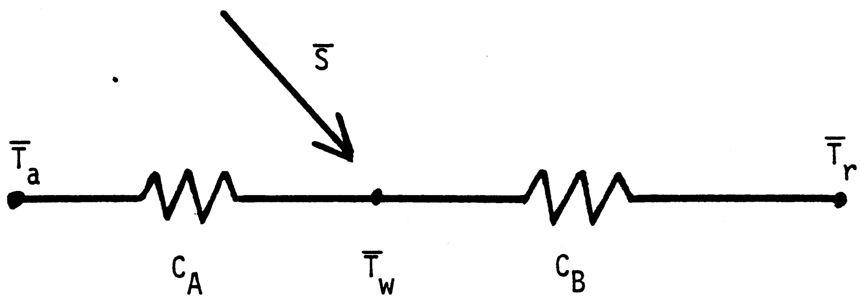
where:

$$C_A = (C_{20} \times C_{19})/(C_{20} + 19) \qquad (3.4.15)$$

$$C_B = \frac{C_{21} \times C_{20} + C_{21} \times C_{19}}{C_{20} + C_{19}} \qquad (3.4.16)$$

$$C_{22} = \frac{C_{19}}{C_{20} + C_{19}} \qquad (3.4.17)$$

For the final version of the sunspace thermal network, shown on Figure 3.7, the combined absorbed solar radiation, $\bar{S}$, is defined as



Monthly-Average Energy Balance:

$$(\overline{T}_a - \overline{T}_w)C_A + \overline{S} = C_B(\overline{T}_w - \overline{T}_r)$$

Figure 3.7. Simplified sunspace thermal network (2).

$$\bar{S} = \bar{S}_w + C_{22} * \bar{S}_F \tag{3.4.18}$$

With the monthly average inside wall surface temperature, $\bar{T}_w$, defined in Equation (3.4.14), the sunspace monthly energy delivery may be calculated from Equation (3.4.19):

$$Q_{IN} = C_B(\bar{T}_w - T_r) \tag{3.4.19}$$

Night Insulation

Night insulation can improve a sunspace system performance and it is possible in the design method described above to include it.

C_5' combines the radiative, convective and conductive conductances for the glazing of the sunspace. A time-weighted average conductive conductance is defined as:

$$C = C_G f_{day} + (1 - f_{day})C_{night} \tag{3.4.20}$$

where: C_G is the thermal conductance of the glazings without night insulation,

C_{night} is the thermal conductance of the glazings including night insulation,

and f_{day} is the fraction of the day between sunrise and sunset for the average day of the month.

Results from this monthly average calculation for Q_{IN} are compared to TRNSYS simulation results in Figure 3.8.

This comparison was done over a range of geometrical and thermal characteristics for the sunspace listed in Table 3.3, using four different locations (Madison, WI; Columbia, MO; Albuquerque, NM; Seattle, WA). The Root Mean Square Error is defined as:

$$RMS = \sqrt{\frac{\sum_{j=1}^{n} (Q_{DESIGN} - Q_{TRNSYS})^2}{n}} \qquad (3.4.21)$$

For the comparison of monthly energy delivery, the RMS error is 0.284 GJ over a range for Q_{IN} from -1 GJ to 7 GJ. Figure 3.9 gives the comparison of annual values for Q_{IN}. The annual RMS error is 2.74 GJ on a scale from 10 to 100 GJ. This monthly calculation for Q_{IN} is in good agreement with TRNSYS simulation results over a wide range of values of parameters: night insulation, number of glazings, area of the sunspace, different type of walls. A more complete study can be done to explore the combined effect of specific parameters on the RMS error for Q_{IN} between the monthly calculation and TRNSYS results, and thus on the ability of the design method to replicate TRNSYS results.

Effect of Geometrical Parameters and Thermal Characteristics

Four groups of parameters, listed in Table 3.3, are selected in this study. To evaluate their effects on the Root Mean Square (RMS)

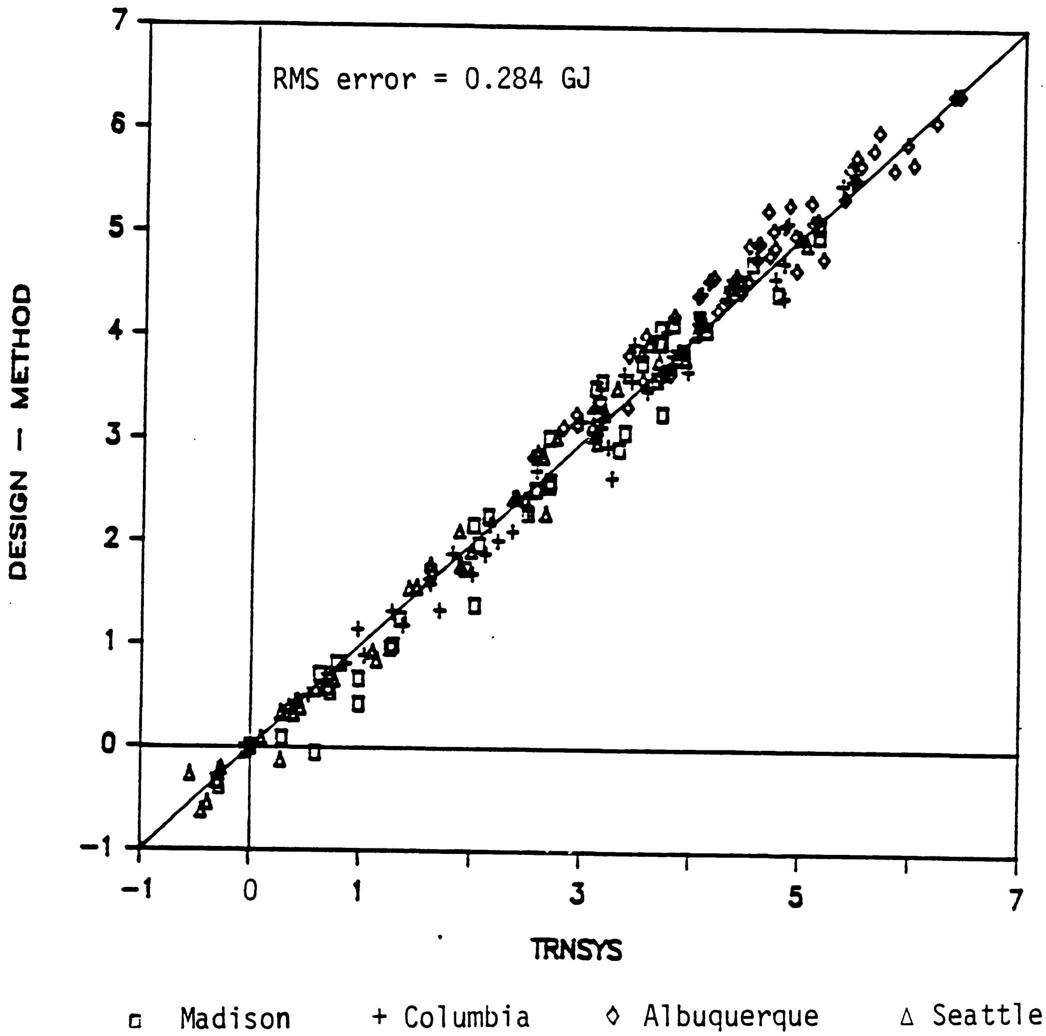


Figure 3.8. Comparison of Monthly Fnc.'gy Delivery from the sunspace between TRNSYS and the Design Method (GJ).

Table 3.3. Range of Geometrical Parameters and Thermal Characteristics for the Sunspace Energy Delivery Study

	Symbols		Bounds	
			Lower	Upper
1.	RINS	Glazing night insulation	0	0.44
2.	NCOV	Number of glazing layers	1	3
3.	KW	Conductivity of the wall	0.03 W/m°C	2.22 W/m°C
	THW	Thickness of the wall	0.1 m	0.5 m
	RH1	ρC_p of the wall (for TRNSYS only)	250 KJ/m^3-°C	4000 KJ/m^3-°C
4.	XLN	Width of the sunspace	3.5 m	15.75 m
	VER	Height of the lower glazing	2.163 m	0.43 m
	WD	Length of the sunspace	1 m	4 m

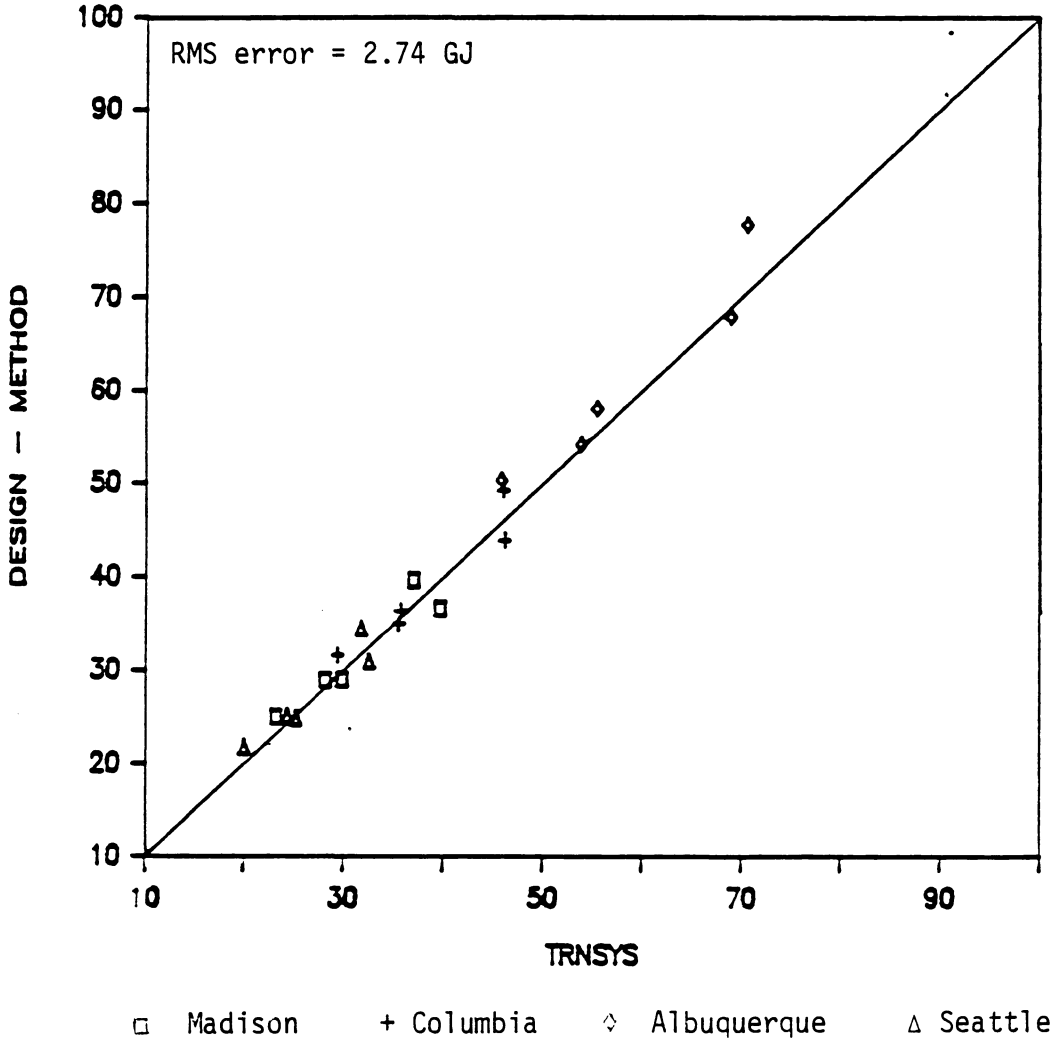


Figure 3.9. Comparison of Annual Energy Delivery from the sunspace between TRNSYS and the Design-Method (GJ).

error between Q_{IN} calculated from TRNSYS and the design method, a factorial design method is undertaken. Details about factorial designs are found in Reference (20).

These parameters are assigned the upper and lower bounds shown in Table 3.3 and sixteen TRNSYS simulations as well as sixteen runs for the design method are performed for Madison, WI. For these two sets of sixteen runs the monthly RMS error is calculated. In order to evaluate the significance of these RMS errors, each monthly RMS error is divided by the highest monthly TRNSYS value for Q_{IN} (see Table 3.4). Then using the Yate's algorithm (20), information about the average effect from a single coefficient and from the interaction of several coefficients are obtained (last column in Table 3.4).

The result of this study shows that the second coefficient, NCOV, the number of glazing layers, has the most significant effect on the RMS error, although its actual effect is small. No coefficient seems to interact either with another one.

In conclusion, the monthly calculation for Q_{IN} has a close agreement with TRNSYS results. The combination of the two components for the absorbed solar radiation on the floor and the wall into a single term, is consequently a valid assumption and, as shown in Section 3.5, will be fundamental to the development of the unutilizability method.

Table 3.4. Results of the Factorial Design Study

Identification	Monthly RMS (GJ)	Input to the Yate's Algorithm Monthly RMS/(Q_{IN})	Output from the Yate's Algorithm Effects
Average	0.0218	0.109	0.087
1	0.0194	0.073	-0.014
2	0.0205	0.079	-0.037
12	0.0247	0.078	0.027
3	0.0856	0.064	-0.029
13	0.1548	0.097	0.027
23	0.0789	0.064	0.028
123	0.1034	0.076	-0.021
4	0.3831	0.249	0.014
14	0.2227	0.107	-0.015
24	0.1083	0.052	-0.026
124	0.1710	0.066	0.023
34	0.9222	0.082	-0.020
134	0.9019	0.065	0.007
234	0.6101	0.052	0.027
1234	1.0377	0.080	-0.007

3.5 The Unutilizability Design Method for Sunspaces

3.5.1 Theoretical Limits of Auxiliary Energy Use

Two theoretical limits for a sunspace system performance can be defined as the upper and lower bounds on auxiliary energy requirements. These limits are similar to those defined for direct gain and collector wall systems (21,22).

An infinite thermal capacity house defines the lower bound and a zero thermal capacity house defines the upper bound for the auxiliary energy. The auxiliary energy consumed by a real building lies between these two limits.

Infinite House Thermal Capacity

The monthly auxiliary energy requirement for an infinite house thermal capacity is defined as the difference between the monthly load and the monthly solar gain from the sunspace:

$$Q_{aux,i} = [L - Q_S]^+ \qquad (3.5.1)$$

The load, L, is defined as:

$$L = L_a + L_w \qquad (3.5.2)$$

where L_a is the load of the non-solar part of the house. This load may be determined by the UA degree-days method (1):

$$L_a = (UA)_{ns}(DD)_b \tag{3.5.3}$$

where $(UA)_{ns}$ is the loss coefficient of the building not including the sunspace losses and $(DD)_b$ is the monthly degree-days for a building base temperature. The base temperature takes into account internal generation due to occupants, appliances, and other energy gains, but not the solar gains from the sunspace:

$$T_b = T_{low} - \frac{\dot{g}}{(UA)_{ns}} \tag{3.5.4}$$

where T_{low} is the low set point temperature and $\dot{g}$ is the monthly internal gain.

L_w is the heating load of the sunspace using the notation from the network in Figure 3.7:

$$L_w = [(C_A\ C_B)/(C_A + C_B)](DD) \tag{3.5.5}$$

Q_S is defined as the sum of Q_{IN} and L_w:

$$Q_S = Q_{IN} + L_w \tag{3.5.6}$$

where Q_{IN} is the net sunspace energy delivery. The calculation of Q_{IN} is discussed in Section 3.4. Finally,

$$Q_{aux,i} = [(L_a + L_w) - (Q_{IN} + L_w)]^+ \tag{3.5.7}$$

$$Q_{aux,i} = [L_a - Q_{IN}]^+ \quad (3.5.8)$$

The building with infinite thermal capacity absorbs and stores any solar gain exceeding the instantaneous load and makes it available later when needed. No month-to-month carryover of stored energy is allowed.

Zero House Thermal Capacity

The second limit is the upper bound for the consumption of auxiliary energy.

In a zero house thermal capacity any solar gain exceeding the instantaneous load cannot be stored and must be dumped in order to keep a constant room temperature. This is shown on Figure 3.10. The energy balance for Q_{aux} is:

$$Q_{aux,z} = [L - (Q_S - Q_{DUMP})]^+ \quad (3.5.9)$$

$(Q_S - Q_{DUMP})$ represents the useful solar gain and Q_{DUMP}, the amount of energy removed.

On Figure 3.11, the Monthly Energy Flows in an attached-sunspace house are shown. For a zero house thermal capacitance the auxiliary energy is at its maximum while the infinite house thermal capacitance minimizes the auxiliary energy by using the energy stored.

On Figure 3.12, the comparison for Columbia, MO, for Q_{aux} between an infinite and zero house thermal capacitance is shown. These results are obtained from TRNSYS simulations. These simulations were

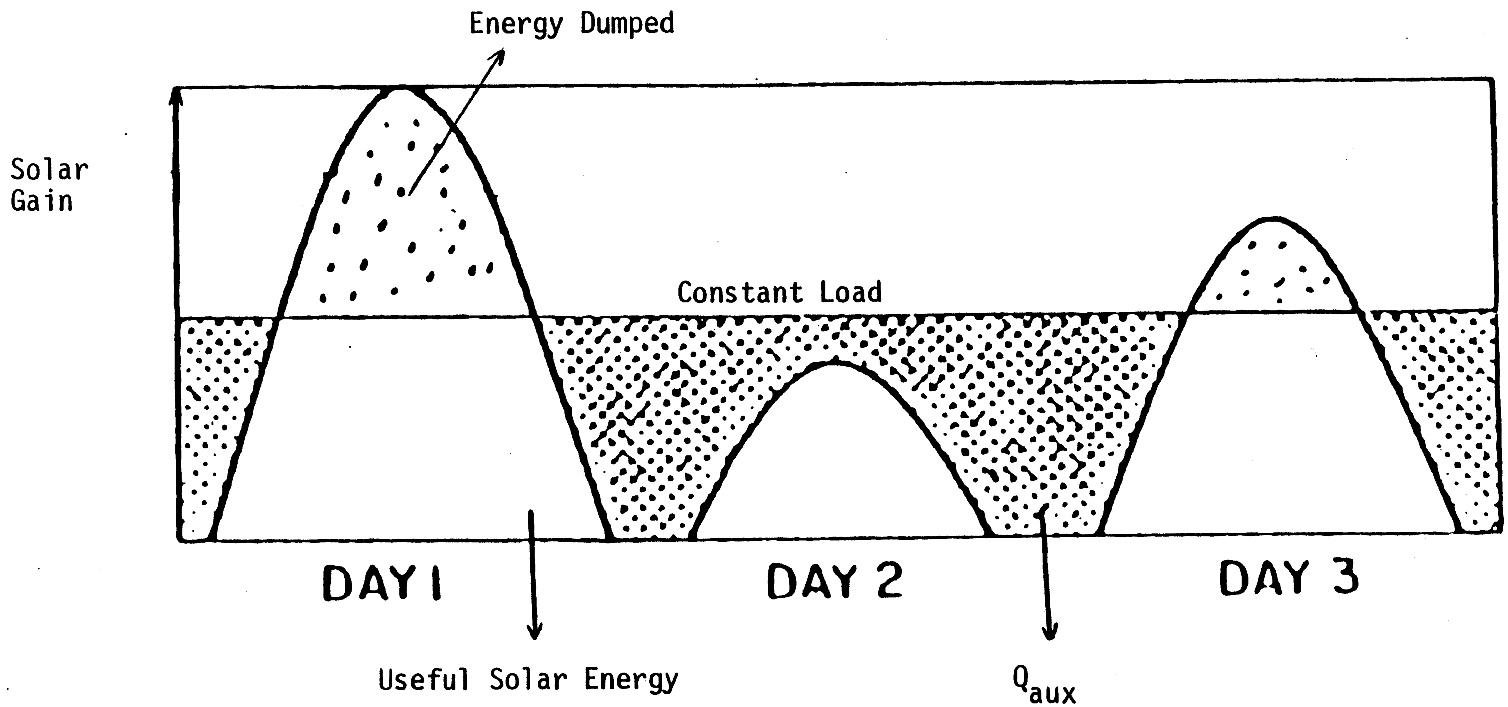
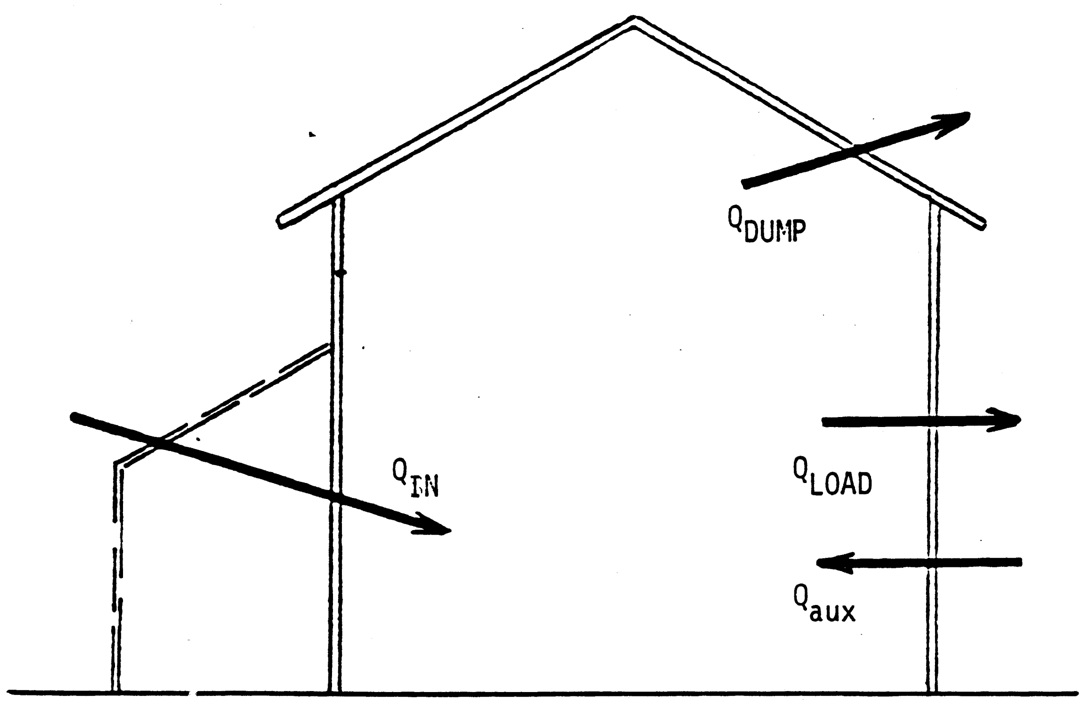


Figure 3.10. Energy flows in a zero thermal storage capacity house.



$$Q_{LOAD} = L_a + L_w$$

Figure 3.11. Monthly energy flows in an attached sunspace house.

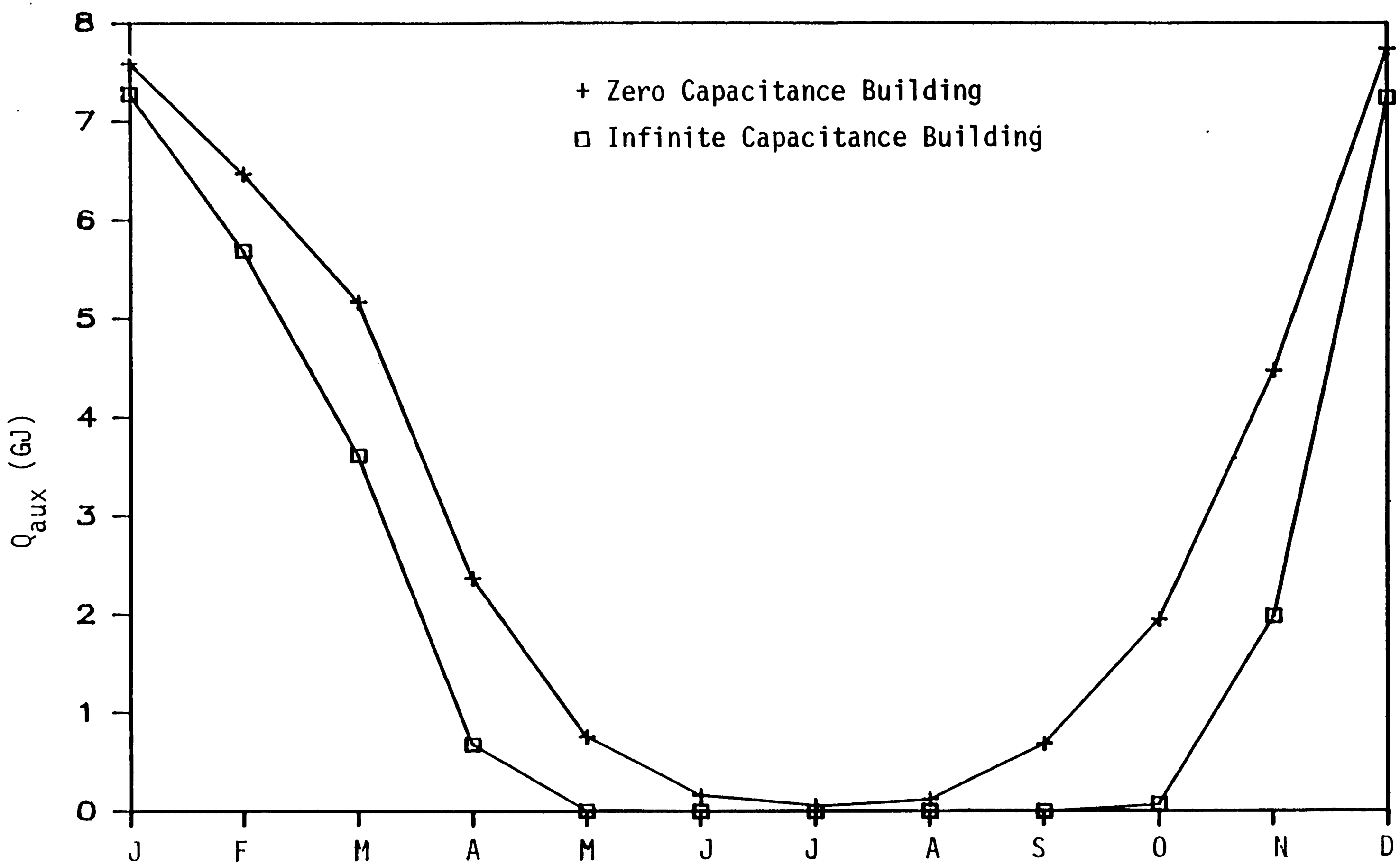


Figure 3.12. Effect of the building capacitance on monthly auxiliary energy requirement for Columbia, MO, for a building with UA = 158 W/°C.

done using the geometry for the sunspace given in Figure 2.3 and the thermal specifications given in Table 2.4. The UA value for the building is 158 W/°C. A real house with a finite thermal capacitance will lie between the two lines shown on Figure 3.12. In winter the difference between the two cases is rather small, as there is not much solar gain above the loads that is available for storage. In summer the load is so small that nearly no auxiliary energy is needed. The thermal capacitance of a house has its biggest effect on the auxiliary energy in spring and fall. The TRNSYS simulation for the zero thermal capacitance house was performed by using Mode 1 in the building type (10). Mode 1 models a zero capacitance structure maintained at a constant set temperature for heating. The auxiliary energy is defined:

$$Q_{aux,z} = UA\ (T_r - T_a) - Q_{gain} \qquad (3.5.10)$$

The TRNSYS simulation for the infinite thermal capacitance house was performed by using mode 3 for the building type. Mode 3 has a floating room temperature oscillating between the low and high set temperatures. This mode takes into account the effect of the capacitance of the building:

$$Q_{aux,i} = UA\ (T_r - T_a) - Q_{gain} + Cap\ (T_{rf} - T_{r1})/\Delta t \qquad (3.5.11)$$

where T_{rf} is the temperature of the room at the end of the timestep,

T_{r1} is the temperature at the beginning of the timestep and Δt is the simulation timestep. The value used for the capacitance in the simulation is 10^9 J/C.

3.5.2 Determination of the Critical Radiation Level and the Energy Dumped for the Zero Capacitance Building

The critical radiation level defines a threshold above which any incident solar energy exceeds the heating load of the house. $\bar{\phi}$, the utilizability factor, defines for a zero capacitance building, this fraction of the total incident solar energy incident on the glazings at an intensity exceeding a specified critical radiation level.

The utilizability concept was first proposed by Whillier (23) to analyze flat-plate solar collector performance. In this case, only the fraction of the total solar input above the critical intensity is useful. The utilizability concept was applied to other systems. For Trombe wall and direct gain systems (14), the critical radiation level defines an upper limit on useful solar input rather than a lower limit. For these cases as well as for the sunspace system, $\bar{\phi}$ represents a non-useful energy fraction which explains the term unutilizability. The amount of energy above this critical radiation level if not stored has to be dumped in order to keep a constant room temperature level. The energy dumped at any time is defined using the notation from Figure 3.7:

$$Q_{DUMP} = [C_B(T_w - T_r) - (UA)_{ns} (T_r - T_a)]^+ \qquad (3.5.12)$$

where T_w is the temperature of the wall inside the sunspace, T_r is the room temperature and T_a is the ambient temperature.

An instantaneous energy balance on the wall yields:

$$S = C_A(T_w - T_a) + C_B(T_w - T_r) \qquad (3.5.13)$$

where S is the absorbed solar energy and is defined as:

$$S = (\tau\alpha)G_T A_G \qquad (3.5.14)$$

and

$$G_T A_G = (G_{T1}A_{g1} + G_{T2}A_{g2}) \qquad (3.5.15)$$

where G_{T1} is the instantaneous solar radiation incident on the upper glazing, G_{T2} is the instantaneous solar radiation incident on the lower glazing, A_{g1} is the area of the upper glazing and A_{g2} is the area of the lower glazing. $(\tau\alpha)$ is the transmittance-absorptance product.

Equation (3.5.13) can be solved for T_W:

$$T_w = (A_G G_T(\tau\alpha) + C_B T_r + C_A T_a)/(C_A + C_B) \qquad (3.5.16)$$

Replacing T_W in Equation (3.5.12):

$$Q_{DUMP} = [C_B(\frac{A_G G_T(\tau\alpha) + C_B T_r + C_A T_a}{C_A + C_B} - T_r) - (UA)_{ns}(T_r - T_a)]^+ \qquad (3.5.17)$$

G_c, the critical radiation, is obtained when Q_{DUMP} of Equation (3.5.17) is exactly zero:

$$G_c = \frac{T_r - T_a}{(\tau\alpha)A_G}\left((UA)_{ns}\left(1 + \frac{C_A}{C_B}\right) + C_A\right) \qquad (3.5.18)$$

Integrating Q_{DUMP} from Equation (3.5.17) over the month:

$$Q_{DUMP} = \left(\frac{C_B}{C_A + C_B}\right) A_G(\overline{\tau\alpha}) \int_{month} (G_T - G_c)^+ \, dt \qquad (3.5.19)$$

where the monthly average $(\overline{\tau\alpha})$ defined as:

$$(\overline{\tau\alpha}) = \frac{A_W\overline{S}}{A_G\overline{G_T}} \qquad (3.5.20)$$

replaces the instantaneous transmittance-absorptance product.

Equation (3.5.19) can be expressed in terms of the monthly-average daily utilizability $\overline{\phi}$.

Klein (24) and Collares-Pereira and Rabl (25) extended Whillier's work to a monthly-average daily utilizability. Recently Clark (26) developed a different approach with hourly utilizability. He directly correlated values of ϕ obtained from many years of hourly horizontal radiation data, rather than integrating a probability distribution. This method is more accurate. As shown on Figure 3.10, the monthly-average daily utilizability, $\overline{\phi}$, is defined as:

$$\bar{\phi} = \frac{\int_{month} (G_T - G_c)^+ \, dt}{\int_{month} G_T \, dt} \qquad (3.5.21)$$

ϕ is a function of the monthly horizontal radiation, critical radiation level (constant over a month), latitude and surface orientation. In Reference (26), analytical expressions for $\bar{\phi}$ can be found.

In the case of sunspaces, the definition of a critical radiation level seems to be rather complex as there are two surfaces on which the solar radiation is absorbed: the floor and the wall. Problems of dealing with absorbed radiation on two surfaces and consequently with two critical radiation levels, can be solved by combining the absorbed radiation on the wall and the floor in a single term. $\bar{S}$, is defined, in Equation (3.4.18), as a combination of the absorbed radiation on the wall and the floor and simultaneously accounts for the distribution of horizontal and vertical solar radiation. This function, $\bar{S}$, allows the definition of the critical radiation level in a simple manner. $(\overline{\tau\alpha})$, the monthly-average transmittance-absorptance product, which appears in Equation (3.5.18), is defined as the ratio of the combined absorbed solar radiation on the wall and the floor to the incident radiation on the glazing (Equation 3.5.20). With this single critical radiation level, it is possible to calculate the monthly average utilizability assuming a slope of 90° (slope where $\bar{S}$ is defined).

Replacing in the expression of Q_{DUMP}:

$$Q_{DUMP} = \left(\frac{C_B}{C_A + C_B}\right) A_G(\overline{\tau\alpha})\ \overline{\phi}\ \overline{G}_T N \qquad (3.5.22)$$

Thus substituting Q_{DUMP} in Equation (3.5.9) $Q_{aux,z}$ is:

$$Q_{aux,z} = \left(L - Q_s + \left(\frac{C_B}{C_A + C_B}\right) A_G(\overline{\tau\alpha})\ \overline{\phi}\ \overline{G}_T N\right)^+ \qquad (3.5.23)$$

3.5.3 Prediction of Auxiliary Heating Requirements for Finite Thermal Capacity Buildings

The auxiliary energy used in a real house lies between the two limits described above. For these limits a dimensionless solar fraction can be defined using the ratio of the auxiliary energy to the building load. The upper limit for this solar fraction is:

$$F_i = 1 - \frac{Q_{aux,i}}{L_a + L_w} \qquad (3.5.24)$$

and the lower limit is defined as:

$$F_z = 1 - \frac{Q_{aux,z}}{L_a + L_w} = F_i - \frac{Q_{DUMP}}{L_a + L_w} \qquad (3.5.25)$$

For a finite thermal capacity house, the solar fraction falls between these two limits depending on its storage capacity. A dimensionless storage-dump ratio Y can be defined as:

$$Y = \frac{S_b + 0.047\ S_w}{Q_{DUMP}} \tag{3.5.26}$$

where: S_b is the building thermal storage capacity,

S_w is the storage capacity of the wall,

0.047 is an empirical constant to take into account that the wall thermal storage capacity is less effective than the house thermal storage capacity,

Q_{DUMP} is the energy dumped in a building having a zero capacity storage.

S_b is defined as:

$$S_b = C_b\ (\Delta T)\ N \tag{3.5.27}$$

where C_b is the effective building storage capacitance, ΔT is the allowable indoor temperature swing and N is the number of days in a month.

$$S_w = \rho C_p t A_w (\Delta T_w) N \tag{3.5.28}$$

where ρC_p is the density-specific heat product of the wall, t is the wall thicknesses and (ΔT_w) is the monthly-average temperature difference between the center of the wall and the inside wall surface. Since the monthly-average temperature profile in the common wall is linear, as shown in Section 3.2, (ΔT_w) is one half of the temperature difference between the outside and inside wall surfaces.

The monthly-average energy flow through the wall, Q_{IN}, can be expressed as:

$$Q_{IN} = \frac{kA_w}{t} 2(\Delta T_w)\Delta t \ N \tag{3.5.29}$$

where Δt is the number of hours in a day and from this equation:

$$(\Delta T_w) = \frac{tQ_{IN}}{2kA_w N} \tag{3.5.30}$$

Then, substituting (ΔT_w) in Equation (3.5.28):

$$S_w = \frac{\rho C_p t^2}{2k\Delta t} Q_{IN} \tag{3.5.31}$$

The two same limits, infinite and zero thermal capacitance, were defined for the Trombe wall (14). A sunspace to a certain extent can be compared to a collector-storage wall. For both systems, solar radiation is collected on the glazing and then transmitted to the heating space by conduction through a wall. The only difference is that for a collector-storage wall, there is one vertical glazing and an air gap of about 10 cm between the glazing and the wall. For a sunspace the distance between the wall and the glazings is much wider and allows to use it as a living space. Treating solar energy delivery to a building from a Trombe wall differently than from a sunspace seems somewhat meaningless. Solar energy delivered by a Trombe wall or by a sunspace should have exactly the same effect on the auxiliary energy needed by a house. Based on this statement, comes the idea of using for the sunspace, the same equation developed for the Trombe wall to correlate F, the solar fraction to the same two dimensionless parameters. A correlation was developed, by Monsen, to calculate F the solar fraction as a function of dimensionless parameters, F_i and Y, for Trombe wall systems (14). It is represented graphically in Figure 3.13, and analytically by Equation (3.5.32).

$$F = \min[(PF_i + 0.88\,(1 - P)(1 - e^{-1.26F_i})),1.0] \quad (3.5.32)$$

where

$$P = (1 - e^{-0.144Y})^{0.53} \quad (3.5.33)$$

This relation for F has been developed from a nonlinear regression analysis of 75 years of hour by hour simulations of collector-storage wall buildings using TRNSYS simulations (22).

Thus, using the correlation defined in Equation (3.5.32), the solar fraction for a finite capacitance building with a sunspace can be evaluated. The auxiliary energy can then be calculated.

The storage capacitance of the floor is assumed to be negligible as shown in Section 3.2 and only the storage capacitance of the wall is considered. The accuracy of such calculation has now to be checked.

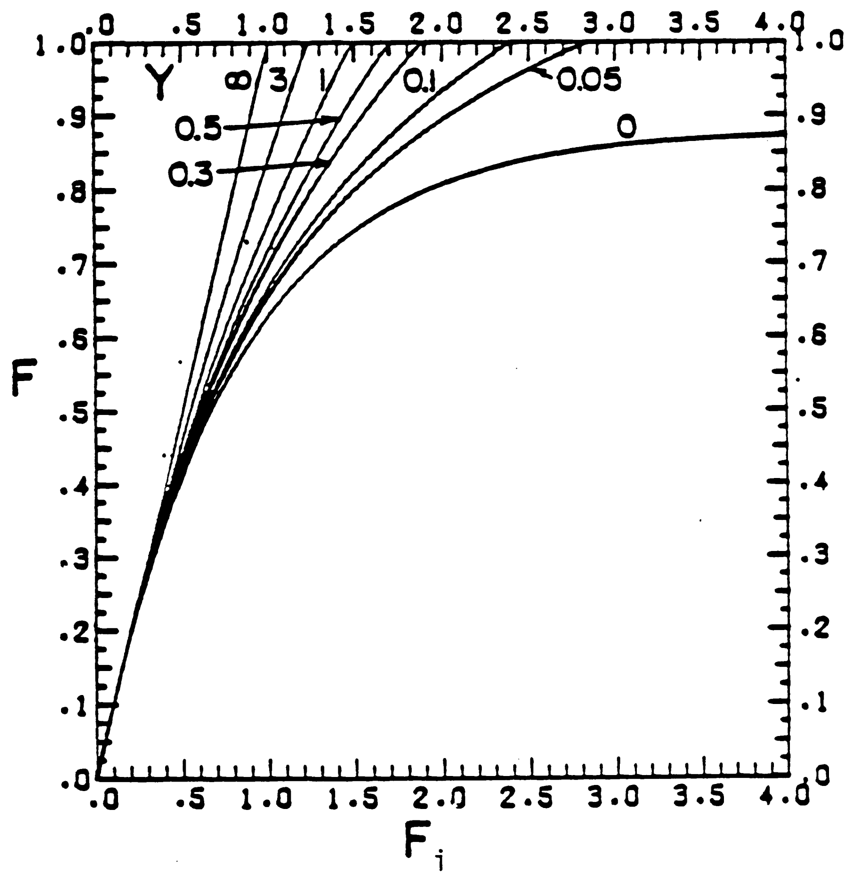


Figure 3.13. Unutilizability correlation for F in terms of F_i and Y, the storage-dump ratio (22).

3.6 Comparisons of Results from the Unutilizability Method and TRNSYS

Comparisons of monthly and annual auxiliary energy with TRNSYS results are shown on Figures 3.14 and 3.15. The RMS error between TRNSYS and the Unutilizability method on a yearly basis is 3.4 GJ on a scale from 0 to 160 GJ.

These comparisons were done over a range of parameters listed in Table 3.5. This good agreement between TRNSYS and the design-method proves that the correlation developed by Monsen to calculate the solar fraction of a house with a collector-storage wall can be used for a sunspace system. Solar energy delivered to a building from a collector-storage wall or from a sunspace has the same effect on the auxiliary needed by a house. (In Appendix A are the degree-days for 26 cities with different base temperatures.)

3.7 Example of the Unutilizability Design Method for Sunspaces

The same house and sunspace described for Figure 3.9 will be analyzed for the month of March with the climate of Madison, WI. The sunspace characteristics are given in Table 3.6.

First, Q_{IN}, the net monthly energy gain to the building from the sunspace, has to be calculated using the Equation (3.4.19):

$$Q_{IN} = (\bar{T}_w - \bar{T}_r)N \times 24 \times C_B = (27.086 - 18.33)31 \times 303.51 \times 24$$

$$Q_{IN} = 1.977 \text{ GJ}$$

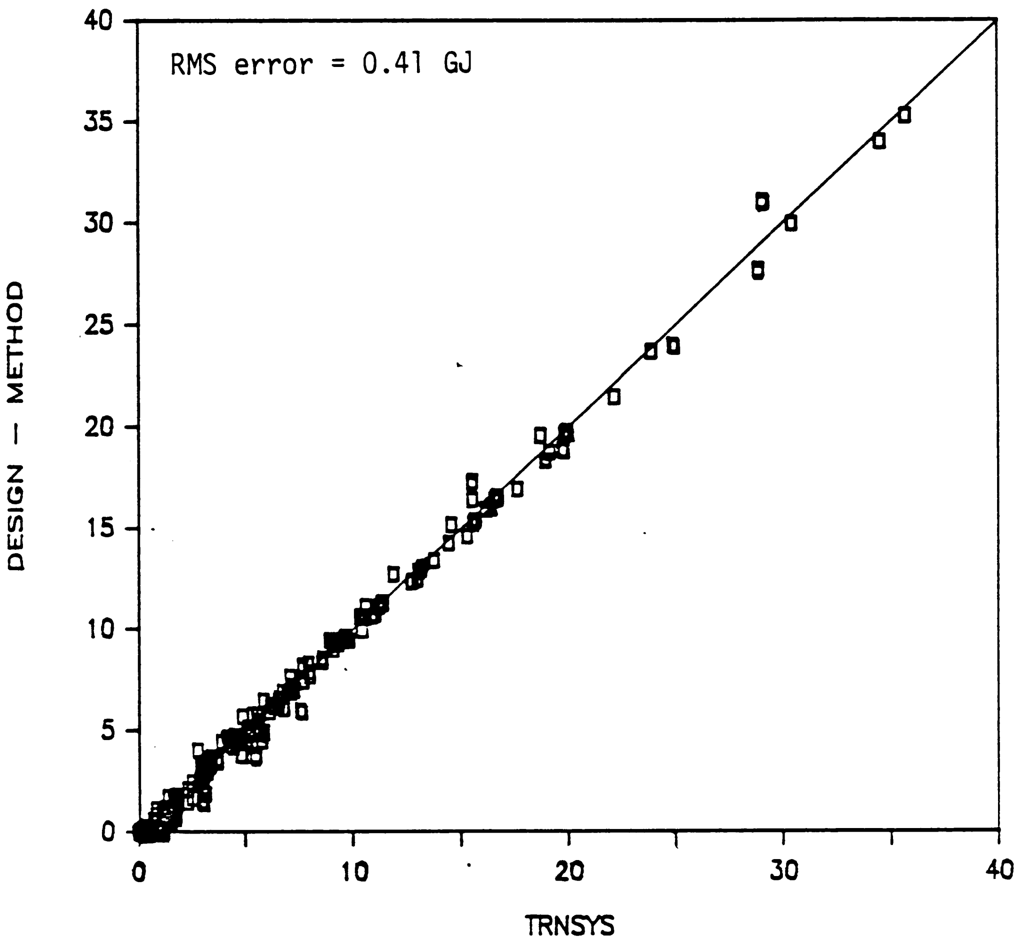


Figure 3.14. Comparison of Monthly Auxiliary Energy between TRNSYS and the Design Method (GJ) covering the range of parameters given in Table 3.5.

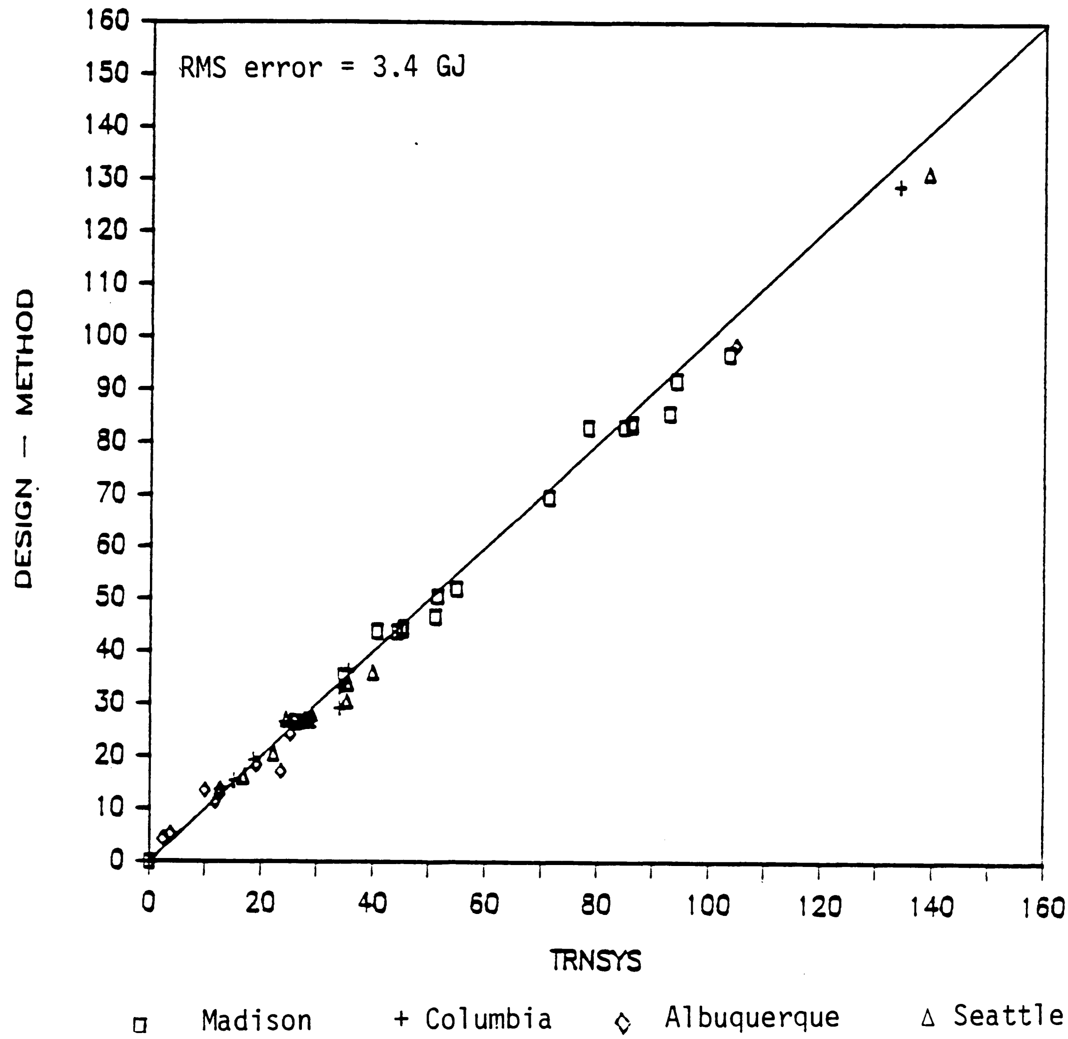


Figure 3.15. Comparison of Annual Auxiliary Energy between TRNSYS and the Design Method (GJ) covering the range of parameters given in Table 3.5.

Table 3.5. Range of Sunspace Parameters Examined for the Auxiliary Energy Study

- Locations:	Madison, WI
	Albuquerque, NM
	Columbia, MO
	Seattle, WA
- (UA):	100-600 W/°C
- Sunspace Glazing Area:	11.6-79.5 m^2
- House Thermal Capacitance:	10^6 J/°C - 10^9 J/°C
- (ρC_p) Wall:	250-4000 KJ/m^3-°C
- Low Set Point Temperature:	17-21°C
- Room Temperature Swing:	5-10°C

Table 3.6. Parameters for Sunspace Unutilizability Design Method Example

- Location:	Madison, WI
Degree Days for March:	616°C days
Monthly Average Ambient Temperature:	$\bar{T}_a$ = -1.86°C
$\bar{H}$:	13,760 KJ/m^2
- Monthly Average Wall Temperature:	$\bar{T}_w$ = 27.09°C
Total Area of the Sunspace Glazing:	A_G = 33.35 m^2
Thickness of the Wall:	THW = 0.305 m
ρC_p of the Wall:	2009 KJ/m^3-°C
Conductivity of the Wall:	k = 1.73 W/m°C
C_A = 266.97 KJ/hr°C	
C_B = 303.51 KJ/hr°C	
Solar Radiation Absorbed by the Wall and the Floor:	$A_w\bar{S}$ = 7.73 GJ
Solar Radiation Incident on the Glazings:	$A_G\bar{G}_T$ = 15.74 GJ
- Monthly-Average Room Temperature (low set point temperature)	$\bar{T}_r$ = 18.33°C
UA:	158 W/°C
Allowable Room Temperature Swing:	5.5°C
Capacitance of the House:	C_b = 25,000 KJ/°C

Then, L_w, the monthly-average load through the sunspace, is found from Equation (3.5.5):

$$L_w = \frac{266.97 \times 303.51 \times 616 \times 24}{(266.97 + 303.51)} = 2.09 \text{ GJ}$$

Thus, Q_s, the solar gain from the sunspace, is equal to $Q_{IN} + L_w$ or 4.07 GJ.

The monthly load of the non-solar part of the building, L_a, is equal to, from Equation (3.5.3):

$$L_a = 568.8 \times 616 \times 24 = 8.41 \text{ GJ}$$

The total load is:

$$L = L_a + L_w = 10.50 \text{ GJ}$$

In order to determine F, the solar fraction, the parameters, F_i and Y, have to be calculated. F_i is defined from Equation (3.5.24), and $Q_{aux,i}$ from Equation (3.5.8):

$$Q_{aux,i} = 10.50 - 4.07 = 6.43 \text{ GJ}$$

$$F_i = 1 - \frac{6.43}{10.50} = 0.39$$

Y is defined from Equation (3.5.26).

S_b, the thermal storage in the house from Equation (3.5.27):

$$S_b = 25{,}000(5.5)31 = 4.262 \text{ GJ}$$

and S_w, the monthly storage in the wall from Equation (3.5.31):

$$S_w = \frac{2009(0.305)^2}{2 \times 6.23 \times 24} \times 1.977 = 1.235 \text{ GJ}$$

To determine $\overline{\Phi}$, the critical radiation level, G_c, is needed. $(\overline{\tau\alpha})$ from Equation (3.5.20) is equal to:

$$(\overline{\tau\alpha}) = \frac{A_w S}{A_G \overline{G}_T} = \frac{7.73 \text{ GJ}}{15.74 \text{ GJ}} = 0.491$$

and G_c from Equation (3.5.18):

$$G_c = \frac{18.33 - (-1.86)}{33.35 \times 0.491}\left(568.8\left(1 + \frac{266.97}{303.51}\right) + 266.97\right) = 457.72 \text{ W/m}^2$$

Using the value of $\overline{H} = 13{,}760$ KJ/m^2, an orientation of 90° and this critical radiation level of 457.72 W/m^2, $\overline{\Phi}$ is 0.185.

Therefore, Q_{DUMP} from Equation (3.5.22) is:

$$Q_{DUMP} = \left(\frac{303.51}{303.51 + 266.97}\right) \times 0.185 \times 15.736 \times 10^6 \times 0.491$$

$$Q_{DUMP} = 0.76 \text{ GJ}$$

Then Y from Equation (3.5.26) is:

$$Y = \frac{4.262 + 0.047 \times 1.235}{0.76} = 5.684$$

Thus from Equation (3.5.33):

$$P = \left(1 - e^{-0.144 \times 5.684}\right)^{0.53} = 0.735$$

and F from Equation (3.5.32) is 0.375. Finally, Q_{aux}, for March is:

$$Q_{aux} = L(1 - F) = 10.50(1 - 0.375) = 6.56 \text{ GJ}$$

For a zero capacitance building, Q_{aux} is from Equation (3.5.9):

$$Q_{aux,i} = [L - (Q_S - Q_{DUMP})]^+ = 10.50 - (4.07 - 0.76) = 7.19 \text{ GJ}$$

For an infinite capacitance building, Q_{aux} is from Equation (3.5.1):

$$Q_{aux,i} = [L - Q_s] = 10.50 - 4.07 = 6.43 \text{ GJ} .$$

The value for Q_{aux} for a finite capacitance building is 6.56 GJ which is found to lie between the two limits: infinite and zero capacitance building.

As discussed in Section 2.2.5, the net effect of a sunspace on the building auxiliary energy can be evaluated. For the same house described in the example, it is interesting to calculate what would have been the load without the sunspace. Assuming a value for UA of 174 W/°C instead of 158 W/°C for the house without the sunspace accounting for the losses on the south wall, the load, L, is equal to:

$$L = (174 \times 616 \times 24)3.6 = 9.26 \text{ GJ}$$

As there is no solar gain from a sunspace, Q_{aux} is:

$$Q_{aux} = L = 9.26 \text{ GJ}$$

The net effect of the sunspace is the difference of the energy auxiliary for a house with and without a sunspace which is 2.76 GJ:

$$9.26 - 6.56 = 2.70 \text{ GJ} .$$

The configuration of the sunspace given in Table 3.6 being the same as the sunspace reference type B_3 (from the SLR method), results from the two design method can be compared directly with TRNSYS simulation results for the whole year. These monthly results for Madison, WI are presented in Table 3.7.

Table 3.7. Performance of Sunspace in Madison, WI

Month	$\bar{\phi}$	Load (GJ)	Q_S (GJ)	Q_{aux} (GJ)	Q_{aux} TRNSYS (GJ)	Q_{aux} (SLR (GJ)
January	0.129	13.93	2.70	11.24	11.30	11.01
February	0.143	11.45	3.09	8.39	8.52	7.92
March	0.185	10.50	4.07	6.56	6.51	6.31
April	0.383	4.91	3.50	1.81	1.85	1.90
May	0.661	2.55	4.00	0.00	0.60	0.35
June	1.000	0.68	4.26	0.00	0.00	0.00
July	1.000	0.14	4.74	0.00	0.00	0.00
August	1.000	0.37	4.61	0.00	0.00	0.00
September	0.890	1.49	4.15	0.00	0.00	0.04
October	0.570	4.09	3.41	1.2	1.27	1.35
November	0.276	7.99	2.25	5.78	5.53	5.62
December	0.147	11.44	1.86	9.58	9.61	9.18
		69.44	42.64	44.56	45.19	43.68

3.8 Comparisons of Results from the Unutilizability Method and the SLR Method

Having compared the unutilizability method to TRNSYS, another comparison for the auxiliary energy requirement for sunspaces can be done with results from the SLR method. As described in Section 2.3, the SLR method is also a correlation method. It was developed for specific reference design systems with particular characteristics (given in Table 2.5). For the comparison done in this section, a type B sunspace was selected among the different reference designs. (See Figure 2.3 for its geometrical description). Table 3.8 gives the range of sunspace parameters examined for the comparison done on the auxiliary energy. The SLR method being developed for a precise set of characteristics, the complete range of parameters examined, in Tables 3.3 and 3.5, for a similar comparison with TRNSYS results, was not covered. Restrictions are listed in Table 3.8.

Figure 3.16 shows this comparison of monthly auxiliary energy. The monthly RMS error is 0.29 GJ on a scale from 0 to 22 GJ. The annual RMS error is 1.67 GJ on a scale from 0 to 120 GJ. This shows a good agreement between the unutilizability method and the SLR method.

Table 3.8. Range of Sunspace Parameters Examined for the Auxiliary Energy Study Done with the SLR Method

1. Locations: Madison, WI
   Columbia, MO
   Seattle, WA
2. (UA) 158-300 W/°C
3. Night insulation: R = 1.58 m^2-°C/W

- No possibility to change the house thermal capacitance
- No possibility to change the number of glazing layers
- No possibility to change the (ρC_p) of the wall without changing all the characteristics of the wall
- No possibility to change the low set point temperature
- No possibility to change the room temperature swing

Comparison done with the fixed following parameters:

- ρC_p = 2009 KJ/m^3-°C
- Thickness of the wall = 0.305 cm
- Infiltration rate = 0.5 air change/hour
- Low set room temperature = 18.33°C
- Double glazing
- Allowable room temperature swing = 5.5°C
- Capacitance of the house = 25,000 KJ/°C

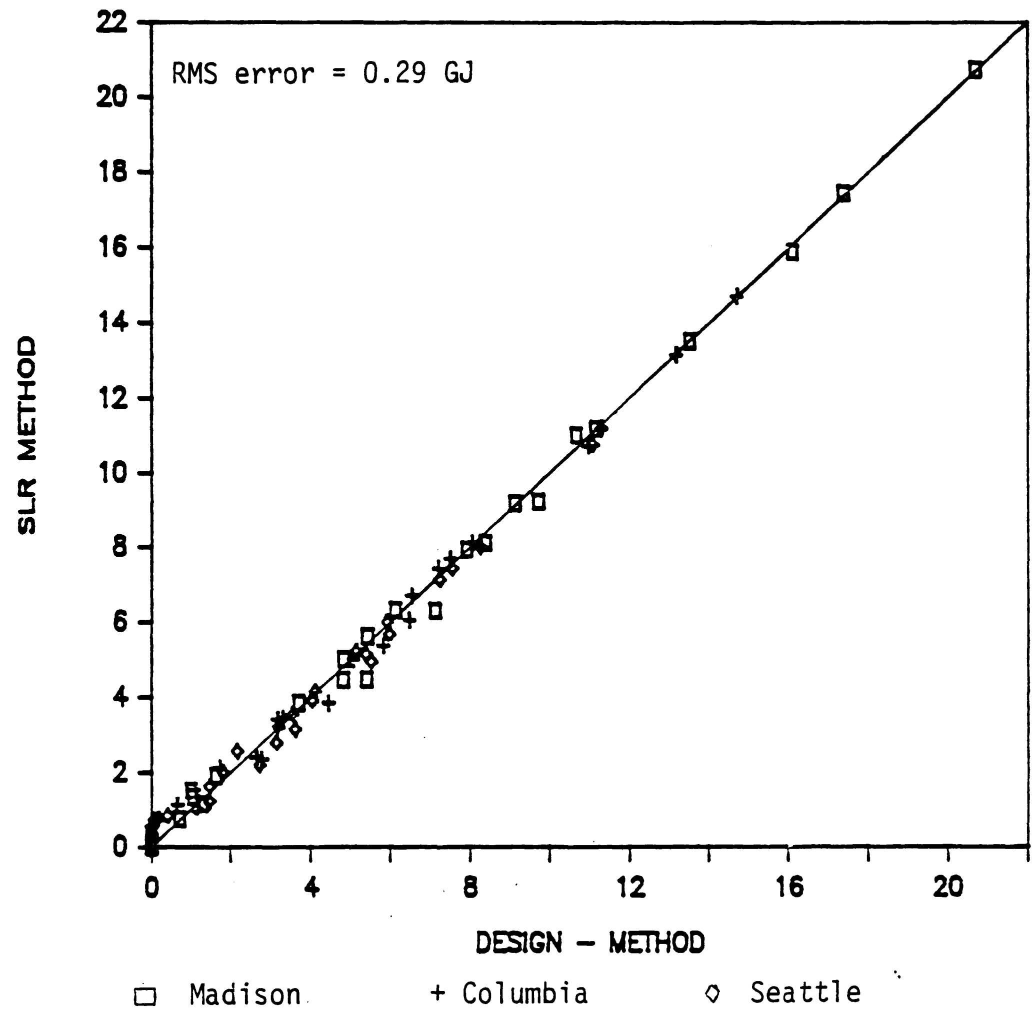


Figure 3.16. Comparison of Monthly Auxiliary Energy between the SLR Method and the Design Method (GJ).

CHAPTER 4: CONCLUSIONS, LIMITATIONS TO THE DESIGN METHOD AND FUTURE WORK

4.1 Conclusions

A design method for attached sunspace systems has been presented. This design method can be divided into two fundamental steps.

The first one is the prediction of Q_{IN}, the net monthly energy delivery from the sunspace, by an analytical method. This method, based on monthly average weather data was checked with TRNSYS simulation results. The second step evaluates the auxiliary energy needed by the building based on the unutilizability concept. This method is an extension of the unutilizability method of Monsen, which was developed for collector-storage walls. When applied to sunspaces it agrees with TRNSYS simulation results with an annual RMS error of 3.4 GJ on a scale from 0 to 160 GJ (Figure 3.15). As shown in Section 3 it also agrees with the SLR method results with an annual RMS error of 1.67 GJ on a scale from 0 to 120 GJ. The SLR method is another correlation method but it was developed for specific reference design systems with particular characteristics. Although the Solar Load Ratio method uses less computation, the unutilizability method for sunspaces is more general in the sense that it allows changes in the sunspace geometry, thermal characteristics such as the thermal mass of the common wall and the thermal capacitance of the house.

Its limitations are now discussed.

4.2 Limitations to the Utilizability Design Method for Sunspaces

One of the main limitations of this design method developed for the sunspace, is that the sunspace is assumed to face south (or north in the southern hemisphere). This is due to the calculation of the monthly average incident radiation. To account for a derivation of more than about 30° in the azimuth angle, γ, the angle of the solar beam radiation projected on the sunspace wall would have to be redefined. Variation of the azimuth angle from the south orientation is, however, possible in the correlation Clark developed for the utilizability, ϕ (26). Another limitation of the design method is that only one mode of heat transfer, the conduction, from the sunspace to the house is considered. Although ventilation of sunspaces was assumed to have a negligible effect (Section 3.2), it will improve the design method in its generality if done only during the day. (Ventilation of the sunspace at night will not improve its performance).

4.3 Future Work

One of the main drawbacks in this design method is that the possibility of an additional mass storage inside the sunspace is not included.

As shown on Figures 2.4a and 2.4b, temperatures in the sunspace fluctuates from 0°C to 30°C in winter. To help dampen such fluctuations, the sunspace should contain additional thermal mass. A sunspace with a masonry common wall, having daily fluctuations on the order of 25° to 40°C, might be reduced to 10°C to 20°C with appropriate mass storage (5). The design method presented in this study calculates the auxiliary heat requirement only. However, in summer, overheating in the sunspace is a problem. Passive cooling techniques such as ventilation of the sunspace to the ambient is one possibility. Additional thermal mass and ventilation to the house and to the ambient are the directions in which this design method would gain major improvements.

Further work could be done in combined active-passive systems. A proposed combination of active-passive system for a sunspace has an active rock bed storage system below the sunspace floor. Warm air is taken from the sunspace and blown to the rock bed with a fan. This energy stored in the rock bed will be released at a later time to the sunspace by natural convection. The investigation of such a system should be helpful to understand better the combination of active-passive systems.

APPENDIX A. SOLMET TMY MONTHLY AVERAGE METEOROLOGICAL DATA (19)

In order to use the design method presented in this thesis, monthly average weather data are needed. This appendix contains weather data for 26 cities.

For each city is given:

City and Latitude of Station

$\bar{H}$: Monthly average daily total radiation on the horizontal surface, (KJ/m^2-day).

$\bar{K}_T$: The monthly average clearness index, which is defined to be the monthly average total radiation on a horizontal surface divided by the monthly average extraterrestrial radiation on a horizontal surface.

T_a: The monthly average ambient temperature (°C).

V: The monthly average wind velocity (m/sec).

SC: The fraction of the month that there is snow cover (0 = no snow, 1 = snow for entire month).

DD: The heating degree-days at the base temperature specified (°C-days).

FORT WORTH, TX LATITUDE: 32.83

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	8842.35	.455	7.01	4.1	.00	558.	406.	262.	142.	59.	15.	2.	0.
FEB.	11997.21	.500	9.72	5.2	.03	428.	294.	177.	86.	26.	1.	0.	0.
MAR.	16619.19	.551	12.10	6.2	.02	401.	255.	138.	60.	21.	4.	0.	0.
APR.	17337.03	.483	17.71	5.0	.00	223.	98.	27.	4.	0.	0.	0.	0.
MAY	21202.03	.536	21.55	4.0	.00	130.	45.	9.	0.	0.	0.	0.	0.
JUN.	24721.83	.604	26.86	4.9	.00	27.	1.	0.	0.	0.	0.	0.	0.
JUL.	25149.48	.626	30.09	3.4	.00	5.	0.	0.	0.	0.	0.	0.	0.
AUG.	23203.84	.624	28.74	4.1	.00	12.	0.	0.	0.	0.	0.	0.	0.
SEP.	19188.57	.599	23.61	4.4	.00	90.	22.	1.	0.	0.	0.	0.	0.
OCT.	14439.39	.560	19.52	3.7	.00	183.	75.	23.	4.	0.	0.	0.	0.
NOV.	10834.73	.531	13.73	4.3	.00	340.	204.	99.	30.	1.	0.	0.	0.
DEC.	8644.39	.481	7.96	4.7	.00	528.	374.	227.	115.	40.	8.	0.	0.

LAKE CHARLES, LA LATITUDE: 30.22

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	8284.45	.395	10.82	3.5	.00	440.	289.	164.	67.	13.	0.	0.	0.
FEB.	11872.64	.468	12.72	3.8	.00	344.	211.	105.	39.	10.	0.	0.	0.
MAR.	14716.90	.473	16.11	3.8	.00	277.	142.	54.	10.	1.	0.	0.	0.
APR.	18038.93	.496	19.96	4.8	.00	155.	54.	12.	1.	0.	0.	0.	0.
MAY	21244.03	.537	23.57	3.5	.00	72.	9.	0.	0.	0.	0.	0.	0.
JUN.	22850.77	.561	26.45	3.5	.00	21.	0.	0.	0.	0.	0.	0.	0.
JUL.	20136.74	.503	27.48	2.9	.00	9.	0.	0.	0.	0.	0.	0.	0.
AUG.	17814.29	.476	26.95	2.2	.00	11.	0.	0.	0.	0.	0.	0.	0.
SEP.	16669.10	.508	25.12	3.0	.00	46.	7.	0.	0.	0.	0.	0.	0.
OCT.	14151.90	.524	19.77	3.0	.00	171.	63.	12.	0.	0.	0.	0.	0.
NOV.	10054.03	.459	16.52	3.6	.00	258.	139.	54.	12.	3.	0.	0.	0.
DEC.	8359.77	.428	10.96	3.8	.00	435.	283.	145.	53.	17.	5.	1.	0.

COLUMBIA, MO LATITUDE: 38.97

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	6929.97	.441	-.26	4.9	.14	783.	628.	479.	338.	213.	113.	48.	17.
FEB.	9179.25	.444	.32	4.6	.14	691.	551.	412.	279.	162.	71.	29.	13.
MAR.	13167.32	.477	4.79	5.1	.07	627.	473.	324.	188.	87.	29.	4.	0.
APR.	17630.07	.510	12.91	5.0	.02	366.	232.	123.	48.	11.	0.	0.	0.
MAY	22554.13	.573	18.68	3.9	.00	206.	92.	27.	6.	0.	0.	0.	0.
JUN.	22659.63	.549	22.80	3.9	.00	98.	26.	4.	0.	0.	0.	0.	0.
JUL.	23953.77	.595	24.96	3.3	.00	61.	11.	1.	0.	0.	0.	0.	0.
AUG.	21190.10	.585	24.12	3.5	.00	81.	21.	1.	0.	0.	0.	0.	0.
SEP.	16416.13	.549	19.01	3.4	.00	186.	81.	27.	5.	0.	0.	0.	0.
OCT.	12459.26	.549	13.37	3.6	.00	361.	214.	97.	33.	6.	0.	0.	0.
NOV.	8068.97	.480	7.31	5.0	.08	531.	384.	252.	142.	57.	8.	0.	0.
DEC.	5794.61	.407	.04	4.9	.17	774.	619.	465.	315.	180.	83.	26.	6.

APALACHICOLA, FL LATITUDE: 29.75

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	9799.23	.462	11.68	3.2	.00	413.	259.	129.	49.	12.	1.	0.	0.
FEB.	13423.71	.524	11.40	4.5	.00	381.	241.	118.	39.	7.	0.	0.	0.
MAR.	16546.94	.528	15.94	3.8	.00	281.	132.	38.	6.	0.	0.	0.	0.
APR.	22471.43	.616	20.56	3.4	.00	135.	33.	4.	0.	0.	0.	0.	0.
MAY	24227.03	.612	23.79	3.2	.00	69.	13.	0.	0.	0.	0.	0.	0.
JUN.	21744.30	.535	27.04	2.5	.00	11.	0.	0.	0.	0.	0.	0.	0.
JUL.	21288.16	.532	27.57	2.3	.00	6.	0.	0.	0.	0.	0.	0.	0.
AUG.	20254.00	.540	27.73	1.9	.00	6.	0.	0.	0.	0.	0.	0.	0.
SEP.	17668.53	.536	26.26	2.6	.00	21.	1.	0.	0.	0.	0.	0.	0.
OCT.	16382.16	.602	21.01	3.0	.00	140.	49.	8.	0.	0.	0.	0.	0.
NOV.	11883.13	.536	15.52	2.6	.00	286.	155.	69.	24.	4.	0.	0.	0.
DEC.	9451.87	.477	12.87	2.8	.00	376.	225.	100.	28.	3.	0.	0.	0.

MIAMI, FL LATITUDE: 25.78

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	11858.45	.504	20.00	4.0	.00	158.	60.	20.	4.	0.	0.	0.	0.
FEB.	15224.46	.552	20.64	3.8	.00	128.	46.	13.	2.	0.	0.	0.	0.
MAR.	18076.77	.553	22.53	4.3	.00	85.	10.	0.	0.	0.	0.	0.	0.
APR.	21586.03	.583	23.71	3.4	.00	59.	8.	1.	0.	0.	0.	0.	0.
MAY	20368.16	.517	25.38	3.2	.00	23.	1.	0.	0.	0.	0.	0.	0.
JUN.	19001.50	.473	26.89	4.0	.00	7.	0.	0.	0.	0.	0.	0.	0.
JUL.	19846.32	.500	27.18	2.6	.00	8.	0.	0.	0.	0.	0.	0.	0.
AUG.	19208.94	.509	27.94	3.6	.00	3.	0.	0.	0.	0.	0.	0.	0.
SEP.	16981.93	.499	27.44	3.0	.00	4.	0.	0.	0.	0.	0.	0.	0.
OCT.	14593.29	.503	25.05	3.1	.00	33.	2.	0.	0.	0.	0.	0.	0.
NOV.	13441.80	.552	22.89	3.8	.00	74.	12.	0.	0.	0.	0.	0.	0.
DEC.	11697.29	.527	19.40	3.5	.00	178.	79.	29.	6.	1.	0.	0.	0.

BROWNSVILLE, TX LATITUDE: 25.92

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	10383.74	.443	15.08	5.0	.00	308.	168.	75.	24.	4.	0.	0.	0.
FEB.	13259.21	.482	16.62	5.0	.00	235.	116.	46.	10.	1.	0.	0.	0.
MAR.	16955.71	.520	19.96	5.8	.00	165.	64.	16.	2.	0.	0.	0.	0.
APR.	21566.90	.583	23.88	6.3	.00	59.	7.	0.	0.	0.	0.	0.	0.
MAY	21691.61	.550	25.59	5.9	.00	33.	4.	0.	0.	0.	0.	0.	0.
JUN.	23586.80	.587	27.20	5.4	.00	13.	1.	0.	0.	0.	0.	0.	0.
JUL.	24966.39	.629	28.08	5.1	.00	7.	0.	0.	0.	0.	0.	0.	0.
AUG.	24013.77	.637	28.31	4.8	.00	4.	0.	0.	0.	0.	0.	0.	0.
SEP.	19364.60	.570	27.00	4.0	.00	14.	0.	0.	0.	0.	0.	0.	0.
OCT.	15747.32	.544	24.13	4.3	.00	63.	10.	0.	0.	0.	0.	0.	0.
NOV.	11729.97	.483	19.95	4.9	.00	164.	71.	25.	4.	0.	0.	0.	0.
DEC.	9870.42	.447	15.94	4.6	.00	283.	155.	69.	20.	1.	0.	0.	0.

CHARLESTON, SC LATITUDE: 32.90

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	8113.90	.419	9.26	3.4	.00	488.	334.	193.	90.	31.	7.	0.	0.
FEB.	11774.96	.491	9.28	4.2	.00	440.	301.	173.	73.	19.	1.	0.	0.
MAR.	15533.16	.516	13.72	4.5	.00	350.	208.	102.	38.	9.	1.	0.	0.
APR.	19973.63	.555	18.02	3.8	.00	214.	96.	35.	8.	0.	0.	0.	0.
MAY	21184.68	.535	21.76	3.9	.00	121.	34.	6.	0.	0.	0.	0.	0.
JUN.	20185.70	.493	24.11	3.5	.00	66.	13.	1.	0.	0.	0.	0.	0.
JUL.	19715.77	.491	26.10	3.2	.00	27.	0.	0.	0.	0.	0.	0.	0.
AUG.	18082.19	.487	25.62	3.2	.00	36.	4.	0.	0.	0.	0.	0.	0.
SEP.	15990.47	.499	23.67	3.7	.00	66.	7.	0.	0.	0.	0.	0.	0.
OCT.	12917.77	.502	17.98	3.5	.00	223.	103.	36.	10.	1.	0.	0.	0.
NOV.	11357.77	.558	13.38	3.4	.00	350.	216.	111.	41.	8.	0.	0.	0.
DEC.	7865.10	.439	9.62	3.1	.00	477.	324.	189.	88.	29.	4.	0.	0.

NASHVILLE, TN LATITUDE: 36.12

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	6280.42	.360	4.53	3.7	.00	635.	480.	326.	193.	92.	27.	6.	0.
FEB.	9179.39	.413	5.67	3.6	.00	541.	402.	270.	158.	75.	22.	3.	0.
MAR.	13395.10	.465	9.58	4.8	.00	478.	325.	191.	89.	27.	4.	0.	0.
APR.	17721.83	.503	14.72	4.4	.00	311.	180.	85.	30.	4.	0.	0.	0.
MAY	19525.13	.494	19.75	3.3	.00	177.	75.	23.	6.	1.	0.	0.	0.
JUN.	23070.40	.560	23.96	2.8	.00	74.	15.	2.	0.	0.	0.	0.	0.
JUL.	21782.42	.541	25.70	2.7	.00	43.	3.	0.	0.	0.	0.	0.	0.
AUG.	19959.65	.544	24.94	2.4	.00	53.	6.	0.	0.	0.	0.	0.	0.
SEP.	16103.07	.520	21.89	2.3	.00	120.	37.	6.	0.	0.	0.	0.	0.
OCT.	12064.00	.500	15.73	3.1	.00	293.	161.	71.	19.	3.	0.	0.	0.
NOV.	7844.90	.424	10.40	4.0	.08	438.	289.	166.	73.	21.	2.	0.	0.
DEC.	5786.68	.362	4.73	3.9	.16	628.	473.	325.	195.	91.	25.	3.	1.

DODGE CITY, KS LATITUDE: 37.77

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	9213.42	.560	-2.39	5.9	.39	849.	694.	539.	386.	245.	126.	51.	10.
FEB.	12402.14	.581	1.16	5.3	.04	667.	527.	388.	255.	136.	46.	10.	0.
MAR.	16826.06	.598	4.16	7.1	.00	646.	493.	349.	218.	113.	44.	11.	1.
APR.	21669.17	.622	11.86	5.0	.00	397.	260.	143.	55.	12.	2.	0.	0.
MAY	23546.03	.597	18.42	6.9	.00	214.	95.	19.	0.	0.	0.	0.	0.
JUN.	26528.67	.643	24.11	5.7	.00	87.	20.	1.	0.	0.	0.	0.	0.
JUL.	26155.45	.650	24.97	4.4	.00	69.	11.	0.	0.	0.	0.	0.	0.
AUG.	24008.16	.659	25.44	6.8	.00	69.	12.	1.	0.	0.	0.	0.	0.
SEP.	19563.53	.644	18.84	4.8	.00	198.	89.	22.	1.	0.	0.	0.	0.
OCT.	14804.45	.635	13.76	6.4	.00	357.	226.	120.	47.	12.	1.	0.	0.
NOV.	9895.50	.565	5.85	5.3	.00	574.	426.	283.	156.	63.	10.	0.	0.
DEC.	8141.71	.544	.09	6.0	.16	772.	617.	463.	314.	178.	73.	16.	1.

CARIBOU, ME LATITUDE: 46.87

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	4662.06	.427	-11.04	5.1	1.00	1117.	962.	807.	652.	498.	346.	207.	101.
FEB.	8365.32	.520	-10.24	5.1	1.00	987.	847.	707.	567.	429.	301.	190.	102.
MAR.	13294.23	.557	-3.43	4.6	1.00	881.	726.	571.	416.	264.	126.	42.	7.
APR.	16184.77	.502	2.29	4.7	.77	681.	531.	382.	236.	108.	31.	8.	2.
MAY	18360.26	.476	10.90	4.6	.00	437.	290.	158.	57.	7.	0.	0.	0.
JUN.	20604.37	.499	15.98	4.2	.00	275.	150.	59.	14.	1.	0.	0.	0.
JUL.	19812.10	.497	18.14	3.5	.00	215.	86.	14.	0.	0.	0.	0.	0.
AUG.	16668.68	.483	16.41	3.6	.00	271.	140.	47.	7.	0.	0.	0.	0.
SEP.	11681.57	.438	12.51	4.2	.00	375.	230.	102.	33.	5.	0.	0.	0.
OCT.	7802.16	.425	6.54	4.2	.00	572.	417.	264.	127.	36.	5.	0.	0.
NOV.	4293.57	.356	-.16	4.4	.00	755.	605.	455.	306.	167.	65.	16.	2.
DEC.	3496.39	.371	-8.57	5.2	.62	1041.	886.	731.	576.	421.	273.	149.	60.

MADISON, WI LATITUDE: 43.05

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	5913.39	.446	-8.40	4.0	.30	1035.	880.	725.	570.	416.	274.	165.	89.
FEB.	9133.46	.498	-5.98	4.6	.95	868.	728.	588.	448.	308.	170.	64.	18.
MAR.	13765.13	.535	-1.87	5.1	.45	833.	678.	523.	369.	221.	102.	43.	13.
APR.	15698.80	.469	8.67	5.1	.02	491.	344.	208.	102.	35.	7.	0.	0.
MAY	19319.74	.495	14.60	4.3	.00	329.	196.	92.	27.	3.	0.	0.	0.
JUN.	21277.93	.515	19.60	4.4	.00	177.	74.	17.	2.	0.	0.	0.	0.
JUL.	21748.16	.543	22.11	3.4	.00	115.	31.	3.	0.	0.	0.	0.	0.
AUG.	19867.45	.561	20.01	2.8	.00	168.	65.	17.	2.	0.	0.	0.	0.
SEP.	15161.10	.535	16.79	3.9	.00	250.	125.	47.	9.	1.	0.	0.	0.
OCT.	9816.97	.479	10.49	3.4	.00	450.	298.	166.	73.	23.	3.	0.	0.
NOV.	5808.07	.405	2.35	4.3	.00	679.	529.	380.	239.	121.	40.	6.	0.
DEC.	4279.13	.365	-3.72	3.4	.94	890.	735.	580.	425.	270.	122.	34.	5.

EL PASO, TX LATITUDE: 31.80

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	12515.23	.625	6.88	3.5	.00	562.	408.	261.	140.	58.	14.	1.	0.
FEB.	17420.07	.710	9.34	3.4	.00	438.	299.	173.	83.	28.	4.	0.	0.
MAR.	21656.35	.709	13.51	4.8	.00	357.	217.	110.	41.	5.	0.	0.	0.
APR.	26432.97	.732	18.86	4.7	.00	200.	95.	33.	5.	0.	0.	0.	0.
MAY	29878.13	.755	23.49	4.8	.00	95.	31.	5.	0.	0.	0.	0.	0.
JUN.	30539.13	.747	27.57	3.1	.00	38.	5.	0.	0.	0.	0.	0.	0.
JUL.	28154.81	.702	28.01	3.1	.00	23.	1.	0.	0.	0.	0.	0.	0.
AUG.	25742.65	.691	26.91	2.6	.00	32.	1.	0.	0.	0.	0.	0.	0.
SEP.	21993.33	.680	23.24	3.1	.00	106.	41.	10.	0.	0.	0.	0.	0.
OCT.	19275.29	.734	18.11	2.5	.00	224.	113.	44.	12.	2.	0.	0.	0.
NOV.	14210.17	.677	11.21	2.7	.00	414.	267.	139.	47.	6.	0.	0.	0.
DEC.	11800.84	.634	6.86	4.5	.00	562.	407.	256.	129.	44.	7.	0.	0.

ALBUQUERQUE, NM LATITUDE: 35.00

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	11116.26	.613	1.41	2.9	.07	731.	576.	421.	268.	129.	37.	5.	0.
FEB.	15269.25	.668	3.37	3.9	.01	606.	466.	328.	201.	95.	28.	4.	0.
MAR.	19791.00	.676	6.77	3.6	.00	565.	411.	265.	143.	61.	20.	3.	0.
APR.	25988.77	.733	12.60	4.6	.00	372.	229.	114.	37.	8.	0.	0.	0.
MAY	29318.71	.741	18.62	4.0	.00	216.	107.	38.	9.	1.	0.	0.	0.
JUN.	30117.27	.733	22.92	4.8	.00	110.	35.	3.	0.	0.	0.	0.	0.
JUL.	28215.23	.701	25.53	2.9	.00	61.	7.	0.	0.	0.	0.	0.	0.
AUG.	26195.13	.710	24.01	3.5	.00	81.	14.	0.	0.	0.	0.	0.	0.
SEP.	22198.60	.709	19.53	3.6	.00	174.	66.	9.	0.	0.	0.	0.	0.
OCT.	18120.58	.734	14.06	2.5	.00	342.	203.	95.	26.	1.	0.	0.	0.
NOV.	13291.43	.694	6.46	2.7	.00	556.	406.	259.	131.	44.	10.	1.	0.
DEC.	10785.29	.648	2.07	3.2	.00	711.	556.	401.	253.	127.	44.	8.	0.

ELY, NV LATITUDE: 39.28

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	9180.68	.591	-5.11	3.8	.00	933.	778.	623.	468.	317.	184.	88.	35.
FEB.	12957.57	.632	-1.59	3.9	.00	745.	605.	465.	326.	195.	88.	27.	6.
MAR.	18688.81	.680	1.37	4.0	.00	733.	578.	424.	282.	164.	76.	27.	8.
APR.	22167.20	.643	5.16	4.1	.00	595.	445.	301.	176.	79.	17.	1.	0.
MAY	25676.45	.653	10.42	4.7	.02	452.	306.	181.	86.	26,	3.	0.	0.
JUN.	28324.23	.686	14.96	4.3	.00	307.	185.	93.	34.	6.	0.	0.	0.
JUL.	28283.19	.703	20.11	4.3	.00	185.	98.	40.	8.	0.	0.	0.	0.
AUG.	25169.71	.696	18.92	4.1	.00	207.	100.	32.	5.	0.	0.	0.	0.
SEP.	21453.10	.720	14.75	4.0	.00	310.	186.	88.	25.	4.	0.	0.	0.
OCT.	16464.06	.731	7.24	3.4	.00	551.	397.	258.	145.	65.	17.	2.	0.
NOV.	10445.63	.629	1.00	3.6	.38	720.	570.	421.	281.	160.	70.	24.	6.
DEC.	8195.68	.584	-4.43	4.1	.83	912.	757.	602.	448.	300.	170.	90.	41.

PHOENIX, AZ LATITUDE: 33.43

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	11635.71	.610	11.25	2.3	.00	426.	273.	140.	51.	9.	0.	0.	0.
FEB.	15920.14	.672	12.31	2.6	.00	356.	222.	111.	37.	4.	0.	0.	0.
MAR.	20987.29	.701	16.37	2.8	.00	275.	152.	64.	15.	0.	0.	0.	0.
APR.	26458.83	.739	20.06	2.3	.00	168.	75.	21.	2.	0.	0.	0.	0.
MAY	30746.55	.777	25.95	2.7	.00	68.	17.	1.	0.	0.	0.	0.	0.
JUN.	30611.60	.747	31.35	2.5	.00	10.	0.	0.	0.	0.	0.	0.	0.
JUL.	27564.55	.686	33.87	3.4	.00	1.	0.	0.	0.	0.	0.	0.	0.
AUG.	25998.77	.701	32.41	2.9	.00	1.	0.	0.	0.	0.	0.	0.	0.
SEP.	23058.90	.724	29.46	2.8	.00	18.	1.	0.	0.	0.	0.	0.	0.
OCT.	17832.52	.700	22.66	2.3	.00	122.	44.	6.	0.	0.	0.	0.	0.
NOV.	13707.67	.683	15.95	2.3	.00	272.	137.	46.	8.	0.	0.	0.	0.
DEC.	10448.23	.593	11.01	2.4	.00	434.	283.	160.	70.	18.	1.	0.	0.

SANTA MARIA, CA LATITUDE: 34.90

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	9576.13	.527	9.40	2.1	.00	484.	330.	183.	76.	25.	3.	0.	0.
FEB.	12497.75	.546	10.61	2.9	.00	403.	264.	135.	45.	7.	0.	0.	0.
MAR.	17592.52	.600	11.63	3.4	.00	415.	261.	118.	23.	2.	0.	0.	0.
APR.	21797.27	.614	12.29	3.0	.00	381.	234.	105.	23.	1.	0.	0.	0.
MAY	23200.52	.587	13.64	3.0	.00	355.	207.	74.	7.	0.	0.	0.	0.
JUN.	27179.07	.661	13.58	4.1	.00	343.	194.	73.	4.	0.	0.	0.	0.
JUL.	26887.19	.668	16.11	2.2	.00	281.	143.	44.	1.	0.	0.	0.	0.
AUG.	23936.77	.649	15.97	2.7	.00	285.	142.	38.	0.	0.	0.	0.	0.
SEP.	19169.67	.611	16.00	2.5	.00	275.	137.	34.	1.	0.	0.	0.	0.
OCT.	15507.16	.626	14.56	2.3	.00	325.	180.	64.	6.	0.	0.	0.	0.
NOV.	10877.73	.566	12.93	3.3	.00	363.	218.	93.	19.	1.	0.	0.	0.
DEC.	9111.03	.545	10.91	1.9	.00	437.	285.	149.	57.	14.	1.	0.	0.

BISMARK, ND LATITUDE: 46.87

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	5366.81	.491	-11.20	4.9	1.00	1122.	967.	812.	657.	502.	353.	218.	113.
FEB.	8897.46	.553	-9.97	3.6	1.00	979.	839.	699.	559.	419.	289.	182.	104.
MAR.	12748.71	.534	-2.36	5.1	.14	848.	693.	539.	388.	242.	117.	40.	8.
APR.	16567.97	.514	4.72	5.5	.08	608.	461.	319.	192.	97.	44.	19.	6.
MAY	21130.77	.548	12.98	5.5	.00	374.	232.	114.	36.	4.	0.	0.	0.
JUN.	23624.13	.573	17.65	3.7	.00	226.	108.	35.	4.	0.	0.	0.	0.
JUL.	24835.77	.623	21.55	3.7	.00	131.	40.	5.	0.	0.	0.	0.	0.
AUG.	21437.45	.621	22.46	4.4	.00	125.	43.	10.	1.	0.	0.	0.	0.
SEP.	14997.53	.562	13.17	4.4	.00	357.	220.	112.	38.	7.	0.	0.	0.
OCT.	9958.94	.542	7.09	4.3	.00	555.	401.	257.	130.	41.	6.	0.	0.
NOV.	5783.87	.480	-1.83	4.5	.02	805.	655.	505.	356.	214.	97.	29.	6.
DEC.	4525.29	.480	-10.26	4.4	.49	1093.	938.	783.	628.	475.	328.	203.	111.

GREAT FALLS, MT LATITUDE: 47.48

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	4774.29	.452	-5.52	6.4	.00	946.	791.	636.	484.	348.	243.	165.	105.
FEB.	8145.57	.518	-2.83	6.0	.59	779.	639.	499.	362.	245.	156.	84.	34.
MAR.	13117.26	.557	.01	6.4	.00	775.	620.	465.	313.	178.	82.	30.	7.
APR.	17195.73	.536	5.92	5.2	.11	572.	425.	284.	159.	66.	15.	1.	0.
MAY	20491.35	.533	12.14	4.4	.00	399.	253.	130.	44.	8.	0.	0.	0.
JUN.	23699.17	.575	17.22	3.2	.00	242.	124.	42.	5.	0.	0.	0.	0.
JUL.	26966.19	.678	21.80	4.9	.00	138.	53.	11.	0.	0.	0.	0.	0.
AUG.	21918.90	.638	19.38	4.6	.00	199.	94.	27.	3.	0.	0.	0.	0.
SEP.	15348.10	.581	14.13	4.6	.00	329.	197.	94.	33.	9.	0.	0.	0.
OCT.	10292.90	.571	7.09	5.8	.00	556.	405.	269.	159.	85.	36.	15.	4.
NOV.	5729.97	.490	2.61	6.1	.00	672.	522.	373.	235.	123.	52.	24.	12.
DEC.	4022.71	.444	-1.52	4.5	.35	822.	667.	512.	363.	234.	139.	76.	44.

MEDFORD, OR LATITUDE: 42.38

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	4515.26	.331	3.30	1.6	.07	673.	518.	363.	209.	80.	14.	1.	0.
FEB.	8145.64	.435	4.18	2.0	.00	583.	443.	303.	169.	70.	20.	3.	0.
MAR.	12886.61	.495	6.67	2.1	.01	568.	414.	265.	130.	34.	3.	0.	0.
APR.	18057.80	.537	9.51	2.1	.00	465.	316.	178.	69.	11.	0.	0.	0.
MAY	23112.81	.592	12.64	2.3	.00	386.	245.	129.	48.	9.	0.	0.	0.
JUN.	26451.60	.640	18.62	2.3	.00	213.	104.	32.	4.	0.	0.	0.	0.
JUL.	28696.13	.715	21.95	1.7	.00	143.	60.	12.	0.	0.	0.	0.	0.
AUG.	24299.65	.683	21.09	2.2	.00	163.	72.	19.	1.	0.	0.	0.	0.
SEP.	18197.57	.637	17.84	1.9	.00	242.	133.	52.	9.	0.	0.	0.	0.
OCT.	11125.68	.533	11.76	1.4	.00	416.	273.	147.	55.	9.	0.	0.	0.
NOV.	5875.77	.398	6.27	1.2	.00	562.	412.	264.	129.	34.	3.	0.	0.
DEC.	3281.48	.270	1.90	.8	.06	716.	561.	406.	251.	108.	20.	1.	0.

SEATTLE, WA LATITUDE: 47.45

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	3162.90	.299	3.83	3.9	.00	656.	501.	346.	192.	59.	3.	0.	0.
FEB.	5297.50	.336	5.67	3.7	.00	541.	401.	261.	124.	30.	1.	0.	0.
MAR.	10189.71	.432	6.09	4.3	.09	586.	431.	278.	135.	33.	1.	0.	0.
APR.	14688.53	.458	8.11	4.1	.00	507.	357.	211.	78.	8.	0.	0.	0.
MAY	18696.74	.486	11.90	3.2	.00	407.	257.	122.	26.	1.	0.	0.	0.
JUN.	20056.40	.486	15.00	3.7	.00	302.	159.	44.	1.	0.	0.	0.	0.
JUL.	22678.10	.570	17.06	3.4	.00	255.	127.	34.	0.	0.	0.	0.	0.
AUG.	19058.23	.554	17.47	3.0	.00	236.	101.	14.	0.	0.	0.	0.	0.
SEP.	13025.17	.493	14.83	3.3	.00	306.	165.	50.	3.	0.	0.	0.	0.
OCT.	7243.87	.402	10.62	2.6	.00	446.	291.	142.	35.	1.	0.	0.	0.
NOV.	3741.40	.319	7.92	3.7	.00	512.	362.	212.	72.	6.	0.	0.	0.
DEC.	2287.35	.252	4.61	5.4	.11	632.	477.	322.	168.	58.	12.	0.	0.

FRESNO, CA LATITUDE: 36.77

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	7606.00	.446	6.30	2.0	.00	580.	425.	270.	126.	29.	2.	0.	0.
FEB.	11724.93	.536	9.72	2.3	.00	428.	288.	157.	54.	12.	0.	0.	0.
MAR.	18046.03	.632	13.00	2.6	.00	373.	227.	103.	24.	0.	0.	0.	0.
APR.	24026.27	.685	15.18	2.9	.00	300.	172.	71.	18.	2.	0.	0.	0.
MAY	28406.58	.720	20.05	3.4	.00	185.	86.	25.	1.	0.	0.	0.	0.
JUN.	30875.30	.749	24.50	3.1	.00	96.	33.	4.	0.	0.	0.	0.	0.
JUL.	30738.52	.764	27.55	2.4	.00	50.	9.	0.	0.	0.	0.	0.	0.
AUG.	27231.26	.744	26.00	2.2	.00	68.	16.	1.	0.	0.	0.	0.	0.
SEP.	22974.33	.748	22.74	2.5	.00	127.	50.	11.	1.	0.	0.	0.	0.
OCT.	16518.68	.694	17.59	1.9	.00	242.	127.	46.	8.	0.	0.	0.	0.
NOV.	10339.23	.571	11.03	1.6	.00	419.	271.	137.	43.	5.	0.	0.	0.
DEC.	6476.68	.416	5.88	2.1	.00	593.	438.	283.	137.	41.	2.	0.	0.

CAPE HATTERAS, NC LATITUDE: 35.27

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	8168.16	.455	7.89	5.3	.00	530.	376.	226.	102.	31.	6.	0.	0.
FEB.	11028.79	.486	7.54	5.9	.00	489.	349.	213.	108.	36.	8.	0.	0.
MAR.	14461.52	.496	10.74	6.1	.00	442.	287.	142.	40.	5.	0.	0.	0.
APR.	19745.07	.557	15.59	5.5	.00	282.	138.	43.	6.	1.	0.	0.	0.
MAY	22254.55	.563	19.72	4.9	.00	164.	47.	4.	0.	0.	0.	0.	0.
JUN.	23256.73	.566	23.99	4.4	.00	53.	3.	0.	0.	0.	0.	0.	0.
JUL.	21551.55	.536	25.94	3.7	.00	17.	0.	0.	0.	0.	0.	0.	0.
AUG.	19131.13	.519	25.54	4.4	.00	22.	1.	0.	0.	0.	0.	0.	0.
SEP.	17095.77	.547	23.20	4.5	.00	67.	11.	2.	0.	0.	0.	0.	0.
OCT.	13505.16	.542	18.70	5.3	.00	197.	73.	12.	1.	0.	0.	0.	0.
NOV.	10191.80	.537	13.16	4.8	.00	355.	213.	99.	33.	6.	0.	0.	0.
DEC.	7240.29	.439	8.34	5.4	.00	516.	363.	221.	97.	22.	1.	0.	0.

STERLING, VA LATITUDE: 38.85

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	6906.16	.437	-.74	3.3	.00	798.	643.	488.	338.	199.	96.	36.	9.
FEB.	9230.46	.445	.61	3.8	.00	683.	543.	403.	268.	147.	57.	13.	2.
MAR.	13400.35	.484	6.29	4.4	.00	580.	427.	284.	154.	58.	9.	0.	0.
APR.	16828.17	.487	12.76	3.7	.00	370.	234.	120.	40.	6.	0.	0.	0.
MAY	19423.58	.493	17.50	4.5	.00	245.	119.	37.	4.	0.	0.	0.	0.
JUN.	21471.90	.520	21.10	2.5	.00	140.	49.	10.	0.	0.	0.	0.	0.
JUL.	19486.45	.484	24.39	2.6	.00	64.	9.	0.	0.	0.	0.	0.	0.
AUG.	19303.03	.532	23.52	2.2	.00	87.	21.	3.	0.	0.	0.	0.	0.
SEP.	14901.63	.497	20.73	2.3	.00	146.	51.	10.	1.	0.	0.	0.	0.
OCT.	11155.29	.491	13.77	2.5	.00	350.	205.	89.	28.	7.	1.	0.	0.
NOV.	7677.40	.455	8.13	3.3	.00	506.	359.	222.	111.	36.	9.	1.	0.
DEC.	5554.19	.388	2.74	3.1	.00	690.	535.	380.	230.	97.	18.	1.	0.

BOSTON, MA LATITUDE: 42.37

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	5156.26	.377	-1.68	6.5	.60	827.	672.	517.	364.	215.	92.	32.	4.
FEB.	7572.43	.410	1.57	6.0	.34	656.	516.	376.	239.	117.	30.	4.	1.
MAR.	11679.74	.448	2.47	5.7	.19	698.	543.	389.	238.	106.	22.	4.	0.
APR.	14560.93	.433	8.57	5.1	.00	493.	344.	201.	78.	10.	0.	0.	0.
MAY	18389.23	.471	13.56	5.5	.00	359.	217.	97.	24.	0.	0.	0.	0.
JUN.	21679.53	.525	19.49	4.9	.00	181.	81.	24.	1.	0.	0.	0.	0.
JUL.	19586.97	.488	22.49	4.8	.00	103.	21.	0.	0.	0.	0.	0.	0.
AUG.	16780.42	.472	21.85	4.3	.00	119.	28.	0.	0.	0.	0.	0.	0.
SEP.	14624.00	.511	16.97	5.6	.00	243.	113.	28.	3.	0.	0.	0.	0.
OCT.	9478.97	.454	12.20	4.5	.00	397.	245.	109.	34.	4.	0.	0.	0.
NOV.	5698.07	.386	6.98	6.2	.02	541.	392.	249.	126.	39.	3.	0.	0.
DEC.	4375.68	.360	.29	6.2	.29	766.	611.	456.	302.	154.	48.	8.	0.

NEW YORK, NY   LATITUDE: 40.77

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	5299.19	.362	.06	4.6	.40	773.	618.	463.	308.	159.	57.	13.	0.
FEB.	8255.89	.420	.12	6.0	.00	697.	557.	417.	277.	141.	55.	15.	2.
MAR.	11755.10	.439	3.98	6.9	.12	652.	497.	343.	193.	70.	11.	0.	0.
APR.	15344.43	.450	11.11	5.6	.00	417.	270.	133.	34.	4.	0.	0.	0.
MAY	18814.81	.480	15.27	4.9	.00	303.	155.	45.	3.	0.	0.	0.	0.
JUN.	19531.13	.473	19.86	4.8	.00	163.	44.	2.	0.	0.	0.	0.	0.
JUL.	18447.19	.459	23.03	4.4	.00	78.	6.	0.	0.	0.	0.	0.	0.
AUG.	17053.58	.475	23.55	4.2	.00	65.	6.	0.	0.	0.	0.	0.	0.
SEP.	13507.60	.462	19.11	4.2	.00	180.	60.	7.	0.	0.	0.	0.	0.
OCT.	10293.06	.474	14.06	4.8	.00	339.	186.	63.	10.	0.	0.	0.	0.
NOV.	5951.80	.378	8.55	5.2	.00	493.	344.	206.	85.	16.	0.	0.	0.
DEC.	4302.16	.328	2.81	4.8	.11	688.	533.	378.	224.	97.	23.	2.	0.

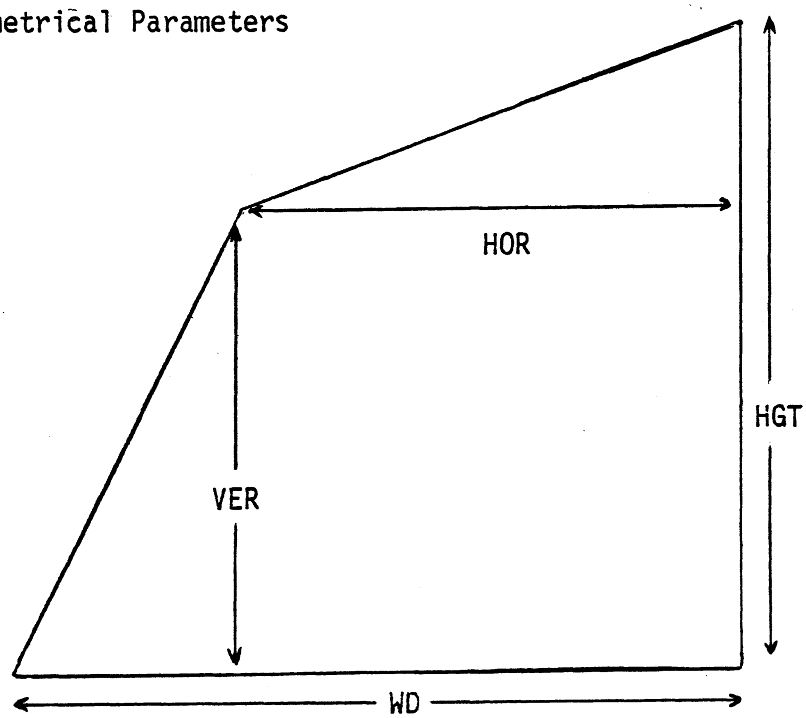
OMAHA, NB   LATITUDE: 41.37

MON.	H (KJ/M2-DAY)	KT	TA (C)	V (M/SEC)	SC	DD (25 C)	DD (20 C)	DD (15 C)	DD (10 C)	DD (05 C)	DD (00 C)	DD (-05 C)	DD (-10 C)
JAN.	7521.71	.527	-6.40	4.0	.29	973.	818.	663.	508.	358.	228.	135.	72.
FEB.	10569.89	.548	-3.88	4.5	.19	809.	669.	529.	389.	255.	141.	62.	19.
MAR.	13462.00	.507	3.95	5.8	.28	653.	498.	348.	206.	90.	20.	1.	0.
APR.	17144.73	.506	12.23	5.3	.00	384.	243.	125.	43.	5.	0.	0.	0.
MAY	22729.06	.580	18.84	3.6	.00	200.	87.	25.	3.	0.	0.	0.	0.
JUN.	24775.10	.600	22.53	3.6	.00	110.	32.	5.	0.	0.	0.	0.	0.
JUL.	23416.32	.583	24.76	3.8	.00	64.	9.	0.	0.	0.	0.	0.	0.
AUG.	21252.26	.594	24.08	4.3	.00	72.	11.	0.	0.	0.	0.	0.	0.
SEP.	15823.03	.546	17.45	3.1	.00	232.	113.	35.	3.	0.	0.	0.	0.
OCT.	11463.32	.536	13.03	4.1	.00	372.	232.	121.	45.	9.	0.	0.	0.
NOV.	7762.73	.505	4.57	4.7	.00	613.	463.	315.	176.	75.	16.	1.	0.
DEC.	5969.81	.468	-2.22	4.7	.46	844.	689.	534.	386.	254.	138.	61.	21.

APPENDIX B. COMPUTER PROGRAM LISTINGS

B.1. Unutilizability Method

Geometrical Parameters



XLN : sunspace width

Uses subroutine RAD, TWBAR, FHAT, BPHI.

```
C---------------------------------------------------------
C
C      THIS PROGRAM CALCULATES THE ENERGY DELIVERED
C      TO THE ROOM FROM THE SUNSPACE WITH A
C      SIMPLIFIED NETWORK AND QAUX FOR THE HOUSE
C      WITH THE UN-UTILIZABILITY METHOD  USING
C      MONTHLY AVERAGE WEATHER DATA
C
C          TR : THE LOW SET POINT ROOM TEMPERATURE
C          DELT : ROOM TEMPERATURE SWING
C          QIN : THE ENERGY DELIVERED TO THE ROOM
C          IC : THE CRITICAL RADIATION LEVEL
C          PHID : PHI-BAR FOR A MONTH
C          QD : THE ENERGY DUMPED
C          TAU : THE TRANSMITTANCE-ABSORBTANCE PRODUCT
C
C---------------------------------------------------------
C
      DIMENSION WIND(12),C5(12),CA(12),T1(12),T2(12),
     @TW(12),N(12),S(12),SW(12),SF(12),TA(12),
     @B(12),QIN(12),IC(12),ES(3),
     @A1(12),A2(12),A3(12),R20(12),C20(12),C22(12)
     @,CB(12),QI(12),QZ(12),QS(12),QD(12),FI(12),
     @FZ(12),TAU(12),FHATI(3,3),DN(12),DECL(12),
     @COSDEC(12),SINDEC(12),TANDEC(12),
     @DAYHRS(12),FDAY(12),C(12),MN(12),H(12),DA(12),
     @RADI(3),HA(12),TWLBAR(12),ABWL(12),ABFL(12),Q(12),
     @QRAD(12),S2(12),HT1(12),HT2(12),FI2(12),
     @SFR(12),EW(12),EH(12),Y(12)
     @,CURVE(12),
     @QAUX(12),QAUXD(12),AB(12)
      CHARACTER*5 AMN(12)
      REAL NUM,IC,INF,KW,M,KF
      REAL NU(12),R5(12),PHID(12),LA(12),LW(12)
      REAL L(12),DD(12),P(12)
      DATA SIG/5.67E-08/
      DATA DN/17.,47.,75.,105.,135.,162.,198.,
     @228.,258.,288.,318.,344./
      DATA PI/3.1415927/ ,RDCONV/0.01745329/,
     @GJ/1000000./
      DATA AMN/'JAN','FEB','MARCH','APRIL','MAY',
     @'JUNE','JULY','AUG',
     @'SEP','OCT','NOV','DEC'/
C
      READ(18,15)RHO
15    FORMAT(F3.1)
      READ(19,25)ALAT
```

```
25    FORMAT(F5.2)
C
      WRITE(26,37)
37    FORMAT(//,'MONTH',5X'PHID',3X,'LOAD',6X,'QS',
     @10X,'S',8X,'Y',7X,
     @'QAUX DES',5X,'QAUX TRNSYS')
C
      QT=0
      AQAUXD=0
C
C  LOOP FOR 12 MONTHS
C
      DO 500 I=1,12
      TR=18.33
C
C  Room temperature swing
C
      DELT=5.5
C
C  Input weather data
C
      READ(10,10)WIND(I)
10    FORMAT(F5.3)
      READ(12,20)TA(I)
20    FORMAT(F5.2)
      READ(16,50)N(I)
50    FORMAT(I3)
      READ(23,55)DD(I)
55    FORMAT(F5.1)
C
C  UA IN KJ/HR-C
C
      UA=1080.
C
C  capacitance in KJ/C
C
      CAP=25000.
C
C  Geometrical data
C
      HGT=2.74
      WD=1.58
      HOR=1.58
      VER=1.82
      XLN=9.14
      INF=0.5
      VENT=0.
      M=500.
C
```

```
C  Wall specifications
C
      KW=6.23
      THW=0.305
      RCP=2009.
C
      ES(1)=0.9
      ES(2)=0.9
      ES(3)=0.9
C
C  Glazing specifications
C
      NCOV=2.
      RGL=0.0611
      RINS=0.
C
C  calculation of the geometry of the sunspace
C
      VC=HGT-VER
      AW=HGT*XLN
      AF=WD*XLN
      XUG=SQRT(VC**2+HOR**2)
      AUG=XUG*XLN
      XLG=SQRT((WD-HOR)**2+VER**2)
      ALG=XLG*XLN
      AGL=AUG+ALG
      VOL1=VER*HOR*XLN
      VOL2=(HOR*VC*XLN)/2
      VOL3=VER*(WD-HOR)*XLN/2
      VOL=VOL1+VOL2+VOL3
C
C  CALCULATION OF ABSORBED SOLAR RADIATION
C
      AZMTH=0.
      RHO=0.3
      RI=1.526
      XKL=0.0625
      SFRAC=0.2
      READ(21,40)H(I)
40    FORMAT(F6.0)
      MN(I)=I
C
C  Subroutine to calculate the incident radiation on
C  the wall and the floor
C
      CALL RAD(MN(I),H(I),ALAT,AZMTH,RHO,NCOV,RI,XKL,
     @HGT,WD,HOR,VER,XLN,RADI,XKT,RBAR3,RN,GN,
     @SFRAC,HT1(I),HT2(I))
C
```

```
C  Number of days in a month
C
      READ(17,45)DA(I)
45    FORMAT(F3.0)
      HT1(I)=HT1(I)*DA(I)
      HT2(I)=HT2(I)*DA(I)
      QRAD(I)=HT1(I)*AUG+HT2(I)*ALG
      RGL1=RGL*3.6
      SFRAC=0.2
      EGL=0.9
      EWL=0.9
      EFL=0.9
      CNW=KW/3.6
      CNF=0.865
      THF=0.1525
      RGR=8.
      ESW=0.8
      ESF=0.8
      HS=4.
      HR=8.27
      AIRCH=1.
      HA(I)=(2.8+3*WIND(I))
      TGRBAR=10.
C
C  Subroutine to calculate the absorbed solar radiation
C
      CALL TWBAR(HGT,WD,HOR,VER,XLN,NCOV,RI,XKL,RGL1,
     @SFRAC,EGL,EWL,EFL,THW,THF,CNW,CNF,RGR,ESW,ESF,
     @HS,HR,HA(I),AIRCH,RADI,TA(I),TGRBAR,TR,TWNS,
     @XLS,TWLBAR(I),Q(I),ABWL(I),ABFL(I))
C
C  SW is the absorbed solar radiation on the wall
C
      SW(I)=ABWL(I)*DA(I)
C
C  SF is the absorbed solar radiation on the floor
C
      SF(I)=ABFL(I)*DA(I)
C
C   calculation of conductances
C
C     convection
      C6=14.4*AGL
      C7=14.4*AW
      C8=14.4*AF
      R6=1/C6
      R7=1/C7
      R8=1/C8
      NUM=R7*R6+R7*R8+R8*R6
```

```
      R13=NUM/R6
      R12=NUM/R8
      R14=NUM/R7
C
C     radiation
C
      CALL FHAT(HGT,WD,XLG,XUG,ES,FHATI)
      T=293
      C9=3.6*SIG*ES(3)*FHATI(1,3)*ES(1)*AW*4*(T**3)
      C10=3.6*SIG*ES(1)*FHATI(1,2)*ES(2)*AW*4*(T**3)
      C11=3.6*SIG*ES(3)*FHATI(2,3)*ES(2)*AF*4*(T**3)
      R9=1/C9
      R10=1/C10
      R11=1/C11
      R15=(R9*R12)/(R9+R12)
      R16=(R10*R13)/(R10+R13)
      R17=(R11*R14)/(R11+R14)
      A=3.6*SIG*ES(3)*A*(T**3)*AGL
      CG=AGL/(RGL*NCOV)
C
C  night insulation calculation
C
      DECL(I)=23.45*SIN(PI*2*(284+DN(I))/365)
      COSDEC(I) = COS(DECL(I)*RDCONV)
      SINDEC(I) = SIN(DECL(I)*RDCONV)
      COSLAT = COS(ALAT*RDCONV)
      SINLAT = SIN(ALAT*RDCONV)
      TANDEC(I) = SINDEC(I)/COSDEC(I)
      TANLAT = SINLAT/COSLAT
      DAYHRS(I) = 7.5*ACOS(-TANDEC(I)*TANLAT)
      FDAY(I) = DAYHRS(I)/24
      CNIGHT=AGL/((RGL*NCOV)+RINS)
      C(I)=CG*FDAY(I)+(1-FDAY(I))*CNIGHT
      B(I)=3.6*(2.8+3*WIND(I))*33.34
      C52=(VOL*1.204*1.012*INF)
      C5(I)=(C(I)*(A+B(I)))/(A+B(I)+C(I))+C52
      C1=AW*KW/THW
      CH1=29.8*AW
      C21=(C1*CH1)/(C1+CH1)
C
C  Simplified network
C
      C19=(R15+R16+R17)/(R15*R16)
      R18=(R15*R17)/(R15+R16+R17)
      R20(I)=1/C5(I)+R18
      C20(I)=1/R20(I)
      C22(I)=C19/(C20(I)+C19)
      CA(I)=(C20(I)*C19)/(C20(I)+C19)
      CB(I)=(C21*C20(I)+C21*C19)/(C20(I)+C19)
```

```
C
C  Combined absorbed solar radiation
C
      S(I)=SW(I)+C22(I)*SF(I)
      NU(I)=S(I)+N(I)*CA(I)*TA(I)+N(I)*CB(I)*TR
      TW(I)=NU(I)/((CA(I)+CB(I))*N(I))
      QIN(I)=(TW(I)-TR)*N(I)*CB(I)
      QIN(I)=QIN(I)/GJ
      QT=QT+QIN(I)
C
C  Critical radiation level
C
      IF((TR-TA(I)) .LT. 0) THEN
      IC(I)=0
      GO TO 110
      ELSE
C  .
C Transmittance-absorptance product
C
      TAU(I)=S(I)/QRAD(I)
      A1(I)=(TR-TA(I))/(TAU(I)*AGL)
      A2(I)=UA*(1+(CA(I)/CB(I)))
      A3(I)=CA(I)
      IC(I)=A1(I)*(A2(I)+A3(I))
      END IF
C
C  Calculation of PHIBAR
C
110   CALL BPHI(H(I),IC(I),I,ALAT,RHO,PHID(I))
C
C  Determination of QDUMP
C
      QD(I)=(CB(I)*S(I)*PHID(I))/(CA(I)+CB(I))
C
C  Total load
C
C     Monthly load if the sunspace were adiabatic
C
      LA(I)=UA*DD(I)*24
C      LA(I)=LA(I)/GJ
C
C     Monthly average load through the sunspace
C
      LW(I)=(CA(I)*CB(I)*DD(I)*24)/(CA(I)+CB(I))
C
      L(I)=LW(I)+LA(I)
C
C     QS
C
```

```
      QS(I)=LW(I)+QIN(I)*GJ
C
C     QAUX FOR INFINITE CAPACITANCE BUILDING
C
      QI(I)=LA(I)-QIN(I)*GJ
      IF( QI(I).LT. 0) QI(I)=0
      IF( DD(I).EQ. 0) THEN
      FI(I)=1.
      FZ(I)=1.
      GO TO 400
      END IF
      FI(I)=1-(QI(I)/L(I))
      IF(FI(I) .LT. 0) FI(I)=0
C
C     QAUX FOR ZERO CAPACITANCE BUILDING
C
      QZ(I)=LA(I)-QIN(I)*GJ+QD(I)
      IF ( QZ(I).LT. 0) QZ(I)=0
      FZ(I)=1-(QZ(I)/L(I))
      IF(FZ(I) .LT. 0) FZ(I)=0
C
C   The 2 dimensionless parameters
C
      EW(I)=RCP*(THW**2)*QIN(I)*GJ/(2*KW*24)
      EH(I)=CAP*DELT*DA(I)
      G=0.0471
      IF(QD(I) .EQ. 0) THEN
      Y(I)=20
      GO TO 400
      END IF
      Y(I)=(EH(I)+G*EW(I))/QD(I)
      FI2(I)=(QIN(I)*GJ+LW(I))/L(I)
C
400   CONTINUE
      QZT=QZT+QZ(I)
      QD(I)=QD(I)/GJ
      L(I)=L(I)/GJ
      QS(I)=QS(I)/GJ
      QI(I)=QI(I)/GJ
      LA(I)=LA(I)/GJ
      LW(I)=LW(I)/GJ
C
C  READ TRNSYS RESULTS
C
      READ(29,430)QAUX(I)
430   FORMAT(T31,E9.3)
      QAUX(I)=QAUX(I)/GJ
C
C  Calculation of the solar fraction
```

```
C
      AB(I)=(1-EXP(-0.144*Y(I)))
      IF(AB(I) .LT. 0) AB(I)=0
      P(I)=AB(I)**0.53
      IF(L(I) .EQ. 0) THEN
      SFR(I)=1.
      GO TO 455
      END IF
      IF(FI2(I) .LT. 0) FI2(I)=0
      CURVE(I)=(1-(EXP(FI2(I)*(-1.26))))*0.88
      SFR(I)=CURVE(I)*(1-P(I))+P(I)*FI2(I)
      SFR(I)=AMIN1(SFR(I),1.0)
455   QAUXD(I)=L(I)*(1-SFR(I))
      AQAUXD=AQAUXD+QAUXD(I)
C
C Printing of the results
C
      WRITE(26,460)AMN(I),PHID(I),L(I),QS(I),
     @FI2(I),Y(I),QAUXD(I),QAUX(I)
460   FORMAT(A5,2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,
     @2X,F8.3,2X,F8.3,6X,F7.3)
C
500   CONTINUE
C
      WRITE(26,660)AQAUXD
660   FORMAT(/,'ANNUAL',47X,F9.3)
      STOP
      END
```

B.2. SUBROUTINES

Subroutine RAD

Call Statement:

```
Call RAD (MN,H,ALAT,AZMTH,RHO,NCOV,RI,XL,HGT,WD,HOR,VER,XLN,
    RADI,XKT,RBAR3,RN,GN,SFRAC,HT1,HT2).
```

Passed Arguments:

MN: month

H: monthly average daily horizontal radiation (KJ/m^2)

ALAT: latitude (degrees)

AZMTH: azimuth, as written must be zero

RHO: ground reflectance

NCOV: number of glazing sheets

RI: refractive index of the glazing

XKL: extinction coefficient of the glazing (per sheet)

HGT: sunspace wall height (m)

WD: sunspace floor width (m)

HOR: horizontal distance from the wall to the intersection of the glazing planes (m)

VER: vertical distance from the floor to the intersection of the glazing planes (m)

XLN: sunspace width (m)

Returned Arguments:

RADI: matrix with incident radiation values for the monthly average day (KJ); 1: wall, 2: floor; 3: glazing

XKT: monthly average daily clearness index

RBAR3: ratio of daily incident radiation on a vertical surface to that on a horizontal surface

RN: ratio of incident radiation on a vertical surface to that on a horizontal surface at noon of the average day

GN: intensity of radiation on a vertical surface at noon on the average day (KJ/m^2)

SFRAC: fraction glazing that is opaque to solar radiation

HT1: incident radiation on the upper glazing (KJ/m^2) for the monthly average day

HT2: incident radiation on the lower glazing (KJ/m^2) for the monthly average day

Subroutine RAD uses function TALF

```
C-----------------------------------------------------
C   THIS SUBROUTINE CALCULATES THE MONTHLY AVERAGE
C   RADIATION ON THE TWO SUNSPACE GLAZING SURFACES
C   AND THE AMOUNT OF THIS RADIATION THAT
C   STRICKS THE WALL AND THE FLOOR OF THE SUNSPACE.
C   THE RADIATION IS BROKEN INTO BEAM AND DIFFUSE
C   COMPONENTS AND SEPERATE GLAZING TRANSMITTANCES
C   ARE USED.  FOR INFORMATION ON THE TILTED
C   RADIATION AND THE MONTHLY AVERAGE TRANSMITTANCES,
C   SEE KLIEN, 'AN ALGORYTHM FOR CALCULATING
C   MONTHLY-AVERAGE RADIATION ON INCLINED SURFACES'
C   AND 'CALCULATION OF THE MONTHLY-AVERAGE
C   RANSMITTANCE-ABSORBTANCE PRODUCT RATIO',
C   SOLAR ENERGY
C-----------------------------------------------------
      SUBROUTINE RAD(MN,H,ALAT,AZMTH,RHO,NG,RI,XKL
     2 ,HGT,WD,HOR,VER,XLN,RADI,XKT,RBAR3,RN,GN,SFRAC,
     .HT1,HT2)
      DIMENSION DAY(12),FDU(3),FDL(3),BU(3),BL(3),
     . GBRAD(3),HBRAD(3),HDRAD(3),RADI(3),BEAM(3),
     .DIFF(3)
     .,UB(3),LB(3),BEAMU(3),BEAML(3)
      DATA DAY/17.,47.,75.,105.,135.,162.,198.,228.,
     .258.,288.,
     1   318.,344./
      DATA RDCONV/0.0174533/,PI/3.1415927/
      DATA IDELT/12/,SC/4871./
C.
      WRITE(3,*)'H =',H
      AFL=WD*XLN
      AW=HGT*XLN
      VC=HGT-VER
      HC=HOR
      XUG=SQRT(VC**2+HOR**2)
      AUG=XUG*XLN
      XLG=SQRT((WD-HOR)**2+VER**2)
      ALG=XLG*XLN
      XAR=VER*HOR+((WD-HOR)*VER+HOR*VC)/2.
      AGL=2.*XAR+AUG+ALG
C      AGL=AUG+ALG
      BETA=0.0
      PHI=1.570796
      IF((WD-HOR).GT.0.)BETA=ATAN(VC/(WD-HOR))
      IF(HOR.GT.0.)PHI=ATAN(VER/HOR)
      SLOPE1=0.0
       SLOPE2=1.570796/RDCONV
      IF(HC.GT.0.0) SLOPE1=ATAN(VC/HC)/RDCONV
```

```
      IF((WD-HOR).GT.0.0) SLOPE2=ATAN(VER/(WD-HOR))
     ./RDCONV
      SLOPE3=90.
      DECL = 23.45*SIN((284.+DAY(MN))/365.*2.0*PI)
      DECL = SIGN(AMIN1(ABS(DECL),89.0-ABS(ALAT)),DECL)
      COSLP1 = COS(SLOPE1*RDCONV)
      SINSL1 = SIN(SLOPE1*RDCONV)
      COSLP2 = COS(SLOPE2*RDCONV)
      SINSL2 = SIN(SLOPE2*RDCONV)
      COSLP3 = COS(SLOPE3*RDCONV)
      SINSL3 = SIN(SLOPE3*RDCONV)
      IF(ABS(AMOD(AZMTH,90.0)) .LT. 0.001)
      AZMTH = AZMTH + 0.001
      COSAZM = COS(AZMTH*RDCONV)
      SINAZM = SIN(AZMTH*RDCONV)
      TANAZM = SINAZM/COSAZM
      SINLAT = SIN(ALAT*RDCONV)
      COSLAT = COS(ALAT*RDCONV)
      TANLAT = SINLAT/COSLAT
      SINDEC = SIN(DECL*RDCONV)
      COSDEC = COS(DECL*RDCONV)
      TANDEC = SINDEC/COSDEC
      COSWS = -TANDEC*TANLAT
      WS = ACOS(COSWS)
      SINWS = SIN(WS)
      ECC = 1.0+0.033*COS(2.0*PI*DAY(MN)/365.)
      HO = 24.0/PI*ECC*SC*(COSLAT*COSDEC*SINWS+WS
     .*SINLAT*SINDEC)
      H = AMIN1(H,HO)
      XKT = H/HO
C  ERBS MONTHLY-AVERAGE NON-SEASONAL DIFFUSE CORRELATION
      DRF=1.317-3.023*XKT+3.372*XKT*XKT-1.769*XKT*XKT*XKT
      A = 0.409+0.5016*SIN(WS-1.047)
      B = 0.6609-0.4767*SIN(WS-1.047)
      DIAG1=SQRT(WD**2+HGT**2)
      DIAG2=SQRT((WD-HOR)**2+VER**2)
C      VIEW FACTORS FOR DIFFUSE RADIATION -OLD DFRACT
      FDU(1)=(XUG+HGT-DIAG2)/(XUG*2.)
      FDU(2)=(DIAG1+DIAG2-HGT-XLG)/(2.*XUG)
      FDU(3)=1.-FDU(1)-FDU(2)
      FDL(1)=(DIAG1+DIAG2-XUG-WD)/(2.*XLG)
      FDL(2)=(WD+XLG-DIAG2)/(2.*XLG)
      FDL(3)=1.-FDL(1)-FDL(2)
C.  THE A AND B COEFFICIENTS ARE FOR A CURVE FIT TO THE
C   HOURLY
C.  TO DAILY TOTAL RADIATION GIVEN BY COLLARES-PEREIRA
C   AND RABL.
C.  DETERMINE RECEIVER VIEW FACTORS
C   AND TRANSMITTANCE-ABSORPTANCE
```

```
C.  PRODUCT RATIOS FOR DIFFUSE AND
C   GROUND REFLECTED RADIATION
C  FLAT PLATES
      FSKY1 = (1.+COSLP1)/2.
      FGND1 = (1.-COSLP1)/2.
      ROHD=-1.
      TADR = TALF(NG,60.,XKL,RI,1.,ROHD)
      FSKY2 = (1.+COSLP2)/2.
      FGND2 = (1.-COSLP2)/2.
      FSKY3 = (1.+COSLP3)/3.
      FGND3 = (1.-COSLP3)/3.
8     DELT = 2.*WS/FLOAT(IDELT)
      HRSTP=DELT*12./PI
      HB = 0.
      HD = 0.
      HBTT1 = 0.
      HBT1 = 0.
      HBTT3 = 0.
      HBT3 = 0.
      HBTTA1 = 0.
      RBBAR1 = 0.
      TABAR1 = 0.
      HBTT2 = 0.
      HBT2 = 0.
      HBTTA2 = 0.
      RBBAR2 = 0.
      TABAR2 = 0.
      IFLAG=0
      DO 73 I=1,3
      UB(I)=0.0
      LB(I)=0.0
73    HBRAD(I)=0.0
      IF(WS .LT. 0.0001) GO TO 110
      OMEGA = WS + DELT/2.
C.  DETERMINE BEAM RADIATION COMPONENTS
C   USING NUMERICAL
C.  INTEGRATION OVER AN AVERAGE DAY
      DO 75 J = 1,IDELT
      OMEGA = OMEGA - DELT
74    IF(IFLAG.EQ.1) OMEGA=0.
      COSHR = COS(OMEGA)
      SINHR = SIN(OMEGA)
      COSTZ = COSLAT*COSDEC*COSHR+SINLAT*SINDEC
      IF(COSTZ .LT. 0.0001) GO TO 75
C.  COSTZ IS THE COSINE OF THE ANGLE OF BEAM RADIATION
C.  INCIDENT
C.  ON A HORIZONTAL SURFACE
C.
```

```
      SINTZ = SIN(ACOS(COSTZ))
      SAZM = 0.0
      IF(SINTZ .LT. 0.0001) GO TO 10
      SINSZM = COSDEC*SINHR/SINTZ
      SAZM = ASIN(SINSZM)/RDCONV
C  DETERMINE IF THE ABSOLUTE VALUE OF THE SOLAR AZIMUTH
C  IS GREATER THAN 90 DEGREES BY COMPARING THE HOUR
C  ANGLE WITH THE HOUR ANGLE AT WHICH THE SOLAR AZIMUTH IS
C  +/- 90 DEGREES
      CWEW = TANDEC/TANLAT
      CWEW = SIGN(AMIN1(ABS(CWEW),1.),CWEW)
      WEW = PI
      IF(ALAT*(DECL-ALAT) .LE. 0.0) WEW = ACOS(CWEW)
      IF((ABS(OMEGA)-ABS(WEW))*ALAT*(DECL-ALAT) .LE. 0.)
     .        SAZM = SIGN(180.,SAZM) - SAZM
C  FLAT PLATES
10    COSTT1 = COSTZ*COSLP1+SINTZ*SINSL1
     .*COS((SAZM-AZMTH)*RDCONV)
      COSTT2 = COSTZ*COSLP2+SINTZ*SINSL2
     .*COS((SAZM-AZMTH)*RDCONV)
      COSTT3 = COSTZ*COSLP3+SINTZ*SINSL3
     .*COS((SAZM-AZMTH)*RDCONV)
      IF(COSTT1 .LT. 0.0001) GO TO 70
      THETA1 = ACOS(COSTT1)/RDCONV
      TABR1 = TALF(NG,THETA1,XKL,RI,1.,ROHD)
70    RB1 = AMAX1(COSTT1/COSTZ,0.0)
      IF(COSTT2 .LT. 0.0001) GO TO 71
      THETA2 = ACOS(COSTT2)/RDCONV
      TABR2 = TALF(NG,THETA2,XKL,RI,1.,ROHD)
71    RB2 = AMAX1(COSTT2/COSTZ,0.0)
       RB3 = AMAX1(COSTT3/COSTZ,0.0)
      RDIF = PI/24.0*(COSHR-COSWS)/(SINWS-WS*COSWS)
      IF (RDIF.LT.0.0) RDIF = 0.0
      RT = RDIF*(A+B*COSHR)
      IF (RT.LT.0.0) RT = 0.
      GD = RDIF*DRF
      GB = (RT-GD)
C.  RDIF IS THE AVERAGE HOURLY TO DAILY DIFFUSE
C   RADIATION RATIO.
C.  RT IS THE AVERAGE HOURLY TO DAILY TOTAL
C   RADIATION RATIO
      GBT1 = GB*RB1
      GBTTA1 = GBT1*TABR1
      HBTT1 = HBTT1+GBT1
      HBT1 =HBT1+GBT1
      HBTTA1 = HBTTA1+GBTTA1
      GBT2 = GB*RB2
      GBTTA2 = GBT2*TABR2
      HBTT2 = HBTT2+GBT2
```

```
      HBT2 =HBT2+GBT2
      HBTTA2 = HBTTA2+GBTTA2
      GBT3 = GB*RB3
      HBTT3 = HBTT3+GBT3
      HBT3 =HBT3+GBT3
      HB = HB + GB
      HD = HD + GD
      TSE=ATAN((SINTZ/COSTZ)*COS(SAZM*RDCONV))
      DO 1950 I=1,3
      BU(I)=0.0
1950  BL(I)=0.0
      IF(TSE.GE.0.0) GOTO 2100
      ANGCK=TSE+1.5707963
      IF(ANGCK.GE.PHI)THEN
      BU(2)=1.
      BL(2)=1.
      ELSE
      WP=HGT/TAN(ANGCK)
      IF(WP.GE.WD) THEN
      BU(3)=1.
      ELSE
      CP=VER/TAN(ANGCK)
      OS=CP-HOR
      SIS=WD-WP
      BU(2)=SIS/(SIS+OS)
      BU(3)=OS/(SIS+OS)
      ENDIF
      ENDIF
      GOTO 2200
2100  FP=(WD-HOR)-VER*TAN(TSE)
      IF(FP.LT.0.0) THEN
      FP=-FP
      BU(1)=1.
      BL(1)=FP/(FP+WD)
      BL(2)=1.-BL(1)
      ELSE
      BL(2)=1.
      WP=FP/TAN(TSE)
      BU(2)=WP/(WP+HGT)
      BU(1)=1.-BU(2)
      ENDIF
2200  DO 72 I=1,3
      GBRAD(I)=GBTTA1*BU(I)*AUG+GBTTA2*BL(I)*ALG
      BEAMU(I)=GBTTA1*BU(I)*AUG
      BEAML(I)=GBTTA2*BL(I)*ALG
      UB(I)=UB(I)+BEAMU(I)
      LB(I)=LB(I)+BEAML(I)
72    HBRAD(I)=HBRAD(I)+GBRAD(I)
```

```
C      WRITE(3,*)' GBTTA1 =',GBTTA1
C      WRITE(3,*)' BU(2) =',BU(2)
C      WRITE(3,*)' BL(2) =',BL(2)
C      WRITE(3,*)' BEAMU = ',BEAMU(2)
C      WRITE(3,*)' BEAML = ',BEAML(2)
C      WRITE(3,*)' HBRAD =',HBRAD(2)
      IF(IFLAG.EQ.1) GOTO 130
75    CONTINUE
C.
110   IF(HB .GT. 0.) RBBAR1 = HBTT1/HB
      RBAR1 = (1.0-DRF)*RBBAR1+DRF*(1.+COSLP1)/2.
     .+RHO*(1.-COSLP1)/2.
      HT1= H*RBAR1
      IF(HT1 .GT. 0.) TABAR1 = (HBTTA1 + HD*FSKY1*TADR
     .  + RHO*(HB+HD)*FGND1*TADR)/(HBT1+HD*FSKY1+
     .RHO*(HB+HD)*FGND1)
      IF(HB .GT. 0.) RBBAR2 = HBTT2/HB
      RBAR2 = (1.0-DRF)*RBBAR2+DRF*(1.+COSLP2)/2.
     .+RHO*(1.-COSLP2)/2.
      IF(HB .GT. 0.) RBBAR3 = HBTT3/HB
      RBAR3 = (1.0-DRF)*RBBAR3+DRF*(1.+COSLP3)/2.
     .+RHO*(1.-COSLP3)/2.
      HT2 = H*RBAR2
      IF(HT2 .GT. 0.) TABAR2 = (HBTTA2 + HD*FSKY2*TADR
     .  + RHO*(HB+HD)*FGND2*TADR)/(HBT2+HD*FSKY2+
     .RHO*(HB+HD)*FGND2)
      HDS1=DRF*FSKY1+RHO*FGND1
      HDS2=DRF*FSKY2+RHO*FGND2
      DO 120 I=1,3
      HBRAD(I)=HBRAD(I)*HRSTP
      UB(I)=UB(I)*HRSTP
      LB(I)=LB(I)*HRSTP
      HDRAD(I)=TADR*(HDS1*FDU(I)*AUG+HDS2*FDL(I)*ALG)
C      READ(17,460)DAY(I)
C 460   FORMAT(F3.0)
      BEAM(I)=H*HBRAD(I)
      UB(I)=H*UB(I)
      LB(I)=H*LB(I)
      DIFF(I)=H*HDRAD(I)
     IN  RADI(I)=(HBRAD(I)+HDRAD(I))*H
120   RADI(I)=RADI(I)*(1.-SFRAC)
      IFLAG=1
      GOTO 74
130   CONTINUE
      RN=(GBT3+GD*FSKY3+RT*RHO*FGND3)/RT
      GN=RN*RT*H
C      WRITE(3,*)'RADI(I) =',RADI
C      WRITE(3,*)' BEAM =',BEAM
C      WRITE(3,*)' DIFFUSE =',DIFF
```

```
C       WRITE(3,*)' BEAM2U =',UB
C       WRITE(3,*)' BEAM2L =',LB
C       WRITE(3,*)' BU(2) =',BU
C       WRITE(3,*)' BL(2) =',BL
        RETURN
        END
```

Function TALF

TALF(NG,THETA,XKL,RI,1.,RHOD)

Arguments:

NG: number of glazing covers

THETA: angle of incidence

XKL: extinction coefficient of the glazing (per sheet)

RI: refractive index of the glazing

RHO: reflectivity of the glazing to diffuse radiation; if RHO < 0 the function will compute RHO using an angle of incidence of 60 degrees

Function TALF is taken from TRNSYS (10).

```
      FUNCTION TALF(N,THETA,XKL,REFRIN,ALPHA,RHOD)
      DIMENSION R(2),T(2),RHO(2),TAU(2),REF(2)
C.    THIS FUNCTION SUBPROGRAM CALCULATES THE
C     TRANSMITTANCE-ABSORPTANCE
C.    PRODUCT FOR A SOLAR COLLECTOR WITH N COVERS,
C     A REFRACTIVE INDEX
C.    REFRIN, A KL VALUE OF XKL, AND A FLAT
C     BLACK ABSORBER SURFACE.  THE
C.    INCIDENT RADIATION IS AT AN ANGLE THETA.
C     FOR THE FIRST CALL TO THIS
C.    FUNCTION BY EACH UNIT, RHOD MUST BE LESS THAN ZERO.
      DATA PI/3.1415927/
      IF(N.GE.1) GO TO 5
      TAUALF=ALPHA
      RETURN
5     IF(RHOD.GT.0.) GO TO 40
      THETA1=PI/3.
10    THETA2=ASIN(SIN(THETA1)/REFRIN)
      R(1)=SIN(THETA2-THETA1)
      R(2)=SIN(THETA2+THETA1)
      T(1)=R(1)/COS(THETA2-THETA1)
      T(2)=R(2)/COS(THETA2+THETA1)
      RHO(1)=R(1)*R(1)/R(2)/R(2)
      RHO(2)=T(1)*T(1)/T(2)/T(2)
      TABS=EXP(-XKL/COS(THETA2))
      DO 30 J=1,2
      T(J)=TABS*(1.-RHO(J))**2/(1.-TABS*TABS*
     .RHO(J)*RHO(J))
      R(J)=RHO(J)*(1.+TABS*T(J))
      TAU(J)=T(J)
      REF(J)=R(J)
      IF(N.EQ.1) GO TO 30
      DO 20 I=2,N
      TAU(J)=TAU(J)*T(J)/(1.-REF(J)*R(J))
      REF(J)=REF(J)+TAU(J)*TAU(J)*R(J)/(1.-REF(J)*R(J))
20    CONTINUE
30    CONTINUE
      IF(RHOD.GT.0.) GO TO 50
C..INITIALIZE RHOD.
      RHOD=(REF(1)+REF(2))/2.
40    THETA1=THETA*PI/180.
      IF(THETA1.LT.0.001) THETA1=0.001
      GO TO 10
50    TALF=(TAU(1)+TAU(2))/2.*ALPHA/(1.-(1.-ALPHA)*RHOD)
      RETURN
      END
```

Subroutine TWBAR

Call Statement:

Call TWBAR (HGT,WD,HOR,VER,XLN,NG,RI,XKL,RGL,SFRAC,EGL,EWL,
EFL,THW,THF,CNW,CNF,RGR,ESW,ESF,HS,HR,HA,AIRCH,RADI,
TABAR,TGRBAR,TRMBAR,TWNS,XLS,TWLBAR,QIN,ABWL,ABFL).

Passed Arguments:

HGT: sunspace wall height (m)

WD: sunspace floor width (m)

HOR: horizontal distance from the wall to the intersection of the glazing planes (m)

VER: vertical distance from the floor to the intersection of the glazing planes (m)

XLN: length of the sunspace (m)

NG: number of glazing sheets

RI: refractive index of the glazing

XKL: extinction coefficient of the glazing (per sheet)

RGL: R-value of the glazing system (m^2-°C/W)

SFRAC: fraction of the glazing planes which is opaque to solar radiation

EGL: infrared emittance of the glazing system

EWL: infrared emittance of the wall

EFL: infrared emittance of the floor

THW: wall thickness (m)

THF: floor thickness (m)

CNW: wall thermal conductivity (W/m-°C)

CNF: floor thermal conductivity (W/m-°C)

RGR: R-value from the bottom of the floor to the ground

ESW: wall solar absorptance

ESF: floor solar absorptance

HS: convection coefficient from the glazing, wall and floor to the sunspace air (W/m^2-°C)

HR: heat transfer coefficient from the wall to the building (W/m^2-°C)

HA: convection coefficient from the glazing to ambient (W/m^2-°C)

AIRCH: sunspace infiltration air changes per hour

RADI: matrix with incident radiation values for the monthly average day (KJ); 1: wall, 2: floor, 3: glazing

TABAR: monthly average ambient temperature (°C)

TGRBAR: monthly average ground temperature (°C)

TRMBAR: monthly average building temperature (°C)

Returned Arguments:

TWNS: monthly average wall temperature if solar radiation equals zero (°C)

XLS: heating load on the building due to the sunspace if solar radiation equals zero (KJ/day)

TWLBAR: monthly average wall temperature (°C)

QIN: monthly average sunspace energy delivery (KJ/day)

ABWL: monthly average solar radiation absorbed by the wall (KJ/day)

ABFL: monthly average solar radiation absorbed by the floor (KJ/day)

TWBAR uses subroutines TALF, FHAT, GAUSS.

```
C---------------------------------------------
C  SUBROUTINE TO CALCULATE THE ABSORBED
C  SOLAR RADIATION ON THE FLOOR AND THE
C  WALL OF THE SUNSPACE
C
C------------------------------------------------
      SUBROUTINE TWBAR(HGT,WD,HOR,VER,XLN,NG,RI,
     .XKL,RGL,SFRAC,EGL
     . ,EWL,EFL,THW,THF,CNW,CNF,RGR,ESW,ESF,HS,
     .HR,HA,AIRCH,RADI
     . ,TABAR,TGRBAR,TRMBAR,TWNS,XLS,TWLBAR,
     .QIN,ABWL,ABFL)
      DIMENSION FHATS(3,3),RADI(3),QSRAD(3),ES(3),
     .ROH(3),EI(3)
     2 ,FHATI(3,3),A(20,20)
      DATA WKJDCV/86.4/,SIG/5.67E-08/
      AZMTH=0.0
      ES(1)=ESW
      ES(2)=ESF
      ROHD=-1
      TAUD=TALF(NG,60.,XKL,RI,1.,ROHD)
      ES(3)=1.-ROHD
      DO 15 I=1,3
15    ROH(I)=1.-ES(I)
      GLLOW=SQRT(VER**2+(WD-HOR)**2)
      GLUP=SQRT((HGT-VER)**2+HOR**2)
      END=HOR*VER+0.5*HOR*(HGT-VER)+0.5*VER*(WD-HOR)
      AGL=(GLLOW+GLUP)*XLN+2.*END
      CALL FHAT(HGT,WD,GLLOW,GLUP,ES,FHATS)
      EI(1)=EWL
      EI(2)=EFL
      EI(3)=EGL
C   INITIALIZE 4TBAR**3 FOR ALL IR C'S
      TB8=1.08E08
      TB9=TB8
      TB7=TB8
      TB3=TB8
      TGL=300.
      TAIR=TGL
      TFL=TGL
      TWL=TGL
      C6=HS*WKJDCV*AGL
      C5=HS*WKJDCV*WD*XLN
      C4=HS*WKJDCV*HGT*XLN
      C1=WKJDCV/(1./(HR*HGT*XLN)+THW/(CNW*HGT*XLN))
      C10=AIRCH*END*XLN*1.204*1.012*24
      C2=WKJDCV/(THF/(CNF*WD*XLN)+RGR/(WD*XLN))
```

```
      CALL FHAT(HGT,WD,GLLOW,GLUP,EI,FHATI)
      TA=TABAR+273.
      TRM=TRMBAR+273.
      TGR=TGRBAR+273.
      DO 76 I=1,3
76    QSRAD(I)=0.0
78    DO 80 II=1,11
C   TEMP DEPENDENT C'S
      C8=EI(3)*EI(2)*(GLLOW+GLUP)*XLN*FHATI(3,2)
     .*TB8*SIG*WKJDCV
      C9=EI(3)*EI(1)*(GLLOW+GLUP)*XLN*FHATI(3,1)
     .*TB9*SIG*WKJDCV
      HIR=EI(3)*SIG*TB3
      HTOT=HA+HIR
      C3=AGL/(RGL+1./HTOT)*WKJDCV
      C7=EI(1)*EI(2)*WD*XLN*FHATI(2,1)*TB7*SIG*WKJDCV
      A(1,1)=-(C3+C6+C8+C9)
      A(1,2)=C6
      A(1,3)=C8
      A(1,4)=C9
      A(1,5)=-C3*TA
      A(2,1)=C6
      A(2,2)=-(C4+C5+C6+C10)
      A(2,3)=C5
      A(2,4)=C4
      A(2,5)=-C10*TA
      A(3,1)=C8
      A(3,2)=C5
      A(3,3)=-(C2+C5+C7+C8)
      A(3,4)=C7
      A(3,5)=-QSRAD(2)-C2*TGR
      A(4,1)=C9
      A(4,2)=C4
      A(4,3)=C7
      A(4,4)=-(C1+C4+C7+C9)
      A(4,5)=-QSRAD(1)-C1*TRM
      CALL GAUSS(4,5,A)
      TGL=A(1,5)
      TAIR=A(2,5)
      TFL=A(3,5)
      TWLN=A(4,5)
      TGLO=TGL-C1*RGL/(AGL*WKJDCV)*(TGL-TA)
      TB3=(TGLO**2+TA**2)*(TGLO+TA)
      TB8=(TGL**2+TFL**2)*(TGL+TFL)
      TB9=(TGL**2+TWLN**2)*(TGL+TWLN)
      TB7=(TWLN**2+TFL**2)*(TWLN+TFL)
      IF(ABS(TWLN-TWL).LT.0.001)GOTO 85
80    TWL=TWLN
85    QIN=C1*(TWL-TRM)
```

```
      TGLBAR=TGL-273.
      TSSBAR=TAIR-273.
      TFLBAR=TFL-273.
      TWLBAR=TWL-273.
      ABWL=QSRAD(1)
      ABFL=QSRAD(2)
      IF(QSRAD(1).GT.0.0)RETURN
      XLS=C1*(TRM-TWL)
      TWNS=TWLBAR
      ES(3)=0.0
      DO 75 I=1,3
      SQSFHR=0.0
      DO 70 J=1,3
70    SQSFHR=SQSFHR+RADI(J)*ROH(J)*FHATS(J,I)
75    QSRAD(I)=ES(I)*(RADI(I)+SQSFHR)
      GOTO 78
      END
```

Subroutine GAUSS

Call Statement:

Call GAUSS (K,L,A)

Passed Arguments:

K: number of rows in the coefficient matrix

L: number of columns in the coefficient matrix

A: a K × L augmented coefficient matrix containing the coefficients of the linear equations, see the example below

Example: To solve the following system of equations

$$5A + 2B + 3C = 1$$

$$2A + B + 8C = 10$$

$$3A + 4B + C = 3$$

the augmented A matrix is

5	2	3	1
2	1	8	10
3	4	1	3

the solution is returned in the last column

A = (1,4)   B = (2,4)   C = (3,4)

```
C--------------------------------------
C
      SUBROUTINE GAUSS(K,L,A)
C
C--------------------------------------
      DIMENSION M(20),N(20),A(20,20)
      IP=0
      DO 60 I=1,K
      DO 10 J=1,L
10    IF(A(I,J).NE.0.0) GOTO 20
      IF(A(I,L+1).EQ.0.0) GOTO 60
      WRITE(*,15)
15    FORMAT(' EQUATIONS ARE INCONSISTANT')
      RETURN
20    IP=IP+1
      M(IP)=I
      N(IP)=J
      DO 30 JJ=J+1,L+1
30    A(I,JJ)=A(I,JJ)/A(I,J)
      A(I,J)=1.
      IF(I.EQ.K) GOTO 60
      DO 50 II=I+1,K
      DO 40 JJ=J+1,L+1
      A(II,JJ)=A(II,JJ)-A(I,JJ)*A(II,J)
40    IF(ABS(A(II,JJ)).LT.0.00000001) A(II,JJ)=0.0
50    A(II,J)=0.0
60    CONTINUE
69    DO 80 II=1,M(IP)-1
      DO 70 JJ=N(IP)+1,L+1
      A(II,JJ)=A(II,JJ)-A(II,N(IP))*A(M(IP),JJ)
70    IF(ABS(A(II,JJ)).LT.0.00000001) A(II,JJ)=0.0
80    A(II,N(IP))=0.0
      IP=IP-1
      IF(IP.EQ.1) RETURN
      GOTO 69
      END
```

Subroutine FHAT

Call Statement:

Call FHAT (XLW,XLFL,XLG,XUG,ES,FHATS)

Passed Arguments:

XLW: height of the wall (m)

XLFL: width of the floor (m)

XLG: length of the lower glazing (m)

XUG: length of the upper glazing (m)

ES: a matrix containing the emittance (or absorptance) of the surfaces; 1: wall, 2: floor, 3: glazing

Returned Arguments:

FHATS: a 3×3 matrix containing $\hat{F}$ values

```
C-----------------------------------------------
C
      SUBROUTINE FHAT(XLW,XLFL,XLG,XUG,ES,FHATS)
C
C-----------------------------------------------
      DIMENSION ES(3),FHATS(3,3),F(3,3),RSR(3,3),
     .RSRIV(3,3)
      DIAG1=SQRT(XLFL**2+XLW**2)
      F(1,1)=0.0
      F(2,2)=0.0
      F(1,2)=(XLW+XLFL-DIAG1)/(2.*XLW)
      F(2,1)=F(1,2)*XLW/XLFL
      F(1,3)=1.-F(1,2)
      F(3,1)=F(1,3)*XLW/(XUG+XLG)
      F(2,3)=1.-F(2,1)
      F(3,2)=F(2,3)*XLFL/(XUG+XLG)
      F(3,3)=1.-F(3,1)-F(3,2)
      DO 1400 I=1,3
      DO 1400 J=1,3
      RSR(I,J)=(ES(J)-1.)*F(I,J)
      FHATS(I,J)=0.0
1400    IF(I.EQ.J) RSR(I,J)=RSR(I,J)+1.
      PTRSR=RSR(1,1)*RSR(2,2)*RSR(3,3)+RSR(1,2)
     .*RSR(2,3)*RSR(3,1)+RSR
     2 (1,3)*RSR(2,1)*RSR(3,2)
      QTRSR=RSR(1,3)*RSR(2,2)*RSR(3,1)+RSR(1,2)
     .*RSR(2,1)*RSR(3,3)+RSR
     2 (1,1)*RSR(2,3)*RSR(3,2)
      DETSR=PTRSR-QTRSR
      RSRIV(1,1)=RSR(2,2)*RSR(3,3)-RSR(2,3)*RSR(3,2)
      RSRIV(1,2)=RSR(1,3)*RSR(3,2)-RSR(1,2)*RSR(3,3)
      RSRIV(1,3)=RSR(1,2)*RSR(2,3)-RSR(1,3)*RSR(2,2)
      RSRIV(2,1)=RSR(2,3)*RSR(3,1)-RSR(2,1)*RSR(3,3)
      RSRIV(2,2)=RSR(1,1)*RSR(3,3)-RSR(1,3)*RSR(3,1)
      RSRIV(2,3)=RSR(1,3)*RSR(2,1)-RSR(1,1)*RSR(2,3)
      RSRIV(3,1)=RSR(2,1)*RSR(3,2)-RSR(2,2)*RSR(3,1)
      RSRIV(3,2)=RSR(1,2)*RSR(3,1)-RSR(1,1)*RSR(3,2)
      RSRIV(3,3)=RSR(1,1)*RSR(2,2)-RSR(1,2)*RSR(2,1)
      DO 1500 I=1,3
      DO 1500 J=1,3
1500   RSRIV(I,J)=RSRIV(I,J)/DETSR
      DO 1600 I=1,3
      DO 1600 K=1,3
      DO 1600 J=1,3
1600  FHATS(I,K)=FHATS(I,K)+RSRIV(I,J)*F(J,K)
      RETURN
      END
```

Subroutine BPHI

Call Statement:

Call BPHI (H,IC,I,ALAT,RHO,PHID)

Passed Arguments:

H: monthly average daily horizontal radiation (kJ/m^2)

IC: critical radiation level (KJ/m^2-hr)

I: month

ALAT: latitude (degrees)

RHO: ground reflectance

Returned Argument:

PHID: monthly average daily unutilizability factor

Uses subroutine CLARK.

```
C-----------------------------------------------------
C
      SUBROUTINE BPHI(H,CRIT,MONTH,ALAT,RHO,PHID)
C
C-----------------------------------------------------
C  PROGRAM TO FIND THE DAILY UTILIZABILITY BY
C  CLARK'S CORRELATION.
C  FOR SLOPE ANGLE 90 DEGREES.
C  CRITICAL LEVELS IN (KJ/M2-HR)
C  B = SLOPE
C  AZMTH = AZIMUTH
C
      INTEGER B
      REAL CRIT, SLOPE, PHID
      DATA SLOPE/90.0/
      AZMTH = 0.0
      CALL CLARK(SLOPE,CRIT,H,AZMTH,PHID,MONTH,ALAT,RHO)
C
850   FORMAT('IC(KJ/HR-M2)',1X,4(2X,A5))
900   FORMAT(F7.1,2X,4(2X,F5.2))
C
      RETURN
      END
```

Subroutine CLARK

Call Statement:

Call CLARK (SLOPE,CRIT,H,AZMTH,PHID,MONTH,ALAT,RHO)

Passed Arguments:

SLOPE: slope (here 90°)

CRIT: critical radiation level (KJ/m^2-hr)

H: monthly average daily horizontal radiation (KJ/m^2)

AZMTH: azimuth (here equals 0)

MONTH: month

ALAT: latitude (degrees)

RHO: ground reflectance

Returned Argument:

PHID: monthly average daily unutilizability factor

Uses subroutine RAD2 and function PHIBAR.

```
C--------------------------------------------------
C
      SUBROUTINE CLARK(SLOPE,CRIT,H,AZMTH,PHID,
     @MN,ALAT,RHO)
C
C--------------------------------------------------
      CHARACTER*1 YN
      DIMENSION CDATA(8),G(25),SC(2)
      DATA CDATA/.9,.9,.9,.8,.7,.6,.3,.1/,XKL/.04/,
     @XIAM/.0001/,NG/2/
      DATA THETAC/13/,RI/1.53/,ICTY/127/
      DATA SC/4871.,428./
      IC=1
      CONC = 1.0
C
      PHID=0.0
      CALL RAD2(MN,H,ALAT,SLOPE,AZMTH,RHO,NG,RI,XKL,
     .  ICTY,XKT,G,XIAM,CDATA,0,SC,IC,THETAC)
      PHID=PHIBAR(MN,XKT,RHO,CRIT,G,1,0,SC)
100   RETURN
      END
```

Subroutine RAD2

Call Statement:

```
Call RAD2 (MN,H,ALAT,SLOPE,AZMTH,RHO,NG,RI,XKL,127,XKT,G,
    0.0001,.9,0,SC,IC,13)
```

Passed Arguments:

MN:	month
H:	monthly average daily horizontal radiation (KJ/m^2)
ALAT:	latitude (degrees)
SLOPE:	slope (degrees)
AZMTH:	azimuth
RHO:	ground reflectance
NG:	number of glazing sheets
RI:	refractive index of the glazing
XKL:	extinction coefficient of the glazing (per sheet)
SC:	solar constant
IC:	concentrating ratio (as written is one)

Returned Arguments:

XKT:	monthly average daily clearness index
G:	array of angles: declination, latitude, azimuth, etc.

```
C-----------------------------------------------
C
C.  THIS SUBROUTINE WILL CALCULATE RBAR AND TABAR,
C.  THE MONTHLY-AVERAGE
C.  RATIO OF RADIATION ON A TILTED SURFACE TO THAT
C.  ON A HORIZ. SURFACE
C.  AND THE MONTHLY-AVERAGE TRANSMITTANCE-ABSORPTANCE
C.  PRODUCT RATIO.
C.  (SEE KLEIN, 'AN ALGORITHM FOR CALCULATING
C.  MONTHLY-AVERAGE RADIATION ON INCLINED SURFACES'
C.  SUBMITTED TO SOLAR ENERGY, AND
C.  'CALCULATION OF THE MONTHLY-AVERAGE
C.  TRANSMITTANCE-ABSORPTANCE
C.  PRODUCT RATIO', SOLAR ENERGY (IN PRESS))
C
C-----------------------------------------------
      SUBROUTINE RAD2(MN,H,ALAT,SLOPE,AZMTH,RHO,NG,RI,XKL,
     .  ICTY,XKT,G,XIAM,CDATA,IALF,SC,IC,THETAC)
      DIMENSION DAY(12),G(25),CDATA(8),OPTIC(10)
C####################################################
C#  THE FOLLOWING ARRAYS ARE USED TO SAVE PERTINENT
C#  INFO ON THE ORIENTATION OF THE COLLECTOR.
C#  IF THERE IS NO CHANGE SINCE THE LAST RUN,
C#  NO CALCULATIONS ARE PERFORMED.
      DIMENSION XSL(12),XAZ(12),XRHO(12),XCDATA(8),
     .STABAR(12),SRBAR(12),
     ;           SXKT(12),SDRF(12),SHT(12),SG(25,12)
      DATA XSL/12*0./,XAZ/12*0./,XRHO/12*0./,
     .XCDATA/8*-1./,XXKL/0./
     ;     XRI/0./,NNG/1/,XXIAM/1./,NIC/1/,XTHETA/1./
C####################################################
      DATA DAY/17.,47.,75.,105.,135.,162.,198.,
     .228.,258.,288.,
     1   318.,344./
      DATA IDELT/12/,DTHETA/10./
      DATA RDCONV/0.0174533/,PI/3.1415927/
C CHECK TO SEE IF ORIENTATION OR LOCATION HAS CHANGED
      IF(NCTY.NE.ICTY) GOTO 1000
      IF(XSL(MN).NE.SLOPE) GOTO 1000
      IF(XAZ(MN).NE.AZMTH) GOTO 1000
      IF(XRHO(MN).NE.RHO) GOTO 1000
C CHECK TO SEE IF INCIDENCE ANGLE MOD'S ARE CHANGED
      IF(XXKL.NE.XKL) GOTO 1000
      IF(XRI.NE.RI) GOTO 1000
      IF(NNG.NE.NG) GOTO 1000
      IF(NIC.NE.IC) GOTO 1000
      IF(XXIAM.NE.XIAM) GOTO 1000
      IF(XTHETA.NE.THETAC) GOTO 1000
      DO 990 I=1,8
```

```
990   IF(XCDATA(I).NE.CDATA(I)) GOTO 1000
C NOTHING HAS CHANGED  -  SET OUTPUTS AND RETURN
      DO 991 I=1,25
991   G(I)=SG(I,MN)
      RBAR=SRBAR(MN)
      TABAR=STABAR(MN)
      XKT=SXKT(MN)
      DRF=SDRF(MN)
      HT=SHT(MN)
      RETURN
C
C SOMETHING HAS CHANGED -
C SAVE VALUES AND PERFORM CALC'S
C
1000  NCTY=ICTY
      XSL(MN)=SLOPE
      XAZ(MN)=AZMTH
      XRHO(MN)=RHO
      XXKL=XKL
      XRI=RI
      NNG=NG
      NIC=IC
      XXIAM=XIAM
      XTHETA=THETAC
      DO 1001 I=1,8
1001  XCDATA(I)=CDATA(I)
C.
      DECL = 23.45*SIN((284.+DAY(MN))/365.*2.0*PI)
      DECL = SIGN(AMIN1(ABS(DECL),89.0-ABS(ALAT)),DECL)
      COSSLP = COS(SLOPE*RDCONV)
      SINSLP = SIN(SLOPE*RDCONV)
      TANSLP = SINSLP/COSSLP
      IF(ABS(AMOD(AZMTH,90.0)) .LT. 0.001)
      AZMTH = AZMTH + 0.001
      END IF
      COSAZM = COS(AZMTH*RDCONV)
      SINAZM = SIN(AZMTH*RDCONV)
      TANAZM = SINAZM/COSAZM
      SINLAT = SIN(ALAT*RDCONV)
      COSLAT = COS(ALAT*RDCONV)
      TANLAT = SINLAT/COSLAT
      SINDEC = SIN(DECL*RDCONV)
      COSDEC = COS(DECL*RDCONV)
      TANDEC = SINDEC/COSDEC
      COSWS = -TANDEC*TANLAT
      WS = ACOS(COSWS)
      SINWS = SIN(WS)
      ECC = 1.0+0.033*COS(2.0*PI*DAY(MN)/365.)
      HO = 24.0/PI*ECC*SC*(COSLAT*COSDEC*SINWS+
```

```
     .WS*SINLAT*SINDEC)
      H = AMIN1(H,HO)
      XKT = H/HO
C  ERBS MONTHLY-AVERAGE NON-SEASONAL DIFFUSE CORRELATION
      DRF=1.317-3.023*XKT+3.372*XKT*XKT-1.769*XKT*XKT*XKT
      A = 0.409+0.5016*SIN(WS-1.047)
      B = 0.6609-0.4767*SIN(WS-1.047)
C.  THE A AND B COEFFICIENTS ARE FOR A CURVE FIT TO
C.  THE HOURLY TO DAILY TOTAL RADIATION
C.  GIVEN BY COLLARES-PEREIRA AND RABL.
C.  DETERMINE RECIEVER VIEW FACTORS
C.  AND TRANSMITTANCE-ABSORPTANCE
C.  PRODUCT RATIOS FOR DIFFUSE
C.  AND GROUND REFLECTED RADIATION
      OPTIC(1) = 1.0
      OPTIC(10) = 0.0
      DO 1 I = 2,9
1     OPTIC(I) = CDATA(I-1)
C
C  FLAT PLATES
C
2     WC = WS
      FSKY = (1.+COSSLP)/2.
      FGND = (1.-COSSLP)/2.
      THETAR = 89.8-0.5788*SLOPE+0.002693*SLOPE*SLOPE
      IF(NG.GT.0) GO TO 802
      TADR=OPTIC(7)
      I=0
801   I=I+1
      THETA1 = FLOAT(I-1)*DTHETA
      IF(THETAR .GT. THETA1) GO TO 801
      TARR = OPTIC(I-1) + (OPTIC(I)-OPTIC(I-1))*
     .  (THETAR-THETA1+DTHETA)/DTHETA
      GO TO 8
802   IF(XIAM.GT.0.0001 .OR. XIAM.LT.-0.0001) GO TO 3
      TALN = TAUALF(NG,0.,XKL,RI,IALF)
      TADR = TAUALF(NG,60.,XKL,RI,IALF)/TALN
      TARR = TAUALF(NG,THETAR,XKL,RI,IALF)/TALN
      GO TO 8
3     TADR = 1.0 - XIAM
      TARR = 1.0 - XIAM*(1.0/COS(THETAR*RDCONV) - 1.0)
      GO TO 8
8     DELT = 2.*WS/FLOAT(IDELT)
      HB = 0.
      HD = 0.
      HBTT = 0.
      HBT = 0.
      HTT = 0.
      HBTTA = 0.
```

```
      RBBAR = 0.
      TABAR = 0.
      IF(WS .LT. 0.0001) GO TO 110
      OMEGA = WS + DELT/2.
C.  DETERMINE BEAM RADIATION COMPONENTS USING NUMERICAL
C.  INTEGRATION OVER AN AVERAGE DAY
      DO 75 J = 1,IDELT
      OMEGA = OMEGA - DELT
      COSHR = COS(OMEGA)
      SINHR = SIN(OMEGA)
      COSTZ = COSLAT*COSDEC*COSHR+SINLAT*SINDEC
      IF(COSTZ .LT. 0.0001) GO TO 75
C.  COSTZ IS THE COSINE OF THE ANGLE OF
C.  BEAM RADIATION INCIDENT
C.  ON A HORIZONTAL SURFACE
C.
      SINTZ = SIN(ACOS(COSTZ))
      SAZM = 0.0
      IF(SINTZ .LT. 0.0001) GO TO 9
      SINSZM = COSDEC*SINHR/SINTZ
      SAZM = ASIN(SINSZM)/RDCONV
C  DETERMINE IF THE ABSOLUTE VALUE OF THE SOLAR AZIMUTH
C  IS GREATER THAN 90 DEGREES BY COMPARING THE HOUR
C  ANGLE WITH THE HOUR ANGLE AT WHICH THE SOLAR AZIMUTH
C  IS +/- 90 DEGREES
      CWEW = TANDEC/TANLAT
      CWEW = SIGN(AMIN1(ABS(CWEW),1.),CWEW)
      WEW = PI
      IF(ALAT*(DECL-ALAT) .LE. 0.0) WEW = ACOS(CWEW)
      IF((ABS(OMEGA)-ABS(WEW))*ALAT*(DECL-ALAT) .LE. 0.)
     .         SAZM = SIGN(180.,SAZM) - SAZM
9     CONTINUE
C  FLAT PLATES
10    COSTT = COSTZ*COSSLP+SINTZ*SINSLP*COS((SAZM-AZMTH)
     .*RDCONV)
      IF(COSTT .LT. 0.0001) GO TO 70
      THETA = ACOS(COSTT)/RDCONV
       IF(NG.LE.0) GO TO 50
      IF(XIAM.GT.0.0001 .OR. XIAM.LT.-0.0001) GO TO 15
      TABR = TAUALF(NG,THETA,XKL,RI,IALF)/TALN
      GO TO 70
15    THETA1 = AMIN1(THETA,60.)
      TABR = 1.0-XIAM*(1.0/COS(THETA1*RDCONV)-1.0)
      IF(THETA .GT. 60.) TABR = TABR*(3.-THETA/30.)
      GO TO 70
70    RB = AMAX1(COSTT/COSTZ,0.0)
      RDIF = PI/24.0*(COSHR-COSWS)/(SINWS-WS*COSWS)
      IF (RDIF.LT.0.0) RDIF = 0.0
      RT = RDIF*(A+B*COSHR)
```

```
      IF (RT.LT.0.0) RT = 0.
      GD = RDIF*DRF
      GB = (RT-GD)
C.  RDIF IS THE AVERAGE HOURLY TO
C.  DAILY DIFFUSE RADIATION RATIO.
C.  RT IS THE AVERAGE HOURLY
C.  TO DAILY TOTAL RADIATION RATIO
      GBT = GB*RB
      GBTTA = GBT*TABR
      HBTT = HBTT+GBT
      IF(ABS(OMEGA) .LT. WC) HBT = HBT+GBT
      IF(IC .LT. 3) GO TO 72
      GTT = GBT+GD*(1.+COS(SLP))/2.+(GB+GD)*RHO
     .*(1.-COS(SLP))/2.
      HTT = HTT+GTT
72    HBTTA = HBTTA+GBTTA
      HB = HB + GB
      HD = HD + GD
75    CONTINUE
C.
110   IF(HB .GT. 0.) RBBAR = HBTT/HB
      RBAR = (1.0-DRF)*RBBAR+DRF*(1.+COSSLP)/2.+
     .RHO*(1.-COSSLP)/2.
      IF(IC.GT.2 .AND. (HB+HD).GT.0.) RBAR=HTT/(HB+HD)
      HT = H*RBAR
      IF(HT .GT. 0.) TABAR = (HBTTA + HD*FSKY*TADR
     .  + RHO*(HB+HD)*FGND*TARR)/(HBT+HD*FSKY+
     .RHO*(HB+HD)*FGND)
      G(1) = DECL
      G(2) = SINDEC
      G(3) = COSDEC
      G(4) = TANDEC
      G(5) = ALAT
      G(6) = SINLAT
      G(7) = COSLAT
      G(8) = TANLAT
      G(9) = SLOPE
      G(10) = SINSLP
      G(11) = COSSLP
      G(12) = TANSLP
      G(13) = AZMTH
      G(14) = SINAZM
      G(15) = COSAZM
      G(16) = TANAZM
      G(17) = WS
      G(18) = SINWS
      G(19) = COSWS
      G(20) = RBBAR
      G(21) = HO
```

```
C SAVE THIS MONTHS VALUES IN CASE THEY
C CAN BE USED NEXT RUN
      DO 200 I=1,25
200   SG(I,MN)=G(I)
      SRBAR(MN)=RBAR
      STABAR(MN)=TABAR
      SXKT(MN)=XKT
      SDRF(MN)=DRF
      SHT(MN)=HT
      RETURN
      END
```

Function PHIBAR

Call Statement:

```
PHID = PHIBAR (MN,XKT,RHO,CRIT,G,1,0,SC)
```

Passed Arguments:

MN:	month
XKT:	monthly average daily clearness index
RHO:	ground reflectance
CRIT:	critical radiation level (KJ/m^2-hr)
G:	array of angles: declination, latitude, azimuth, etc.
SC:	solar constant

Returned Argument:

PHID:	monthly average daily unutilizability factor

```
C---------------------------------------------------------
C
      FUNCTION PHIBAR(MN,XKT,RHO,CRIT,G,INDEX,CRITP,SC)
C
C---------------------------------------------------------
      DIMENSION G(25),GT(12),R(12),HRKT(12),
     @DAY(12),SC(2)
C       COMMON /UNITS/ IU,SC(2)
      DATA RDCONV/0.017453293/,PI/3.1415927/,NSTEP/12/
      DATA DAY/17.,47.,75.,105.,135.,162.,198.,228.,
     @258.,288.,
     1   318.,344./,IU/1/
C
      PHIBAR=1.0
      TBAR=0.
      IF(XKT.LT.1.E-06) RETURN
      IF(INDEX.GT.1) GO TO 100
C.  READ DATA FROM G ARRAY:
      DECL=G(1)
      SINDEC=G(2)
      COSDEC=G(3)
      TANDEC=G(4)
      ALAT=G(5)
      SINLAT=G(6)
      COSLAT=G(7)
      TANLAT=G(8)
      SINSLP=G(10)
      COSSLP=G(11)
      AZMTH=G(13)
      SINAZM=G(14)
      COSAZM=G(15)
      WS=G(17)
      SINWS=G(18)
      COSWS=G(19)
C
      FSKY=(1.+COSSLP)/2.
      FGND=(1.-COSSLP)/2.
      ECC = 1.0+0.033*COS(2.0*PI*DAY(MN)/365.)
C  ERBS MONTHLY-AVERAGE NON-SEASONAL DIFFUSE CORRELATION
      DRF=1.317-3.023*XKT+3.372*XKT*XKT-1.769*XKT*XKT*XKT
      A = 0.409+0.5016*SIN(WS-1.047)
      B = 0.6609-0.4767*SIN(WS-1.047)
C.  THE A AND B COEFFICIENTS ARE FOR A
C.  CURVE FIT TO THE HOURLY
C.  TO DAILY TOTAL RADIATION
C.  GIVEN BY COLLARES-PEREIRA AND RABL.
      DO 20 I=1,NSTEP
      GT(I)=0.0
      R(I)=0.0
```

```
20    HRKT(I)=0.0
      HT=0.
      DELT=2.*WS/FLOAT(NSTEP)
      IF(WS.LT.1.E-06) RETURN
      W=-WS-DELT/2.
C  STEP THROUGH THE DAY TO DETERMINE HOURLY
C  RADIATION VALUES
      DO 50 I=1,NSTEP
      W=W+DELT
      COSHR=COS(W)
      SINHR=SIN(W)
      COSTZ=COSLAT*COSDEC*COSHR+SINLAT*SINDEC
      IF(COSTZ.LT.1.E-06) GO TO 50
C.  COSTZ IS THE COSINE OF THE ANGLE
C.  OF BEAM RADIATION INCIDENT
C.  ON A HORIZONTAL SURFACE
C.
      SINTZ = SIN(ACOS(COSTZ))
      SAZM = 0.0
      IF(SINTZ .LT. 1.E-06) GO TO 9
      SINSZM = COSDEC*SINHR/SINTZ
      SAZM = ASIN(SINSZM)/RDCONV
C  DETERMINE IF THE ABSOLUTE VALUE OF THE SOLAR AZIMUTH
C  IS GREATER THAN 90 DEGREES BY COMPARING THE HOUR
C  ANGLE WITH THE HOUR ANGLE AT WHICH THE SOLAR AZIMUTH
C  IS +/- 90 DEGREES
      CWEW = TANDEC/TANLAT
      CWEW = SIGN(AMIN1(ABS(CWEW),1.),CWEW)
      WEW = PI
      IF(ALAT*(DECL-ALAT) .LE. 0.0) WEW = ACOS(CWEW)
      IF((ABS(W)-ABS(WEW))*ALAT*(DECL-ALAT) .LE. 0.)
     .        SAZM = SIGN(180.,SAZM) - SAZM
C
9     COSTT=COSTZ*COSSLP+SINTZ*SINSLP*COS((SAZM-AZMTH)
     .*RDCONV)
      RB=AMAX1(COSTT/COSTZ,0.0)
C
      RD = PI/24.0*(COSHR-COSWS)/(SINWS-WS*COSWS)
      IF (RD.LT.0.0) RD = 0.0
      RT = RD*(A+B*COSHR)
      IF (RT.LT.0.0) RT = 0.
      HRKT(I)=XKT*RT/RD
      GO=ECC*COSTZ*SC(IU)
      R(I)=RB*(1.-RD/RT*DRF)+DRF*RD/RT*FSKY+RHO*FGND
      GT(I)=R(I)*GO*HRKT(I)
      HT=HT+GT(I)*DELT/RDCONV/15.
50    CONTINUE
C  CALCULATE PHIBAR
100   PHIBAR=0.0
```

```
      TBAR=0.0
      IF(HT.LT.1.E-06) RETURN
      BEGIN=0.0
      END=0.0
      DO 122 I=1,NSTEP
      PHI=0.
      IF(GT(I).LT.1.E-06 .OR. HRKT(I).LT.1.E-06) GO TO 120
      XC=CRIT/GT(I)
      XM=1.85+.169*R(I)/HRKT(I)/HRKT(I)-.0696*
     .COSSLP/HRKT(I)/HRKT(I)
     .   -.981*HRKT(I)/COSDEC/COSDEC
      XM=AMAX1(XM,1.)
      IF(I.LT.2) BEGIN=0.0
      IF(I.GE.2) BEGIN=END
      IF(I.LT.NSTEP) END=GT(I)+(GT(I+1)-GT(I))/2.
      IF(I.EQ.NSTEP) END=0.0
      IF(XC.GT.XM) GO TO 120
      IF(XM.NE.2.) GO TO 110
      PHI=(1.-XC/XM)*(1.-XC/XM)
      GO TO 120
110   A=(XM-1.)/(2.-XM)
      DISCR=A*A+(1.+2.*A)*(XM-XC)*(XM-XC)/XM/XM
      DISCR=AMAX1(DISCR,0.)
      PHI=ABS(ABS(A)-SQRT(DISCR))
      PRATIO=0.0
      IF(CRITP.GE.BEGIN.AND.CRITP.LT.END.OR.
     .CRITP.LE.BEGIN.AND.
     ;CRITP.GT.END) GOTO 119
      IF(CRITP.GT.GT(I)) GOTO 121
      GOTO 120
119   PRATIO=((CRITP-BEGIN)/(END-BEGIN))
      IF(BEGIN.LT.END)PRATIO=1.0-((CRITP-BEGIN)
     ./(END-BEGIN))
      GOTO 121
120   PRATIO=1.0
121   PHIBAR=PHIBAR+PHI*PRATIO*GT(I)*DELT/RDCONV/15./HT
122   CONTINUE
      RETURN
      END
```

APPENDIX B.3. THE SLR METHOD*

*Balcomb, J.D., et al., Passive Solar Heating Analysis, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (1984).

```
C----------------------------------------------
C
C  THIS PROGRAM CALCULATES QAUX FOR A BUILDING
C  HAVING AN ATTACHED SUNSPACE WITH THE SLR METHOD
C
C------------------------------------------------
C
      REAL KT,LD,LCR ,NLC
      DIMENSION N(12),C(12),D(12),H(12),LCRS(12),
     @DD(12),KT(12),LD(12),HS(12),Y(12),E(12),
     @F(12),A(12),S(12),SLR(12),SSF(12),QN(12),
     @QAUX(12),QSAV(12),B1(12),B2(12),B3(12),
     @B4(12),B5(12),B6(12)
C
C  PROJECTED AREA OF THE GLAZINGS  ( M2 )
C
      AP=25.08
C
C  COEFFICIENT FROM THE SLR CORRELATION
C   ( TYPE B1-B8,E1-E4)
C
      DATA (N(J),J=1,12)/31,28,31,30,31,30,31,
     @31,30,31,30,31/
      DATA (C(K),K=1,12)/0.9683,1.0029,0.9689,
     @1.0029,0.9408,1.0068,
     @0.9395,1.0047,0.9968,1.0468,0.9565,1.0214/
      DATA (D(K),K=1,12)/0.4954,0.6802,0.4685,
     @0.6641,0.3866,0.6778,
     @0.3363,0.6469,0.7004,0.9054,0.4827,0.7694/
      DATA (H(K),K=1,12)/0.84,0.74,0.82,0.76,
     @0.97,0.84,0.95,0.87,0.77,0.76,0.81,0.79/
      DATA (LCRS(K),K=1,12)/16.3,8.5,19.3,9.7,
     @16.3,8.5,19.3,9.7,19.6,10.8,19.6,10.8/
      DATA (B1(K),K=1,12)/.58932,0.58932,
     @0.62569,0.62569,.58932,
     @.58932,0.62569,0.62569,
     @0.61661,0.61661,0.61661,0.61661/
      DATA (B2(K),K=1,12)/-0.09693,-0.09693,
     @-0.13941,-0.13941,-0.09693,-0.09693,
     @-0.13941,-0.13941,-0.10127,-0.10127,
     @-0.10127,-0.10127/
      DATA (B3(K),K=1,12)/0.38955,0.38955,
     @0.43331,0.43331,0.38955,
     @0.38955,0.43331,0.43331,
     @0.40703,0.40703,0.40703,0.40703/
      DATA (B4(K),K=1,12)/-0.14699,-0.14699,
     @-0.14982,-0.14982,-0.14699,
```

```
     @-0.14699,-0.14982,-0.14982,
     @-0.15367,-0.15367,-0.15367,-0.15367/
      DATA (B5(K),K=1,12)/-0.39149,-0.39149,
     @-0.26401,-0.26401,-0.39149
     @,-0.39149,-0.26401,-0.26401,
     @-0.4094,-0.4094,-0.4094,-0.4094/
      DATA (B6(K),K=1,12)/3.9171,3.9171,
     @3.5685,3.5685,3.9171,3.9171,
     @3.5685,3.5685,4.0969,4.0969,4.0969,4.0969/
C
C  DATA FOR THE SPECIFIC HOUSE
C
      WRITE(3,10)
10    FORMAT(///'  UA OF THE BUILDING (W/C)')
      READ(7,11)UA
11    FORMAT(F4.0)
      WRITE(12,12)UA
12    FORMAT(/////,10X,'UA OF THE BUILDING : ',
     @F4.0,'W/C')
      WRITE(12,13)AP
13    FORMAT(2X,'PROJECTED AREA OF THE GLAZING :',
     @F6.1,'M2')
      DO 60 J=1,12
      READ(8,*)DD(J)
      DD(J)=(DD(J)*9/5)
60    CONTINUE
      DO 90 J=1,12
      READ(9,*)KT(J)
90    CONTINUE
      DO 120 J=1,12
      READ(11,*)LD(J)
120   CONTINUE
      DO 140 J=1,12
      READ(13,*)HS(J)
      HS(J)=HS(J)/11.354
140   CONTINUE
      NLC=UA*45.45
      AP=AP*10.764
      LCR=NLC/AP
150   CONTINUE
      QAUXY=0
      QSAVY=0
      QNY=0
      WRITE(3,160)
160   FORMAT('  TYPE OF SUNSPACE (B1,B8;E1,E4) ')
      READ(0,170)K
170   FORMAT(I2)
C
C  EQUATIONS   (  ENGLISH UNITS  )
```

```
C
      DO 200 J=1,12
      Y(J)=LD(J)/100
      E(J)=B1(K)+(B2(K)*Y(K))+(B3(K)*(Y(J)**2))
      F(J)=KT(J)*(B4(K)+(B5(K)*Y(J))+(B6(K)*(Y(J)**2)))
      A(J)=E(J)+F(J)
      S(J)=HS(J)*A(J)*N(J)
      IF (DD(J) .EQ. 0) THEN
      SLR(J)=0
      GO TO 190
      END IF
      SLR(J)=((S(J)/DD(J))-(LCRS(K)*H(K)))/LCR
190   SSF(J)=1-(C(K)*EXP(-D(K)*SLR(J)))
      IF (SSF(J) .LT. 0) SSF(J)=0
      QN(J)=NLC*DD(J)
      QN(J)=QN(J)*1.0548E-06
      QAUX(J)=QN(J)*(1-SSF(J))
      QSAV(J)=QN(J)*SSF(J)
      QNY=QNY+QN(J)
      QAUXY=QAUXY+QAUX(J)
      QSAVY=QSAVY+QSAV(J)
200   CONTINUE
      WRITE(12,201)K
201   FORMAT(///,'TYPE OF SUNSPACE =',I2)
      WRITE(12,210)
210   FORMAT(/,7X,'NET REF LOAD',3X,'SOLAR SAVINGS',
     @4X,'AUX ENERGY')
      DO 300 J=1,12
C
C  RESULTS IN GJ
C
      WRITE(12,220)QN(J),QSAV(J),QAUX(J)
220   FORMAT(12X,F5.2,9X,F5.2,7X,F5.2)
300   CONTINUE
      WRITE(12,310)QNY,QSAVY,QAUXY
310   FORMAT(/,'ANNUAL(GJ)',1X,F6.2,9X,F6.2,7X,F6.2)
      WRITE(3,320)
320   FORMAT('  NEW TYPE OF SUNSPACE ? (YES=1 NO=2)')
      READ(0,*)ANS
      IF(ANS .EQ. 1) GO TO 150
340   STOP

      END
```

APPENDIX B.4. THE TRNSYS SUNSPACE COMPONENT*

*Klein, S.A., et al., "TRNSYS -- A Transient Simulation Program," Engineering Experiment Station Report 38, Version 12.1, University of Wisconsin-Madison (1983).

PARAMETER NO.	DESCRIPTION
1	Units 1 - SI 2 - English
2	H_w - wall height (m, ft)
3	d_w - wall thickness (m, ft)
4	L_f - length of floor (m, ft)
5	d_f - thickness of floor (m, ft)
6	W - width of sunspace (m, ft)
7	W_g - horizontal distance from intersection of lower glazing and floor to intersection of upper and lower glazings (m, ft)
8	H_g - height of intersection of glazings above floor (m, ft)
9	N_w - number of wall nodes
10	N_f - number of floor nodes
11	K_w - conductivity of wall material (KJ/hr-m-°C, Btu/hr-ft-°F)
12	K_f - conductivity of floor material (KJ/hr-m-°C, Btu/hr-ft-°F)
13	$(\rho C_p)_N$ - density specific heat product of wall material (KJ/m^3-°C, Btu/ft^3-°F)
14	$(\rho C_p)_f$ - density specific heat product of floor material (KJ/m^3-°C, Btu/ft^3-°F)
15	α_w - solar absorbtance of wall
16	ε_w - infrared emittance of wall

PARAMETER NO.	DESCRIPTION
17	α_f - solar absorbtance of floor
18	ε_f - infrared emittance of floor
19	N_G - number of glazings
20	ε_g - infrared emittance of glazing
21	K_L - extinction coefficient times thickness of each glazing
22	h_R - refractive index of each glazing
23	R_g - R-value of glazings (m^2-°C-hr/KJ, ft^2-°F-hr/Btu)
24	$R_{g,i}$ - R-value of glazing night insulation (m^2-°C-hr/KJ, ft^2-°F-hr/Btu)
25	$R_{f,i}$ - R-value of floor insulation (m^2-°C-hr/KJ, ft^2-°F-hr/Btu)
26	Air - number of air changes per hour
27	f_{op} - fraction glazing that is opaque to solar radiation
28	T_o - initial temperature of mass nodes
29	R_{gnd} - effective R-value of ground (m^2-°C-hr/KJ, ft^2-°F-hr/Btu)
30*	H_m - average height of additional thermal mass (m, ft)
31	W_m - average width of additional thermal mass (m, ft)
32	C_m - capacitance of additional thermal mass (KJ/°C, Btu/°F)

*Parameters 30-35 are optional.

10	h_{cg}	- convection coefficient between glass and sunspace air (KJ/hr-m^2-°C, Btu/hr-m^2-°F)
11	$I_{bT,u}$	- input beam radiation on upper glazing (KJ/hr-m^2-°C, Btu/hr-m^2-°F)
12	$I_{dT,u}$	- incident diffuse radiation on upper air glazing (KJ/hr-m^2-°C, Btu/hr-m^2-°F)

INPUT NO.		DESCRIPTION
13	$I_{bT,L}$	- incident beam radiaton on lower glazing (KJ/hr-m^2-°C, Btu/hr-m^2-°F)
14	$I_{dT,L}$	- incident diffuse radiation on lower glazing (KJ/hr-m^2-°C, Btu/hr-m^2-°F)
15	θ_u	- solar incidence angle for upper glazing
16	θ_L	- solar incidence angle for lower glazing
17	θ_z	- solar zenith angle
18	γ_s	- solar azimuth angle
19	$\dot{m}_v$	- mass flow rate of ventilation flow stream (kg/hr, lbm/hr)
20	$\dot{Q}_{aux}$	- rate of auxiliary energy added to sunspace (KJ/hr, Btu/hr)
21*	h_{cm}	- convection coefficient from additional mass to sunspace (KJ/m^2-°C, Btu/ft^2-°F)

*Required only if parameters 29-34 are supplied.

OUTPUT NO.	DESCRIPTION
1	T_{ss} - temperature of sunspace air (°C, °F)
2	$\dot{m}_v$ - mass flow rate of ventilation flow stream (kg/hr, lbm/hr)
3	$T_{g,i}$ - inside glazing temperature (°C, °F)
4	$T_{w,i}$ - inside wall surface temperature (°C, °F)
5	$T_{f,i}$ - inside floor surface temperature (°C, °F)
6	$\dot{Q}_R$ - total rate of energy delivery to adjoining room (KJ/hr, Btu/hr)
7	$\dot{Q}_c$ - rate of energy delivery to room by conduction (KJ/hr, Btu/hr)
8	$\dot{Q}_{amb}$ - rate of heat loss to ambient (KJ/hr, Btu/hr)
9	$\dot{Q}_{L,g}$ - rate of energy loss by conduction through glazings (KJ/hr, Btu/hr)
10	$\dot{Q}_{L,gnd}$ - rate of energy loss to ground (KJ/hr, Btu/hr)
11	$\dot{Q}_s$ - rate of solar energy passing through glazings (KJ/hr, Btu/hr)
12	$\dot{Q}_{abs}$ - rate of solar energy absorbed by wall, floor, and additional mass (KJ/hr, Btu/hr)
13	$\frac{dU}{dt}$ - rate of change of internal energy in sunspace (KJ/hr, Btu/hr)

```
*-------------------------------------------------
*
*   TRNSYS SUNSPACE COMPONENT  ( EXAMPLE )
*
*-------------------------------------------------
CONSTANTS  23
       H1=1  , VENT=0. ,RH1=2009. , AF=.8 ,EF=0.9,
       H2=8760 ,  MVENT=500. ,LAT=35.03 ,KF=3.115 ,
       FINS=0.44, RG=1.958,
       RGL=0.121, INS=0. ,NCOV=2. ,KW=6.23 ,THW=0.315
       ,XLN=9.14 ,VER=1.82,
       WD=1.58, TEMP=18.33  ,CAP=25000.  ,
       UA=568.8 ,HIGH=28.88
*
NOLIST
*
SIMULATION H1 H2 1
*
WIDTH 132
*
UNIT 1 TYPE 9 CARD READER
    PARAMETERS 16
    3.,1.,-1.,1.,0.,-2.,.1,0.,-3.,1.,0.,-4.,1.,0.,0,1
(T25,F4.0,T30,F4.0,T58,F2.0,T14,F2.0)
*
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
    PARAMETERS 6
    1 1 1 LAT 4871 0
    INPUTS 8
    1,1 1,19 1,20 0,0 0,0 0,0 0,0 0,0
    0   0    0    0.3 30.2  0   90  0
*
UNIT 3 TYPE 37 ATTACHED SUNSPACE
TRACE 10,11
    PARAMETERS 29
    1  2.74   THW  WD  0.1525  XLN  0  VER  3  2
    KW  KF  RH1  2009  0.8  0.9  AF  EF  NCOV
    0.9  0.0625  1.526  RGL  0.44  FINS  1  .2  15  RG
    INPUTS 20
    0,0  0,0  0,0  1,2  0,0 6,1  0,0  0,0  0,0  0,0
    2,7  2,8  2,12 5,1  2,9  2,13 2,2  2,3  0,0  0,0
    VENT INS  10   0    TEMP   0    29.8 14.4 14.4 14.4
    0    0    0    0    0    0    0    0    MVENT 0
*
UNIT 4 TYPE 15
      PARAMETERS 14
      0 0 3 -1 16.73 1 -4 0 0 3 -1 16.63 1 -4
      INPUTS 4
      2,7 2,8 2,12 5,1
```

```
     0   0   0    0
*
UNIT 13 TYPE 12 BUILDING LOAD
    PARAMETERS 8
    3  UA CAP  TEMP 1.012 0. TEMP HIGH
    INPUTS 5
    0,0  0,0  1,2  3,6  1,4
    0    0    0    0    0
*
UNIT 5 TYPE 15
    PARAMETER 1
    4
    INPUTS 2
    2,11 2,12
    0     0
*
UNIT 6 TYPE 15
    PARAMETERS 8
    -1,10.8,0,1,-1,10.08,3,-3
    INPUT 1
    1,3
    0
*
UNIT 10 TYPE 15
    PARAMETERS 6
    0,8,0,9,10,-4
    INPUTS 2
    2,6 0,0
    0   1
*
UNIT 28 TYPE 28 SIMULATION SUMMARY
     PARAMETERS 20
     -1 H1  H2 12 2 -11 -4 -12 -4 -12 0 2
     -1 1 4 7 8 -4 -14 -4
     INPUTS 5
     13,1 13,6 13,3 3,6 13,7
     LABELS 4
     LOAD QAUX SF QR
*
UNIT 27 TYPE 27 HISTOGRAM PLOTTER
      PARAMETERS 9
      1 -1 -1 H1 H2 -10 70 16
      INPUT 1
      3,1
      TEMP
*
END
```

```
C-----------------------------------------------------
C
C   THIS TRNSYS SUBROUTINE CALCULATES THE ENERGY FLOWS
C   AND TEMPERATURES FOR AN ATTACHED SUNSPACE.
C   FOR A DETAILED DISCUSSION OF THE COMPONENT
C   SEE B.PARSONS MASTERS THESIS;
C   UNIVERSITY OF WISCONSIN-MADISON, 1983.
C   UPDATED BY I.SOMMEREUX.( OCTOBER 1985 )
C
C------------------------------------------------------
      SUBROUTINE TYPE37(TIME,XIN,OUT,T,DTDT,PAR,INFO)
      DIMENSION XIN(21),OUT(20),PAR(50),INFO(10),
     2F(4,4),EIR(4),ES(4),RSR(4,4),RIR(4,4),T(20)
     2 ,FHAT(4,4),FHATS(4,4),FDL(4),FDU(4),
     2 BU(4),BL(4),RAD(4),COND(4,4),QSRAD(4),TM(21),
     2QDTDT(21),TI(21),
     2 ROH(4),DTDT(21),SIGMA(2),RHO(2),CP(2),
     2AB(2),BEAMU(4),DIFF(4),BEAML(4)
      REAL PC
      COMMON /SIM/ TIMEO,TIMEF,DELT
      COMMON /LUNITS/ LUR,LUW,IFORM
      DATA SIGMA/2.0411E-07,1.17122E-02/,RHO/1.204,.075/
      DATA CP/1.012,.24/AB/273.3,459.7/
      DATA ICALL/0/
C
      IF(INFO(7).GT.-1)GOTO 55
      ICALL=ICALL+1
      IF(ICALL.EQ.1) GO TO 2
      CALL TYPECK(-6,INFO,0,0,0)
      RETURN
C
C     SET PARAMETERS
2     IU=INT(PAR(1)+0.1)
      XLW=PAR(2)
      THW=PAR(3)
      XLFL=PAR(4)
      THF=PAR(5)
      WTH=PAR(6)
      HC=PAR(7)
      VG=PAR(8)
      NWL=PAR(9)
      NFL=PAR(10)
      WK=PAR(11)
      FK=PAR(12)
      RCPW=PAR(13)
      RCPF=PAR(14)
      ES(1)=PAR(15)
      EIR(1)=PAR(16)
      ES(2)=PAR(17)
```

```
      EIR(2)=PAR(18)
      NCOV=IFIX(PAR(19)+.1)
      EIR(3)=PAR(20)
      XKL=PAR(21)
      RI=PAR(22)
      RGL=PAR(23)
      RNI=PAR(24)
      RFI=PAR(25)
      RATE=PAR(26)
      SFRAC=PAR(27)
      NFI=NWL+1
      NMN=NWL+NFL
      TIN=PAR(28)
      RGR=PAR(29)
C
C  Number of surfaces
C
      NSUR=3
      EIR(4)=0.
      ES(4)=0.
      NEM=NMN
      IF(INFO(4).LT.30) GOTO 5
C
C Additional mass
C
      NEM=NMN+1
      HTM=PAR(30)
      WDM=PAR(31)
      CAPX=PAR(32)
      XSA=PAR(33)
      ES(4)=PAR(34)
      EIR(4)=PAR(35)
      NSUR=4
5     CONTINUE
      INFO(6)=13
C  INITIALIZE AIR AND GLAZING TEMPS
      DO 10 I=1,NEM
10    TM(I)=TIN
      XNC=FLOAT(NCOV)
      TGLI=(TM(1)*XNC+XIN(4))/(XNC+1.)
      TSS=(TM(1)+TGLI)/2.
      TGLO=TGLI
C
C       CALCULATION OF SUNSPACE GEOMETRY
C
      AFL=XLFL*WTH
      AWL=XLW*WTH
      VC=XLW-VG
      HG=XLFL-HC
```

```
      XUG=SQRT(VC**2+HG**2)
      AUG=XUG*WTH
      XLG=SQRT(HC**2+VG**2)
      ALG=XLG*WTH
      XAR=VG*HC+(HG*VG+HC*VC)/2.
      AGL=2.*XAR+AUG+ALG
      BETA=0.0
      PHI=1.5707963
      IF(HC.GT.0.)BETA=ATAN(VC/HC)
      IF(HG.GT.0.)PHI=ATAN(VG/HG)
      NPAR=29
      NINP=20
C
C  Test on additional mass
C
      IF(NSUR.LE.3)GOTO 15
      NPAR=35
      NINP=21
      A1=ATAN(VA/WDM)
      A2=ATAN(VG/HA)
      A3=ATAN(HC/VA)
15      CALL TYPECK(1,INFO,NINP,NPAR,0)
C
C   SET CONSTANT HEAT TRANSFER COEFF.
C   Conduction
C
      DXW=THW/(NWL-1)
      DXF=THF/(NFL-1)
      H1=WK/DXW*AWL
      H3=FK/DXF*AFL
      H4=AFL/(RFI+RGR)
      CAPW=DXW*RCPW*AWL
      CAPF=DXF*RCPF*AFL
      H12=RATE*XAR*WTH*RHO(IU)*CP(IU)
C       CALCULATE VIEW FACTORS
      DIAG1=SQRT(XLFL**2+XLW**2)
C
C  Test on additional mass
C
      IF(NSUR.EQ.3) GOTO 25
      HA=XLFL-WDM-HG
      VA=XLW-HTM-VC
      D2=SQRT(HA**2+VA**2)
      D3=SQRT(HA**2+(VA+HTM)**2)
      D4=SQRT(VA**2+HC**2)
      D5=SQRT((HG+HA)**2+HTM**2)
      D6=SQRT(WDM**2+(VA+VC)**2)
      F(1,1)=0.
      F(2,2)=0.
```

```
      F(4,4)=0.
      F(1,2)=(WDM+D5+D6+HTM-DIAG1-WDM-HTM)/((VA+VC)*2.)
      F(2,1)=F(1,2)*(VA+VC)/(HG+HA)
      F(1,3)=(VA+VC+DIAG1-WDM-D5)/(2.*(VA+VC))
      F(3,1)=F(1,3)*(VA+VC)/(XLG+XUG)
      F(1,4)=1.-F(1,2)-F(1,3)
      F(4,1)=F(1,4)*(VA+VC)/(WDM+HTM)
      F(2,3)=(D3+DIAG1-HTM-D6)/(2.*(HG+HA))
      F(3,2)=F(2,3)*(HG+HA)/(XLG+XUG)
      F(2,4)=1.-F(2,1)-F(2,3)
      F(3,4)=(D6+HTM+D5+WDM-HG-HA-VA-VC)/(2.*(XLG+XUG))
      F(4,3)=F(3,4)*(XUG+XLG)/(WDM+HTM)
      F(3,3)=1.-F(3,1)-F(3,2)-F(3,4)
      F(4,2)=F(2,4)*(HG+HA)/(HTM+WDM)
      FDU(1)=(XUG+VA+VC-D4)/(2.*XUG)
      FDU(2)=(DIAG1+D3-D6-HTM-XLG)/(2.*XUG)
      FDU(4)=(D6+HTM+D4-VA-VC-D3)/(2.*XUG)
      FDU(3)=1.-FDU(1)-FDU(2)-FDU(4)
      FDL(1)=(DIAG1+D4-D5-WDM-XUG)/(2.*XLG)
      FDL(2)=(XLG+HG+HA-D3)/(2.*XLG)
      FDL(4)=(D3+D5+WDM-D4-HG-HA)/(2.*XLG)
      FDL(3)=1.-FDL(1)-FDL(2)-FDL(4)
      GOTO 30
25    DIAG2=SQRT(HC**2+VG**2)
      F(1,1)=0.0
      F(2,2)=0.0
      F(1,2)=(XLW+XLFL-DIAG1)/(2.*XLW)
      F(2,1)=F(1,2)*XLW/XLFL
      F(1,3)=1.-F(1,2)
      F(3,1)=F(1,3)*XLW/(XUG+XLG)
      F(2,3)=1.-F(2,1)
      F(3,2)=F(2,3)*XLFL/(XUG+XLG)
      F(3,3)=1.-F(3,1)-F(3,2)
      FDU(1)=(XUG+XLW-DIAG2)/(XUG*2.)
      FDU(2)=(DIAG1+DIAG2-XLW-XLG)/(2.*XUG)
      FDU(3)=1.-FDU(1)-FDU(2)
      FDL(1)=(DIAG1+DIAG2-XUG-XLFL)/(2.*XLG)
      FDL(2)=(XLFL+XLG-DIAG2)/(2.*XLG)
      FDL(3)=1.-FDL(1)-FDL(2)
C  COMPUTE TRANSMITTANCE TO DIFFUSE &
C  REFLECTIVITY TO SOLAR
30    ROHD=-1.
      TAUD=TALF(NCOV,60.,XKL,RI,1.,ROHD)
      ES(3)=1.-ROHD
C    COMPUTE REFLECTIVITY MATRICIES
      DO 35 I=1,NSUR
      DO 35 J=1,NSUR
      RIR(I,J)=(EIR(J)-1.)*F(I,J)
      FHAT(I,J)=0.0
```

```
      RSR(I,J)=(ES(J)-1.)*F(I,J)
      FHATS(I,J)=0.0
      IF(I.EQ.J) RIR(I,J)=RIR(I,J)+1.
35    IF(I.EQ.J) RSR(I,J)=RSR(I,J)+1.
C     CALCULATE FHATS & CONDUCTANCES
      CALL INVERT(4,NSUR,RIR,IFLAG)
      IF(IFLAG.EQ.1) GO TO 500
      CALL INVERT(4,NSUR,RSR,IFLAG)
      IF(IFLAG.EQ.1) GO TO 500
      DO 45 I=1,NSUR
      DO 45 K=1,NSUR
      DO 40 J=1,NSUR
      FHAT(I,K)=FHAT(I,K)+RIR(I,J)*F(J,K)
      FHATS(I,K)=FHATS(I,K)+RSR(I,J)*F(J,K)
40    CONTINUE
      COND(I,K)=EIR(I)*EIR(K)*FHAT(I,K)*SIGMA(IU)
45    CONTINUE
      ROH(1)=1.-ES(1)
      ROH(2)=1-ES(2)
      ROH(3)=ROHD
C  SET INITIAL VALUES OF CONDUCTANCES FOR TIMESTEP CHECK
      TGLIA=TGLI+AB(IU)
      TGLOA=TGLO+AB(IU)
      TWA=TM(1)+AB(IU)
      TAMBA=TAMB+AB(IU)
      TFA=TM(NFI)+AB(IU)
C    SET VARIABLE CONDUCTANCES
      H14=0.
      H15=0.
      H16=0.
      H17=0.
C
C  Test on additional mass
C
      IF(NSUR.LE.3) GOTO 50
      TMA=TM(NEM)+AB(IU)
      ROH(4)=1.-ES(4)
      AWL=(VA+VC)*WTH
      AFL=(HG+HA)*WTH
      H14=XSA*XIN(21)
C
C  Radiation
C
      H15=COND(2,4)*AFL*(TFA**2+TMA**2)*(TFA+TMA)
      H16=COND(1,4)*AWL*(TWA**2+TMA**2)*(TWA+TMA)
      H17=COND(3,4)*(AUG+ALG)*(TGLIA**2+TMA**2)
     .*(TGLIA+TMA)
50    H5A=SIGMA(IU)*EIR(3)*(TGLOA**2+TAMBA**2)
     .*(TGLOA+TAMBA)*AGL
```

```
C
C  Convection
C
      H5B=XIN(6)*AGL
      H5=H5A+H5B
      IF(RGL.GT.0) H5=1./(1./H5+RGL/(AGL))
      H9=COND(1,3)*AWL*(TWA**2+TGLIA**2)*(TWA+TGLIA)
      H10=COND(1,2)*AWL*(TWA**2+TFA**2)*(TWA+TFA)
      H11=COND(2,3)*AFL*(TFA**2+TGLIA**2)*(TFA+TGLIA)
      IF(RNI.NE.0.AND.XIN(2).GT.0.99)H5=1./(1./H5+
     .RNI/(AGL))
55    IGAMG=INT(XIN(2)+0.1)
      IF(INFO(7).GT.0)GOTO 140
C    BEAM RADIATION CALCULATIONS
      DO 60 I=1,NSUR
      BU(I)=0.0
60    BL(I)=0.0
      TRAD=XIN(11)+XIN(12)+XIN(13)+XIN(14)
      IF(TRAD.GT.0.0001.AND.IGAMG.EQ.0)GOTO 70
      DO 65 I=1,NSUR
65    RAD(I)=0.0
      GOTO 125
70    CONTINUE
      TSE=ATAN(TAN(XIN(17)/57.29578)*COS(XIN(18)
     ./57.29578))
C
C  Test on additional mass
C
      IF (NSUR.LE.3) GOTO 100
      IF(TSE.NE.90.) GOTO 75
      BU(1)=1.
      BL(1)=VA/VG
      BL(4)=1.-BL(1)
      GOTO 115
75    IF(TSE.GT.0.) GOTO 85
      ANGCK=TSE+1.5707693
      BL(2)=1.
      BP1=XLW/TAN(ANGCK)
      BP2=VG/TAN(ANGCK)+HC
      IF(ANGCK.GT.A1) GOTO 80
      IF(BP1.LT.XLFL) THEN
      BU(3)=(BP2-XLFL)/(BP2-BP1)
      BU(2)=1.-BU(3)
      ELSE
      BU(3)=1
      ENDIF
      GOTO 115
80    BP3=HTM/TAN(ANGCK)+WDM
      BU(4)=(BP3-BP1)/(BP2-BP1)
```

```
      BU(3)=(BP2-XLFL)/(BP2-BP1)
      BU(2)=1.-BU(4)-BU(3)
      GOTO 115
85    CONTINUE
      ANGCK=1.5707963-TSE
      BP1=TAN(ANGCK)*HC
      BP2=TAN(ANGCK)*WDM+VG
      BP3=TAN(ANGCK)*XLFL+VG
      IF(TSE.LT.A3) GOTO 90
      BU(1)=1.
      BL(1)=(VA-BP1)/(BP3-BP1)
      BL(2)=(BP3-BP2)/(BP3-BP1)
      BL(4)=1.-BL(1)-BL(2)
      GOTO 115
90    IF(TSE.GT.A2) GOTO 95
      BL(2)=1
      BU(2)=(BP1-BP2)/(BP1+VC)
      BU(1)=(VA+VC)/(BP1+VC)
      BU(4)=1.-BU(1)-BU(2)
      GOTO 115
95    BL(2)=(BP3-BP2)/(BP3-BP1)
      BL(4)=1.-BL(2)
      BU(1)=(VA+VC)/(BP1+VC)
      BU(4)=1.-BU(1)
      GOTO 115
100   IF(XIN(17).NE.90.0) GOTO 105
      BU(1)=1
      BL(1)=1
      GOTO 115
105   IF(TSE.GE.0.0) GOTO 110
      ANGCK=TSE+1.5707963
      IF(ANGCK.GE.PHI)THEN
      BU(2)=1
      BL(2)=1
      ELSE
      WP=XLW/TAN(ANGCK)
      IF(WP.GE.XLFL) THEN
      BU(3)=1.
      ELSE
      PC=VG/TAN(ANGCK)
      OS=PC-HG
      SIS=XLFL-WP
      BU(2)=SIS/(SIS+OS)
      BU(3)=OS/(SIS+OS)
      ENDIF
      ENDIF
      GOTO 115
110   FP=HC-VG*TAN(TSE)
      IF(FP.LT.0.0) THEN
```

```
      FP=-FP
      BU(1)=1
      BL(1)=FP/(FP+XLFL)
      BL(2)=1-BL(1)
      ELSE
      BL(2)=1
      WP=FP/TAN(TSE)
      BU(2)=WP/(WP+XLW)
      BU(1)=1-BU(2)
      ENDIF
C    CALCULATE TRANSMITTANCE OF THE GLASS TO SOLAR
C
C   Upper glazing
C
115   TALFU=TALF(NCOV,XIN(15),XKL,RI,1.0,ROHD)
C
C   Lower glazing
C
      TALFL=TALF(NCOV,XIN(16),XKL,RI,1.0,ROHD)
C   COMPUTE TOTAL INCIDENT SOLAR
      DO 120 I=1,NSUR
      DIFF(I)=(FDU(I)*XIN(12)*AUG+FDL(I)*
     .XIN(14)*ALG)*TAUD
      BEAMU(I)=BU(I)*AUG*XIN(11)*TALFU
      BEAML(I)=BL(I)*ALG*XIN(13)*TALFL
120   RAD(I)=(BEAMU(I)+BEAML(I)+DIFF(I))*(1.-SFRAC)
125   CONTINUE
      TRADI=0.
      TRADAB=0.
      QSRAD(4)=0.
C TOTAL RAD INCIDENT & REFLECTED
      ES(3)=0.0
      DO 135 I=1,NSUR
      TRADI=TRADI+RAD(I)
      SQSFHR=0.0
      DO 130 J=1,NSUR
130   SQSFHR=SQSFHR +RAD(J)*ROH(J)*FHATS(J,I)
      QSRAD(I)=ES(I)*(RAD(I)+SQSFHR)
135   TRADAB=TRADAB+QSRAD(I)
C    SET INPUT TEMPERATURES
140   TGR=XIN(3)
      TAMB=XIN(4)
      TRM=XIN(5)
      QV=0.
      QAMB=0.
      QRMC=0.
      QRMT=0.
      QGR=0.
      QSTORE=0.
```

```
      QGL=0.
C   CHECK FOR EXTERNAL ITERATIONS
      IF(INFO(7).GT.0)THEN
      DO 145 I=1,NEM
145   TM(I)=TI(I)
      ELSE
      DO 150 I=1,NEM
150   TI(I)=TM(I)
      ENDIF
      H2=XIN(7)*AWL
      H5B=XIN(6)*AGL
      H6=XIN(10)*AGL
      H7=XIN(9)*AWL
      H8=XIN(8)*AFL
      IF(NSUR.GT.3) H14=XSA*XIN(21)
C   TIME STEP CHECK
      CK1=CAPW/2./(H1+H7+H9+H11+H16)
      CK2=CAPW/2./(H1+H2)
      CK3=CAPF/2./(H3+H8+H10+H11+H15)
      CK4=CAPF/2./(H3+H4)
      CK5=1.
      IF(NSUR.GT.3) CK5=CAPX/(H15+H14+H16+H17)
      DTMAX=AMIN1(CK1,CK2,CK3,CK4,CK5)
      NTS=IFIX(DELT/DTMAX+1)
      DTMAX=DELT/FLOAT(NTS)
      DO 225 ITS=1,NTS
      NCHECK=0
155   IF(NCHECK.GT.20)GOTO 185
      TSSOLD=TSS
      TGLIA=TGLI+AB(IU)
      TGLOA=TGLO+AB(IU)
      TWA=TM(1)+AB(IU)
      TAMBA=TAMB+AB(IU)
      TFA=TM(NFI)+AB(IU)
C     SET VARIABLE CONDUCTANCES
      H5A=SIGMA(IU)*EIR(3)*(TGLOA**2+TAMBA**2)
     .*(TGLOA+TAMBA)*AGL
      H5=H5A+H5B
      IF(RGL.GT.0) H5=1./(1./H5+RGL/(AGL))
      H9=COND(1,3)*AWL*(TWA**2+TGLIA**2)*(TWA+TGLIA)
      H10=COND(1,2)*AWL*(TWA**2+TFA**2)*(TWA+TFA)
      H11=COND(2,3)*AFL*(TFA**2+TGLIA**2)*(TFA+TGLIA)
      IF(RNI.NE.0.AND.IGAMG.EQ.1)H5=1./(1./H5+RNI/(AGL))
      IF(NSUR.EQ.3) GOTO 160
      TMA=TM(NEM)+AB(IU)
      H15=COND(2,4)*AFL*(TFA**2+TMA**2)*(TFA+TMA)
      H16=COND(1,4)*AWL*(TWA**2+TMA**2)*(TWA+TMA)
      H17=COND(3,4)*(AUG+ALG)*(TGLIA**2+TMA**2)
     .*(TGLIA+TMA)
```

```
160    AMDOT=XIN(19)
       H13=AMDOT*CP(IU)
       IGAMV=INT(XIN(1)+SIGN(.1,XIN(1)))
       IF(IGAMV) 165,175,170
C
C  Ventilation to the ambient
C
165    TS=TAMB
       EA=1.
       RM=0
       GOTO 180
C
C Ventilation to the room
C
170    TS=TRM
       RM=1
       EA=0
       GOTO 180
C
C No ventilation
C
175    TS=TSS
       EA=0
       RM=0
       AMDOT=0.
180    CONTINUE
C  FIND GLASS &MEAN AIR TEMP
       F1=(H6+H7+H8+H12+H13+H14)/H6
       F2=H5+H6+H9+H11+H17
       F3=H6-F1*F2
       F4=H12+H5*F1
       F5=H7+H9*F1
       F6=H8+H11*F1
       F7=H14+H17*F1
       TGLI=-(TAMB*F4+TM(1)*F5+TM(NFI)*F6+
      .TM(NEM)*F7+TS*H13+XIN(20))/F3
       TSS=(TGLI*F2-H5*TAMB-H9*TM(1)-H11*
      .TM(NFI)-H17*TM(NEM))/H6
       QGLI=H5*(TGLI-TAMB)
       TGLO=TGLI-QGLI*RGL/(AGL)
       NCHECK=NCHECK+1
       DTAIR=TSSOLD-TSS
       IF(ABS(DTAIR).GT.0.01)GOTO 155
185    TO=TSS
C    CALCULATE HEAT FLUXES
       QV=H13*(TSS-TS)
       QAMB=(QGLI+H12*(TSS-TAMB)+QV*EA)/NTS+QAMB
       QRMC=H2*(TM(NWL)-TRM)/NTS+QRMC
       QRMT=(H2*(TM(NWL)-TRM)+QV*RM)/NTS+QRMT
```

```
      QGR=H4*(TM(NMN)-TGR)/NTS+QGR
      QGL=H5*(TGLI-TAMB)/NTS+QGL
      QDTDT(1)=(QSRAD(1)+(TM(2)-TM(1))*H1+(TGLI-TM(1))
     .*H9+(TM(NFI)-TM(1)
     2 )*H10 +(TSS-TM(1))*H7+H16*(TM(NEM)-TM(1)))
      IF(NSUR.GT.3) QDTDT(NEM)=H14*(TSS-TM(NEM))+H15*
     2 (TM(NFI)-TM(NEM))+H16*(TM(1)-TM(NEM))+QSRAD(4)
     .+H17*(TGLI-TM(NEM))
      NM1=NWL-1
      DO 190 I=2,NM1
190   QDTDT(I)=(TM(I-1)+TM(I+1)-2.*TM(I))*H1
      QDTDT(NWL)=((TRM-TM(NWL))*H2+(TM(NM1)-TM(NWL))*H1)
      QDTDT(NFI)=((TM(1)-TM(NFI))*H10+(TSS-TM(NFI))*H8+
     .(TGLI-TM(NFI))
     2 *H11+(TM(NFI+1)-TM(NFI))*H3+QSRAD(2)+H15*
     .(TM(NEM)-TM(NFI)))
      NFF=NMN-1
      DO 195 I=NFI+1,NFF
195   QDTDT(I)=(TM(I-1)+TM(I+1)-2.*TM(I))*H3
      QDTDT(NMN)=((TGR-TM(NMN))*H4+(TM(NFF)-TM(NMN))*H3)
C  CALC NEW TEMPERATURES OF MASS NODES
      IF(TIME.EQ.TIMEO) GOTO 210
      TM(1)=TM(1)+QDTDT(1)*DTMAX*2./CAPW
      DO 200 I=2,NWL-1
200   TM(I)=TM(I)+QDTDT(I)*DTMAX/CAPW
      TM(NWL)=TM(NWL)+QDTDT(NWL)*DTMAX*2./CAPW
      TM(NFI)=TM(NFI)+QDTDT(NFI)*DTMAX*2./CAPF
      DO 205 I=NFI+1,NMN-1
205   TM(I)=TM(I)+QDTDT(I)*DTMAX/CAPF
      TM(NMN)=TM(NMN)+QDTDT(NMN)*DTMAX*2./CAPF
      IF(NSUR.GT.3) TM(NEM)=TM(NEM)+QDTDT(NEM)*DTMAX/CAPX
210   QST=0.
      DO 220 I=1,NEM
220   QST=QST+QDTDT(I)
      QSTORE=QSTORE+QST/NTS
225   CONTINUE
C  SET OUTPUTS
      OUT(1)=TO
      OUT(2)=AMDOT
      OUT(3)=TGLI
      OUT(4)=TM(1)
      OUT(5)=TM(NFI)
      OUT(6)=QRMT
      OUT(7)=QRMC
      OUT(8)=QAMB
      OUT(9)=QGL
      OUT(10)=QGR
      OUT(11)=TRADI
      OUT(12)=TRADAB
```

```
      OUT(13)=QSTORE
      RETURN
C
C  MATRIX IS SINGULAR
500   WRITE(LUW,501) INFO(1),INFO(2)
501   FORMAT(//2X,22H***** ERROR ***** UNIT,I3,5H TYPE,
     .I3/4X,36HSINGULAR MATRIX - SIMULATION STOPPED)
      STOP

      END
```

```
C-------------------------------------------------
C
      SUBROUTINE INVERT(NRC,N,A,IFLAG)
C
C---------------------------------------------------
      DIMENSION IROW(50),JCOL(50),Y(50),A(NRC,NRC)
      DATA EPS/1.E-06/
      IFLAG=0
C
C  CHECK FOR TOO LARGE A MATRIX
      IF(N.LE.50) GO TO 5
      IFLAG=1
      RETURN
C
C  BEGIN ELIMINATION
5     DO 18 K=1,N
      KM1=K-1
C  SEARCH FOR THE PIVOT ELEMENT
      PIVOT=0.
      DO 11 I=1,N
      DO 11 J=1,N
C  LOOK FOR INVALID PIVOT SUBSCRIPTS
      IF(K.EQ.1) GO TO 9
      DO 8 ISCAN=1,KM1
      DO 8 JSCAN=1,KM1
      IF(I.EQ.IROW(ISCAN) ) GO TO 11
      IF(J.EQ.JCOL(JSCAN) ) GO TO 11
8     CONTINUE
9     IF (ABS(A(I,J)).LE.ABS(PIVOT) ) GO TO 11
      PIVOT=A(I,J)
      IROW(K)=I
      JCOL(K)=J
11    CONTINUE
C  CHECK FOR TOO SMALL A PIVOT
      IF(ABS(PIVOT).GT.EPS) GO TO 13
      IFLAG=2
      RETURN
C  NORMALIZE PIVOT ROW ELEMENTS
13    IROWK=IROW(K)
      JCOLK=JCOL(K)
      DO 14 J=1,N
14    A(IROWK,J)=A(IROWK,J)/PIVOT
C  DETERMINE INVERSE
      A(IROWK,JCOLK)=1./PIVOT
      DO 18 I=1,N
      AIJCK=A(I,JCOLK)
      IF(I.EQ.IROWK) GO TO 18
      A(I,JCOLK)= -AIJCK/PIVOT
      DO 17 J=1,N
```

```
17    IF(J.NE.JCOLK) A(I,J)=A(I,J)-AIJCK*A(IROWK,J)
18    CONTINUE
C  UNSCRAMBLE INVERSE
26    DO 28 J=1,N
      DO 27 I=1,N
      IROWI=IROW(I)
      JCOLI=JCOL(I)
27    Y(JCOLI)=A(IROWI,J)
      DO 28 I=1,N
28    A(I,J)=Y(I)
      DO 30 I=1,N
      DO 29 J=1,N
      IROWJ=IROW(J)
      JCOLJ=JCOL(J)
29    Y(IROWJ)=A(I,JCOLJ)
      DO 30 J=1,N
30    A(I,J)=Y(J)
      RETURN
      END
```

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