

# **SUNREL™**

## **Technical Reference Manual**

Prepared by Michael Deru, Ron Judkoff,  
and Paul Torcellini



**NREL**

**National Renewable Energy Laboratory**

1617 Cole Boulevard  
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory  
Operated by Midwest Research Institute • Battelle • Bechtel

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Prepared under Task No. BE90.6001



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## Foreword

In the past 30 years, numerous building energy simulation programs have been developed. Most have been dropped and forgotten because of poor physical models, lack of funding, lack of interest, and probably many other reasons. SUNREL is an upgrade of one of these programs, SERI-RES, which was released in the early 1980s. SERI-RES is an hourly calculation program based on fundamental models of physical behavior, but it needed to be upgraded to take advantage of the newer computing power of personal computers. SUNREL is the same basic program with some new models and a simple graphical interface. Along the way, a few bugs were also found and corrected.

The original program was created to model small buildings with loads driven by the envelope. Some algorithms are specifically for passive technologies, such as Trombe walls and programmable window shading. SUNREL has added new features to make this a stronger program like models for advanced glazings and natural ventilation. The program has been used by researchers around the world and been proven to be accurate and reliable.

Many people were involved with the creation of the original version of this program, when it was called SERI-RES. The major contributors were Larry Palmiter, Terry Wheeling, David Simms, David Wortman, Bob O'Doherty, and Ron Judkoff.

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## 1. Introduction

### 1.1. Description

SUNREL is a building energy simulation software for small, envelope-dominated buildings. It is an upgrade of SERIRES version 1.0, which was written under the guidance of the Solar Energy Research Institute (SERI, now the National Renewable Energy Laboratory [NREL]). SERIRES was originally written in FORTRAN 66 for main-frame computers. As personal computers became more powerful, various groups around the world converted SERIRES to this platform. SERIRES has been well tested through experimentation and practical use and is one of the benchmark programs for the International Energy Association testing procedure, BESTEST (Judkoff and Neymark 1995). The current version of SUNREL has also been tested satisfactorily using the BESTEST procedure (Deru 1997).

The upgrade of SERIRES to SUNREL was completed by Colorado State University and NREL (Deru 1996). The first item changed was the input structure, which is based on the FORTRAN namelist format. This format makes the program flexible for future upgrades and provides an excellent bridge file for graphical user interfaces. The second alteration was to include a more sophisticated model for advanced window systems. SUNREL reads optical and thermal properties of the window from a data file created by WINDOW-4.1 (Arasteh et al. 1994). More information about this program and the data file is presented in Appendix C. The third enhancement was to include algorithms to handle shading by overhangs and sidefins of finite length. These algorithms also cover shading of diffuse radiation and diffuse reflections off the shading devices. The final addition was a comprehensive routine for infiltration and natural ventilation, driven by temperature and wind effects. The infiltration is based on the effective leakage area of each zone, such as that determined through blower door tests.

Energy-efficient buildings tend to be more free-floating than buildings that are controlled by large HVAC systems; therefore, proper design is essential for comfort and usability. SUNREL can aid in the design of such buildings by modeling the following energy-efficient design strategies: moveable insulation, interior shading control, energy-efficient windows, thermochromatic glazings, Trombe walls, water walls, phase change materials, and rockbins.

### 1.2. Limitations of the Program

The complex nature of building energy simulation, combined with time and budgetary constraints, requires tradeoffs between what is desired and what is realistic. SUNREL's major limitations are discussed in this section.



The present program has no model for HVAC systems or energy plant performance. SUNREL only determines the loads that the HVAC systems would encounter.

The distribution of incoming solar radiation is not modeled in SUNREL, except as determined through user-defined constant values. This can be a major limitation for buildings with large solar gains. However, relatively accurate results may be obtained with wise selection of the solar distribution constants, as was shown in the BESTEST manual for SERIRES (Judkoff and Neymark 1995). Long-wave radiation exchange between interior surfaces is also not modeled explicitly. Interior surfaces are thermally connected to a single-zone air node via a combined radiative and convective surface heat-transfer coefficient. As a result, the zone air temperature calculated by SUNREL is a combination of the air temperature and the mean radiant temperature.

The exterior radiation and convection terms are combined into a constant term. Walls usually have insulation levels far larger than the surface heat-transfer resistance; therefore, a constant surface coefficient is not a major concern. However, windows have a low thermal resistance, and this could be a concern for the user.

Ground-coupled heat transfer from underground walls or slabs-on-grade is a difficult problem and not well understood. The problem is complicated by the wide variations in soil composition and properties, moisture transport, latent heat effects, and the three-dimensional nature of the heat transfer. A knowledgeable user can obtain reasonably accurate results with the one-dimensional heat transfer model in SUNREL.

The SUNREL model for diffuse sky radiation assumes a simple isotropic sky. This model neglects the effects of horizon brightening and circumsolar diffuse radiation. Therefore, this model tends to underestimate the incident solar radiation on sloped surfaces, such as windows (Duffie and Beckman 1991). For most applications this effect tends to be small, although the user should be aware of it.

### **1.3. Organization of the Code**

The original SERIRES program was written in FORTRAN 66, and the SUNREL upgrades were written in FORTRAN 77. The executable program is compiled to run on IBM-compatible personal computers and is named SUNREL.EXE. The FORTRAN code is contained in three files: SUNLOAD.FOR, SUNIN.FOR, and SUNOUT.FOR. The main program is in SUNLOAD.FOR with preprocessing subroutines in SUNIN.FOR and output subroutines in SUNOUT.FOR. Eight include-files contain variable definitions and declarations, common blocks, namelist blocks, and parameter

---

assignments. These files are RUN.INC, ZONE.INC, SURF.INC, HVAC.INC, SHADE.INC, SCHED.INC, OUT.INC, and PARAM.INC.

#### 1.4. Running the Program

The following is a description of how to run the program without the aid of a graphical user interface. If you are using an interface, you may want to skip this section.

To use SUNREL, a user must prepare a building description file (Chapter 3). This file has a unique user name with the ".blg" extension. Another necessary item is a weather file for the building location (or a location with similar weather patterns) with hourly data for the following items: global horizontal radiation, direct beam radiation, dry bulb temperature, dew point temperature, wind speed, and wind direction (optional, but recommended). The user may use one of four different weather file formats: TMY (Typical Meteorological Year), TMY2 (an updated version of TMY), BLAST (Building Loads Analysis and System Thermodynamics), or a SUNREL text weather file. A description of each of these is included in Appendix B.

SUNREL repeats the first day several times to allow the building to reach equilibrium before continuing to the second day. The number of warm-up days is defined in the PARAMETERS input section by WUDAYS. The following steps can be used to run SUNREL:

##### Step 1.

Type SUNREL at a DOS prompt in the directory containing the program, or double click on the SUNREL.EXE icon.

This initiates the program, and the following response will appear on the screen:

```
ENTER THE NAME OF THE BUILDING DESCRIPTION  
FILE.
```

##### Step 2.

Type in the name of the building description file including the extension. After pressing <ENTER>, the program will read the input file, check the input for errors, and perform some preprocessing. If errors are present, the following warning will appear on the screen:

```
THE RUN COULD NOT BE COMPLETED DUE TO  
ERROR(S) IN THE INPUT FILE, SEE THE OUTPUT  
FILE FOR ERROR MESSAGES.  
MYFILE.OUT
```

**Step 3.**

If there are no errors, the program will then ask two more questions requiring user response:

MINIMUM NUMBER OF TIMESTEPS PER HOUR =  $n$

DO YOU WISH TO USE THIS VALUE? (YES, NO, or SUMMARY)

The “ $n$ ” is the minimum number of timesteps for stable solution to the nodal energy balance equations (Chapter 4). Using a smaller number will cause the program to become unstable and not converge to a correct solution. The user should answer "y" or "n." If the user enters “ $n$ ,” then a larger number should be used. However, the larger number will increase computing time.

**Step 4.**

The program will next ask:

PERFORM ZONE LATENT LOAD CALCULATIONS? (Y/N)

The user response determines if the latent loads are important and should be calculated. SUNREL treats latent loads in a very simple manner and only for cooling loads (See Chapter 4 for more details). The program will complete the run after this question.

The output is written to a file in the same directory as the input file. If the user requested the output with headers (by entering "y" for FRMT in the OUTPUT section of the input file), then the output will appear in a file with the same name as the input file, but with the ".out" extension. For example, if the input file was MYBUILD.BLG, the output would appear in MYBUILD.OUT. This file also contains an echo of the building description and any error messages from the preprocessing. The user can request no headers for the output by entering "n" for FRMT in the OUTPUT section of the input file. This response is used when exporting the output to a spreadsheet program. The output is then located in a file with the same name as the input file, but with the extensions ".dt1," ".dt2," ... ".dt9." Thus, up to nine outputs to separate files are available for graphing or analysis without the hassle of removing the text headers. See Appendix A for more information on the output.

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## 2. Thermal Modeling of the Buildings

### 2.1. General

The thermal behavior of buildings depends upon many complex and interrelated factors. The engineering analysis of such a dynamic system is always a compromise between accuracy and cost. Using a higher level of detail generally improves the accuracy of the results, but entails greater costs. The choice of an appropriate level of detail is an important aspect of practical analytic work.

Just as the authors of a program must strive for an appropriate level of detail in developing the equations in the program, the user must also represent the building with an appropriate level of detail. All thermal programs for buildings allow the user flexibility in the level of detail with which the building is described. Choosing the appropriate level of detail requires a certain amount of engineering judgment (i.e., knowledge of what is and what is not important in the solution of a particular problem).

The desired output also dictates the required detail of the building description. If the desired output is the annual heating load of a modestly insulated building located in a cold climate, a simplified building description will provide quite accurate results. However, a much more detailed description will be necessary if the desired outputs are accurate hourly zone air-temperature profiles of a multizone structure with thermostatically controlled fans between zones.

To use a building analysis program, the user must create a thermal model of the building within the constraints of the program. The program checks the user's thermal model and converts it to a mathematical form suitable for solution of the problem. Most of the differences in results obtained in the use of different programs to analyze the same building can be traced to differences in the user-created thermal model, rather than differences due to the internal solution techniques.

This chapter presents the basic descriptive constructs provided by SUNREL for developing the thermal model of the building. It should also serve as a helpful tutorial in the choice of a thermal model appropriate to the user's purpose. Some guidance is provided for levels of detail in modeling. It is not intended to be a text on thermal modeling.

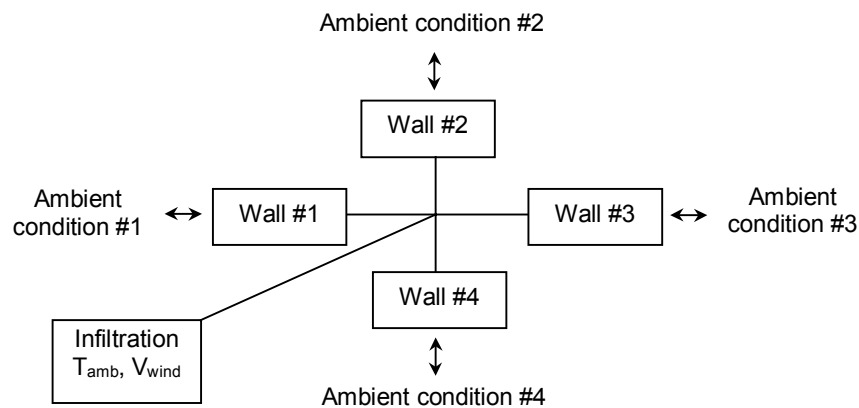
### 2.2. The Building Description

SUNREL is organized around the major thermal components or heat-flow paths of a structure. The fundamental concept is that of a *thermal zone*. A

thermal zone is either a room, or group of rooms, that operates with the same temperature control. The temperature of an internal zone is a conductance-weighted average of surface temperatures. Two special zones are AMBIENT and GROUND. The AMBIENT zone is the outdoor air temperature, and GROUND zone is a user-defined ground temperature. Conceptually, a building is represented as one or more zones with thermal communication between one another and the outdoor temperature and solar radiation.

The most common paths of thermal communication are walls, windows, and infiltration. Other paths of thermal communication include fan-forced convection, special storage elements such as rockbins, and special types of walls such as Trombe walls and walls made of phase-change materials. In addition, the user must provide equipment specifications and schedules and details of the components of the major heat-flow elements.

For instance, a simple building could be represented as shown in Figure 2.1. This single zone is connected by four walls to the ambient and an infiltration heat-flow path. This simple conceptual model of the building is then developed into a building description for use by the program. The major features are specified (that is, one zone and four walls), and necessary details are provided for each major element. For instance, the walls are described, the layers that compose each wall are specified, as are the properties of the materials that compose each layer.



**Figure 2-1. Thermal model of a simple building**

A building description file is composed of several data sections, each of which might contain one or more lines of data values. Each section is a group of parameters describing a particular thermal component of the building. A complete list of the names of all data sections, with a brief description of the information contained in each, is given in Table 2.1. Note that some sections require at least one parameter value be entered, whereas others may be skipped entirely if they are not relevant to the problem at hand. Chapter 3

contains a complete description of all data sections, and a sample input file is given in Appendix D.

**Table 2-1. List of Data Sections**

<b>DATA SECTION</b>	<b>INFORMATION CONTENT</b>	<b>CATEGORY</b>
RUNS	location and duration of simulation run	Primary-Req.
ZONES	defines building zones	Primary-Req.
INTERZONE	heat and solar transfer between zones	Primary-Opt.
WINDOWS	location and size of windows	Primary-Opt.
WALLS	location, size, and type of walls	Primary-Opt.
TROMBEWALLS	location and size of Trombe walls	Primary-Opt.
FANS	location and type of fans	Primary-Opt.
ROCKBINS	location and type of rockbins	Primary-Opt.
SURFACES	orientation and size of exterior surfaces	Component
HVACTYPES	properties of HVAC equipment	Component
NATURALVENT	vent size, location, and controls	Component
TROMBETYPES	detail description of Trombe wall types	Component
WALLTYPES	single or multi-layered wall types	Component
MASSTYPES	wall material properties	Component
PCMTYPES	Phase-change material properties	Component
GLAZINGTYPES	glazing material properties	Component
BINTYPES	detail description of rockbin types	Component
FANTYPES	detail description of fan types	Component
OVERHANGTYPES	dimensions of overhangs	Component
SIDEFINTYPES	dimensions of sidefins	Component
SKYLINETYPES	specification of skyline shading	Component
OUTPUT	output definition	Primary-Opt.
SCHEDULES	multi-season/24-hour schedules	Component
SEASONS	duration of seasons of year	Component
PARAMETERS	detailed simulation run parameters	Component
STATIONS	Definition of weather data files	Component

A workable procedure for defining a building is described by the following seven-step process. Given the flexibility of SUNREL and the diversity of applications, users will eventually develop their own style.

1. Specify the location and duration of the run(s) by entering the parameters of the RUNS section.
2. Define the zones of the building by entering the parameters of the ZONES section.
3. Specify the heat flow paths between zones by entering parameters in the INTERZONE, WALLS, FANS, and ROCKBINS sections.
4. Define the orientation and size of the exterior surfaces of the building by entering the parameters of the SURFACES section.
5. Specify the elements that compose the surfaces by entering the parameters for the WINDOWS, WALLS, and TROMBEWALLS sections.
6. Define the components for each of the component sections referenced in the Primary sections above, or incorporate them from other files.
7. Enter the parameters for the OUTPUT or PARAMETERS sections.

Guidelines to consider for each of these steps are discussed in the following sections.

## **2.3. Runs**

### **2.3.1. General**

Parameters related to the building location are entered in the RUNS data section. The building location is entered as the station (the corresponding weather file must then be described in the STATIONS data section). In addition, the user enters the simulation start date and stop date for each run.

Note that more than one run can be specified at one time. For instance, the same building can be simulated in several locations by specifying several stations.

### **2.3.2. Ground Reflectance**

When short-wave solar radiation strikes the ground, it is reflected diffusely. The fraction reflected can vary from about 0.1 for extremely dark surfaces to 0.7 or more for freshly fallen snow. This effect is modeled using the ground reflectance value(s). The user may enter either a single value to be used for the entire run or the name of a schedule of monthly values. Typically, a constant value of 0.2 or 0.3 is used.

### **2.3.3. Ground Temperature**

SUNREL provides for the use of a ground-temperature node. Walls, rockbins, and zone conductance coefficients may be connected to the ground node by

use of the keyword `GROUND` for the back or sink zone. The ground temperature is either a constant annual value or a schedule of values. The temperature of the earth at depths of 10 feet or more is approximately the mean annual air temperature for the location.

Ground-coupled heat transfer phenomena are characterized by three-dimensional effects, variability in the soil properties, moisture transport, and phase-change effects. `SUNREL` only calculates one-dimensional heat transfer with constant properties; however, reasonable results can be obtained with the appropriate assumptions. For slab-on-grade floors, a 1- to 2-m-wide strip around the perimeter of the floor loses most of its heat to the atmosphere. The remaining central section of the floor exchanges heat with the deep ground. One method of approximating this is to model a 1.5-m-wide strip using the floor construction with 1 m of soil connected to the `AMBIENT` zone, and model the central portion of the floor with 2 m of soil connected to the `GROUND` zone. This is a crude approximation, but it can produce reliable results with good engineering judgement for the soil properties and insulation values.

When using the `GROUND` node, the surface heat transfer coefficient on the ground side of the wall should be specified as the reciprocal of the desired pure resistance between the last mass layer and the ground node. If no resistance is desired, the coefficient may be set to a large value (e.g., 100).

#### **2.3.4. Other**

A skyline profile may be referenced by entering the name of a skyline profile. This must be defined in the `SKYLINE.TYPES` data section. For further discussion, read Section 2.6.7 on solar radiation.

The parameter type contains convergence criteria and other run control parameters. The default parameter values may be used by entering "default" or no input. This causes the program to use hard-coded values for the various convergence criteria used in the numerical solution. In nearly all cases the default values will be used. However, for unusual cases, the user can create new convergence criteria by entering the name of a parameter type and defining it in the `PARAMETER TYPES` data section.

The units of the input data are specified as English or Metric units. `SUNREL` calculates the degree days by two methods: one that is used in the United States and one that is common in Europe. The United States method is based only on an indoor balance temperature. The European method also includes an outdoor temperature limit to start the degree-day calculations. For example, if the indoor balance temperature is 18°C and the outdoor limit is 15°C, a heating degree-day will only be calculated if the average daily temperature is below 15°C.



## **2.4. Zones**

### **2.4.1. Using Multiple Zones**

SUNREL allows the user to model a building as either a single zone or multiple zones. The decision as to whether multiple zones are necessary depends primarily on the specification of heating, venting, and cooling setpoints. If two zones are to be operated at different temperatures during parts of the year, or if one of the zones (perhaps a sunspace) is uncontrolled, then the use of multiple zones is necessary. Attics, basements, and crawl-spaces may also be modeled as additional uncontrolled zones. A little experimentation on the part of the user will soon reveal those cases in which a more complex multi-zone description is desirable.

### **2.4.2. Infiltration Rate**

Heat gain or loss due to wind- and temperature-induced infiltration of outdoor air is a major element of the overall heat transfer in a typical residence. Infiltration effects are handled by two methods: a constant or scheduled air change per hour for each zone; or a variable rate based on the effective leakage area for each zone, the inside to outside temperature difference, and the wind speed.

For the constant air change per hour method, the user must enter a floor area and zone height for each zone. These are multiplied to obtain the zone volume upon which the air changes per hour are based. A numeric constant or the name of a user-defined schedule is entered for the zone air change rate.

The second method is based on the effective leakage area of each zone, such as that determined from a blower door test. The infiltration is determined every timestep from a mass balance on each zone in the building. Note that there may also be interzone infiltration in this method. To use this method, the user must enter a floor area, zone height, and effective leakage area. The user also has the option of entering the fraction of leakage in each wall, the height of the lower edge of each surface, and distinguishing each wall with one of the key words: WALL, FLOOR, or CEILING.

### **2.4.3. Natural Ventilation**

Natural ventilation can be an important feature for maintaining comfort and energy efficiency in small buildings. Natural ventilation is driven by temperature differences and wind in a manner similar to the infiltration. To include natural ventilation, the user must enter the vent size and location along with the temperature setpoint for operation as a constant or as a user-defined schedule.

#### **2.4.4. Sensible Gains**

Sensible gains are an important factor in residential thermal modeling. Sensible gains are specified by either a constant rate or a user-defined schedule. Studies indicate that, for typical residences, the use of constant rates gives satisfactory accuracy for annual heating and cooling loads.

#### **2.4.5. Latent Gains**

Latent heat is the heat required to evaporate or condense water vapor in a zone. Its primary importance is for air-conditioning calculations, where the condensation of the vapor on the coils of the air conditioner creates an additional load on the equipment. A typical value is 450 BTU per hour. This corresponds to the evaporation of about 10 pounds of water per day. Latent gains are specified by a constant value or the name of a schedule.

### **2.5. Conduction**

Perhaps the simplest heat transfer mechanism in buildings is the gain or loss of heat by conductance through walls, ceilings, etc. For convenience, all building elements separating zones from each other and from AMBIENT and GROUND are referred to as walls. The program provides three ways to describe conductance through walls: steady-state heat transfer coefficient (INTERZONE section), pure resistances, and multiple layers of materials with heat capacity. The user can use one of three methods to model wall elements. Thus, if the heat capacity of a given wall is judged to be nonessential to the problem, it may be ignored. This approach also minimizes the labor of preparing a building description for the program.

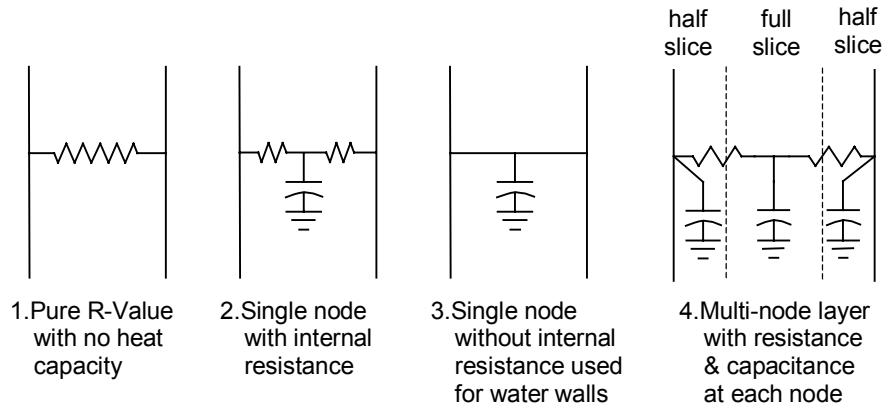
#### **2.5.1. Use of Conductance Coefficients**

The user might wish to ignore the thermal capacity of the wall, solar effects on the inside and outside of the wall, and the exterior and interior surface temperatures of the wall. In that case, the product of the wall area and U-value is entered as a conductance coefficient in the INTERZONE data section. These coefficients may also be used to model estimated convective transfers between zones. When a conductance is specified between two building zones or from a zone to AMBIENT or GROUND, it must include all walls or paths of heat transfer not accounted for in the WALLS data section.

#### **2.5.2. Walls**

The second and third levels of detail require use of the WALLS data section. Walls are constructed of layers (Figure 2.2) and are defined in the WALLTYPES input section. Each wall has a front side, which must face a user-defined ZONE, and a back side, which may face either a ZONE, an EXTERIOR SURFACE, or one of the keywords, AMBIENT or GROUND. If

AMBIENT or GROUND is specified, no solar effects on the exterior side will be modeled. A wall may have the same zone specified on both sides so that it is wholly contained within the zone.



**Figure 2-2. Layers available for making walls**

The required inputs are the interior zone, the exterior surface for the wall, and the wall height and length. In addition, a surface coefficient and solar absorptance may be input. The surface coefficient is a combined radiation and convection heat transfer coefficient. A typical value for interior vertical surfaces is  $1.46 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ . For exterior surfaces, a typical value is about  $4 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ . A table of surface conductances can be found in the *ASHRAE Handbook of Fundamentals* (1993). The solar absorptance for an interior surface is the fraction of the total solar available in the zone that falls upon the given surface. If not input, the program will determine this by the area of each surface in a zone. For an exterior surface, the solar absorptance is the absorptivity of the surface for short-wave solar radiation.

### 2.5.3. Use of R-Value Walls

The second level of detail provided for wall descriptions is the use of an R-value together with the area of the wall. When represented in this way, the program calculates heat flow through the wall using the interior and exterior surface temperatures, but does not include capacitance effects. However, the program does calculate all solar effects on such walls.

Individual layers of a wall may be treated as R-values by entering R-*n* for the appropriate layer in the WALLTYPES data section. Detailed output is available summarizing all of the factors relating to the performance of such walls.

#### 2.5.4. Use of Capacity Walls

The third level of detail allows for the description of the wall as composed of one or more layers of material. Each of these layers may consist of either an R-value or a specified material described by its thickness, specific heat, density, and conductivity. In this way, walls of almost arbitrary complexity may be treated. Additionally, if the walls are part of an exterior surface and the user wishes to determine the effects of solar energy on the wall, the azimuth, absorptance, and parameters for shading must also be specified.

Since the program uses a thermal network model, nodes (each representing a thin slice of material) must be specified in materials with heat capacity. A variety of types of capacity layers are available. These include the following:

1. *Single node with internal resistance* Used for thin layers of solid material or, in some cases, for thick layers where accurate surface temperatures are unimportant.
2. *Single node without internal resistance* Used for water walls or drums where convective stirring effectively eliminates internal resistance (i.e., the entire thickness is at the same temperature as the surface).
3. *Single node phase change* Allows the user to model thin layers of phase-change material.
4. *Multi-node with internal resistance* Allows the user to specify any number of nodes within any given layer of material so that the temperature at any point within the material can be modeled to any desired degree of accuracy.

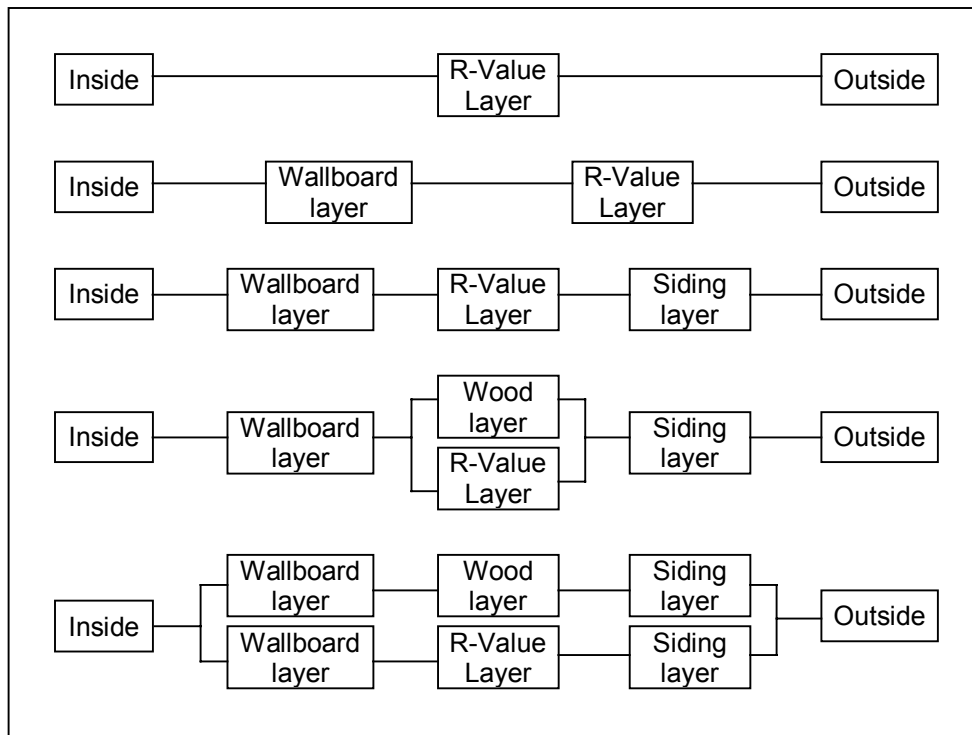
The execution time of a simulation depends in a linear way upon the number of mass nodes used and can be strongly affected by the use of layers of low thermal capacitance next to layers of high thermal capacitance. Therefore, the user must exercise good engineering judgment in the selection of the level of detail in modeling capacity elements. The following guidelines may be useful:

1. For walls experiencing large temperature variations at the surface (i.e., Trombe walls), a node spacing of about 2 inches will give accurate results. If the temperature variations and their dynamic effects are small, a larger spacing will be adequate.
2. Walls 2 or more feet thick may be modeled with surface layers spaced at 2 inches and an internal layer at 4- to 6-inch spacing without loss of accuracy. Earth berms and, similarly, very thick walls may have nodes 1 foot or more apart in the interior.
3. Walls less than 4 inches thick can generally be modeled with a single node.

4. Where there is a dominant thermal capacitance, such as a concrete floor in a zone, the capacitance of other elements such as wallboard and furniture may be safely ignored.
5. When using layers of thin metal or air with low capacitance next to layers with a higher thermal capacitance, model the low capacitance layers as a pure resistance by entering the R-value in the WALLTYPES section.

For walls constructed of multiple layers, the name of each layer is entered in the WALLTYPES data section with the first layer representing the layer closest to the user-specified front ZONE. The parameters conductivity, density, specific heat, thickness, and number of nodes for each layer are entered in the MASSTYPES data section.

Composite walls, such as a typical wood frame wall with studs and insulation, may be modeled as two separate walls belonging to the same exterior surface (Figure 2.3). The user must enter the same exterior surface for each wall, the same wall height and length, and the percent of the entire wall area that each wall type occupies.



**Figure 2-3. Levels of detail for modeling a wood frame wall**

### **2.5.5. Trombe Walls**

Trombe walls are special walls that passively collect and store thermal energy from the sun and release it slowly at a later time to the interior zone. They consist of a massive wall (e.g., brick, concrete, water, or phase-change material) and a glazing cover to trap the heat. Trombe walls may be vented or unvented; unvented walls generally give the best performance. Information for Trombe walls are entered in the TROMBE WALLS and TROMBE TYPES input sections.

Trombe walls are treated similar to windows in that they are assigned to an exterior surface, and a wall must also be assigned to this same surface. The wall must be given the dimensions of the entire surface area, even if the Trombe wall occupies the whole surface. SUNREL subtracts the area of the Trombe wall from the area of the wall.

For vented Trombe walls, the vent-area-ratio is the ratio of one row of vent areas to the total area of the Trombe wall. The vent coefficient is a number between zero and one that is multiplied by the volumetric flow rate. This accounts for the flow resistance due to the vents. A value used in other studies is 0.8; however, the true magnitude of the thermocirculation is controversial.

## **2.6. Solar Gains**

Solar gains through windows and on exterior walls are one of the most important energy inputs in low-energy buildings. SUNREL treats all solar gains in great detail.

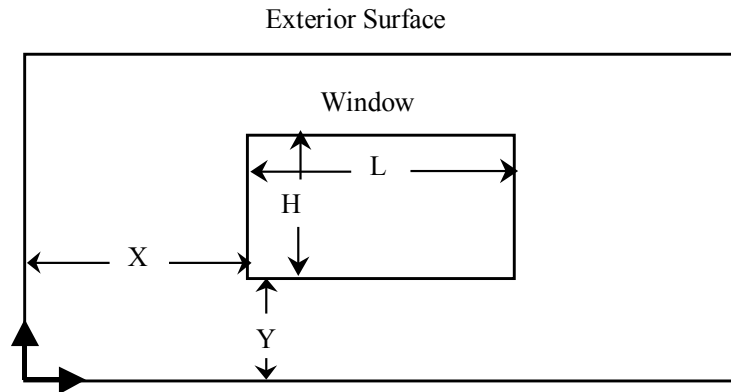
### **2.6.1. Exterior Surfaces**

The user may define and name exterior SURFACES. Subsequently, walls, windows, and Trombe walls are defined as belonging to an exterior surface. The underlying logic is to minimize the geometric input required from the user. For each exterior surface, the user must enter the azimuth, tilt from horizontal, height, and length.

### **2.6.2. Windows**

Each window is defined as belonging to an exterior surface and facing an interior zone. The names of the exterior SURFACE, the interior ZONE, and the GLAZING TYPE are entered in the WINDOWS data section. The user must also enter a HEIGHT and LENGTH for each window, which are used to calculate the window area. The window is located by the horizontal and vertical distance of the lower left hand corner from the origin of the surface as viewed from the outside (Figure 2.4). The user may also specify values for the interior and exterior surface coefficients for the window; if these are not input, the default values will be used.

SUNREL has two methods for the treatment of windows. The first assumes that each window is composed of one or more identical layers of partially transparent material. The program accounts for all multiple reflection and absorptance within and between the glazing layers. The user must enter the following material properties: glazing U-value (surface to surface), extinction coefficient, index of refraction, layer thickness, and number of layers in the GLAZINGTYPES data section. An optional shading factor may also be input.



**Figure 2-4. Window size and location on an exterior surface.**

The shading factor (SF) concept used in this program is similar to the shading coefficient (SC) found in the ASHRAE Handbook of Fundamentals (1993); however, the numerical values are not the same. The shading coefficient in the ASHRAE Handbook is defined as the ratio of the solar heat gain through a given glazing assembly to that of a reference single-pane, double-strength, clear (DSA) glass (1993). The shading factor used in this program is the ratio of the solar heat gain through the given assembly to the solar heat gain through a similar glazing assembly with clear glass of the same thickness. For glazing systems with only clear glass, the shading factor used is one. However, for glazing systems with tinted glass or with selective coatings, the shading factor will have a value less than one.

For example, consider the following fictitious windows: Window A is a triple-pane window with clear glass and would have a shading factor of one. Window B is the same as window A, but with a spectrally selective coating on one of the layers; the shading factor would then be the ratio of the solar heat gain through window B to that of window A. Or the ratio of the two shading coefficients as defined in the ASHRAE Handbook of Fundamentals (1993).

$$SC_A = 0.86$$

$$SC_B = 0.75$$

$$SF_A = 0.86/0.86 = 1.0$$

$$SF_B = 0.75/0.86 = 0.872$$

The shading factor also allows the user to model the effects of curtains, venetian blinds, and various types of external shading devices. The shading factor multiplies the solar heat gain, which is defined as the sum of the transmitted short-wave radiation, and the inward-flowing fraction of the solar radiation absorbed in the glazing layers. This parameter can be scheduled, to allow for solar control during periods of high heat gain.

Some error may be introduced by this method because the shading coefficient is dependent on the angle of incidence and the environmental conditions, and it does not include spectrally selective effects. A more accurate model of windows with other than clear glass was developed by Lawrence Berkeley Laboratories in WINDOW-4.1 (Arasteh et al. 1994). WINDOW-4.1 calculated the angular dependent window transmittance and the layer absorptance for almost any window configuration. The second method of analysis of windows in SUNREL uses this information from WINDOW 4.1. To use this method, the user simply enters the name of the WINDOW-4.1 data file under GLAZINGTYPES. All of the necessary information is included in this file. These files may either be in the library of glazing types or developed by the user using the WINDOW-4.1 program. See Appendix C for information on how to prepare the glazing data file.

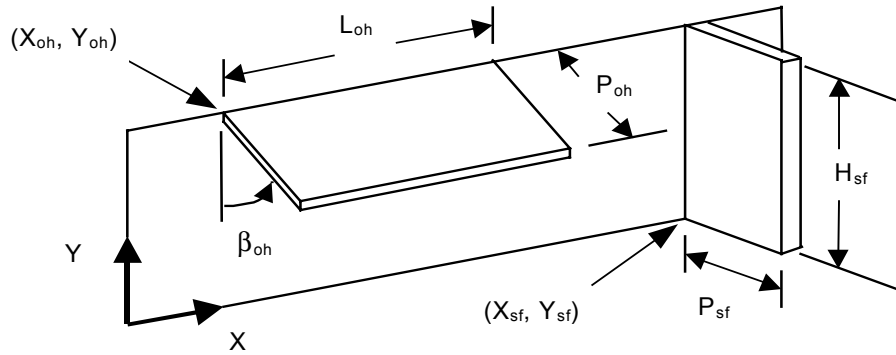
### **2.6.3. Overhangs**

Overhangs are assigned to an exterior surface and are defined by the location of the left-hand corner on the surface, the length, the projection, and the angle between the surface and the underside of the overhang (Figure 2.5). Shading of direct and diffuse radiation is determined for the surface and windows on the surface. Diffuse reflections off the bottom of the surface of the overhang are also determined, and the user may enter the diffuse reflectivity of this surface.

### **2.6.4. Sidesfins**

In a similar fashion, the user may specify left or right sidesfins, or both. Sidesfins are defined by the location of the bottom corner on the surface, the height, and the projection from the surface. Sidesfins are assumed to project normal to the shaded surface. See the SIDEFINTYPES data section for further details on sidesfins and Figure 2.5 for a diagram showing sidesfin dimensions.





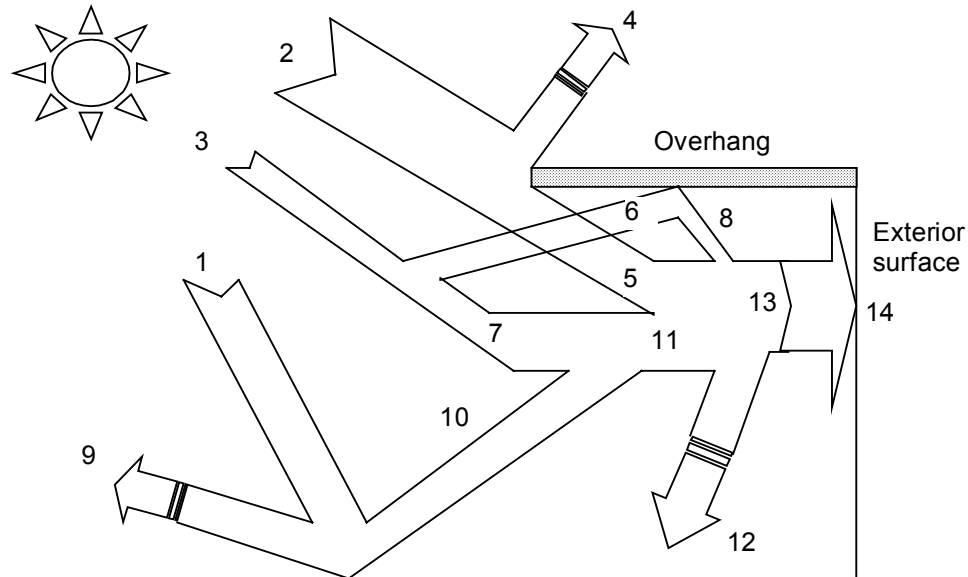
**Figure 2-5. Overhang and sidefin dimensions relative to an exterior surface**

### **2.6.5. Skyline Profiles**

The program can model the effect of trees, buildings, or other nearby objects in solar availability at the simulated building site. Skyline profiles are specified in the RUNS data section and defined in the SKYLINETYPER data section. Shading due to skyline obstructions is considered before all other shading effects, and transmitted radiation values are calculated.

### **2.6.6. External Distribution of Solar Radiation**

Solar radiation on the exterior of the building is distributed as shown in Figure 2.6.



**Figure 2-6 . Illustration of exterior distribution of solar radiation**

Explanation of Figure 2-6:

1. Total horizontal radiation after skyline shading
2. Direct solar on tilted surface after skyline shading (unshaded by overhang); calculated by the program
3. Sky diffuse on tilted surface (unshaded); calculated by the program
4. Direct solar lost by overhang shading; calculated by the program
5. Shaded direct solar on tilted surface; calculated by the program
6. Direct solar and sky diffuse solar incident on the shading device
7. Shaded sky diffuse solar on tilted surface, calculated by the program
8. Diffuse solar reflected off the shading device incident on the exterior surface
9. Ground scattering calculated by the program
10. Ground diffuse on tilted surface; calculated by the program. This might also be reduced by sidefin shading (not shown)
11. Total shaded diffuse on tilted surface; calculated as  $(7)+(8)+(10)$
12. Reflection losses; see (14)
13. Total incident solar see Figure 2.5 for further effects on glazing systems
14. Solar absorbed, specified by user for each exterior wall as a fraction of total incident solar (13).

### **2.6.7. Internal Distribution of Solar Radiation**

The following parameters affect the magnitude and distribution of solar radiation in each zone as shown in Figure 2.7:

1. Shading factor for each window in the zone
2. Solar transfer and reverse solar transfer in the INTERZONE data section
3. Solar to air and solar lost in the ZONES data section.

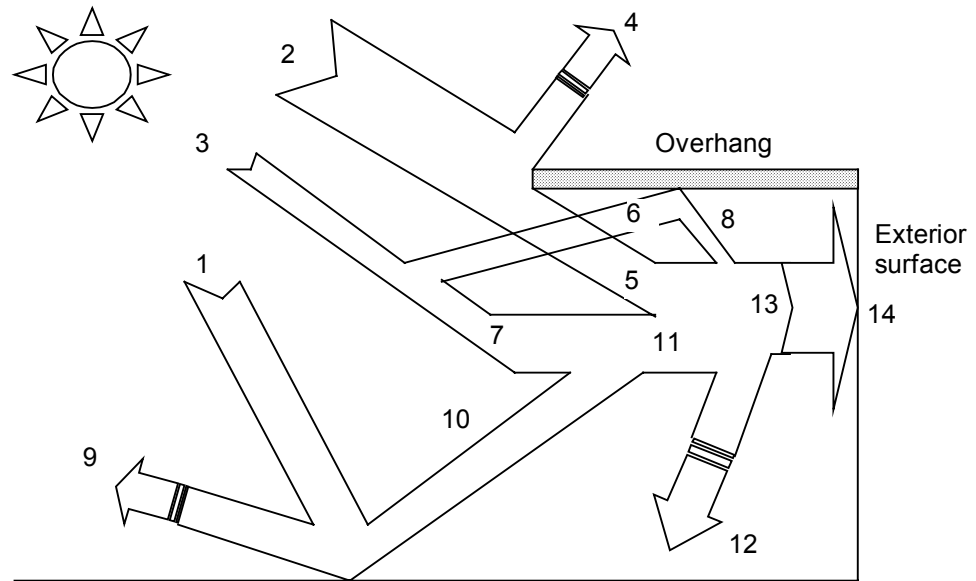
Each window may have a user-specified shading factor that multiplies solar heat gain through that window. The solar heat gain has two components: the short-wave solar transmitted through the window and the inward-flowing fraction of the solar radiation absorbed in the glazing layers. The inward-flowing absorbed radiation goes directly to the zone air-temperature node.

The sum of the transmitted short-wave radiation multiplied by the shading factor over all windows is then adjusted by a solar-lost factor. This factor accounts for the short-wave radiation reflected back through the glazing and lost. The solar lost can be thought of as the effective cavity absorptance of the zone. Typical values vary from 0.05 to 0.10.

If there are multiple zones, any fraction of radiation entering one zone might be passed to another and vice versa. The user enters these fractions as the solar transfer and reverse transfer in the INTERZONE data section. This allows for a crude treatment of the presence of transparent surfaces between zones.

After accounting for interzone transfers in each zone, a fraction of the remaining available short-wave radiation may be put immediately into the zone air-temperature node. This is the solar-to-air variable in the ZONES data section, and it allows the user to account for that portion of the radiation absorbed by non-massive objects and converted quickly into heat. Typical values vary from 0.05 to 0.2.

Two methods are available to determine the amount of solar absorbed by each wall: the first method allows the program to distribute the radiation over all walls in a given zone in proportion to their areas; the second method requires the user to determine the fraction absorbed in each wall. The user thus controls the relative amounts of radiation received by each wall. The fraction absorbed by each wall is entered as the solar absorbed for each wall or Trombe wall. For each zone, the sum of all the solar absorbed for wall surfaces facing that zone, plus the solar lost, plus the solar to air must equal one.



**Figure 2-7. Illustration of interior distribution of solar radiation**

Explanation of Figure 2.7:

1. Total solar incident on window
2. Reflection losses from glazing layers
3. Reflection losses from shading device (Shading Factor)
4. Outward-flowing portion of solar absorbed in glass
5. Loss of inward-flowing portion of solar absorbed due to shading device (Shading Factor)
6. Net inward-flowing portion of solar absorbed in glass goes to air node
7. Short-wave solar loss to other zones (defined under INTERZONES)
8. Short-wave solar gain from other zones (defined under INTERZONES)
9. Short-wave to air node (Solar-to-Air defined under ZONES)
10. Short-wave to mass #1 (Solar Abs defined under WALLS)
11. Short-wave to mass #2

## 2.7. Equipment

### 2.7.1. General

When zone temperatures fall above or below the comfort range, equipment must be brought into operation to maintain comfort, if possible. The user may define cooling, venting, and heating setpoints and capacities for each zone.

Equipment operation follows the sequence: fans are operated first, then rockbins, then venting. Finally, any remaining loads are satisfied, if possible, by the heating and cooling equipment. By this strategy, the program calculates the loads on the various types of equipment without going into the details of particular types of equipment and their associated control systems. Thus, the program evaluates equipment loads, but not the input energy required to satisfy those loads by some particular set of equipment and controls.

## **2.7.2. HVAC**

### **2.7.2.1. Heater**

The heater provides heat to a zone as necessary to maintain its heating setpoint. If the user specifies a maximum capacity for the heater that is too low at a given moment, heat is added at the maximum rate, and the resulting zone temperature is calculated. The heater deals only with sensible heat and does not include any latent heat effects. The heating setpoint and heating capacity are entered in the HVACTYPES data section. No heating is selected by leaving heating setpoint at its default value, no entry, or a negative number.

### **2.7.2.2. Venter**

The venter provides for thermostatically controlled exchange of zone air with outdoor air. The intent is to model two phenomena: first, the venter can be seen as an economizer cycle for an air-conditioning system, whereby cooling is achieved by forced ventilation with cooler outside air without activation of the cooling coils; or the venter can be seen simply as an exhaust fan. The venter removes heat to maintain a venting setpoint subject to its maximum capacity whenever the outdoor air is cooler than the indoor air. Note that natural ventilation is not part of the mechanical equipment algorithms and is used as a first option to meet cooling loads when it is defined.

The venting setpoint and venting capacity (in air changes per hour) are entered in the HVACTYPES data section. As for heating, no venting is selected by the default venting setpoint value of no entry or a negative number.

### **2.7.2.3. Cooler**

The cooler removes heat from a zone as necessary to maintain the cooling setpoint subject to its maximum capacity. As with the heater, if the capacity is inadequate, it is operated at the maximum rate, and the resulting zone conditions are calculated. The cooler is thermostatically controlled and does not respond to latent loads.

The cooling setpoint and cooling capacity are entered in the HVACTYPES data section. No cooling is selected by the default cooling setpoint value of no entry or a negative number.

#### **2.7.2.4. Latent Heat**

SUNREL has limited capabilities for handling latent heat effects. Latent calculations are made in a similar fashion to those for a variable volume air system. The cooler is controlled by a dry-bulb thermostat. The sensible cooling load determines the rate of air flow through the cooler. The air is cooled to a user-specified cooler-coil temperature and any resulting dehumidification of the zone air is calculated. The humidity ratio and relative humidity of the zone air are updated hourly.

The cooler-coil temperature is entered in the HVACTYPES data section. A typical value is 55°F. Detailed output regarding latent effects is available in the LATENT HEAT section of the ZONE SUMMARY.

#### **2.7.3. Fans**

The user may specify one or more fans between zones. Because fans are assumed to be unidirectional, the zones may be uniquely labeled as a source zone (the warmer one) and a sink zone (the cooler one). A sink zone may be connected to only one source zone by fan; however, a source zone may supply several sink zones. The operation of a fan may be disabled for one user-defined season of the year.

The names of the source and sink zones, the name of the FAN TYPE, and the name of the off-season are entered in the FANS data section. The maximum capacity (volumetric flow rate), and the minimum temperature differential for operation are entered in the FANTYPES data section.

Detailed output on fan performance is available in the fan summary output block.

#### **2.7.4. Rockbins**

The rockbin model used in the program is the infinite NTU model developed at the University of Wisconsin by Pat Hughes and others. It is nearly identical to the rockbin module in TRNSYS 10 (Hughes et al. 1976). Rockbins are one-way flow devices in any given operating mode. The source zone provides the inlet air during the charge cycle, while the sink zone receives the outlet air during the discharge cycle. A single zone may be specified as both the source zone and the sink zone for a rockbin.

A rockbin loses or gains heat passively to one user-defined zone and to the pre-defined zones AMBIENT and GROUND. The names of the source zone, the sink zone, the ROCKBIN TYPE, the zone for passive losses, and the values for the passive conductances are entered in the ROCKBINS data section.

The user may specify either of two types of air-flow control. In the first type, air flow is always in the same direction; that is, the inlet is always at the same physical end of the rockbin.

The second type has reversing flow; that is, the direction of air flow in the charge mode is opposite to that of the discharge mode. The second type allows for maximum advantage from stratification of temperature within the rockbin and generally provides superior performance.

The user must specify the type of flow control, the volumetric heat capacity of the rockbin, the axial conductance of the rockbin, the length and cross-sectional area of the rockbin, the names of the FAN TYPES for the charge and discharge fans, and the name of a user-defined charge off season. These parameters are entered in the BINTYPES data section. The charge and discharge fans may be of different types.

Detailed output on rockbin performance is available in the ROCKBIN SUMMARY output block.

### **2.7.5. Fan and Rockbin Control Strategy**

Fans are modeled as a thermostatically controlled conductance between zones or between a zone and a rockbin. Each fan has an ideal controller. An ideal controller is one that delivers the maximum amount of heat from the source to the sink while obeying the following four constraints: *maximum capacity constraint*, *minimum temperature difference constraint*, *maximum energy available constraint*, and *maximum energy needed constraint*. This requires the controller to be able to cycle the fan on and off at an arbitrarily high rate during a time increment. Equivalently, the fan controller can also select the fan speed between zero and the specified maximum capacity that maximizes fan performance. The term *duty cycle* can be thought of as the fraction of time increment in which the fan is on, or the fraction of full capacity at which the fan is operated. Each fan operates at no more than its specified maximum capacity; that is, its duty cycle cannot be larger than unity. This is referred to as the *maximum capacity constraint*.

Each fan controller has a minimum temperature difference between a source zone and a sink zone. For the fan to operate, the temperature in the source zone must be higher than the temperature of the sink zone, plus the specified minimum temperature difference. This is referred to as the *minimum temperature difference constraint*.

In addition, the fan controller interacts with the source- and sink-zone setpoints in the following ways. The setpoints in each zone must satisfy the following inequality:

$$\text{HEATING SETPOINT} < \text{VENTING SETPOINT} < \text{COOLING SETPOINT}$$

Note that not all setpoints need be specified. For instance, a zone may have venting and cooling, but not heating. But all defined setpoints must obey the above inequalities.

If a heating setpoint is specified for the source zone, the operation of the fan will not lower the temperature of the source zone below its heating setpoint. This is referred to as the *maximum energy available constraint*.

In addition, the fan will not raise the temperature of the sink zone above the lowest setpoint specified (if any). That is, if the sink zone has a heating setpoint specified, the fan will not raise the sink-zone temperature above the heating setpoint. If the sink zone does not have a heating setpoint, but does have a venting setpoint specified, then the fan will not raise the sink-zone temperature above the venting setpoint. In the same way, the fan will not raise the sink-zone temperature above the cooling setpoint, if one is defined. This is referred to as the *maximum energy needed constraint*.

If no thermostat setpoints are specified, the fans will operate so as to deliver the maximum energy from the source zone to the sink zone, subject to the minimum temperature difference and maximum capacity constraints. Note that these interactions with HVAC thermostats cause the fans to operate primarily as a heating device for the sink zone (subject to the constraint of not causing heating in the source zone), rather than as a cooling device for the source zone.

Rockbins may be either charging (receiving energy from the source zone) or discharging (delivering energy to the sink zone) during a time increment, but not both. When conditions are such that either could occur, the rockbin will charge (charge priority).

Subject to the four constraints defined above, each zone fan or rockbin fan will operate to deliver the maximum energy possible, with one exception. The energy delivered from a rockbin will be limited to the maximum capacity of the heater, and the temperature of the sink zone will be the same as it would have been had the rockbin not operated. In particular, note that a rockbin sink zone must be heated (i.e., a heating setpoint must be specified) for the rockbin to discharge.

The assumption of ideal control is formulated as a constrained optimization problem. The four constraints, combined with the restrictions discussed below, result in a uniquely determined duty cycle for each time increment.

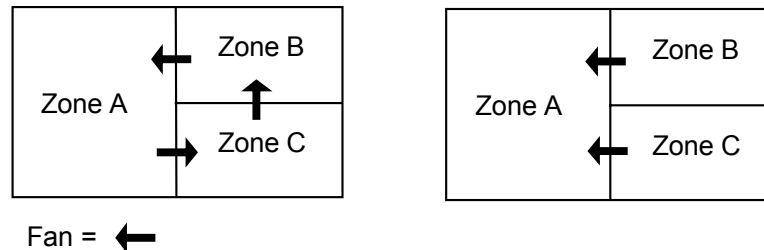
### **2.7.6. Fan and Rockbin Placement Restrictions**

The placement of fans and rockbins is restricted for two reasons. The first is the complexity of creating a consistent logic within the program for handling such situations. For instance, should a living room be kept at its cooling



setpoint by heat delivered from a sunspace, so that excess heat can be moved from the living room to the bedroom?

A second and related reason is the difficulty in the real-world situation of devising adequate control of such arrangements, combined with the fact that need for such complex fan arrangements may indicate that effort would be better invested in improving the building design. Generally, the restrictions are intended to avoid the situations diagramed below in Figure 2.8.

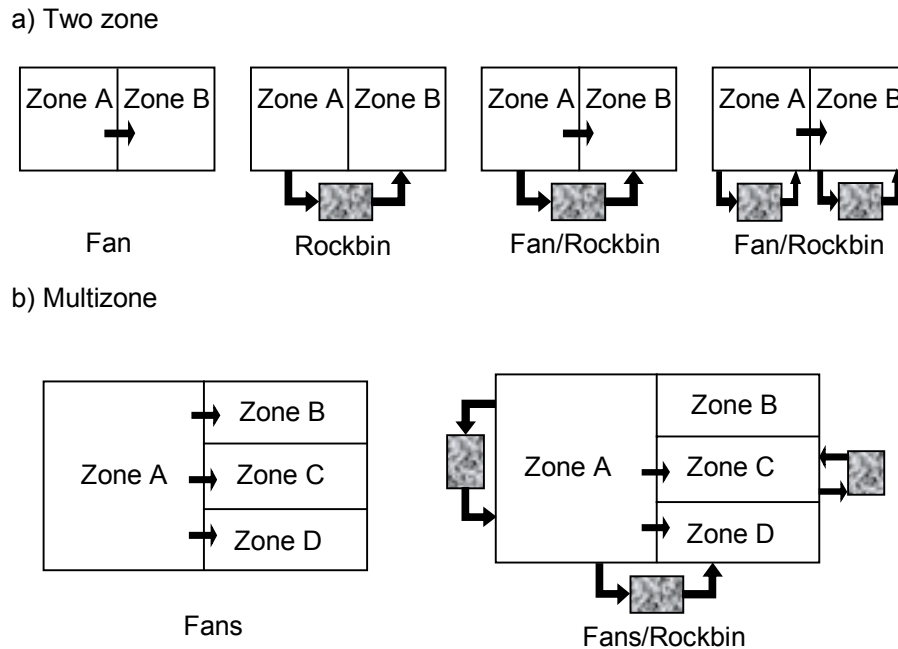


**Figure 2-8. Illegal placement of fans**

Specifically, the restrictions are the following:

1. A zone may be the sink zone for at most one fan
2. A zone may be the sink zone for at most one rockbin
3. A zone that is the sink zone for a fan may be connected to a rockbin only if it is (a) both the source zone and the sink zone for the rockbin, or (b) the sink zone for the rockbin, and the source zone for the fan is also the source zone for the rockbin
4. A zone may *not* be the source zone for one fan and the sink zone for another fan
5. A zone that is the source zone for a fan may be the sink zone for a rockbin, only if it is also the source zone for that rockbin.

Note that the restrictions allow a zone to be the source zone for several fans and rockbins, but limit a zone to be the sink zone for at most one fan or rockbin. Examples of allowable fan and rockbin placements are shown in Figure 2.9.



**Figure 2-9. Examples of allowable fan and rockbin placements**

## 2.8. Schedules

Some of the input variables may be scheduled. That is, they can be assigned different values for each hour of the day or different values for different seasons of the year. Parameters that may be scheduled are

GROUND REFLECTANCE	GROUND TEMPERATURE
INFILTRATION RATE	SENSIBLE GAIN
LATENT GAIN	SOLAR TRANSFER
REVERSE TRANSFER	GLAZING U-VALUE
SHADING FACTOR	HEATING SETPOINT
VENTING SETPOINT	COOLING SETPOINT
NATURAL VENTILATION SETPOINT	

When the name of a schedule in the SCHEDULES section is specified for one of these parameters, the set of data values contained within the schedule entry are used for that parameter when the SCHEDULE is active. Otherwise the constant value or default value is used for that parameter. The SCHEDULE assigns to the parameter the same data value for a given hour over a contiguous set of days (a season). SEASONS are defined by a start and stop date in the SEASONS section. A SCHEDULE may have a different set of values for different SEASONS (i.e., different times of the year). For example, the heating setpoint may have one set of values during the winter and another

during the summer. The input data sections for SCHEDULES and SEASONS explains in detail how to define SCHEDULES and SEASONS along with examples.

## 2.9. Output

The method of specifying output is designed to allow the user the maximum amount of flexibility regarding the level of detail for various components of the building. The possible outputs are given in detail in Appendix A. The output is divided into blocks organized around the major thermal components of the building. The complete building description used for the simulation is also echoed in the output.

The output specification section will have one or more lines specifying the block of output data desired, the timestep for the output, the season for that output desired, the units (English or Metric) desired, the element of a given type for output desired (for instance, the third of six walls), the Page or Output Data Section in the block desired, and the type of format for the output file. The standard output file format includes an echo of the building description and headers for each output section. The name of this file is the input file name with a “.out” extension. A second file format is a tab-delimited file with no headers that may be imported into a spreadsheet program. This file type contains only one output section per file for up to nine files and are named with extensions ".dt1" through ".dt9." Output summaries will be created in the file in the order in which they are specified.

For the convenience of the users, a standard output specification is defined and will be automatically produced if no values are entered in the Output Data Section. This output will consist of monthly and run-length summaries for the AMBIENT and BUILDING output data blocks. All output pages for these blocks will be produced in the units in which the building description was entered. The format will include headers describing each variable and its units.

As an example, suppose that the user desired to run the building for a full year with monthly summaries for the AMBIENT, BUILDING, and ZONES output blocks. In addition, hourly output is desired for the zone and outdoor temperatures for July 15. The user would define a season for the day of July 15. In the output data section, the user would then enter the following:

```
&OUTPUT
OUTTYPE = 'AMBIENT' 'BUILDING' 'ZONES'
        'AMBIENT' 'ZONES'
PERIOD = 'M' 'M' 'M' 'H' 'H'
OUTUNITS = 'E' 'E' 'E' 'E' 'E'
OUTSEASON='ALL' 'ALL' 'ALL' 'JUL15' 'JUL15'
IOPAGE = -1 -1 -1 1 7
```

### 3. Building Description Input File

#### 3.1. General

SUNREL uses the FORTRAN Namelist structure for the input of the building description variables. This input structure allows the program to be extremely flexible for future changes and provides an excellent format for bridge files to graphical user interfaces. A description of the Namelist format as it applies to SUNREL is given in Section 3.2. Consult a FORTRAN language reference for more information. The last section covers each input section and all of the variables in detail.

#### 3.2. Description of Namelist Input

The Namelist format allows variables of a similar function to be grouped together. For example, all of the variables describing windows are in a group called WINDOWS. The SUNREL input file has 26 groups or input sections. The following rules apply to the input files:

1. Every input section must appear in the input file, but may appear in any order. Every section must begin with an "&" followed by the section name (case is not important) and end with "/." Only the allowed variable names followed by an equals sign and their values may appear within each input section. Comments may be placed between the different input sections.
2. All variables are arrays of length equal to the maximum number given at the beginning of each input section. Variable names of each section may appear in any order and may appear more than once between the section name and the "/." Not all of the variable names have to appear in the input file; those values that are not required may be left out. If the default value is desired, the variables may be omitted. Variable names are case insensitive.
3. The program assigns values to successive elements in the arrays starting with the element specified or the first element of the array if none is specified. If there is more than one input value, they must be delimited by spaces or commas.
4. All character strings must be enclosed in single quotes. All user names are case sensitive; therefore, a wall type referenced under WALLS must match exactly one of the wall type names under WALLTYPES. SUNREL keywords, such as month names or "yes" and "no," are not case sensitive. For example: jan, JAN, or Jan are all equivalent. All months are three characters long; all yes/no questions and units (English or metric) may be input as one letter (i.e., "y", "n", "e," or "m"). All user-defined character variables have a maximum length of 10 characters. Exceptions to this rule

are the station name and weather data file name, which are limited to 100 characters, and the run label, which may be 30 characters long. Character variables may exceed the maximum length limit; however, extra letters will be ignored by the program.

5. Values may be entered for any element in the arrays, but should start with the first element. Values that are repeated may be entered using an "\*" and the number of repeating values. (e.g., 3\*0.3 is the same as 0.3, 0.3, 0.3).
6. If a constant value and a schedule are entered for the same variable (i.e., grefl and grelscd), the schedule will override the constant value when the schedule is in affect, otherwise the constant or the default value will be used.
7. The solar radiation that enters a zone is divided into components through user-defined constants. These constants are the solar absorbed by the walls in a zone: WFSOLABS for the front side and WBSOLABS for the back side of an interior wall; the interzone solar transfer and reverse transfer: IZSOLTRN and IZREVTRN; the solar radiation absorbed by the zone air node: SOL2AIR; and the solar radiation lost from the zone through the window: SOLLOST. All of these values vary between zero and one, and their sum for each zone must equal one to account for all the solar radiation in the zone.
8. The default values are shown in "[ ]," the units and acceptable inputs are listed in "()." Some variables have "default = negative number." This flag alerts the program to perform some calculations or set the default to different values depending on the input. The default values are explained below and, if they are desired, any negative number (or no input) may be used to activate the default values in the program.

Examples of input:

#1 Correct input

```
&ZONES
zonename =   'living' 'sunspace' 'upstairs'
zhgt =   2.3   2.3   3.0
/
```

#2 Correct input

```
&Zones
zonename(1) = 'living'   'sunspace'
zonename(3) =   'upstairs'
zhgt = 2*2.3  3.0
/
```

#3 Incorrect input

```

&ZONES
zonename = 'living'      'sunspace'
zhgt = 2.3      2.3
zonename = 'upstairs'
zhgt = 3.0
/

```

The first two examples will produce the same correct result. In the third example, the program will write over the zone name "living" and the first zone height of 2.3 with zone name "upstairs" and height of 3.0.

Each of the SUNREL input section and the variables are defined below

\* Indicates a required input.

**&RUNS** (max RUNS = 5)

```

* LABEL      = Run label (30 characters maximum).
* STATION    = User name of the station defined in the STATIONS
              section (100 characters maximum).
GREFL       = Ground reflectance. [0.3]
GREFSCD     = User name of ground reflectance schedule.
GTEMP       = Ground temperature. [50°F, 10°C]
GTEMPSCD    = User name of ground temperature schedule.
* RSTRTMN   = Starting month of the run (jan, feb, ...). [JAN]
* RSTRTDY   = Day of the month to start the run. [1]
* RSTOPMN   = Stopping month of the run. [DEC]
* RSTOPDY   = Day of the month to stop the run. [31]
SKYLINE     = User name of the skyline defined in the SKYLINES
              section.
PARAM       = User name of the parameters defined under the
              PARAMETER section. Not required, to use default
              values leave blank or input "default."
RUNITS      = Units used for the input (English, E, or Metric, M). [M]
DDTYPE     = Type of degree day calculations (US or EURO) [US]
/

```

**&ZONES** (max ZONES = 100)

```

* ZONENAME  = User name of the zone (10 characters maximum).
* ZAREA     = Zone floor area (m2, ft2).
* ZHGT      = Zone height (m, ft). The zone area and height are used to
              determine the zone volume.
ZONEZ      = Height of the bottom of the zone above the building
              origin (m or ft). Used to determine the stack effect for
              infiltration if an effective leakage area is input for
              ZLEAK. [0.0]

```

ZACH	=	Fixed zone infiltration rate with the ambient air. (air-changes/hour). [0.0]
ZINFSCD	=	User name of the infiltration schedule for zach defined under SCHEDULES.
ZLEAK	=	Effective leakage area for infiltration as determined by blower door tests or estimated from experience ( $\text{cm}^2$ or $\text{in.}^2$ ). If this is input, infiltration will vary with the temperature differences and wind pressures on the zone. This will override any value input for ZACH [0.0]
SOL2AIR	=	Fraction of the total solar available in the zone that goes directly to the air node. This accounts for the solar radiation that is absorbed by light weight objects in the room and immediately emitted to the air in the zone. Typical values range from 0.05 to 0.1. [0.0]
SOLLOST	=	Fraction of the total solar available in the zone that is lost from the system or the cavity albedo. A typical value is around 0.05, although it may be much higher if the zone has a very low solar absorptivity. [0.0]
GAINSENS	=	Rate of sensible heat gain from internal sources (kW, kBtu/hr). This accounts for heat gains from people, appliances, lights, etc. [0.0]
SENSSCD	=	User name of the sensible heat gain schedule defined under SCHEDULES.
GAINLAT	=	Rate of latent heat gain from internal sources (kW, kBtu/hr). This is a load on the zone due to moisture added to air. [0.0]
LATSCD	=	User name of the latent heat gain schedule defined under SCHEDULES.

/

**&INTERZONES** (max INTERZONES = 100)

IZSRCZONE	=	User name of the source zone defined under the ZONES section.
IZSINKZONE	=	User name of the sink zone defined under the ZONES section or one of the keywords "AMBIENT" or "GROUND." If "AMBIENT" or "GROUND" is defined then only the conduction term is considered (i.e., the terms izsoltrn and izrevtrn are ignored).
IZCONDCOEF	=	Thermal conductance between the zones. May be used to approximate conduction or convection. ( $\text{W}/^\circ\text{C}$ , $\text{BTU}/\text{hr}\cdot^\circ\text{F}$ ) [0.0]
IZSOLTRN	=	Fraction of total transmitted solar radiation into the source zone that is transferred to the sink zone. This may account for transparent surfaces between the zones, such as windows. [0.0]
IZSOLTRNSCD	=	User name of the interzone solar transfer schedule defined under SCHEDULES.

IZREVTRN = Fraction of total transmitted solar radiation into the sink zone that is transferred to the source zone. [0.0]  
 IZREVTRNSED = User name of the reverse interzone solar transfer schedule defined under SCHEDULES.

/

**&WINDOWS** (max WINDOWS = 200)

WINZONE = User name of the interior zone defined under ZONES.  
 WEXTSURF = User name of the exterior surface defined under SURFACES that the window is located on.  
 GLAZTYPE = User name of the glazing type defined under GLAZINGTYPES.  
 WINHGT = Window height (m, ft). [1.0]  
 WINLONG = Window length (m, ft). [1.0]  
 WINX = Horizontal distance from the lower left hand corner of the exterior surface to the lower left hand corner of the window looking from the exterior of the building. This is only important if overhangs or sidefins are used (m, ft). See Figure 2.4 for diagram of the window placement. [0.0]  
 WINY = Same as winx except for the vertical distance.  
 HWININ = Combined convective and radiative inner surface heat transfer coefficient for the window [8.28 W/m<sup>2</sup>·°C or 1.46 BTU/hr·ft<sup>2</sup>·°F].  
 HWINOUT = Combined convective and radiative exterior surface heat transfer coefficient for the window. [29.0 W/m<sup>2</sup>·°C or 5.11 BTU/hr·ft<sup>2</sup>·°F]  
 FRAMEPCNT = Percent of the overall window area that is occupied by window frame. This is used to reduce the window area for transmission of solar radiation only and not for heat conduction calculations (0 to 100). [0.0]

/

**&WALLS** (max WALLS = 200)

\* WALLTYPE = User name of the wall type defined under WALLTYPES.  
 WALLKIND = One of the following key words "wall", "floor," or "ceiling." Floors and ceilings must be horizontal, everything else is considered a wall. Only used for calculation of interzonal infiltration through interior walls if a value for ZLEAK is input. [WALL]  
 WALLHGT = Overall wall height [1.0 m or 1.0 ft].  
 WALLONG = Overall wall length [1.0 m or 1.0 ft].  
 WALLPERCENT = Percent of the opaque wall area occupied by this wall construction. This allows for the modeling of stud and cavity walls. A maximum of two wall constructions are allowed on one surface, and the percentages must add up to 100. See example below. (0 to 100) [100]



- FINTLEAK = Percent of the total zone effective leakage area (ZLEAK) for this wall. Used for interior walls only, ignored for exterior walls. Exterior wall leakage is input using FLEAK under SURFACES. (0 to 100) [default = negative number, calculates leakage by area]
- \* WFRNTZONE = User name of the interior or front zone defined under ZONES.
- WFRNTH = A fixed value that represents the combined convective and radiative heat transfer coefficient for the interior or front side of the wall. [for default input negative number,  $8.28\text{W/m}^2\cdot^{\circ}\text{C}$  or  $1.46\text{BTU/hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}$ ]
- WFSOLABS = Fraction of the total solar available in the zone that is absorbed in the front side of the wall. [for default input negative number, fraction of the total zone surface area]
- \* WBACKZONE = User name of the back zone defined under ZONES, the name of the exterior surface defined under SURFACES, or one the keywords "AMBIENT" or "GROUND." May define the same zone for the front and the backside of the wall. In order to perform detailed infiltration or solar calculations, exterior walls must have a surface assigned to them. May define up to two walls for one surface to model composite type walls (i.e., stud and cavity wall in the example below).
- WBACKH = Same as wfrnth for the backside of the wall. [for default input negative number, interior walls same as wfrnth, exterior walls  $29.0\text{W/m}^2\cdot^{\circ}\text{C}$ ,  $5.11\text{BTU/hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}$ ]
- WBSOLABS = Same as wfsolabs for interior walls or the solar absorptivity for exterior walls on a defined exterior surface. Ignored if "AMBIENT" or "GROUND" is specified for wbackzone. [for default input negative number, for exterior surfaces default = 0.6, for interior surfaces default = fraction of the total zone surface area]

/

Example input for a stud/insulated wall

```
&WALLS
walltype   = 'stud'   'cavity'
wfrntzone  = 'house'  'house'
wbackzone  = 'south'  'south'
wallhgt    = 2.5     2.5
wallong    = 10.0    10.0
wallpercent = 15.0   85.0
/
```

&amp;TROMBEWALLS (max TROMBEWALLS = 10)

TWINZONE = User name of the interior zone defined under ZONES.

- TWEXTSURF = User name of the exterior surface defined under SURFACES. There MUST also be a WALL with the dimensions of the entire surface assigned to surfaces that have Trombe walls, even if the Trombe wall occupies the entire area of the surface.
- TWTYPE = User name of the Trombe wall type defined under TROMBETYPES.
- TWHIN = A fixed value that represents the combined convective and radiative heat transfer coefficient for the interior surface of the Trombe wall. [for default input negative number, 8.28 W/m<sup>2</sup>·°C or 1.46 BTU/hr·ft<sup>2</sup>·°F]
- TWHWINOUT = A fixed value that represents the combined convective and radiative heat transfer coefficient for the exterior surface of the Trombe wall glazing. [for default input negative number, 29.0 W/m<sup>2</sup>·°C or 5.11 BTU/hr·ft<sup>2</sup>·°F]
- TWINSOLABS = Fraction of the total solar available in the interior zone that is absorbed in the interior surface of the Trombe wall. [for default input negative number, percent of the total zone surface area]
- TWHGT = Trombe wall height (m, ft). [1.0]
- TWLONG = Trombe wall length (m, ft). [1.0]
- TWX = The x-coordinate of the lower left hand corner of the Trombe wall relative to the origin of the surface. Similar to WINX for windows. [0.0]
- TWY = Same as TWX for the y-coordinate.

/

**&FANS** (max FANS = 50)

- FSINKZONE = User name of the sink zone (where the fan delivers the warm air) for the fan defined under ZONES.
- FSRCZONE = User name of the source zone (where the fan draws the warm from) for the fan defined under ZONES.
- FANTYPE = User name of the fan type defined under FANTYPES.
- FOFFSEASON = User name of the fan off season defined under SEASONS. [none]

/

**&ROCKBINS** (max ROCKBINS = 5)

- RBINSINK = User name of the sink zone (where the rockbin delivers warm air) for the rockbin defined under ZONES.
- RBINSRC = User name of the source zone (where the rockbin draws warm air from) defined under ZONES. See section 1.7.6 for the restrictions on placement of rockbins.
- RBINTYPE = User name of the rockbin type defined under BINTYPES.
- RBINZONE = User name of the zone for passive heat losses from the rockbin defined under ZONES. [none]

UBINZONE	= Heat transfer coefficient for passive heat losses to the zone defined as rbinzone. [0.0 W/°C or 0.0 BTU/hr·°F]
UBINAMB	= Same as ubinzone for losses to the "ABMBIENT" zone.
UBINGND	= Same as ubinzone for losses to the "GROUND" zone.
/	
<b>&amp;SURFACES</b> (max SURFACES = 100)	
NAMESURF	= User name of the surface.
SURFAZIM	= Surface azimuthal angle in degrees. (north = 0, east = 90, south = 180 and west = 270) [180.0]
SURFTILT	= Surface tilt angle from the horizontal in degrees. [90.0]
SURFZ	= Height of the bottom edge of the surface above the zone origin. This is only used for detailed infiltration calculations or natural ventilation is simulated. [0]
FLEAK	= Percent of the total zone leakage that is in this surface. The total for all surfaces and interior walls for each zone must add to 100. This is only used for detailed infiltration calculations if a value for ZLEAK is input. [negative number allows percentage to be determined by area]
PRESSCOEF	= Constant wind pressure coefficient. This is only used for detailed infiltration calculations if a value for ZLEAK is input or if natural ventilation is simulated. [no input or -999 allows this to be calculated hour by hour with the wind speed and direction.]
/	
<b>&amp;HVACTYPES</b> (max HVACTYPES = 100)	
HVACZONE	= User name of the zone defined under ZONES for the HVAC system.
HEATSET	= The heating thermostat setpoint. If no setpoint is specified then no heating is simulated for this system. (°C or °F) [negative number or no input for no heating]
HSETSCD	= User name of the heating setpoint schedule defined under the SCHEDULES section. [none]
VENTSET	= Same as heatset except for venting.
VSETSCD	= Same as hsetscd except for venting.
COOLSET	= Same as heatset except for cooling.
CSETSCD	= Same as hsetscd except for cooling.
HEATRATE	= Maximum heating capacity of the HVAC system, if not specified then the system has adequate capacity to meet all heating loads. (kW or kBTU/hr) [no input or negative number for adequate capacity]
VENTRATE	= Maximum venting capacity of the HVAC system, if not specified then the system has adequate capacity to meet all venting loads when the ambient temperature is cooler than the zone temperature. (ACH) [no input or negative number for adequate capacity]

COOLRATE	= Same as heatrate except for cooling.
COILTEMP	= Temperature of the coiling coil. Used for modeling the interactions of the cooling equipment with latent loads. [12.8°C or 55.0°F]
/	
<b>&amp;NATURALVENT</b> (max NATURALVENT = 50, max vents per zone = 10)	
VENTSURF	= User name of the exterior surface that contains the vent opening.
NVENTSET	= Setpoint temperature to control the opening and closing of the vents. Natural ventilation will be used if the zone air temperature is above this temperature provided the minimum delta-T requirement is also met (see VMINDT)[22°C or 72°F].
NVENTSCD	= User name of the schedule controlling the natural ventilation setpoint. To ensure that the vents stay closed at certain times of the year, schedule the setpoint artificially high (e.g., 200°F).
VMINDT	= Minimum inside-outside temperature difference for vent operation. For example, if (Tzone - Tamb) >= vmindt and Tzone > nventset then, the vent will be open. [1°C or 2°F]
VENTY	= Vertical distance from the bottom of the surface to the bottom of the vent opening. (m or ft) [0.0]
VENTHGT	= Height of the vent opening. (m or ft) [1.0]
VENTAREA	= Effective vent opening area. (m <sup>2</sup> or ft <sup>2</sup> )
VENTCD	= Discharge coefficient for the vent opening. It is strongly recommended that the default values are used. See section 2.3.2 for a more detailed description. [0.6]
VENTEXP	= Flow exponent for the mass flow rate through the opening. It is strongly recommended that the default values are used. See section 2.3.2 for a more detailed description. [0.5]
/	
<b>&amp;TROMBETYPES</b> (max TROMBETYPES = 10)	
NAMETRMTYPE	= User name of the Trombe wall type.
TWALLTYPE	= User name of the wall type used for the Trombe wall type defined under WALLTYPES.
TWGLZTYPE	= User name of the glazing type used for the Trombe wall type defined under GLAZINGTYPES.
VENTOH	= Indicates whether the vents will allow overheating of the zone (i.e., an answer of yes indicates that the vents do not close and will allow the Trombe wall thermocirculation to overheat the zone). (Y or N) [Y]

TWHOUT = Combined convective and radiative heat transfer coefficient for the exterior surface of the Trombe wall type (i.e. the surface between the Trombe wall and the glazing). [8.28W/m<sup>2</sup>·°C or 1.46 BTU/hr·ft<sup>2</sup>·°F]

TWHWININ = Combined convective and radiative heat transfer coefficient for the interior surface of the Trombe wall glazing. [8.28W/m<sup>2</sup>·°C or 1.46 BTU/hr·ft<sup>2</sup>·°F]

TWABS = Solar absorptivity of the exterior Trombe wall surface.[0.9]

VENTRATIO = Area of one row of vents (top and bottom must be of equal area) divided by the total area of the Trombe wall. For an unvented Trombe wall set this value to zero. [0.0]

VENTSPRTN = Distance from the bottom row of vents to the top row of vents. (m or ft) [0.0]

VENTCOEF = Dimensionless multiplier specifying the resistance to the thermocirculation air flow through the vent openings. A value between 0.2 and 0.8 are recommended. [0.0]

/

**&WALLTYPES** (max WALLTYPES = 100, max layers per wall type = 10)

NAMEWALLTYPE = User name of the wall type.

WALLAYER(layer#,walltype#) = Wall types are built up as layers starting from the inside and working out, up to 10 layers. The layers are the user names of MASSTYPES or PCMTYPES, or may be entered as a resistance value (e.g., "R-10"). If an R-value is entered, no thermal capacitance is simulated for that layer.

For example, if wall type 1 has three layers, wall type 2 has two layers and wall type 3 only one layer, it may be input as shown below.

WALLAYER(1,1) = "drywall" "concrete" "siding"

WALLAYER(1,2) = "drywall" "R-20"

WALLAYER(1,3) = "R-10"

/

**&MASSTYPES** (max MASSTYPES = 100)

NAMEMASSTYPE = User name of the mass type. The use of "R-" for the first two letters should be avoided, as this is reserved for defining a pure resistance wall in WALLTYPES.

MASSCOND = Thermal conductivity of the mass type. (W/m·°C, BTU/hr·ft·°F) [a negative number signifies infinite conductivity and only one mass node is used in the simulation]

MASSDENS = Density of the material. [1.0 kg/m<sup>3</sup> or 1.0 lb/ft<sup>3</sup>]

MASSCP = Specific heat of the material (kJ/kg·°C, 1.0 BTU/lb·°F) [1.0].  
 MASSTHICK = Thickness of the mass (m, ft) [1.0].  
 MASSNODES = Number of mass nodes. For the default value of conductivity, infinite, this value is ignored and one node is simulated. [1]

/

**&PCMTYPES** (max PCMTYPES = 10)

NAMEPCMTYPE = User name of the phase change material (PCM) type.  
 PCMCOND = Thermal conductivity of the PCM. Default allows infinite conductivity. (W/m·°C or BTU/hr·ft·°F) [negative number]  
 PCMDENS = Density of the PCM (kg/m<sup>3</sup>, lb/ft<sup>3</sup>) [1.0].  
 PCMCP = Specific heat of the PCM (kJ/kg·°C, BTU/lb·°F) [1.0].  
 PCMTHICK = Thickness of the PCM (m, ft) [1.0].  
 HOFUS = Heat of fusion of the PCM (kJ/kg, BTU/lb) [1.0].  
 TMELT = Melting temperature of the PCM. [26.7°C or 80.0°F]

/

Note that one mass node is used to simulate the PCM types.

**&GLAZINGTYPES** (max GLAZINGTYPES = 50, max glazing layers = 10, max switchable glazing types = 5, max switchable glazing property sets = 10)

NAMEGLZTYPE = User name of the glazing type (10 characters allowed).  
 GLZFILE = Name of file containing WINDOW 4.1 data for the glazing type (100 characters maximum). If this is input then the glazing U-value, extinction coefficient, index of refraction, and glazing layer thickness are ignored and do not need to be input. This file must exist in the same directory as the executable file.  
 UGLAZ = The glazing U-value (surface to surface, not including air film resistance). Ignored if glazing data file used. [5.67 W/m<sup>2</sup>·°C or 1.0 BTU/ft<sup>2</sup>·hr·°F]  
 UGLZSCD = User name of the glazing U-value schedule to simulate removable insulation. This value may be used if a glazing data file is used; it will override the U-value from the glazing data file.  
 SHADFACT = Shading factor for the glazing system. Used for windows with non-clear glass or to simulate the reduction in transmitted radiation due to internal shading devices, such as blinds. Note that this is not the same as the shading coefficient as described in the ASHRAE Handbook of Fundamentals. See section 1.6.2 for a more detailed description. This value should not be used if a

glazing data file is used unless an interior shading device is being modeled. [1.0]  
SHDFACTSCD = User name of the shading factor schedule.  
GEXTINCT = Extinction coefficient of the glazing material. Ignored if glazing data file used. [0.0197 1/mm or 0.50 1/in.]  
REFINDEX = Index of refraction of the glazing material. Ignored if glazing data file used. [1.526]  
GLZTHICK = Thickness of the glazing layers. Ignored if glazing data file used. [3.0 mm or 0.125 in.]  
NGLAY = Number of glazing layers. Ignored if glazing data file used. [1]

/

**&ROCKBINTYPES** (max ROCKBINTYPES = 5)

NAMEBINTYPE = User name of the rockbin.  
BIDIR = Indicates whether air flow through the rockbin is bidirectional ("y" or "n"). ["Y"]  
RBINLONG = Length of the rockbin. [1.0 m or 1.0 ft]  
RBINAREA = Cross-sectional area of the rockbin. [1.0 m<sup>2</sup> or 1.0 ft<sup>2</sup>]  
RBINHTCAP = Heat capacitance of the rockbin per unit volume of the rockbin. [1.0 kJ/m<sup>3</sup>·°C or 1.0 BTU/ft<sup>3</sup>·°F]  
RBINAXCOND = Effective axial conductance of the rockbin. Allows the rockbin to de-stratify during periods of no flow. [0.0 W/m·°C or 0.0 BTU/hr-ft·°F]  
CHFANTYPE = User name of the fan used for charging the rockbin. [none]  
DSCHFANTYPE = User name of the fan used for discharging the rockbin. [none]  
RBINOFFSEA = User name of the season during which the rockbin is not charged. [no offseason]

/

**&FANTYPES** (max FANTYPES = 50)

NAMEFANTYPE = User name of the fan type.  
FANFLOW = Maximum volumetric flow rate. [1.0 m<sup>3</sup>/hr or 1.0 CFM]  
FMINDT = Minimum temperature difference between the sink zone and the source zone for fan operation. This will allow the fan to only be operated when it will pay for itself (i.e., when the energy delivered by the fan is greater than the energy to operate the fan). [0.0°C or 0.0°F]

/

**&OVERHANGTYPES** (max OVERHANGTYPES = 50)

OHSURFACE	= Name of the surface which the overhang is on defined under the SURFACES section.
OHX	= X-coordinate of the furthest left hand point of the overhang. The inside edge of the overhang must be in the surface plane, but it does not have to be within the surface area. See Figure 2.5 for an example. [0.0 m or 0.0 ft]
OHY	= Y-coordinate of the inside edge of the overhang. (m or ft) [surface height]
OHPROJ	= Projection from the surface to the outside edge of the overhang measured along the overhang.(m or ft)
OHLONG	= Length of the overhang. (m or ft) [surface length]
OHTILT	= The angle between the surface and the bottom side of the overhang. (0 < ohtilt < 180) [90 degrees]
OHRHO	= Diffuse reflectivity of the bottom side of the overhang. [0.6]
/	

**&SIDEFINTYPES** (max SIDEFINTYPES = 50)

SFSURFACE	= Name of the surface which the sidefin is on defined under the SURFACES section.
SFX	= X-coordinate of the sidefin relative to the lower left hand corner of the surface. The inside edge of sidefins must be in the surface plane, but the sidefin does not have to be within the surface area. See Figure 2.5 for an example. [0.0 m or 0.0 ft]
SFY	= Y-coordinate of the bottom of the sidefin relative to the lower left hand corner of the surface. [0.0 m or 0.0 ft]
SFPROJ	= Projection from the surface plane to the outside edge of the sidefin measured along the sidefin. (m or ft)
SFHGT	= Height of the sidefin. (m or ft) [height of the surface]
SFRHO	= The diffuse reflectivity of the sidefin. [0.6]
/	

**&SKYLINETYPES** (max SKYLINETYPES = 5)

NAMESKYLINE	= User name of the skyline type.
HORIZON(profile, skyline type number)	= The horizon is split up into 11 sections (profiles) centered around due south. Horizon is the altitude angle in degrees of the skyline at each of these eleven azimuthal angles. [0.0 for all values]
/	



The following are examples of two skyline types. The azimuthal angles and the directions are given for reference.

	East	South	West
	100	80 60 40 20 0	20 40 60 80 100
Horizon(1,1)	= 0	10 10 15 20 30 35 20 15 10 0	
Horizon(1,2)	= 0	5 10 10 30 20 10 10 5 0 0	

**&OUTPUT** (max OUTPUT s = 100)

**OUTTYPE** = Indicates the output section printed. One of the SUNREL keywords: "ALL," "AMBIENT," "BUILDING," "ZONES," "WINDOWS," "WALLS," "SURFACES," "FANS," "ROCKBINS," or "TROMBES." ["ALL"]

**PERIOD** = Time period for reporting. ("H" for hourly, "D" for daily, "M" for monthly). ["M"]

**OUTUNITS** = The units desired for the output. This can be different from the run units. ("M" for metric or "E" for English). ["M"]

**OUTSEASON** = User name of the output season defined under SEASONS. Default value produces output at the period specified under "period" for the length of the run. ["ALL"]

**IOCOMP** = The number of a building component for the section listed under OUTTYPE, if allowed to default then output for all of the components defined in that section will be printed. For example, if "WINDOWS" is entered for OUTTYPE and there are five windows defined, but output is only desired for the third window then enter 3 for IOCOMP. [negative number or no input for all]

**IOPAGE** = The page number of the desired output for OUTTYPE. To have all of the pages output do not input a value or input a negative number. See Appendix A for a description of the pages for each output type.

**FRMT** = Indicates whether the output file will be printed with or without headers. Files with no headers may be easily imported into spread sheet programs. Only one set of data should be written to a file with no headers. There are a maximum of nine files available for no header output with the extensions ".dt1," ".dt2," ... ".dt9." See Appendix A for a more detailed explanation. ("Y" or "N") ["Y"]

/

**&SCHEDULES** (max SCHEDULES = 500)

NAMECHEDULE = User name of the schedule (10 characters allowed).

SCHDSEASON = User name of the season for the schedule defined under SEASONS.

SCHDL(hour, schedule number) = Values used for the schedule at each hour of the day starting with 1 and ending with 24. Do not exceed 24 inputs (hours) for a particular schedule, as the program will assign any values past 24 to the next schedule.

/

The following are two example of schedules for a heating setpoint using the long form of input. Schedule number one has a night set-back to 65°F and schedule two is constant at 65°F.

```

schdl (1,1) = 65 65 65 65 65 65 65
schdl (8,1) = 72 72 72 72 72 72 72 72 72 72 72
schdl (19,1) = 65 65 65 65 65 65
shhdl (1,2) = 65 65 65 65 65 65 65 65 65 65 65
65 65 65 65 65 65 65 65 65 65 65

```

The following are the same two schedules as above, but using the multiplier to shorten the input.

```

schdl (1,1) = 7*65    11*72    6*65
schdl (1,2) = 24*65

```

**&SEASONS** (max SEASONS = 500)

NAMESEASON = User name of the season (10 characters allowed).

SEASTRTMN = Starting month of the season (jan, feb, mar, ...)

SEASTRTDY = Starting day of starting month of the season.

SEASTOPMN = Stopping month of the season (jan, feb, mar, ...)

SEASTOPDY = Stopping day of stopping month of the season.

DAYOFWEEK = Specifies the days of the week that the season applies to. ("M-F" = Monday through Friday, "S-S" = Saturday and Sunday or "ALL") ["ALL"]

/

**&PARAMETERS** (max PARAMETERS = 5)

NAMEPARAM	= User name of the parameter set .
IZMAX	= Maximum number of iterations allowed for the zone energy balance calculation. [50]
ZONECONV	= Convergence criteria for zone air temperature. [0.05°C, 0.1°F]
ITMAX	= Maximum number of iterations allowed for the Trombe wall air gap temperature calculation. [50]
TWCONV	= Convergence criteria for the Trombe wall air gap temperature. [0.05°C, 0.1°F]
IGMAX	= Maximum number of iterations allowed for the calculation of the temperature of the switchable glazing layer if defined. [50]
GLZCONV	= Convergence criteria for the switchable glazing layer temperature expressed as a percent value and not an absolute temperature. [1.0%]
INFMAX	= Maximum number of iterations allowed for the infiltration/natural ventilation mass balance. [50]
INFCONV	= Convergence criteria for the infiltration calculations. Expressed as a percent. [0.1%]
FLWEXP	= Flow exponent used for infiltration calculations. [0.5]
TZERO	= Temperature used to initialize all node temperatures. [18.3°C, 65.0°F]
HDDBASE	= Base temperature used for determining the number of heating degree days. [18.0°C, 65.0°F]
CDDBASE	= Same as hddbase except for cooling degree days. [25.0°C, 75.0°F for DDTYPE = EURO]
HDDAMBIENT	= Lower temperature limit to begin calculating heating degree days for the European method. In other words, when Tdayavg falls below HDDAMBIENT, the degree days are calculated as (HDDBASE - Tdayavg), where, Tdayavg is the average daily temperature. [12.0°C, 55.0°F].
CDDAMBIENT	= Same as HDDAMBIENT for cooling. [30.0°C, 85.0°F]
JAN1	= Day of the week for Jan 1 (1 = Monday, 2 = Tuesday ... 7) [1]
DIFAN	= Angle of incidence for diffuse radiation calculations. [60.0]
HGTWINDMET	= Height of meteorological wind speed measurements [10 m or 33 ft]
WUDAYS	= Number of times to repeat the first days calculations to warm-up the building. This allows the temperatures in the building to reach equilibrium before beginning the simulation. (>=0) [10]

/

**&STATIONS** (max STATIONS = 10)

NAMESTATION	= User name of the station (100 characters allowed).
SITELAT	= Latitude of the station in degrees. [no default]
SITELONG	= Longitude of the station in degrees. [no default] {not presently used for any calculations in SUNREL}
ELEV	= Elevation of the station above sea level. [0.0 m, 0.0 ft]
TERRAIN	= Terrain classification, see Table 4.2 for an explanation of each class. (1 through 5) [3]
SHIELD	= Local shielding classification, see Table 4.3 for an explanation of each class. (1 through 5) [3]
WEATHERFILE	= Name of the weather data file (12 characters allowed)
WEATYPE	= Weather file type ("TMY," "TMY2," "BLAST," or "SUNREL"). See the appendix for a description of the file formats. ["TMY"]
WSTRTMN	= Starting month of the weather file. ["JAN"] {not used for BLAST weather files}
WSTRTDY	= First day of the starting month of the weather file.
WSTOPMN	= Stopping month of the weather file. ["DEC"] {not used for BLAST weather files}
WSTOPDY	= Last day of the stopping month of the weather file.
/	



## 4. Technical Algorithms

### 4.1. Introduction

This chapter explains the technical algorithms used by SUNREL. Separate sections describe (a) the handling of solar energy inputs to the building, (b) the calculation of temperatures for zones, walls, and rockbins, (c) the operation of the controllers for heating, venting, and cooling equipment, and for fans between zones or connected to rockbins, and (d) the treatment of humidity levels within the building.

A building is conceptualized as one or more zones. Each zone has independent solar inputs and independent heating, cooling, and ventilation equipment and controls. Each zone may also contain a rockbin. Zones may be thermally connected by walls comprised of layers or pure thermal conductances (i.e., no heat storage). In addition, thermostatically controlled fans may connect zones.

The major simplification in the conceptual model of zones is the use of a single-zone temperature node. The program does not allow for direct radiation heat transfer between walls of a zone with separate calculation of convective heat transfer to the zone air. Instead, the zone is represented by a single temperature node. All heat transfer paths are connected to this central node. Walls are connected by a constant heat-transfer coefficient to the central zone node. This heat-transfer coefficient includes both convective and radiative heat transfer. This simplification avoids the calculation of radiation view factors (which would also require a three-dimensional building description in the input) and the solution of a radiosity matrix at each timestep.

The central zone temperature is not really the air temperature. It is a conductance-weighted average of all temperatures that affect the zone. In the simple case where there are no pure resistances or fans in the zone, the zone temperature is a weighted average of the surface temperatures. In this case it is, in effect, a form of mean radiant temperature. In some circumstances, the central node temperature might differ significantly from the true air temperature. Muncie (1979) included an extensive discussion of the effect of the central node assumption. He showed that, with proper calculation of the combined surface coefficients, the resulting error in temperature is typically comparable to that produced by differences in radiation transfer resulting from the detailed modeling of furniture in the zone. For convenience, the central zone temperature is referred to as the zone “air” temperature in this program.

Walls are coupled to the zone air node by constant coefficients, which include the combined effects of convection and radiation heat transfer. New node temperatures are determined in each wall independently, using explicit finite differences. Equipment operation is controlled on the basis of the zone air temperature node. However, only equipment loads are calculated, no attempt has been made to model the actual performance of the equipment.

The general order of calculations is illustrated in Figure 4.1 as a pseudo-code fragment showing only the heart of the hourly calculations. First, solar intensity values read from the weather data file are used to calculate the amount of solar energy received on exterior surfaces and transmitted into the building. These solar intensity values are held constant for each timestep within the hour.

```
For hour := 1 to 24 do
  calculate solar input variables [sub. SOLAR, et al.];
  distribute solar gains within zones [sub. HRSET];
  For timestep := 1 to number of timesteps do
    calculate new wall node temperatures [sub. WALLTEMP];
    accumulate fixed energy flows: to mass walls, passively to rockbins,
      and to ambient and ground [sub. ZONETEMP];
    Repeat
      For zone := 1 to number of zones do
        If zone has Trombe then
          Repeat
            calculate Trombe thermocirculation [sub. TROMB];
            calculate Trombe air gap temperature [sub. TROMB];
          Until air gap temperature converged;
        If zone has infiltration then
          Repeat
            solve zone mass balance
            Until zone mass balance is converged
            accumulate interzone energy flows [sub. ZONETEMP];
          end;
        set fan and rockbin charge fan operation [sub. EQMTA, et al.];
        set HVAC equipment operation [sub. HVACE];
        calculate new zone air temperatures [sub. HVACE];
        Until zone air temperatures converged;
        calculate wall surface temperatures [sub. SURFS];
        set rockbin discharge operation [sub. ROKON];
        calculate rockbin node temperatures [sub. ROCKS];
      end;
    calculate zone humidity ratios and cooler latent loads [Sub. WATER];
  end;
end.
```

**Figure 4-1. Pseudo-code fragment of the hourly calculations**

For each timestep within the hour, new node temperatures are first calculated for each mass wall defined. These new temperatures are based on the temperature of the node on either side at the end of the previous timestep (i.e., the old temperature). For nodes at the surface of the wall, the old air temperature is used in the calculation. Next, the program accumulates the energy flows from each zone air node to those elements having temperatures that are considered fixed. These include the ambient and ground nodes, mass walls, and passive energy flows to rockbins.

Two levels of iteration can be used in the calculation of new zone air temperatures, depending on the building configuration. Iteration is used in the calculation of new zone air temperatures whenever direct energy flow paths (non-mass walls or loss coefficients) are defined between any interior zones. In this case, energy flows between zones are first calculated based on old zone air temperatures. Then, the equipment controllers for heating, venting, cooling (HVAC), and fans are used to set equipment operation and calculate new zone air temperatures. This process is repeated until the new air temperature for each zone differs from the previous value by less than a user-specified constant. When iteration is not required, the equipment controllers calculate the new air temperature directly.

Nested within the zone air temperature iteration are two second-level iterations. One is used with Trombe walls with natural convection air flow. The rate of air flow through the Trombe wall is calculated as a function of the most recent temperatures for the zone air node and the Trombe wall air gap node. A new air gap temperature is then calculated based on the old zone air temperature and the air flow rate. If required, this calculation of air flow rate and air gap temperature is iterated, holding the zone air temperature constant.

The other second-level iteration is used for the infiltration and natural ventilation flow rates. For constant air change per hour, the air change with the ambient is constant for the hour. For the variable method and natural ventilation, the mass balance is satisfied using the zone temperatures from the previous timestep. These mass flow rates are then used to determine the new zone temperatures.

After new air temperatures are determined for all zones, new wall surface temperatures are calculated. For mass walls, these are based on the new air and new wall node temperatures. When a mass wall has a node at the surface of the wall (i.e., no thermal resistance from the mass wall surface to the first node), the surface temperature is taken as the first node temperature. For massless walls, the surface temperatures are calculated as a function of the new air temperatures on either side of the wall.

Next, if one or more rockbins are defined, they are checked to determine whether all or a part of the zone's heating load can be supplied by the rockbin. After the operational state of the rockbin's charge and discharge fans are determined, new node temperatures for the rockbin are calculated. Finally,



once at the end of each hour, new zone humidity ratios and cooler latent loads are calculated, if they have been requested by the user.

In the following discussion of algorithms, we have attempted to use relatively simple notation, rather than a completely rigorous mathematical format. The equations presented, and particularly the variable names used, are not intended to have a direct one-to-one correspondence with those in the software. A few special symbols are used in this chapter. For example, “min[...]” is the minimum value contained within the brackets and “max[...]” is the maximum value within the brackets.

## **4.2. Solar Algorithms**

### **4.2.1. Discussion**

SUNREL provides for extensive treatment of the thermal effects of solar energy on buildings. The model processes two hourly solar intensity values from the weather data file: global horizontal intensity and direct normal intensity. These parameters are held constant at an hourly input value for each timestep within the hour. The position of the sun is determined for each sunlit hour by calculating its altitude and azimuth angles. Most of the solar geometry formulas used here are taken from McFarland (1978). The declination formula is taken from Duffie and Beckman (1991). The global horizontal intensity is separated into a direct (“beam”) component and a diffuse component. The horizontal direct component is calculated using the space angle between a vertical and the parallel solar rays (zenith angle). The diffuse component is then taken as the difference between the global and direct.

The user may define the elevation of the horizon as seen from the building site in each of several segments of the sky centered about due south in the SKYLINE TYPES section. This has the effect of completely blocking the direct component on all orientations and parts of the building when the sun is below the horizon. In this case, the diffuse component of the horizontal intensity is not altered, but the diffuse component on the other orientations is reduced due to a smaller ground reflectance contribution.

The user may specify several exterior surfaces of the building to consider the effects of solar energy. A surface is defined by the angle of its tilt from horizontal and the azimuth angle of an outward-pointing ray normal to the surface. Each surface is composed of one or two wall elements and possible windows and Trombe walls. An overhang and left and right sidefins can be separately defined for each surface, which will shade the direct and diffuse components of solar energy on the surface and add diffuse reflections of solar energy incident on the shading device.

The intensity of the direct solar component on each exterior surface specified is determined (as for horizontal) by calculating the space angle between the solar rays and an outward pointing ray normal to the surface (angle of incidence). For the diffuse component, the user determines the view factors from the building surface to the skydome and to the ground in front of the surface. This one-time calculation does not consider any skyline profile angles specified, nor any overhangs, sidefins, or other surfaces defined for the building. Sky diffuse radiation is assumed to be evenly distributed (i.e., isotropic). The ground is taken as an infinite horizontal plate with a uniform, user-specified reflectivity.

Overhangs and sidefins are treated as finite in length; hence, edge effects are considered. The algorithms used to find the shaded area created by the overhangs and sidefins use direction cosines and the homogeneous coordinates developed by Walton (1979). Shading by overhangs and sidefins is calculated separately, then adjusted to account for the area contained in both shadows. The extent of shading is first calculated for the entire surface, then separately for each window contained in the surface.

For direct and diffuse solar energy incident on each window, SUNREL separately calculates the fraction transmitted through the window (termed “short-wave”) and the thermal gain due to energy absorbed within the windows (termed “long-wave”). The program contains two methods of calculating the transmitted and absorbed solar radiation. The first method assumes that the window is comprised of one or more layers of identical glazing material (Willier 1977). For solar energy absorbed in the window, a maximum of four layers are considered. Hence, the long-wave thermal gain to the building will be understated when more than four glazing layers are specified. The window model uses the calculated angle of incidence for direct solar and a user-specified constant angle for the diffuse component. The transmitted and absorbed fractions for both direct and diffuse components are reduced by any shading factor specified for the window.

The second method of handling windows uses the data calculated by Window-4.1, which is contained in a library file or a user-created file (Deru 1996). This file contains the glazing-layer effective thermal conductance and the window solar transmittance and layer absorptance as a function of incidence angle in ten-degree increments. The window transmittance and absorptance is determined by linear interpolation in incident angle. Using this method for windows, SUNREL can determine the temperature of any of the glazing layers. Thermochromic switchable glazings can then be modeled. The glazing data file is modified to include the data for each phase of the switchable glazing material.

The inward-flowing fraction of energy absorbed within the window, or long-wave radiation, is used as a thermal gain to the central air temperature node for the zone in which the window is contained. The user can apportion the distribution of the short-wave solar energy transmitted through the window to

building elements within the zone, or they can be automatically apportioned according to the area of each surface in the zone.

First, a fraction of the energy transmitted through all windows in a given zone can be redirected to any other zone as a simplified accounting for the transparent elements between zones. After all such interzone solar transfers are considered, the total short-wave solar energy available in each zone can be divided into a fraction that is removed from the zone (losses due to reflection out the windows), a fraction that is immediate thermal gain to the zone air temperature node (to account for energy striking lightweight surfaces), and a fraction that strikes each wall defined within the zone. For solar energy incident on any interior wall containing one or more mass nodes, the model automatically allocates a portion of the solar energy that is used as an immediate thermal gain to the zone air temperature node, with the remainder absorbed by the first mass node. For solar energy incident on massless walls, the energy is divided into thermal gains to the zone air temperature nodes on either side of the wall.

### NOMENCLATURE

A	= area
A%	= wall construction area percentage, used for composite wall construction (e.g., stud/cavity wall)
abs( $\theta$ )	= absorptivity of glazing at angle of incidence, $\theta$
day	= day number in year 1, 2, ..., 365
DN	= direct normal radiation, read from weather tape
difabs	= inward-flowing fraction of diffuse solar absorbed by glazing
diftrans	= diffuse solar transmitted through window
dirabs	= inward-flowing fraction of direct solar absorbed by glazing
dirtrans	= direct solar transmitted through window
difhor	= diffuse component of horizontal radiation
dirhor	= direct component of horizontal radiation
DIRSF <sub>g</sub>	= sunlit fraction of window
F	= view factor
F'	= effective view factor
F <sub>i,j</sub>	= user-specified solar transfer fraction from zone i to zone j
FA <sub>i</sub>	= user-specified fraction of solar to air node in zone i
FL <sub>i</sub>	= user-specified solar fraction lost for zone i
Fw <sub>i</sub>	= user-specified fraction of sun to wall on the side connected to zone i
H <sub>i</sub>	= wall surface coefficient on side connected to zone i
horizon(i)	= user input value for horizon elevation under SKYLINE.TYPES
hour	= hour number in day 1, 2, ..., 24
I <sub>dir</sub>	= direct component of radiation on surface

---

$I_{\text{diff}}$	= diffuse component of radiation on surface
$K$	= extinction coefficient of glazing material
layers	= number of layers of identical material in glazing
$\ell_x$	= x-direction cosine from the surface to the sun at tilt angle, $\beta$
$\ell'_y$	= y-direction cosine from the surface to the sun at tilt angle $90^\circ$
$n$	= index of refraction of glazing material
$P_{\text{OH}}$	= horizontal projection of overhang
$Q_{\text{abs,w}}$	= solar energy absorbed on exterior of wall w
$Q_{\text{TRANS},i}$	= total solar energy transmitted into zone i
$Q_{\text{AVAIL},i}$	= total solar energy available in zone i
$Q_{\text{LOST},i}$	= solar energy lost from zone i
$Q_{\text{SOLWAL},i}$	= solar absorbed by <i>mass</i> wall on side connected to zone i
$Q_{\text{SOLZON},i}$	= total solar energy input to air temperature node in zone i
$R$	= range between azimuth angles given in SKYLINE.TYPES = 20 degrees
$R$	= radiation exchange factor
$R$	= thermal resistance from surface to surface for massless wall
$R_i$	= thermal resistance from wall surface connected to zone i into first mass node
$S(i)$	= azimuth angle given in SKYLINE.TYPES input data section for $i = 1, \dots, 11$
SF	= user-specified window shading factor
skyshade	= skyline shading multiplier
$t$	= thickness of one layer of glazing material
TH	= total horizontal radiation, read from weather tape
$\alpha_w$	= user-specified exterior wall absorptivity
$\alpha_{\text{sun}}$	= solar altitude angle
$\beta$	= tilt angle between horizontal and surface
$\delta$	= daily solar declination
$\phi$	= station latitude
$\gamma_{\text{sun}}$	= solar azimuth
$\gamma'_{\text{sun}}$	= temporary calculation for solar azimuth
$\pi$	= PI, 3.1415927
$\theta$	= angle of incidence
$\theta_z$	= solar zenith angle
$\rho_{\text{grd}}$	= user-specified ground reflectance value
$\tau$	= transmissivity of glazing assembly
$\omega$	= hourangle
$\omega_{\text{crit}}$	= hourangle when sun crosses the E-W line (i.e., the azimuth = $\pm 90$ degrees)

**Subscripts:**

g	=	glazing or window
grd	=	ground
oh	=	overhang
s	=	surface
sfL, sfR	=	left sidefin and right sidefin
s-sky	=	surface to sky
s-grd	=	surface to ground
sun	=	sun
surf	=	surface
w	=	wall

**4.2.2. Solar Position**SUBROUTINE:

$$[\text{DYSET}] \quad \omega_{\text{crit}} = \arccos \left[ \frac{\sin(\delta) \cdot \cos(\phi)}{\cos(\delta) \cdot \sin(\phi)} \right]$$

$$[\text{SGEOM}] \quad \omega = (\text{hour} - 12.5) \cdot \frac{\pi}{2}$$

$$\cos(\theta_z) = \sin(\delta) \cdot \sin(\phi) + \cos(\delta) \cdot \cos(\phi) \cdot \cos(\omega)$$

$$\gamma'_{\text{sun}} = \left( \frac{\cos \delta \sin \omega}{\cos \alpha_{\text{sun}}} \right)$$

$$\alpha_{\text{sun}} = \arcsin[\cos(\theta_z)]$$

$$\begin{aligned} \gamma_{\text{sun}} &= \gamma'_{\text{sun}}, & \text{if } |\omega| \leq \omega_{\text{crit}} \\ &= (\pi - |\gamma'_{\text{sun}}|) \cdot \frac{\gamma'_{\text{sun}}}{|\gamma'_{\text{sun}}|}, & \text{if } \omega > \omega_{\text{crit}} \end{aligned}$$

**4.2.3. Skyline Shading**SUBROUTINE:

[SKYLN]

IF  $(\alpha_{\text{sun}}) \leq \text{horizon}(i)$  such that  $S(i) - (R/2) < \gamma_{\text{sun}} < S(i) + (R/2)$

skyshade = 0

ELSE

skyshade = 1

**4.2.4. Horizontal Intensity**SUBROUTINE:

$$[\text{SOLAR}] \quad \text{dirhor} = \min[\text{TH}, \cos(\theta_z) \cdot \text{DN}]$$

$$[\text{SOLAR}] \quad \text{difhor} = \text{TH} - \text{dirhor}$$

#### 4.2.5. Intensity on Arbitrary Surfaces

SUBROUTINE:

$$[\text{SETUP}] \quad F_{\text{s-sky}} = 0.5 \cdot (1 + \cos(\beta))$$

$$F_{\text{s-grd}} = 0.5 \cdot (1 - \cos(\beta))$$

$$[\text{COSIN}] \quad \begin{aligned} \cos(\theta) = & \cos(\beta) \cdot [\sin(\delta) \cdot \sin(\phi) + \cos(\delta) \cdot \cos(\phi) \cdot \\ & \cos(\omega)] + \sin(\beta) \cdot [\cos(\delta) \cdot \sin(\gamma) \cdot \sin(\omega) + \\ & \cos(\gamma) \cdot \sin(\phi) \cdot \cos(\delta) \cdot \cos(\omega) - \sin(\delta) \cdot \cos(\phi)] \end{aligned}$$

$$[\text{SOLAR}] \quad I_{\text{dir}} = \cos(\theta) \cdot \text{DN} \cdot \text{skyshade}$$

$$I_{\text{diff}} = F_{\text{s-sky}} \cdot I_{\text{diff,HZ}} + F_{\text{s-grd}} \cdot \rho_{\text{grd}} \cdot I_{\text{diff,HZ}} (1 + \text{skyshade})$$

#### 4.2.6. Overhang and Sidefin Shading

SUBROUTINE:

[SHADING] calculations are performed once per run.

**Direct Beam Shading** sets coordinates of surface and window vertices (x, y). A line (a, b, c) between two vertices can be represented by a vector determined by the cross product of the vertices in homogeneous coordinates. A point in two-dimensional space (x, y), can be converted to homogeneous coordinates by multiplying by a scale factor (xw, yw, w). The scale factor, w, is set to one (Deru 1996, Walton 1979)

$$(a, b, c) = (xw_1, yw_1, w_1) \times (xw_2, yw_2, w_2)$$

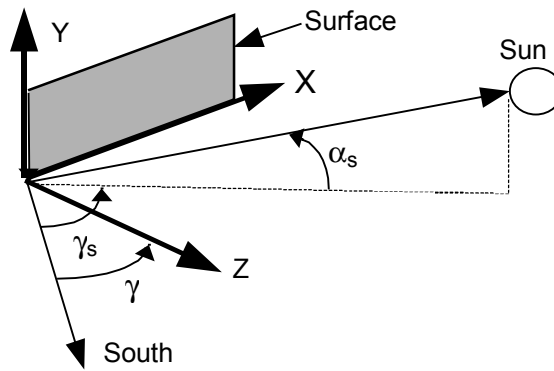
**Diffuse Shading** calculates effective view factors and radiation exchange factors for windows.

$$F'_{\text{w-sky}} = F_{\text{w-sky}} - F_{\text{w-oh}} - F_{\text{w-sky}} F_{\text{w-sfR}} - F_{\text{w-sky}} F_{\text{w-sfL}}$$

$$\begin{aligned} R_{\text{w-sky}} = & (F'_{\text{w-sky}} - \rho_{\text{oh}} F_{\text{w-oh}} F_{\text{oh-sky}} + \rho_{\text{sf}} F_{\text{w-sf}} F_{\text{sf-sky}}) + \\ & \rho_{\text{grd}} (F'_{\text{w-sky}} - \rho_{\text{oh}} F_{\text{w-oh}} F_{\text{oh-sky}} + \rho_{\text{sf}} F_{\text{w-sf}} F_{\text{sf-sky}}) + \\ & \rho_{\text{oh}} F_{\text{w-oh}} + \rho_{\text{sf}} F_{\text{w-sf}} \end{aligned}$$

[SHADE] calculates the shading each hour by overhangs and sidefins by first determining the direction cosines of a vector from the surface to the sun as shown in Figure 4.2.

$$\begin{aligned}l_x &= -\cos \alpha_{\text{sun}} \sin \Delta\gamma \\l'_y &= \sin \alpha_{\text{sun}} \\l'_z &= \cos \alpha_{\text{sun}} \cos \Delta\gamma \\l_y &= l'_y \sin \beta - l'_z \cos \beta \\l_z &= l'_z \sin \beta - l'_y \cos \beta\end{aligned}$$



**Figure 4-2. Angles for calculating the directional cosines of a vector from the surface to the sun**

The lower left hand corner of the shadow,  $H_1$  in Figure 4.3, is found by

$$\begin{aligned}X_{H_1} &= X_{\text{oh}} - P_{\text{oh}} \sin \beta_{\text{oh}} \left( \frac{l_x}{l_z} \right) \\Y_{H_1} &= Y_{\text{oh}} - P_{\text{oh}} \cos \beta_{\text{oh}} - P_{\text{oh}} \sin \beta_{\text{oh}} \left( \frac{l_y}{l_z} \right)\end{aligned}$$

The sunlit fraction of the surface is

$$\text{DIRSF}_{\text{surf}} = \frac{A_{\text{surf}} - A_{\text{oh-shadow}} - A_{\text{sf-shadow}} + A_{\text{oh,sf-overlap}}}{A_{\text{surf}}}$$

[OVERLAP] determines the overlapping area of two polygons (i.e., a surface and a shadow). Coincident points are found by comparing the coordinates. Using homogeneous coordinates with a scale factor of one, the dot-product of a point and a line gives the relative positions of the point and the line. The point is to the right of the line if the dot-product is negative, to the left if the dot-product is positive, and on the line if the dot-product is zero. The intersection of two lines can be found by the cross-product of the two lines and normalizing with respect to the scale factor, w. The area of the overlapping polygon is then determined by

$$A = \frac{1}{2} (x_1y_2 + x_2y_3 + \dots + x_{n-1}y_n + x_ny_1 - y_1x_2 - y_2x_3 - \dots - y_{n-1}x_n - y_nx_1)$$

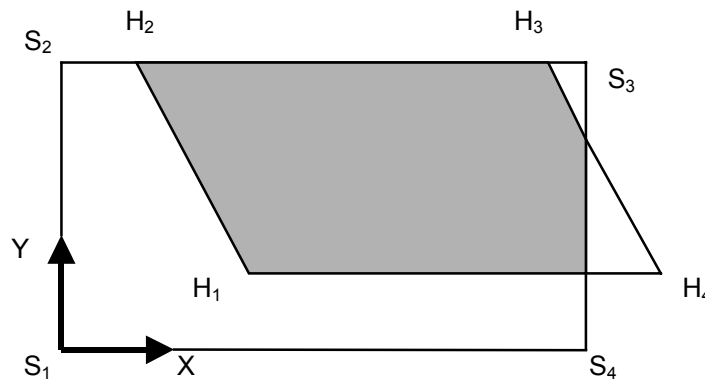


Figure 4-3. Overlapping surface and shadow polygons

**4.2.7. Window Transmissivity**

SUBROUTINE:

[TRANS] N = 2 · layers - 1

$$r = \arcsin \left[ \frac{\sin(\theta)}{n} \right]$$

$$L = N \cdot \frac{t}{\cos(r)}$$



$$x = \left[ \frac{n-1}{n+1} \right]^2$$

$$u = \left[ \frac{\sin(\theta - r)}{\sin(\theta + r)} \right]^2$$

$$v = \left[ \frac{\tan(\theta - r)}{\tan(\theta + r)} \right]^2$$

$$y = \frac{1-x}{1+N \cdot x}, \quad \text{if } \theta = 0$$
$$= 0.5 \cdot \left[ \frac{1-u}{1+N \cdot u} + \frac{1-v}{1+N \cdot v} \right], \quad \text{if } \theta \neq 0$$

$$\tau = y \cdot e^{(-K \cdot L)}$$

When using Window-4.1 data files, the window transmittance is read from the data file into an array as a function of incidence angle in ten degree increments. For direct beam radiation, the window transmittance is determined by linear interpolation in incidence angle. For diffuse radiation, the incidence angle is a constant set in the PARAMETERS input section (the default is 60 degrees).

#### 4.2.8. Window Absorptivity

SUBROUTINE:

[TRANS]

$$w = \frac{1-x}{1+x}, \quad \text{if } \theta = 0$$
$$= 0.5 \cdot \left[ \frac{1-u}{1+u} + \frac{1-v}{1+v} \right], \quad \text{if } \theta \neq 0$$

$$z = w \cdot \exp\left(\frac{-K \cdot L}{\text{layers}}\right)$$

$$Q_{\text{abs}} = \sum_{i=1}^j (A_{ij} \cdot z^{i-1})$$

$A_{ij}$  = coefficients listed in Table 4.1.

**Table 4-1. Coefficients for Calculation of Absorbed Solar Radiation,  $A_{ij}$** 

i	j			
	1	2	3	4
1	0.23	0.17	0.13	0.11
2	-	0.63	0.47	0.39
3	-	-	0.76	0.62
4	-	-	-	0.83

When using WINDOW-4.1 data files, the absorptance of each glazing layer as a function of incidence angle is read into an array. Then the absorptance is linearly interpolated in incidence angle, and the heat that enters the zone by absorption in the glazing layers is determined by the following:

$$N_{ij} = R_{out,j} / R_{tot}$$

$$R_{out,j} = 1 / h_o + \sum_{i=1}^{2j-2} t_i / k_{eff,i}$$

$$Q_{abs} = AI_{dir} \cdot \sum_{i=1}^{layers} N_{i1} \cdot Abs_{dir,i} + AI_{diff} \cdot \sum_{i=1}^{layers} N_{i1} \cdot Abs_{diff,i}$$

#### 4.2.9. Window Calculations

SUBROUTINE:

[SOLAR]

$$dirtrans = I_{dir} \cdot \tau(\theta) \cdot SF \cdot A_g \cdot DIRSF_g$$

$$diftrans = I_{diff} \cdot \tau(\theta_{diff}) \cdot SF \cdot A_g$$

$$dirabs = I_{dir} \cdot abs(\theta) \cdot SF \cdot A_g \cdot DIRSF_g$$

$$difabs = I_{diff} \cdot abs(\theta_{diff}) \cdot SF \cdot A_g$$

#### 4.2.10. Exterior Wall Solar Absorbed

SUBROUTINE:

[SOLAR]

$$Q_{abs,w} = \alpha_w \cdot \left[ A_s \cdot (I_{dir} \cdot DIRSF_s + I_{diff}) - \sum_{windows} (A_g \cdot (I_{dir} \cdot DIRSF_s + I_{diff})) \right] \cdot A_{\%}$$

### 4.2.11. Interior Distribution of Solar

SUBROUTINE:

[HRSET]

$$Q_{\text{trans},i} = \sum (\text{diftrans} + \text{dirtrans})$$

$$Q_{\text{avail},i} = Q_{\text{trans},i} - \sum_{\text{zones}} (F_{ij} \cdot Q_{\text{trans},j}) + \sum_{\text{zones}} (F_{ji} \cdot Q_{\text{trans},j})$$

$$Q_{\text{lost},i} = FL_i \cdot Q_{\text{avail},i}$$

$$Q_{\text{solwal},i} = FW_i \cdot \frac{1.0}{H_i \cdot R_i + 1.0} \cdot Q_{\text{avail},i}$$

$$Q_{\text{solzon},i} = Q_{\text{avail},i} \cdot FA_i + \sum_{\text{windows}} (\text{difabs} + \text{dirabs}) + \sum_{\text{mass.walls}} \left[ \frac{FW_i \cdot Q_{\text{avail},i} \cdot H_i \cdot R_i}{H_i \cdot R_i + 1.0} \right] \\ + \sum_{\text{massless walls}} \left[ \frac{FW_i \cdot Q_{\text{avail},i} \cdot (R \cdot H_i \cdot H_j + H_i)}{R \cdot H_i \cdot H_j + H_i + H_j} + \frac{FW_j \cdot Q_{\text{avail},j} \cdot H_i}{R \cdot H_i \cdot H_j + H_i + H_j} \right]$$

### 4.3. Temperature Algorithms

#### NOMENCLATURE

A	= area
C <sub>p</sub> <sub>air</sub>	= specific heat of air
H	= wall surface coefficient
Q <sub>wall</sub>	= energy flow between zone and enclosing mass walls (including Trombe walls)
Q <sub>pass</sub>	= passive (non-controlled) energy flow between zone and rockbins connected to it
Q <sub>tc</sub>	= Trombe wall thermocirculation energy flow
Q <sub>zone</sub>	= energy flow between zones through explicitly defined interzone loss coefficients or through massless walls between zones
Q <sub>window</sub>	= energy flow through windows
Q <sub>amb</sub>	= energy flow to ambient air through explicitly defined loss coefficients to ambient or through massless walls between the zone and ambient
Q <sub>grd</sub>	= energy flow to user-specified ground node through explicitly defined loss coefficients to ground or through massless walls between zone and ground
Q <sub>inf</sub>	= energy flow due to air infiltration
Q <sub>nvent</sub>	= energy flow due to natural ventilation
Q <sub>solzon</sub>	= total solar gain to zone (see above)
Q <sub>appli</sub>	= user-specified appliance gain
Q <sub>fan</sub>	= energy flow between zones by fans

$Q_{\text{heat}}$	= heating energy supplied to zone
$Q_{\text{vent}}$	= energy removed from zone by venting
$Q_{\text{cool}}$	= energy removed from zone by cooling
$T_{\text{amb}}$	= ambient temperature
$T_{\text{grd}}$	= ground node temperature

#### 4.3.1. Degree-Day Calculations

SUNREL uses two methods of calculating the degree days. The first is the standard used in the United States, with a base temperature for heating and cooling degree day calculations. The base temperature is the outdoor temperature at which the building can maintain the desired indoor temperature with heat gains only from the sun and internal loads. The heating degree days are calculated as the difference between the average daily ambient temperature and the balance point temperature for days when the average daily temperature is less than the balance point temperature. Cooling degree days are calculated in a similar manner, except that the average daily temperature must be greater than the balance point temperature.

If  $T_{\text{amb}} < T_{\text{bal}}$ , then

$$\text{HDD} = \text{HDD} + (T_{\text{bal}} - T_{\text{amb}}) \cdot 1 \text{ day}$$

End if

A method commonly used in Europe for heating degree days includes an outdoor limit temperature along with the base point temperature. Heating degree days are only calculated when the daily average temperature falls below the outdoor limit temperature. In equation form this looks like

If  $T_{\text{amb}} < T_{\text{outdoor limit}}$ , then

$$\text{HDD} = \text{HDD} + (T_{\text{bal}} - T_{\text{amb}}) \cdot 1 \text{ day}$$

End if

#### 4.3.2. Zone Air Temperature

The program uses a central air temperature node for each zone defined by the user. Zone air is assumed to be well-mixed with no temperature stratification. This zone air temperature is used as the primary control for all equipment operation.

The energy balance equation defining the zone air temperature can be written as

$$Q_{\text{wall}} + Q_{\text{pass}} + Q_{\text{TC}} + Q_{\text{zone}} + Q_{\text{window}} + Q_{\text{amb}} + Q_{\text{grd}} + Q_{\text{inf}} + Q_{\text{nvent}} + Q_{\text{solzon}} + Q_{\text{appli}} + Q_{\text{fan}} + Q_{\text{rock}} + Q_{\text{heat}} + Q_{\text{vent}} + Q_{\text{cool}} = 0$$

where

$$Q_{\text{wall}} = \sum_{\text{walls}} [UA_{\text{wall}} \cdot (T_{\text{wall}} - T)]$$

where

$$\begin{aligned} T_{\text{wall}} &= \text{temperature of first mass node in wall} \\ UA_{\text{wall}} &= \text{conductance from zone to first mass node in the wall} \\ &= A_{\text{wall}} \cdot \frac{H}{R \cdot H + 1.0} \end{aligned}$$

where

R = thermal resistance from wall surface to first mass node

$$Q_{\text{pass}} = \sum_{\text{rocks}} [UA_{\text{pass}} \cdot (T_{\text{rock}} - T)]$$

where

UA<sub>pass</sub> = user-specified rockbed passive conductance value  
T<sub>rock</sub> = average of all rockbed node temperatures

$$Q_{\text{tc}} = \sum_{\text{trombes}} [UA_{\text{tc}} \cdot (T_{\text{gap}} - T)]$$

where

T<sub>gap</sub> = Trombe wall air gap temperature  
UA<sub>tc</sub> = thermocirculation equivalent conductance

$$Q_{\text{zone}} = \sum_{\text{losses}} [L_{\text{zone}} \cdot (T_{\text{zone}} - T)] + \sum_{\substack{\text{massless} \\ \text{walls}}} [(UW_z \cdot A_{\text{wall},z}) \cdot (T_{\text{zone}} - T)]$$

where

T<sub>zone</sub> = other zone air temperature  
L<sub>zone</sub> = user-specified interzone loss coefficient  
UW<sub>z</sub> = air-to-air conductance through massless wall  
$$= H_f \cdot \frac{H_b}{H_f + H_b + H_f \cdot H_b \cdot R}$$

where

H<sub>f</sub> = front-side surface coefficient  
H<sub>b</sub> = back-side surface coefficient  
R = thermal resistance of wall from surface to surface

$$Q_{\text{window}} = \sum_{\text{windows}} [UA_{\text{win}} \cdot (T_{\text{amb}} - T)]$$

where

UA<sub>win</sub> = air-to-air conductance through window  
T<sub>amb</sub> = ambient air temperature

$$Q_{\text{amb}} = \sum_{\text{losses}} [L_{\text{amb}} \cdot (T_{\text{amb}} - T)] + \sum_{\substack{\text{massless} \\ \text{walls}}} [(UW_a \cdot A_{\text{wall},a}) \cdot (T_{\text{amb}} - T)]$$

where

$L_{\text{amb}}$  = user-specified loss coefficient to ambient  
 $UW_a$  = air conductance through massless wall  
 = same form as  $UW_z$  above

$$Q_{\text{grd}} = \sum_{\text{losses}} [L_{\text{grd}} \cdot (T_{\text{grd}} - T)] + \sum_{\substack{\text{massless} \\ \text{walls}}} [(UW_g \cdot A_{\text{wall},g}) \cdot (T_{\text{amb}} - T)]$$

where

$L_{\text{grd}}$  = user-specified loss coefficient to ground  
 $UW_g$  = air-to-air conductance through massless wall  
 = same form as  $UW_z$  above

$$Q_{\text{inf}} = \dot{m}_{\text{inf}} C_{p,\text{air}} \cdot (T_{\text{amb}} - T)$$

where

$\dot{m}_{\text{inf}}$  = infiltration mass flow rate

$$Q_{\text{nvent}} = \dot{m}_{\text{nvent}} C_{p,\text{air}} (T_{\text{amb}} - T)$$

The new air temperature,  $T$ , is calculated each timestep by rewriting the energy balance to isolate  $T$  in each term, as

$$T = \frac{\text{NUM}_{\text{hr}} + \text{NUM}_{\text{dtf}} + \text{NUM}_{\text{dti}} + Q_{\text{equip}}}{\text{DEN}_{\text{hr}} + \text{DEN}_{\text{dtf}} + \text{DEN}_{\text{dti}}}$$

where

$$\begin{aligned} \text{NUM}_{\text{hr}} = & \sum_{\text{windows}} (UA_{\text{win}} \cdot T_{\text{amb}}) + \sum_{\text{losses}} (L_{\text{amb}} \cdot T_{\text{amb}}) + \sum_{\substack{\text{massless} \\ \text{walls}}} (UW_a \cdot AW_a \cdot T_{\text{amb}}) \\ & + \sum_{\text{losses}} (L_{\text{grd}} \cdot T_{\text{grd}}) + \sum_{\substack{\text{massless} \\ \text{walls}}} (UW_g \cdot AW_g \cdot T_{\text{grd}}) + Q_{\text{solzon}} + Q_{\text{appli}} \\ \text{DEN}_{\text{hr}} = & \sum_{\text{windows}} UA_{\text{win}} + \sum_{\text{losses}} L_{\text{amb}} + \sum_{\substack{\text{massless} \\ \text{walls}}} (UW_a \cdot AW_a) + \sum_{\text{losses}} L_{\text{grd}} \\ & + \sum_{\substack{\text{massless} \\ \text{walls}}} (UW_g \cdot AW_g) \end{aligned}$$

$$\begin{aligned}
\text{NUM}_{\text{dtf}} &= \sum_{\text{walls}} (\text{UA}_{\text{wall}} \cdot T_{\text{wall}}) + \sum_{\text{rocks}} (\text{UA}_{\text{pass}} \cdot T_{\text{rock}}) \\
\text{DEN}_{\text{dtf}} &= \sum_{\text{walls}} \text{UA}_{\text{walls}} + \sum_{\text{rocks}} \text{UA}_{\text{pass}} \\
\text{NUM}_{\text{dti}} &= \sum_{\text{trombes}} (\text{UA}_{\text{tc}} \cdot T_{\text{gap}}) + \sum_{\text{losses}} (L_{\text{zone}} \cdot T_{\text{zone}}) + \sum_{\substack{\text{massless} \\ \text{walls}}} (\text{UW}_z \cdot \text{AW}_z \cdot T_{\text{zone}}) \\
&\quad + \sum \dot{m}_{\text{inf}} \text{Cp}_{\text{air}} T_{\text{amb}} + \sum \dot{m}_{\text{nvent}} \text{Cp}_{\text{air}} T_{\text{amb}} \\
\text{DEN}_{\text{dti}} &= \sum_{\text{trombes}} \text{UA}_{\text{tc}} + \sum_{\text{losses}} L_{\text{zone}} + \sum_{\substack{\text{massless} \\ \text{walls}}} (\text{UW}_z \cdot \text{AW}_z) + \sum \dot{m}_{\text{inf}} \text{Cp}_{\text{air}} + \sum \dot{m}_{\text{nvent}} \text{Cp}_{\text{air}}
\end{aligned}$$

$$Q_{\text{equip}} = Q_{\text{fan}} + Q_{\text{rock}} + Q_{\text{heat}} - Q_{\text{vent}} - Q_{\text{cool}}$$

Each of the terms in the numerator and the denominator of the zone air temperature equation is calculated by the model as early as possible. Thus, constants are set up by one-time calculations in the subroutine SETUP and subroutine RNSET; energy flows constant for one hour are calculated by subroutine HRSET (NUMhr, DENhr, DENdtf); energy flows that vary each timestep, but do not involve iterations (NUMdtf) and those that may require iteration (NUMdti, DENdti) are set by subroutine ZONETEMP.

The numerator and the denominator of the zone air temperature equation are accumulated within subroutine ZONETEMP with Qequip set to zero. This pseudo-temperature, which would be the zone temperature if no equipment were to operate, is used as the primary control for equipment operation. The final zone temperature is determined by the equipment controller routine discussed in detail in Section 4.4.1.

When non-equipment energy flow paths (loss coefficients or massless walls) exist between any two interior zones, then all zone air temperatures are solved iteratively. In each step of the iteration, the values of NUMdti and DENdti are calculated using the previous set of zone air temperatures. Equipment is then operated to determine a new set of zone air temperatures.

Iteration continues until two successive calculations of each zone air temperature differ by, at most, a user-specified convergence criteria or until reaching the user-specified maximum number of iterations per timestep. The Trombe wall air gap temperature is iteratively calculated within each zone air temperature iteration, if Trombe wall thermocirculation is present (Section 4.3.4). The infiltration and natural ventilation mass balance routines are also nested within the zone air temperature iteration.

### 4.3.3. Infiltration

The program treats infiltration either as a fixed air change per hour or by a detailed mass balance approach on each zone. The latter method is implemented by entering a value for the zone effective leakage area (ZLEAK in the ZONES input section).

#### NOMENCLATURE

AE	= effective leakage area (ELA) in a zone (ft <sup>2</sup> or m <sup>2</sup> )
ACH	= infiltration air change rate, constant or scheduled value (air changes/hour)
CD	= discharge coefficient
C <sub>pair</sub>	= air specific heat = 0.24 (Btu/lb·°F) = 1.00418 (kJ/kg·°C)
CP	= surface pressure coefficient
CP <sub>n</sub>	= surface pressure coefficient at normal incidence (= 0.6)
f	= fraction of zone ELA that is in the wall
g	= acceleration of gravity (ft/s <sup>2</sup> or m/s <sup>2</sup> )
G	= ln(L1/L2) where L1 and L2 are lengths of adjacent sides of the building. This term is set to one for all cases (i.e., assuming a square building).
k	= iteration step number
n	= flow coefficient
P <sub>o</sub>	= base pressure or zone pressure at y = 0 (lb/in. <sup>2</sup> or Pa)
ΔP <sub>S,O</sub>	= pressure difference at the base due to the stack effect
ΔP <sub>S,H</sub>	= pressure difference at H due to the stack effect
V	= zone air volume (ft <sup>3</sup> or m <sup>3</sup> )
y'	= height normalized to the wall height, H (ft or m)
ynpl	= neutral pressure height (ft or m)
α and γ	= terrain dependent parameters from Table 4.2
ε	= convergence tolerance for infiltration mass balance
φ <sub>w</sub>	= wind incidence angle on the surface
ρ <sub>out</sub>	= ambient air density at the station elevation and ambient temperature (lb/ft <sup>3</sup> or kg/m <sup>3</sup> )

Method #1: Constant air-change per-hour method:

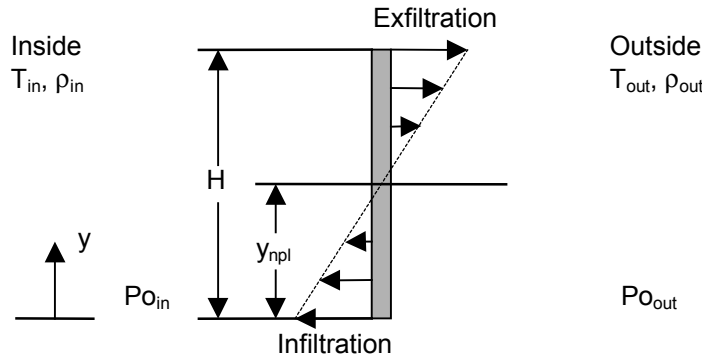
$$\begin{aligned} \dot{m} &= \text{infiltration mass flow rate} \\ &= \text{ACH } V \rho_{\text{out}} \end{aligned}$$

Method #2: Effective leakage area (ELA) method (Deru 1996):

The ELA is distributed to each wall in the zone by user-specified fractions or automatically by wall-area fractions (subroutine LEAKAGE). The airflow is driven by pressure variations due to the stack effect (Figure 4.4) and the wind effect.

$$\Delta P_{\text{stack}}(y) = (P_{o_{\text{in}}} - P_{o_{\text{out}}}) - gHy'(\rho_{\text{in}} - \rho_{\text{out}})$$





**Figure 4-4. Stack pressure across a wall**

The wind pressure is determined in the following equations. The meteorological wind speed from the weather data file must be adjusted to the height and terrain of the building by the second equation with the terrain classifications listed in Table 4.2.

$$P_w = \frac{1}{2} C_p \rho_{out} V_w^2$$

$$V_w = V_{met} \alpha \left( \frac{H}{H_{met}} \right)^\gamma$$

The surface pressure coefficient on each surface is determined from the empirical relationship below (Swami and Chandra 1988). The pressure coefficient at normal incidence is taken to be 0.6 for all cases. The term  $G = \ln(S_1/S_2)$  (the natural log of the adjacent side lengths) is set to one because of the variety of possible building geometries (Deru 1996).

$$\frac{C_p}{C_{pn}} = \ln \left[ \frac{1.248 - 0.703 \sin \frac{\phi_w}{2} - 1.175 (\sin \phi_w)^2 + 0.131 (\sin(2\phi_w G))^2}{+ 0.769 \cos \frac{\phi_w}{2} + 0.07 G^2 \left( \sin \frac{\phi_w}{2} \right)^2 + 0.717 \left( \cos \frac{\phi_w}{2} \right)^2} \right]$$

**Table 4-2. Terrain Classifications for Infiltration Calculations**

Class	$\gamma$	$\alpha$	Description
I	0.10	1.30	ocean or other body of water with at least 5 km of unrestricted expanse
II	0.15	1.00	flat terrain with some isolated obstacles (buildings or trees well separated)
III	0.20	0.85	rural areas with low buildings, trees, etc.
IV	0.25	0.67	urban, industrial, or forest areas
V	0.35	0.47	center of large city

The infiltration and exfiltration mass flow rate equations are integrated over each wall in a zone. The natural ventilation flow rates are determined by similar equations. When natural ventilation is "on," the infiltration is not calculated in this zone because the natural ventilation is much larger than the infiltration. The infiltration mass flow is determined by the following equation, where the density is that of the air flowing through the crack (i.e., for infiltration = density of the outside air; for exfiltration = the density of the inside air):

$$\dot{m}_{inf} = \frac{fA_e C_D \sqrt{2\rho}}{(n+1)\Delta P_{S,H}} \left[ P_o - \Delta P_{S,O} - (SC)^{1/(n+1)} P_w \right]^{n+1}$$

The effects of local shielding on the wind pressure is taken into account by the shielding coefficients shown in Table 4.3.

**Table 4-3. Local Shielding Coefficients Used by SUNREL**

Class	SC	Description
I	1.00	no obstructions of local shielding
II	0.880	light local shielding with few obstructions
III	0.741	moderate local shielding, some obstructions within two house heights
IV	0.571	heavy shielding, obstructions around most of the perimeter
V	0.315	very heavy shielding, large obstructions surrounding perimeter within two house heights

After the infiltration and natural ventilation flow rates are determined for every wall, the mass balance equations are written for each zone. The equations are coupled and must be solved as a system because of interzonal interaction.

$$\dot{m}_{\text{tot}} = \sum_{j=1}^{\# \text{ walls}} \dot{m}_{\text{inf},j} + \sum_{j=1}^{\# \text{ walls}} \dot{m}_{\text{exf},j} = 0$$

SUNREL does not determine mechanical means of air flow from the HVAC systems; therefore, they are not included in the mass balance. The magnitude of this effect will depend on the size of the HVAC fan and the "leakiness" of the zone. Zones with large leakage, such as open windows, will not be affected as much as zones with small leakage areas. The set of mass balance equations represent a system of non-linear equations and are solved using Newton's Method to estimate the base pressure at the new iteration as shown below:

$$P_o^{k+1} = P_o^k - \frac{\dot{m}(P_o^k)}{\dot{m}'(P_o^k)}$$

The system is converged when the mass balance is satisfied to within a user-specified tolerance,  $\epsilon$ , in the PARAMETERS input section (default is 0.5%). Convergence is determined by

$$\frac{\left| \sum_{j=1}^{\# \text{ walls}} \dot{m}_j \right|}{\sum_{j=1}^{\# \text{ walls}} |\dot{m}_j|} \leq \epsilon$$

The speed at which the convergence is proceeding is tested each iteration, and a relaxation coefficient is adjusted to optimize the convergence. Convergence is normally reached within 2-5 iterations.

#### **4.3.4. Trombe Wall Thermocirculation**

A Trombe wall may be specified as a building element between any zone and ambient air. The Trombe wall consists of an outer glazing system (with the option of scheduled shutters), an inner wall, and an air space between. Vents may be specified within the wall (an equal area at the top and bottom of the wall) to model the exchange of air between the Trombe wall air space and the zone to which the Trombe wall is connected (thermocirculation). The energy flow due to thermocirculation is calculated as an equivalent thermal

conductance value that multiplies the difference between zone air temperature and air gap temperature. The formulation of  $UA_{tc}$  is taken from McFarland (1978), where it is stated to be appropriate only when the vents are the dominant resistance to air flow through the Trombe wall.

Moore (1981) indicated that the thermocirculation air movement calculated by this model correlated reasonably well with that produced by more detailed models. However, the magnitude of the thermocirculation is highly dependent on the user-specified vent discharge coefficient. Moore (1981) indicated that, for the Trombe wall configurations studied, the values of this coefficient typically used in the past (approximately 0.8) might be too high by as much as a factor of two.

The thermocirculation equivalent conductance value,  $UA_{tc}$ , is taken to be proportional to the square root of the difference in temperature between the air gap node and the zone air node. It is calculated in subroutine TROMB (with pre-calculation of constants in subroutine RNSET).

### NOMENCLATURE

a	= coefficient derived from exponential curve fit = $3.71781196 \times 10^{-5}/ft$ or $-1.219755 \times 10^{-4}/m$
$A_v$	= ratio of area of one row of vents to area of wall
$A_w$	= area of Trombe wall ( $ft^2$ or $m^2$ )
$C_{p,air}$	= air specific heat = $0.24 \text{ Btu/lb}\cdot^\circ\text{F}$ = $1.00418 \text{ kJ/kg}\cdot^\circ\text{C}$
elev	= station elevation (ft or m)
g	= gravitational constant = $32.2 \text{ ft/s}^2$ = $9.89 \text{ m/s}^2$
$H_v$	= height between top and bottom row of vents (ft or m)
$Q_{solgap}$	= inward flowing fraction of solar energy absorbed by Trombe glazing (see Solar Algorithms above)
$T_{amb}$	= ambient air temperature ( $^\circ\text{F}$ or $^\circ\text{C}$ )
$T_{gap}$	= temperature of air gap node ( $^\circ\text{F}$ or $^\circ\text{C}$ )
$T_{wall}$	= temperature of first mass node in Trombe wall ( $^\circ\text{F}$ or $^\circ\text{C}$ )
$T_z$	= temperature of zone air node ( $^\circ\text{F}$ or $^\circ\text{C}$ )
$T_0$	= conversion to absolute temperature - $459.69^\circ\text{F}$ or $273.16^\circ\text{C}$
$UA_{win}$	= air-to-air thermal conductance through glazing ( $\text{Btu/hr}\cdot^\circ\text{F}$ or $\text{W/K}$ )
$UA_{wall}$	= thermal conductance from air gap node to first mass node in Trombe wall ( $\text{Btu/hr}\cdot^\circ\text{F}$ or $\text{W/K}$ )
$V_d$	= user-specified vent discharge coefficient
3600	= 3600 s/hr
$\rho_{air}$	= air density at sea level ( $\text{lb/ft}^3$ or $\text{kg/m}^3$ )

$$UA_{tc} = C_{tc} \cdot \sqrt{\left(\frac{T_{gap} - T_z}{T_z + T_0}\right)}$$

$$C_{tc} = 2 \cdot 3600 \cdot Cp_{air} \cdot \rho_{air} \cdot e^{a \cdot elev} \cdot V_d \cdot A_v \cdot A_w \cdot \sqrt{(g \cdot H_v)}$$

Thermocirculation is controlled in two ways. First, the model is formulated to prevent reverse thermosiphoning. That is,  $UA_{tc}$  is set to zero whenever  $T_{gap} < T_z$ . Second, when the “prevent zone overhear” option is selected by the user,  $UA_{tc}$  is set to zero whenever a venting setpoint,  $V_z$ , is defined for the zone and  $T_z > V_z$ , or whenever a cooling setpoint,  $C_z$ , is defined and  $T_z > C_z$ .

The Trombe wall air gap temperature is calculated in subroutine TROMB similarly to that for a zone, as

$$T_{gap} = \frac{NUM_{gap}}{DEN_{gap}} = \frac{UA_{win} \cdot T_{amb} + UA_{wall} \cdot T_{wall} + UA_{tc} \cdot T_z + Q_{sogap}}{UA_{win} + UA_{wall} + UA_{tc}}$$

When  $UA_{tc} = 0$ ,  $T_{gap}$  is set once per timestep by the above equation. When  $UA_{tc} > 0$ , the equation defining  $T_{gap}$  is iterated with  $T_z$  held fixed, but with  $UA_{tc}$  updated by the last calculation of  $T_{gap}$ . Iteration continues until two successive calculations of  $T_{gap}$  differ by, at most, a user-specified convergence criteria or until reaching the user-specified maximum number of iterations.

#### **4.3.5. Wall Calculations**

The thermal response of walls is calculated by approximating the wall construction with a thermal network. The network is then solved using the method known as explicit finite differences or Euler's method. This section develops the basic equations for all wall calculations. All building elements with heat capacity are referred to as walls, whether or not they separate rooms in the building. In addition, walls include pure resistance elements that separate zones.

The constant coefficients, which define the nodal network layout, are calculated within subroutine COEF2 during the preprocessing. Additional pre-calculation of coefficients occurs in subroutine SETUP. Solar inputs to walls are set in subroutine HRSET. New wall node temperatures are calculated in subroutine WALLTEMP, with new wall surface temperatures calculated in subroutine SURFS.

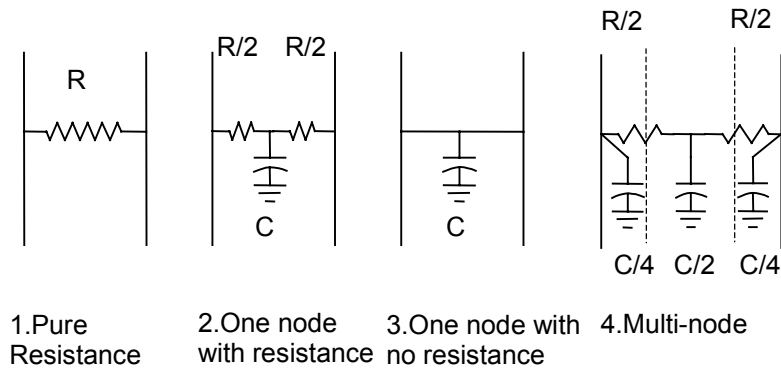
**4.3.5.1. Nodal Layout**

Each wall is connected to zone air temperatures on either side through user-specified surface conductances. These conductances may be zero on one or the other, but not both sides of the wall. They are held constant for the entire run. In addition, the wall can receive solar inputs on either or both sides. That part of the wall between surfaces is composed of one or more layers in series.

There are four possible types of layers:

1. A pure thermal resistance
2. A single node with internal thermal resistance (i.e., finite conductivity)
3. A single node without internal thermal resistance (i.e., a pure thermal capacitance layer or infinite conductivity)
4. A multi-node layer with internal resistance.

These layer types and their thermal network diagrams are shown below in Figure 4.5. The symbols R and C represent the total thermal resistance and the total thermal capacitance of the layer.



**Figure 4-5. Possible wall layer types and the node configurations**

The various combinations of layers to produce thermal networks for walls are shown later in this section. The series combination of layers is most easily phrased in terms of thermal resistances and capacitances. A phase-change material layer is required to have some thermal resistance specified on either side. The resistance would be provided by a surface coefficient, a pure thermal resistance layer, or a one-node layer with finite conductivity. In particular, the program will not allow two consecutive phase-change layers.

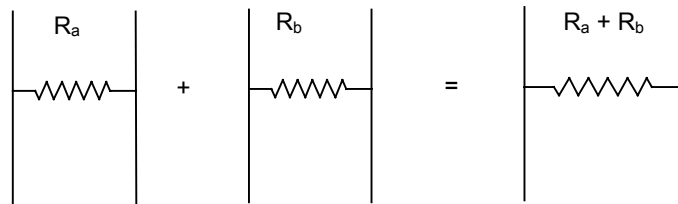
## NOMENCLATURE

$C1$	= total thermal capacitance of layer 1
$C2$	= total thermal capacitance of layer 2
$dT/dt$	= time derivative of middle node temperature
$HL$	= thermal conductance to the left node
$HR$	= thermal conductance to the right node
$Hsa$	= conductance from surface to air temperature node
$Ha$	= overall conductance from layer node to air node $T_a$
$Hw$	= conductance to next node in layer
$Q_{melt}$	= the latent heat of fusion of the material
$Q_s$	= solar radiation absorbed at surface
$Q_{stored}$	= the latent heat stored in the layer
$R1$	= total thermal resistance of layer 1
$R2$	= total thermal resistance of layer 2
$R_w$	= resistance of wall from surface to surface
$T$	= old node temperature
$T'$	= new temperature of node at end of timestep
$T_w$	= old temperature of next node in from surface
$T_{melt}$	= the melting point temperature of the phase-change material
$\Delta t$	= length of timestep

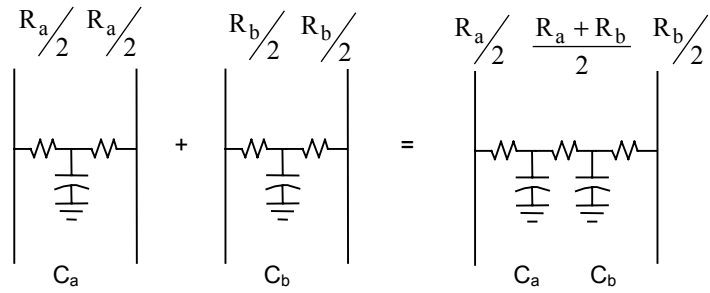
### Subscripts:

$L$	= left node
$R$	= right node
$a$	= air on side A
$b$	= air on side B
$w$	= wall from the surface to the first node in the wall or entire wall for pure resistance wall
$s$	= surface
$n$	= nth node

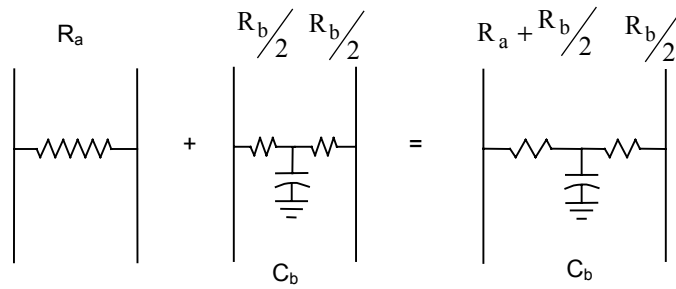
### CASE I. Two pure resistance layers



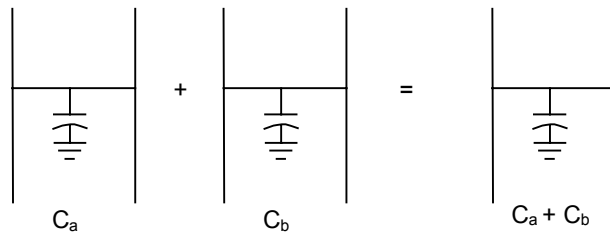
**CASE II. Two single-node layers**



**CASE III. Pure resistance layer and single-node layer**

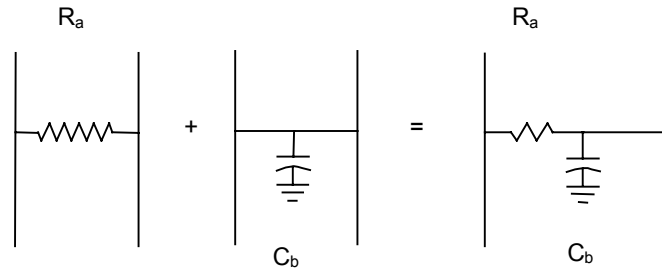


**CASE IV. Two pure capacitance layers**

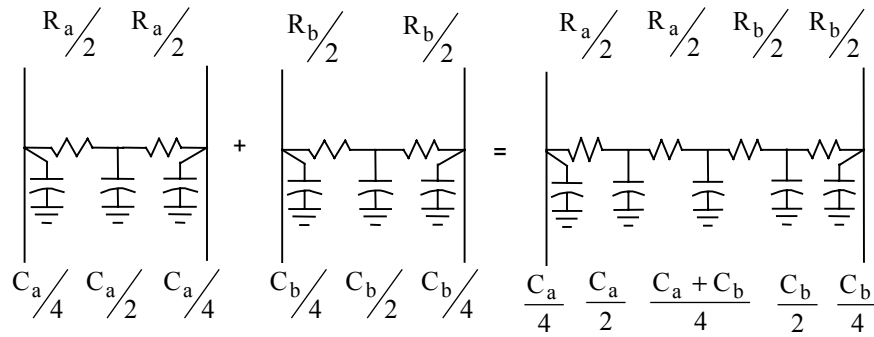




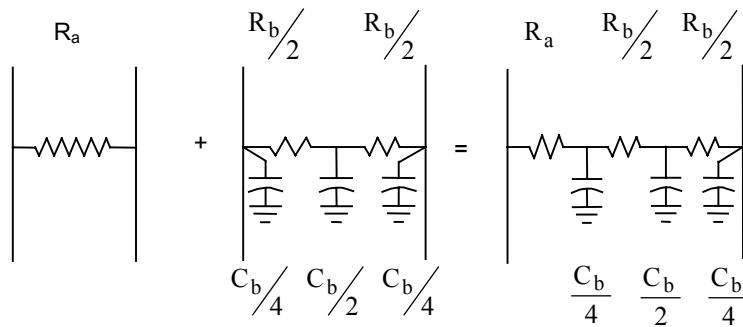
**CASE V. Pure resistance layer and pure capacitance layer**



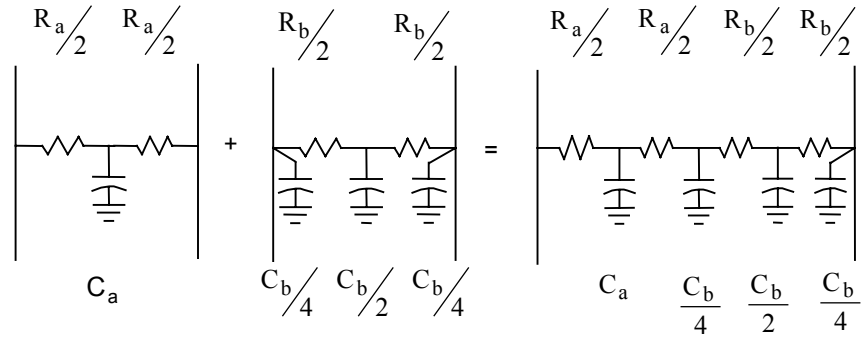
**CASE VI. Two multi-node layers**



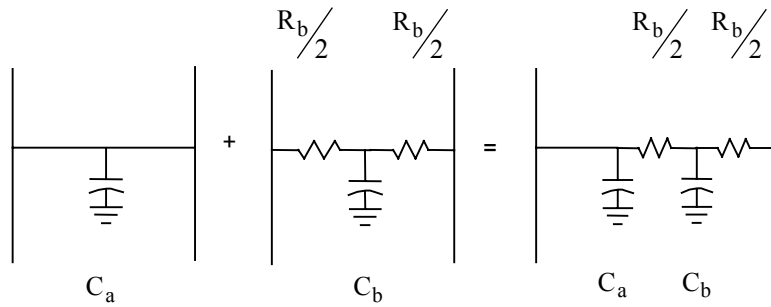
**CASE VII. Pure resistance layer with a multi-node layer**



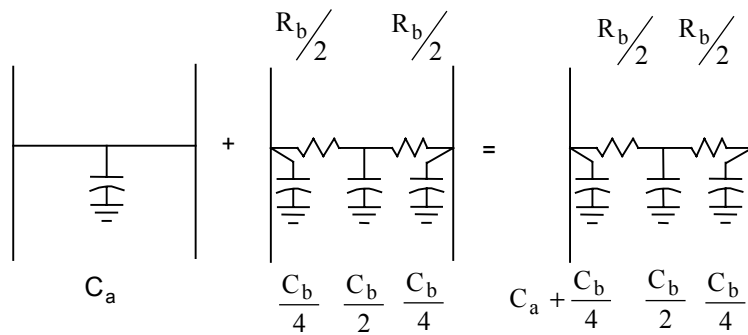
**CASE VIII. Single-node layer and multi-node layer**



**CASE IX. Pure capacitance layer and single-node layer**



**CASE X. Pure capacitance layer and multi-node layer**



#### 4.3.5.2. Interior Node Temperature Solution

The thermal network model contains only nodes with heat capacity in the interior of the wall. The governing equation for these internal nodes is derived from an instantaneous heat balance on the node:

$$\begin{array}{rcl} \text{rate of heat} & = & \text{rate of heat gain} + \text{rate of heat gain} \\ \text{storage} & & \text{from node on left} \quad \text{from node on right} \end{array}$$

Mathematically, this becomes

$$C \cdot \left( \frac{dT}{dt} \right) = H_L \cdot (T_L - T) + H_R \cdot (T_R - T)$$

The differential equations (one for each node) are solved by using explicit finite differences or Euler integration. The main advantages of the explicit technique are simplicity, the fact that each node can be solved independently of the others, and the ability to handle non-linear boundary conditions. The new temperature at the end of a timestep is approximated as follows:

$$T' = T + \Delta t \cdot \left( \frac{dT}{dt} \right)$$

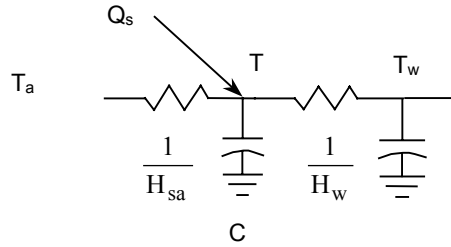
This results in a set of independent equations for the new node temperatures, each of which has the form

$$T' = \left( 1 - \frac{\Delta t \cdot H_L}{C} - \frac{\Delta t \cdot H_R}{C} \right) \cdot T + \left( \frac{\Delta t \cdot H_L}{C} \right) \cdot T_L + \left( \frac{\Delta t \cdot H_R}{C} \right) \cdot T_R$$

The second law of thermodynamics and mathematical stability of the explicit solution technique require that the first term in parentheses be non-negative. The subroutine COEF2 checks this and tells the user the minimum number of timesteps per hour that may be used. If the timestep is unreasonably small, the user may reduce the number of nodes in those layers that required the small step. A small timestep can also be caused by a thin layer with a low thermal capacitance and high thermal conductivity, such as a thin metal sheeting.

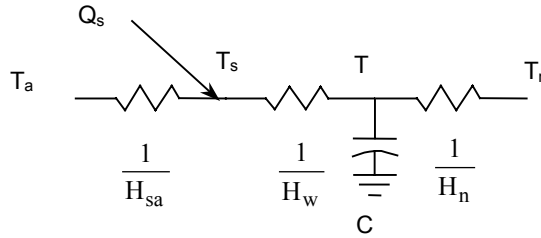
#### 4.3.5.3. Wall Surface Temperature Solution

The equations that define the conditions at the surfaces of the walls are more complex. The derivation of the equations for the first capacity node from the surface, the surface temperature, and the flow of heat and solar radiation at the surface depend on the type of layer that occurs at the surface.

**CASE I. Multi-node layer at surface**


All of the solar is absorbed at the surface node. The node equation is

$$T' = \left(1 - \frac{\Delta t \cdot H_a}{C} - \frac{\Delta t \cdot H_w}{C}\right) \cdot T + \left(\frac{\Delta t \cdot H_a}{C}\right) \cdot T_a + \left(\frac{\Delta t \cdot H_w}{C}\right) \cdot T_w + \left(\frac{\Delta t}{C}\right) \cdot Q_s$$

**CASE II. Single-node layer with internal resistance at surface**


This case is somewhat more complex because there is no node with capacity at the surface where the solar is absorbed. First, the conductance from air temperature to node in layer is defined as

$$H = \frac{H_{sa} \cdot H_w}{H_{sa} + H_w}$$

Then, the solar radiation absorbed at the surface,  $Q_s$ , is broken into two parts: the portion going to the zone air node,  $Q_a$ , and the portion going to the wall node,  $Q_w$ , as follows

$$Q_a = \left(\frac{H}{H_w}\right) \cdot Q_s$$

$$Q_w = Q_s - Q_a$$

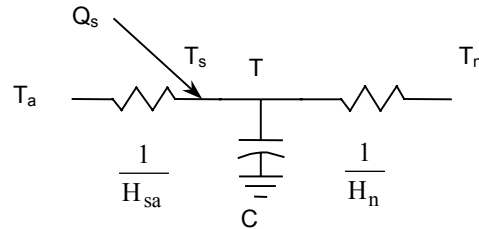
The solar going to the air temperature node is passed to the ZONETEMP subroutine, where it is used in calculating the air temperature. The new node temperature of the layer is

$$T' = \left(1 - \frac{\Delta t \cdot H}{C} - \frac{\Delta t \cdot H_n}{C}\right) \cdot T + \left(\frac{\Delta t \cdot H}{C}\right) \cdot T_a + \left(\frac{\Delta t \cdot H_n}{C}\right) \cdot T_n + \left(\frac{\Delta t}{C}\right) \cdot Q_w$$

The surface temperature (which is calculated in subroutine SURFS after the zone air temperature and the wall node temperatures are updated) is

$$T_s = \left(\frac{H}{H_w}\right) \cdot T_a + \left(1 - \frac{H}{H_w}\right) \cdot T' + \left(\frac{1}{H_{sa} + H_w}\right) \cdot Q_s$$

### CASE III. Single-node layer without internal resistance at surface



All solar energy is absorbed by the wall node. The equation for the new node temperature is

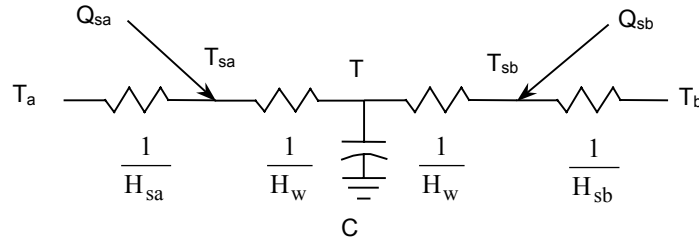
$$T' = \left(1 - \frac{\Delta t \cdot H_{sa}}{C} - \frac{\Delta t \cdot H_n}{C}\right) \cdot T + \left(\frac{\Delta t \cdot H_{sa}}{C}\right) \cdot T_a + \left(\frac{\Delta t \cdot H_n}{C}\right) \cdot T_n + \left(\frac{\Delta t}{C}\right) \cdot Q_s$$

The surface temperature is given by

$$T_s = T'$$

### CASE IV. Pure resistance layer at the surface

The equations are the same as CASE II, setting  $H_w$  equal to the thermal conductance from the surface to the first capacity node in the wall. The case where the wall consists of only a pure resistance layer is treated later in this chapter.

**CASE V. One node wall with internal resistance**


Walls that contain only a single capacity node are a special case because solar effects on both surfaces must be considered.

Let

$$H_a = \frac{H_{sa} \cdot H_w}{H_{sa} + H_w}$$

$$H_b = \frac{H_{sb} \cdot H_w}{H_{sb} + H_w}$$

Then

$$Q_a = \left( \frac{H_a}{H_w} \right) \cdot Q_{sa}$$

$$Q_b = \left( \frac{H_b}{H_w} \right) \cdot Q_{sb}$$

where:

$$\begin{aligned} Q_a &= \text{solar radiation flowing to air node } T_a \\ Q_b &= \text{solar radiation flowing to air node } T_b \end{aligned}$$

The equation for the new node temperature is

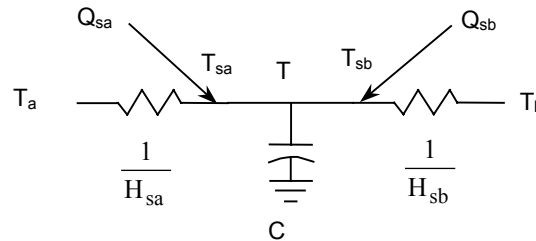
$$\begin{aligned} T' &= \left( 1 - \frac{\Delta t \cdot H_a}{C} - \frac{\Delta t \cdot H_b}{C} \right) \cdot T + \left( \frac{\Delta t \cdot H_a}{C} \right) \cdot T_a \\ &\quad + \left( \frac{\Delta t \cdot H_b}{C} \right) \cdot T_b + \left( \frac{\Delta t}{C} \right) \cdot (Q_{sa} - Q_a - Q_{sb} - Q_b) \end{aligned}$$

The surface temperature equations are

$$\begin{aligned} T_{sa} &= \left( \frac{H_{sa}}{H_{sa} + H_w} \right) \cdot T_a + \left( \frac{H_w}{H_{sa} + H_w} \right) \cdot T' + \left( \frac{1}{H_{sa} H_w} \right) \\ T_{sb} &= \left( \frac{H_{sb}}{H_{sb} + H_w} \right) \cdot T_b + \left( \frac{H_w}{H_{sb} + H_w} \right) \cdot T' + \left( \frac{1}{H_{sb} H_w} \right) \end{aligned}$$

The order of calculation and subroutines used are the same as in CASE II.

### CASE VI. One-node wall without internal resistance



This type of one-node wall is used primarily to model water walls and other situations where the internal resistance is negligible. It is simpler than the previous case. Solar radiation from both sides is absorbed entirely by the capacity node.

The new node temperature equation is

$$T' = \left(1 - \frac{\Delta t \cdot H_{sa}}{C} - \frac{\Delta t \cdot H_{sb}}{C}\right) \cdot T + \left(\frac{\Delta t \cdot H_{sa}}{C}\right) \cdot T_a + \left(\frac{\Delta t \cdot H_{sb}}{C}\right) \cdot T_b + \left(\frac{\Delta t}{C}\right) \cdot (Q_{sa} + Q_{sb})$$

The surface temperature equations are

$$T_{sa} = T'$$

$$T_{sb} = T'$$

The order of calculation and the subroutines used are the same as CASE II.

#### 4.3.5.4. Phase-change Material Layers

Phase-change layers involve special calculations. They have the same nodal equations as the pure capacitance layers, but differ in their ability to store heat without change of temperature. The phase-change material layer will behave as a pure capacitance layer until its temperature reaches the user-specified melting point. Then the temperature of the layer is held constant, while latent energy is stored up to the user-specified total latent storage capability of the layer. When the total latent storage capability is reached, the layer again

behaves as a pure capacitance layer. We calculate the new temperature of the phase-change material as though it were an ordinary material (in subroutine WALLTEMP).

$$T' = \left(1 - \frac{\Delta t \cdot H_L}{C} - \frac{\Delta t \cdot H_R}{C}\right) \cdot T + \left(\frac{\Delta t \cdot H_L}{C}\right) \cdot T_L + \left(\frac{\Delta t \cdot H_R}{C}\right) \cdot T_R + \left(\frac{\Delta t}{C}\right) \cdot Q_s$$

Let  $Q_{in}$  be the total heat flow into the phase-change layer during the timestep, so that

$$Q_{in} = C \cdot (T' - T)$$

Several cases for the calculation of the true new temperature,  $T_{new}$ , and the  $Q_{stored}$  term arise. The appropriate case and resulting values for  $T_{new}$  and  $Q_{stored}$  are selected in subroutine PCMAT.

**CASE I. The temperature of the material stays below or above the melting point.**

$$\begin{aligned} & T < T_{melt} \text{ and } T' < T_{melt} \\ \text{or } & T > T_{melt} \text{ and } T' > T_{melt} \\ \text{or } & T' = T_{melt} \end{aligned}$$

In each of these situations, the material will not change phase.

$$T_{new} = T' \text{ and } Q_{stored} = 0$$

**CASE II. The material is in the solid phase and is melting.**

$$T < T_{melt} \text{ and } T' > T_{melt}$$

Let

$$Q_{latent} = C \cdot (T' - T_{melt})$$

If

$$Q_{latent} \leq Q_{melt}$$

Then

$$Q_{stored} = Q_{latent} \text{ and } T_{new} = T_{melt}$$

Otherwise

$$Q_{stored} = Q_{melt} \text{ and } T_{new} = T_{melt} + \frac{Q_{latent} - Q_{melt}}{C}$$



**CASE III. The material is in the liquid phase and is freezing.**

$$T > T_{\text{melt}} \quad \text{and} \quad T' < T_{\text{melt}}$$

Let

$$Q_{\text{latent}} = C \cdot (T_{\text{melt}} - T')$$

If

$$Q_{\text{latent}} \leq Q_{\text{melt}}$$

Then

$$Q_{\text{stored}} = Q_{\text{melt}} - Q_{\text{latent}} \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}}$$

Otherwise

$$Q_{\text{stored}} = 0 \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}} + \frac{Q_{\text{melt}} - Q_{\text{latent}}}{C}$$

**CASE IV. The material is partially melted and is continuing to melt.**

$$T = T_{\text{melt}} \quad \text{and} \quad T' > T_{\text{melt}}$$

Let

$$Q_{\text{latent}} = Q_{\text{stored}} + C \cdot (T' - T)$$

If

$$Q_{\text{latent}} \leq Q_{\text{melt}}$$

Then

$$Q_{\text{stored}} = Q_{\text{latent}} \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}}$$

Otherwise

$$Q_{\text{stored}}' = 0 \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}} + \frac{Q_{\text{latent}} - Q_{\text{melt}}}{C}$$

**CASE V. The material is partially melted and is freezing.**

$$T = T_{\text{melt}} \quad \text{and} \quad T' < T_{\text{melt}}$$

Let

$$Q_{\text{latent}} = Q_{\text{stored}} + C \cdot (T' - T)$$

If

$$Q_{\text{latent}} > 0$$

Then

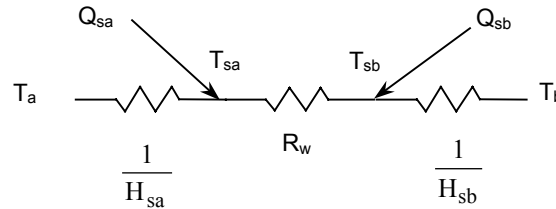
$$Q_{\text{stored}}' = Q_{\text{latent}} \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}}$$

Otherwise

$$Q_{\text{stored}} = 0 \quad \text{and} \quad T_{\text{new}} = T_{\text{melt}} + \frac{Q_{\text{latent}}}{C}$$

#### 4.3.5.5. Pure Resistance Walls

Pure resistance walls are another special case. The network is shown below.



Define the following terms:

$$H_a = H_{sa} + \frac{1}{R_w}$$

$$H_b = H_{sb} + \frac{1}{R_w}$$

$$J = H_{sa} + H_{sb} + H_{sa} \cdot H_{sb} \cdot R_w$$

$$K = \frac{1}{H_{sa} \cdot H_{sb} + \frac{H_{sa} + H_{sb}}{R_w}}$$

The equations for solar heat flow to the air temperature nodes are

$$Q_a = \frac{H_{sa} \cdot R_w \cdot H_b}{J} \cdot Q_{sa} + \frac{H_{sa}}{J} \cdot Q_{sb}$$

$$Q_b = \frac{H_{sb} \cdot R_w \cdot H_a}{J} \cdot Q_{sb} + \frac{H_{sb}}{J} \cdot Q_{sa}$$

The equations for the surface temperatures are

$$T_{sa} = (H_{sa} \cdot H_b \cdot K) \cdot T_a + \left( \frac{H_{sb} \cdot K}{R_w} \right) \cdot T_b + (H_b \cdot K) \cdot Q_{sa} + \left( \frac{K}{R_w} \right) \cdot Q_{sb}$$

$$T_{sb} = \left( \frac{H_{sa} \cdot K}{R_w} \right) \cdot T_a + (H_{sb} \cdot H_a \cdot K) \cdot T_b + \left( \frac{K}{R_w} \right) \cdot Q_{sa} + (H_a \cdot K) \cdot Q_{sb}$$

### 4.3.6. Rockbin Calculations

The rockbin model used in this program is an adaptation of the infinite NTU model developed at the University of Wisconsin (Hughes et al. 1976, Klein et al. 1979]. It is, therefore, similar to the rockbin model in TRNSYS, Version 10. The rockbin is divided into five equal segments. It is assumed that the rock and air temperatures are identical in each segment (infinite NTU) and that there is no cross-sectional temperature gradient. The model allows for axial conductance and passive losses to an internal zone and the special zones AMBIENT and GROUND. Air flow in the rockbin is specified by the user as either unidirectional or bi-directional. If bi-directional flow is specified, the flow direction during the discharge cycle is opposite to that of the charge cycle. The fans that operate during the charge and discharge cycles can have different maximum flow rates and different minimum temperature differentials. The outlet node is used to determine the control logic for the rockbin. In any one mode of operation, the air flows in a closed loop between the rockbin and the zone to which it is connected.

From the user inputs the following parameters are determined:

#### NOMENCLATURE

$C$	= heat capacity of rocks in one segment
$C_a$	= specific heat of air at constant pressure
$dT(i)/dt$	= time derivative of temperature at node $i$
$H_a$	= passive conductance of one segment to the AMBIENT zone
$H_g$	= passive conductance of one segment to the GROUND zone
$H_z$	= passive conductance of one segment to the internal zone
$K$	= axial conductance of the rockbin from one node to the next
$T(i)$	= temperature at node $i$
$T'$	= new temperature at the node
$T$	= old temperature at the node
$T_{amb}$	= temperature of the AMBIENT node
$T_{grd}$	= temperature of the GROUND node
$T_{pz}$	= temperature of the internal zone for passive losses
$T_{zone}$	= temperature of the zone connected by air flow to rockbin
$\dot{V}$	= volumetric air flow rate through the rockbin
$\dot{V}_c$	= maximum volumetric flow rate for the charge fan
$\dot{V}_d$	= maximum volumetric flow rate for the discharge fan
$\Delta t$	= timestep length
$\rho_a$	= density of air at altitude of location

Passive losses from the rockbin are assumed to be evenly spread over each segment of the rockbin. Before operation of the rockbin, the fan/rockbin controller algorithm has already determined the direction of flow (if any) through the rockbin (in subroutines EQMTA or ROKON), the zone to which the rockbin is connected, and the actual volumetric flow rate as a fraction of the maximum flow rate.

The heat balance on each node is

rate of storage = rate of gain from convection + rate of gain from axial conductance + rate of gain from passive conductance

The capacitance flow rate,  $M$ , is calculated as

$$M = C_a \cdot \rho_a \cdot \dot{V}$$

Assuming air flow from node 1 toward node 5, the equation for  $T(1)$ , the inlet node temperature, is

$$C \frac{dT(1)}{dt} = M \cdot (T_{\text{zone}} - T(1)) + K \cdot (T(2) - T(1)) + H_z \cdot (T_{\text{pz}} - T(1)) + H_a \cdot (T_{\text{amb}} - T(1)) + H_g \cdot (T_{\text{grd}} - T(1))$$

For each interior node temperature,  $T_i$

$$C \frac{dT(i)}{dt} = M \cdot (T(i-1) - T(i)) + K \cdot (T(i-1) - T(i)) + K \cdot (T(i+1) - T(i)) + H_z \cdot (T_{\text{pz}} - T(i)) + H_a \cdot (T_{\text{amb}} - T(i)) + H_g \cdot (T_{\text{grd}} - T(i))$$

For the outlet node temperature,  $T(5)$

$$C \frac{dT(5)}{dt} = M \cdot (T(4) - T(5)) + K \cdot (T(4) - T(5)) + H_z \cdot (T_{\text{pz}} - T(5)) + H_a \cdot (T_{\text{amb}} - T(5)) + H_g \cdot (T_{\text{grd}} - T(5))$$

For air flow in the other direction, the node indices are reversed. These differential equations are solved by Euler integration (explicit finite differences) as

$$T' = T + \Delta t \cdot \frac{dT}{dt}$$

This results in the following equations for the new temperatures at each of the nodes. These equations are implemented in subroutine ROCKS.

## 1. Inlet node

$$T'(1) = \left(1 - \frac{\Delta t}{C} \cdot (M - K - H_z - H_a - H_g)\right) \cdot T(1) + \left(\frac{\Delta t \cdot M}{C} \cdot T_{\text{zone}}\right) + \left(\frac{\Delta t \cdot K}{C} \cdot T(2)\right) \\ + \left(\frac{\Delta t \cdot H_z}{C}\right) \cdot T_{\text{pz}} + \left(\frac{\Delta t \cdot H_a}{C} \cdot T_{\text{amb}}\right) + \left(\frac{\Delta t \cdot H_g}{C} \cdot T_{\text{grd}}\right)$$

## 2. Interior Nodes

$$T'(i) = \left(1 - \frac{\Delta t}{C} \cdot (M + 2K + H_z + H_a + H_g)\right) \cdot T(i) + \left(\frac{\Delta t \cdot M}{C} \cdot T(i-1)\right) \\ + \left(\frac{\Delta t \cdot K}{C} \cdot T(i-1)\right) + 2\left(\frac{\Delta t \cdot K}{C} \cdot T(i+1)\right) \\ + \left(\frac{\Delta t \cdot H_z}{C}\right) \cdot T_{\text{pz}} + \left(\frac{\Delta t \cdot H_a}{C} \cdot T_{\text{amb}}\right) + \left(\frac{\Delta t \cdot H_g}{C} \cdot T_{\text{grd}}\right)$$

## 3. Outlet Node

$$T'(5) = \left(1 - \frac{\Delta t}{C} \cdot (M - K - H_z - H_a - H_g)\right) \cdot T(5) + \left(\frac{\Delta t \cdot M}{C} \cdot T(4)\right) \\ + \left(\frac{\Delta t \cdot K}{C} \cdot T(4)\right) + \left(\frac{\Delta t \cdot H_z}{C}\right) \cdot T_{\text{pz}} + \left(\frac{\Delta t \cdot H_a}{C} \cdot T_{\text{amb}}\right) + \left(\frac{\Delta t \cdot H_g}{C} \cdot T_{\text{grd}}\right)$$

As in the wall equations, the term that multiplies the old node temperature on the right side of each equation must be non-negative. This is checked in subroutine COEF2. Typical rockbins will be stable with one-hour timesteps.

Once the node temperatures are updated, the heat stored in the rockbin is calculated as

$$Q_{\text{stored}} = C \cdot \sum_{i=1}^5 T(i)$$

## 4.4. Equipment Algorithms

### 4.4.1. HVAC Controller

This algorithm is implemented in subroutine HVACE. The algorithm does not model the operation of HVAC equipment; rather, it calculates only the heating, venting, and cooling loads that each zone experiences. Heating and cooling are taken as a direct energy gain or loss, respectively. Venting is modeled as a controlled air exchange with ambient air. The algorithm uses separate heating, venting, and cooling setpoints specified by the user and

optional maximum rates of HVAC equipment operation. At any timestep, each zone may be in any one of three states: no HVAC equipment operation, heating only, or some combination of venting and cooling.

The algorithm solves the basic equation

$$T = \frac{N + Q_H - Q_V - Q_C}{D}$$

for the unknown quantities

T	= resultant zone air temperature
QC	= cooling energy removed from the zone
QH	= heating energy delivered to the zone
QV	= venting energy removed from the zone

by using

C	= cooling setpoint, taken as $+\infty$ if none defined
$C_{cap}$	= cooler maximum capacity, taken as $+\infty$ if "adequate"
$Cp_{air}$	= air heat capacity;
D	= total heat flow conductance given for the zone (i.e., the denominator of the zone air temperature defining equation)
H	= heating setpoint, taken as $-\infty$ if none defined
$H_{cap}$	= heater maximum capacity, taken as $+\infty$ if "adequate"
N	= total energy flow to zone excluding HVAC equipment (i.e., the numerator of the zone air temperature defining equation)
$T_{amb}$	= ambient air temperature
V	= venting setpoint, taken as $+\infty$ if none defined
$V_{cap}$	= venter maximum capacity, taken as $+\infty$ if "adequate"
	= $V_{max} \cdot \rho_{air} \cdot Cp_{air} \cdot Vol$
$V_{max}$	= user input maximum venting air change rate
Vol	= zone air volume
W	= zone air temperature, if no HVAC equipment operates
	= $N / D$
$\rho_{air}$	= air density

The algorithm assumes that all specified setpoints obey the inequality

$$H \leq V \leq C$$

If  $W < H$ , then the zone is in the heating mode. In this case, the solution is given as

$$Q_H = \text{MIN}[H \cdot D - N, H_{\text{cap}}]$$

$$T = \frac{N + Q_H}{D}$$

$$Q_V = 0$$

$$Q_C = 0$$

When the zone is not in the heating mode, the algorithm checks for the operation of venting and/or cooling. This solution is more complex because it depends on the relationship of the four temperatures  $W$ ,  $T_{\text{amb}}$ ,  $V$ , and  $C$ . The full solution for each possible case is presented below (in all cases,  $Q_H = 0$ ).

1. No venting or cooling

If  $W < V < +\infty$  or  $W < C < V = +\infty$  or  $V < W < T_{\text{amb}} < C$

or  $V < W < C < T_{\text{amb}}$

then  $T = N / D$

$$Q_V = 0$$

$$Q_C = 0$$

2. Venting only

If  $T_{\text{amb}} < V < W < C$

then if  $N - D \cdot V < V_{\text{cap}} \cdot (V - T_{\text{amb}})$

then  $T = V$

$$Q_V = N - D \cdot V$$

$$Q_C = 0$$

else  $T = (N - V_{\text{cap}} \cdot T_{\text{amb}}) / (D + V_{\text{cap}})$

$$Q_V = V_{\text{cap}} \cdot (T - T_{\text{amb}})$$

$$Q_C = 0$$

3. Venting only

If  $V < T_{\text{amb}} < W < C$

then if  $V_{\text{cap}} = +\infty$

then  $T = T_{\text{amb}}$

$$Q_V = N - D \cdot T_{\text{amb}}$$

$$Q_C = 0$$

else  $T = (N + V_{\text{cap}} \cdot T_{\text{amb}}) / (D + V_{\text{cap}})$

$$Q_V = V_{\text{cap}} \cdot (T - T_{\text{amb}})$$

$$Q_C = 0$$

4. Cooling only

If  $V < C < W < T_{\text{amb}}$  or  $C < W < V = +\infty$

then  $Q_V = 0$

$$Q_C = \text{min} [N - D \cdot C, C_{\text{cap}}]$$

$$T = (N - Q_C) / D$$

## 5. Both venting and cooling

If  $T_{amb} < V < C < W$   
 then if  $N - D \cdot V < V_{cap} \cdot (V - T_{amb})$   
     then  $T = V$   
          $Q_V = N - D \cdot V$   
          $Q_C = 0$   
 else if  $(N + V_{cap} \cdot T_{amb}) / (D + V_{cap}) < C$   
     then  $T = (N + V_{cap} \cdot T_{amb}) / (D + V_{cap})$   
          $Q_V = V_{cap} \cdot (T - T_{amb})$   
          $Q_C = 0$   
 else  $Q_C = \min[N + V_{cap} \cdot T_{amb} - C \cdot (D + V_{cap}), C_{cap}]$   
      $T = (N + V_{cap} \cdot T_{amb} - Q_C) / (D + V_{cap})$   
      $Q_V = V_{cap} \cdot (T - T_{amb})$

## 6. Both venting and cooling.

If  $V < T_{amb} < C < W$   
 then if  $V_{cap} = +\infty$   
     then  $T = T_{amb}$   
          $Q_V = N - D \cdot T_{amb}$   
          $Q_C = 0$   
 else if  $(N + V_{cap} \cdot T_{amb}) / (D + V_{cap}) < C$   
     then  $T = (N + V_{cap} \cdot T_{amb}) / (D + V_{cap})$   
          $Q_V = V_{cap} \cdot (T - T_{amb})$   
          $Q_C = 0$   
 else  $Q_C = \min[N + V_{cap} \cdot T_{amb} - C \cdot (D + V_{cap}), C_{cap}]$   
      $T = (N + V_{cap} \cdot T_{amb} - Q_C) / (D + V_{cap})$   
      $Q_V = V_{cap} \cdot (T - T_{amb})$

## 7. Both venting and cooling

If  $V < C < T_{amb} < W$   
 then if  $N - D \cdot C < C_{cap}$   
     then  $T = C$   
          $Q_V = 0$   
          $Q_C = N - D \cdot C$   
 else if  $(N - C_{cap}) / D < T_{amb}$   
     then  $T = (N - C_{cap}) / D$   
          $Q_V = 0$   
          $Q_C = C_{cap}$   
 else if  $V_{cap} = +\infty$   
     then  $T = T_{amb}$   
          $Q_V = A - D \cdot T_{amb}$   
          $Q_C = 0$



$$\begin{aligned}\text{else } T &= (N + V_{\text{cap}} \cdot T_{\text{amb}} - C_{\text{cap}}) / (D + V_{\text{cap}}) \\ Q_V &= V_{\text{cap}} \cdot (T - T_{\text{amb}}) \\ Q_C &= C_{\text{cap}}\end{aligned}$$

#### **4.4.2. Fan / Rockbin Charge Controller**

The fan controller algorithm calculates the energy moved from a source zone to a sink zone by any fan and the energy delivered from a source zone to any rockbin when the rockbin is in its charging mode. Rockbin discharge control is handled separately and is discussed in a following section. The algorithm also produces source and sink-zone air temperatures (consistent with the derived fan operation) and HVAC energy flows by using the HVAC controller algorithm discussed above.

Fans (including rockbin charge fans) are modeled as thermostatically controlled conductances between the source-zone air temperature node and the sink-zone air temperature node (or rockbin charge outlet node). The fan controller is assumed to be able to cycle the fan on and off at an arbitrarily high rate or, equivalently, to select any fan speed up to the fan's specified capacity. The controller is also assumed to be interconnected with the HVAC thermostat to provide consistent equipment operation (e.g., to avoid having one device trying to heat a zone while another device is trying to cool it).

Four constraints are assumed to limit fan operation. Two of these constraints involve interaction with the HVAC thermostat setpoints. First, the "maximum energy available constraint" prevents any fan from operating whenever the fan source zone is in the heating mode. Second, the energy delivered by any fan is limited to avoid overheating the fan sink zone. This is referred to as the "maximum energy needed constraint" (undefined for rockbin charge fans). It prevents operation of the fan whenever the sink-zone temperature is above the lowest of its defined HVAC setpoints. The third, the "minimum temperature difference constraint," prevents fan operation whenever the difference between source zone and sink temperatures is less than a user-specified minimum. Finally, the "maximum energy delivery constraint" limits fan operation to its user-specified maximum capacity. Subject to these four constraints, the fan controller algorithm maximizes the energy removed from the source zone by fans.

Specifically, the fan controller algorithm solves the following system of equations

$$T_{\text{src}} = \frac{N_{\text{src}} + Q_{\text{HVAC,src}} - \sum_{i=1}^N Q_{\text{fan},i}}{D_{\text{src}}}$$

$$T_i = \frac{N_i + Q_{\text{HVAC},i} + Q_{\text{fan},i}}{D_i} \quad \text{for } I = 1, 2, \dots, n_{\text{fan}}$$

$$Q_{\text{fan},i} = K_i \cdot \text{UAF}_i \cdot (T_{\text{src}} - T_i) \quad \text{for } I = 1, 2, \dots, n$$

for the unknown quantities  $T_{\text{src}}$ ,  $Q_{\text{HVAC,src}}$ ,  $T_i$ ,  $Q_{\text{fan},i}$ ,  $Q_{\text{HVAC},i}$ , and  $K_i$ , the algorithm maximizes

$$\sum_{i=1}^N Q_{\text{fan},i}$$

subject to the condition that  $Q_{\text{fan},i} > 0$ , but only if all four of the following constraints are satisfied:

1. the maximum energy available constraint

$$T_{\text{src}} > H_{\text{src}}$$

2. the maximum energy needed constraint (undefined for rockbins)

$$T_i \leq S_i \quad \text{where } S_i = \min [ H_i, V_i, C_i ]$$

3. the minimum temperature difference constraint

$$T_{\text{src}} \geq T_i + \Delta T_{\text{fan},i}$$

4. the maximum energy delivery constraint

$$0 \leq K_i \leq 1$$

## NOMENCLATURE

$C_i$	= sink-zone cooling setpoint
$D_i$	= zone total conductance, excluding HVAC and fans (i.e., the denominator of the zone air temperature equation)
$H_{\text{cap}}$	= sink-zone heater capacity
$H_i$	= sink-zone heating setpoint
$H_{\text{src}}$	= source-zone heating setpoint
$K_i$	= duty cycle for fan $i$
$n$	= total number of fans, $n_{\text{fan}}$ , plus number of rockbins, $n_{\text{rock}}$ , connected to source
$N_i$	= zone total energy flow, excluding HVAC and fans (i.e., the numerator of the zone air temperature defining equation)
$Q_{\text{HVAC},i}$	= sink-zone HVAC energy
$Q_{\text{HVAC,src}}$	= source-zone HVAC energy
$Q_{\text{fan},i}$	= energy moved from source to sink by fan $i$
$T_{\text{src}}$	= source-zone air temperature

$T_i$	= fan sink temperature = sink-zone air temperature, for $i = 1, \dots, nfan$
or	= rockbin charge outlet node temperature, $i = 1, \dots, nrock$
$T_r$	= rockbin charge outlet node temperature
$\Delta T_{fan,i}$	= user-specified minimum temperature difference for fan $i$
$UA_{fan,i}$	= user-specified maximum capacity for fan $i$
$V_i$	= sink-zone venting setpoint

The following sections discuss the solution technique used by the fan controller algorithm and elaborate on details of its operation.

#### **4.4.2.1. Multi-Fan Controller Algorithm**

This section presents a general overview of the logic of the fan controller algorithm, with additional details contained in following sections. The algorithm separately considers each "fan network," comprised of a single source zone, all sink zones connected to the source by a fan, and the charge cycle of all rockbins connected to the source zone. It produces final air temperatures for each zone, HVAC equipment energy flows for each zone, energy flows for each fan, and the charge cycle of each rockbin. The logic is controlled by subroutine EQMTA, and makes use of subroutines EQMTB, EQMTC, EQMTD, EQMTE, and HVACE. Calculations discussed below are performed by subroutine EQMTA, unless otherwise noted.

First, we define the following quantities:

$T_{max}$	= source-zone air temperature if only HVAC equipment (no fans) operates = $(N_{src} + Q_{HVAC,src})/D_{src}$
$T_{min,i}$	= minimum source-zone air temperature required for fan $i$ to run, = sink-zone air temperature if only HVAC equipment (no fan) operates, plus the user-specified minimum temperature difference for the fan = $\Delta T_{fan} + (N_i + Q_{HVAC,i})/D_i$
or	= rockbin charge outlet node temperature, plus the user-specified minimum temperature difference = $T_r + \Delta T_{fan}$
$Q_{AVL}(T)$	= energy that must be removed from the source zone to produce an air temperature of $T$ . Note that $Q_{AVL}$ is a strictly decreasing function of $T$ . = $N_{src} - D_{src} \cdot T$
$Q_{fan,i}(T)$	= energy that would be delivered by fan $i$ , if it were the only fan and if the source zone were at the temperature $T$ . Note that as discussed below, $Q_{fan}$ is a non-decreasing, piecewise linear function of $T$ .

Assume that each  $T_{\min, i}$  is unique (the general case is discussed in a following section) and that they are ordered such that

$$T_{\min, i} < T_{\min, j} \text{ for } i = 1, \dots, n \text{ and } j = i+1$$

The calculation and sorting of  $T_{\min}$  are performed in subroutine EQMTB.

The controller algorithm operates by using  $T_{\min}$  as successively higher guesses for the final source-zone air temperature  $T_i$ . That is,  $T_i = T_{\min, i}$  for  $i = 1, \dots, n$ . Whenever  $T_{\min, i} > T_{\max}$  or  $i > n$ , then  $T_i$  is set to  $T_{\max}$  as the final temperature guess. Each increasing source-zone temperature guess involves an increasing number of fans, which will operate during the timestep. For each guessed temperature, the energy that would be delivered by the fans, if the source zone were at the given temperature, is compared to the energy that must be removed from the source zone to produce that temperature. The algorithm proceeds until one of the four conditions given below is reached (note that at least one of the conditions is met whenever  $T_i = T_{\max}$ .)

### CASE 1

$$Q_{AVL}(T_i) = \sum_{j=1}^{i-1} Q_{fan, j}(T_i)$$

That is, the energy removed by fans 1, ...,  $i-1$  at the source-zone temperature  $T_i$ , equals the energy needed to be removed to produce temperature  $T_i$ . In this case, the  $i^{\text{th}}$  fan is assumed not to operate.

### CASE 2

$$Q_{AVL}(T_i) = \sum_{j=1}^i Q_{fan, j}(T_i)$$

The energy removed by fans 1, ...,  $i$  at source-zone temperature  $T_i$  equals the energy needed to produce temperature  $T_i$ .

### CASE 3

$$Q_{AVL}(T_i) < \sum_{j=1}^{i-1} Q_{fan, j}(T_i)$$

The energy removed by fans 1, ...,  $i-1$  at source-zone temperature  $T_i$  is greater than the energy available in the source at temperature  $T_i$ .

**CASE 4**

$$\sum_{j=1}^{i-1} Q_{\text{fan},j}(T_i) < Q_{\text{AVL}}(T_i) < \sum_{j=1}^i Q_{\text{fan},j}(T_i)$$

Sufficient energy is available for fans 1, ..., i-1 to operate, but an additional constraint must be placed on fan i to obtain an energy balance.

In the first two cases, the source-zone temperature is taken as  $T_i$ , and the energy moved by each fan j-1, ..., i is taken as  $Q_{\text{fan},j}(T_i)$ . Once these values are established, the HVAC controller is used to calculate final air temperatures for each zone.

For Cases 3 and 4, additional calculations are required to establish the source-zone temperature and fan energy before calculating the sink-zone air temperatures by the HVAC controller. In Case 4, the source-zone temperature is taken as  $T_i$  and each fan j-1, ..., i-1 moves the energy given by  $Q_{\text{fan},j}(T_i)$ . The energy moved by fan i is calculated in subroutine EQMTD as

$$Q_{\text{fan},i}(T_i) = Q_{\text{AVL}}(T_i) - \sum_{j=1}^{i-1} Q_{\text{fan},j}(T_i)$$

For Case 3, the fans 1, ..., i-1 will operate and that the source temperature is bounded above by  $T_i$  and below by the previous temperature guess. We then solve the equation defining the source-zone air temperature in subroutine EQMTC

$$T_{\text{src}} = \frac{N_{\text{src}} - \sum_{j=1}^{i-1} Q_{\text{fan},j}(T_{\text{src}})}{D_{\text{src}}}$$

by using the linear nature of the fan energy delivery function  $Q_{\text{fan}}$  (see below). This results in

$$T_{\text{src}} = \frac{N_{\text{src}} - \sum_{j=1}^{i-1} (B_j + A_j \cdot T_{\text{src}})}{D_{\text{src}}}$$

Source-zone venting and cooling energies do not appear explicitly in these equations because, as discussed below, their effects are accounted for in the summation of fan energies. When solving the above equation for  $T_{\text{src}}$  the fan energy delivery function  $Q_{\text{fan}}$  is piecewise linear. Therefore, subroutine EQMTC must first find a temperature interval that contains the value  $T_{\text{src}}$  and

over which the coefficients  $B_j$  and  $A_j$  do not change. Once this interval is identified, and the appropriate  $B_j$  and  $A_j$  coefficients are selected, we have

$$T_{\text{src}} = \frac{N_{\text{src}} - \sum_{j=1}^{i-1} B_j}{D_{\text{src}} + \sum_{j=1}^{i-1} A_j}$$

Having established the source-zone temperature,  $T_{\text{src}}$ , the fan delivery energies are taken as  $Q_{\text{fan},i}(T_{\text{src}})$  for fans  $j = 1, \dots, i-1$ . Finally, as in the other cases, the HVAC controller is used to calculate zone HVAC energies and sink-zone temperatures.

#### 4.4.2.2. Interaction with Source-Zone HVAC Equipment

The maximum-energy-available constraint for the fan-controller algorithm prevents any fan from operating when the source zone is in the heating mode. However, source-zone venting and cooling can operate in conjunction with one or more fans. If either venting or cooling in the source zone are found to be of adequate capacity to maintain the relevant setpoint, then fans that have a higher minimum on-temperature,  $T_{\text{min}}$ , will not operate.

The controller algorithm, in subroutine EQMTB, adds “dummy” fans to the list of fans fed by the source zone to account for either venting or cooling equipment. Specifically, whenever venting equipment is defined with finite capacity and  $T_{\text{max}}$  is larger than the source-zone venting setpoint,  $V$ , then a dummy fan is created having  $T_{\text{min}}$  set to the maximum of  $V$  and the ambient air temperature,  $T_{\text{amb}}$ . Similarly, whenever cooling equipment is defined with finite capacity, and  $T_{\text{max}}$  is larger than the source-zone cooling setpoint,  $C$ , then a dummy fan is created having  $T_{\text{min}}$  set to  $C$ .

#### 4.4.2.3. Non-Unique Minimum Fan On Temperatures

In any timestep, one or more sets of fans might have the same minimum source-zone temperature for fan operation,  $T_{\text{min}}$ . When this occurs, the algorithm evaluates the performance of fans at that temperature level only once by lumping all fans having the same  $T_{\text{min}}$ . The primary complexity arises in the solution by the fan controller to Case 4 presented above. That is, when

$$\sum_{j=1}^{i-1} Q_{\text{fan},j}(T_i) < Q_{\text{AVL}}(T_i) < \sum_{j=1}^{i-1} Q_{\text{fan},j}(T_i) + \sum_{j=1}^k Q_{\text{fan},j}(T_i)$$

where

$$T_{\text{min } i} = T_{\text{min } j} \text{ for } j = i, \dots, k.$$

This event is also handled by subroutine EQMTD in the following manner. The source-zone air temperature is taken as  $T_i$  and the operation of fans  $i, \dots, k$

is limited to produce this temperature. The fans  $i, \dots, k$  are divided into two groups. The first group consists of all fans with fixed sink temperature. This includes all fan sink zones with adequate heating capacity, all rockbins, and the dummy-source-zone venting and cooling fans. The second group contains all other fans, those with inadequate heaters or no heater defined.

The fans in the second group are assumed not to operate, because any energy delivered to one of these sink zones will raise its air temperature. This, in turn, will raise its minimum fan on-temperature above  $T_i$ . For the fans in the first group, an average duty cycle is calculated as

$$f = \frac{Q}{\sum (UA_{\text{fan}} \cdot \Delta T_{\text{fan}})}$$

where:  $Q = Q_{\text{AVL}}(T_i) - \sum_{j=1}^{i-1} Q_{\text{fan},j}(T_i)$

Then the energy delivered by each fan in the first group at this average duty cycle,  $f \cdot UA_{\text{fan}} \cdot \Delta T_{\text{fan}}$ , is compared to the maximum energy needed,  $Q_{\text{max}}$ , for each fan sink zone. If for any fan  $j$ ,  $Q_{\text{max}} < f \cdot UA_{\text{fan}} \cdot \Delta T_{\text{fan}}$ , then  $Q_{\text{fan},i}$  is set to  $Q_{\text{max}}$  and the  $Q$  in the duty-cycle equation is decremented by  $Q_{\text{max}}$ . A new average-duty cycle is calculated for all remaining fans in the first group. This process is repeated until  $Q_{\text{max}} > f \cdot UA_{\text{fan}} \cdot \Delta T_{\text{fan}}$  for all remaining fans. Then the energy delivered by each of these fans is taken as  $f \cdot UA_{\text{fan}} \cdot \Delta T_{\text{fan}}$ .

#### 4.4.2.4. The Fan Energy Delivery Function

In the full multi-fan problem, the energy delivered by any fan is a complex function of conditions existing in the source zone and conditions in all of the sink zones. A direct algebraic definition of the energy delivered by any fan for the general case is most difficult. However, if we assume we know the source-zone temperature that will result from the operation of all fans, then the energy delivered by any fan can be expressed as a non-decreasing, piecewise linear function of source-zone temperature. Specifically, if  $T_{\text{src}}$  is the assumed source-zone temperature, and  $Q_{\text{fan},i}$  is the energy delivered by fan  $i$ , then:

$$Q_{\text{fan},i} = B_i + A_i \cdot T_{\text{src}}$$

The  $B_i$  and  $A_i$  values are chosen from three sets of coefficients corresponding to each of the three basic fan operation constraints: minimum temperature difference, maximum fan capacity, and maximum energy needed. For any given source-zone temperature,  $T_{\text{src}}$ , we want to choose the coefficients corresponding to the constraint that is the most restrictive. That is, we want to choose  $B_{ij}$  and  $A_{ij}$  such that

$$Q_{\text{fan},i} = \min[B_{ij} + A_{ij} \cdot T_{\text{src}} \text{ for } j = 1,2,3]$$

The form of each of the coefficients differs, depending on the type of fan sink involved. The values used for these coefficients are given in Table 4.4 for the different cases. The coefficients are calculated in subroutine EQMTB and are used by subroutine EQMTE to select the appropriate set and to evaluate the fan energy delivery for a given source-zone temperature.

The full derivation of these coefficients is not presented here, but involves relatively simple algebraic manipulation of the three following equations:

$$\begin{aligned} Q_{\text{fan}} &= UA_{\text{fan}} \cdot (T_{\text{src}} - T) \\ \Delta T_{\text{fan}} &= T_{\text{src}} - T \\ S &= \frac{N + Q_{\text{fan}}}{D} \end{aligned}$$

where

$$S = \text{appropriate HVAC setpoint} = \min[ H, V, C ]$$

The fan sink temperature,  $T$ , can be written in one of the following forms:

$$\begin{aligned} T &= H \\ T &= \frac{N + H_{\text{cap}} Q_{\text{fan}}}{D} \\ T &= \frac{N + Q_{\text{fan}}}{D} \\ T &= T_r \end{aligned}$$

For example, in the case of a fan sink zone that is heated, but for which the heater alone is inadequate to maintain the zone's heating setpoint in the current timestep, the derivation proceeds as follows:

Minimum temperature difference constraint

$$\begin{aligned} \Delta T_{\text{fan}} &= T_{\text{src}} - T \\ &= T_{\text{src}} - \frac{N + H_{\text{cap}} + Q_{\text{fan}}}{D} \end{aligned}$$

hence

$$D \cdot \Delta T_{\text{fan}} = D \cdot T_{\text{src}} - (N + H_{\text{cap}} + Q_{\text{fan}})$$

and

$$Q_{\text{fan}} = -(D \cdot \Delta T_{\text{fan}} + N + H_{\text{cap}}) + D \cdot T_{\text{src}}$$



Maximum energy delivery constraint

$$\begin{aligned} Q_{\text{fan}} &= UA_{\text{fan}} \cdot (T_{\text{src}} - T) \\ &= UA_{\text{fan}} \cdot \left( T_{\text{src}} - \frac{N + H_{\text{cap}} + Q_{\text{fan}}}{D} \right) \end{aligned}$$

When these constraints are rearranged

$$(D + UA_{\text{fan}}) \cdot Q_{\text{fan}} = UA_{\text{fan}} \cdot [D \cdot T_{\text{src}} - (N + H_{\text{cap}})]$$

and

$$Q_{\text{fan}} = -UA_{\text{fan}} \cdot \frac{N + H_{\text{cap}}}{D + UA_{\text{fan}}} + \frac{UA_{\text{fan}} \cdot D}{UA_{\text{fan}} + D} \cdot T_{\text{src}}$$

Maximum energy needed constraint

$$Q_{\text{fan}} = H \cdot D - N$$

The coefficients for the other types of fan sinks are derived similarly.

Table 4.4. Fan Energy Delivery Function Coefficients

Type of Fan Sink	Type of Constraint	Fan Energy Delivery Function Coefficients	
		B	A
zone heated with adequate heater	min delta T	$UA_f \cdot \Delta T_f$	0
	max fan capacity	$-UA_f \cdot H$	$UA_f$
	max needed	$H \cdot D - N$	0
zone heated with inadequate heater	min delta T	$-(D \cdot \Delta T_f + N + H_{cap})$	D
	max fan capacity	-	$(D \cdot UA_f) / (D + UA_f)$
	max needed	$UA_f \cdot (N + H_{cap}) / (D + U)$	0
zone unheated but vented or cooled	min delta T	$-(D \cdot \Delta T_f + N)$	D
	max fan capacity	$-(UA_f \cdot N) / (D + UA_f)$	$(D \cdot UA_f) / (D + UA_f)$
	max needed	$\min[V, C] \cdot D - N$	0
zone neither heated, vented nor cooled	min delta T	$-(D \cdot \Delta T_f + N)$	D
	max fan capacity	$-(UA_f \cdot N) / (D + UA_f)$	$(D \cdot UA_f) / (D + UA_f)$
	max needed	undefined	undefined
rockbin charge cycle	min delta T	$UA_f \cdot \Delta T_f$	0
	max fan capacity	$-UA_f \cdot T_r$	$UA_f$
	max needed	undefined	undefined
dummy source-zone venting fan	min delta T	$V_{cap} \cdot (\max[V, T_{amb}] - T_{amb})$	0
	max fan capacity	$T_{amb}$	$V_{cap}$
	max needed	$-V_{cap} \cdot T_{amb}$	undefined
dummy source-zone cooling fan	min delta T	$C_{cap}$	0
	max fan capacity	$-\infty$	$+\infty$
	max needed	$C_{cap}$	0

where

- C = sink-zone cooling setpoint  
 $C_{cap}$  = sink-zone cooler maximum capacity  
 D = sink-zone total conductance (denominator of zone temperature equation)  
 $\Delta T_f$  = user-specified fan minimum temperature difference  
 H = sink-zone heating setpoint  
 $H_{cap}$  = sink-zone heater maximum capacity  
 N = sink-zone total energy flow (numerator of zone temperature equation)  
 $T_{amb}$  = ambient air temperature  
 $T_r$  = rockbin charge outlet node temperature  
 $UA_f$  = fan maximum capacity  
 V = sink-zone venting setpoint  
 $V_{cap}$  = sink-zone venting capacity

### **4.4.3. Rockbin Discharge Controller**

In the rockbin discharge cycle, energy is removed from the rockbin and supplied to the rockbin sink zone. The controller for the discharge cycle is handled separately from that for the charge cycle by subroutine ROKON. This controller is designed to displace all or part of any heating load experienced by the rockbin sink zone. Therefore, whenever the heating equipment maximum capacity is inadequate to maintain the heating setpoint in the rockbin sink zone, then the amount of energy removed from the rockbin will be limited to the heater maximum capacity.

The rockbin is designed to have charge priority. Whenever the fan controller algorithm has placed a rockbin in the charging mode, that rockbin cannot discharge. If all three of the following conditions are met,

1. the rockbin is not in the charging mode,
2. the heating load for the rockbin sink zone,  $Q_H$ , is larger than zero,
3. the rockbin discharge outlet node temperature,  $T_d$ , is larger than the zone air temperature,  $T_z$ , plus the user-specified minimum temperature difference,  $\Delta T_{fan}$  (that is,  $T_d > T_z + \Delta T_{fan}$ ),

then the rockbin discharge rate,  $Q_{rock}$ , is calculated as

$$Q_{rock} = \min[Q_H, UA_{fan} \cdot (T_d - T_z)]$$

where

$UA_{fan}$  = the rockbin discharge fan maximum capacity.

In this case, the sink-zone air temperature remains unchanged, but the sink-zone heating load is reduced by the amount  $Q_{rock}$ .

## **4.5. Latent Load Algorithms**

### **4.5.1. Cooler Latent Load**

SUNREL provides only a cursory treatment of the effects of moisture within a building. It estimates the mechanical cooling equipment “latent load,” or the energy removed by condensation of water from the zone air being cooled, in subroutine WATER. Cooler operation is totally controlled by the sensible cooling load being calculated by the HVAC controller algorithm. The user-specified cooler maximum capacity also refers only to this sensible load. For the latent load calculations, the algorithm assumes that the supply air from the cooling unit is held at a constant, user-specified temperature. It is assumed that the cooler is of adequate capacity to cool air to this temperature and is

capable of handling arbitrarily large air flow rates. In any hour, the total cooler latent load,  $Q_{\text{lat}}$ , is taken as

$$Q_{\text{lat}} = H_{\text{evap}} \cdot F_c \cdot (W_z - W_c)$$

where

- $H_{\text{evap}}$  = heat of vaporization of water = 1061 (Btu/lb) = 2451 (kJ/kg)
- $F_c$  = air flow rate through cooler
- $W_z$  = humidity ratio of zone air
- $W_c$  = humidity ratio of cooler return air

The cooler air flow rate,  $F_c$ , is calculated as

$$F_c = \frac{Q_C}{\rho_{\text{air}} \cdot C_{p_{\text{air}}} \cdot (T_z - T_c)}$$

where

- $Q_C$  = total sensible cooling, as determined by the HVAC controller
- $\rho_{\text{air}}$  = air density
- $C_{p_{\text{air}}}$  = air heat capacity
- $T_z$  = zone air temperature
- $T_c$  = user-specified cooler return air temperature

Note that the latent load is only calculated when the cooler is operating, otherwise  $F_c = 0$  (when  $T_z < T_c$  and  $Q_C > 0$ , then  $F_c$  is taken as 0).

The total latent load is split into component loads attributed to infiltration, venting, fan operation, and internal moisture release. These are calculated as

$$\begin{aligned} Q_{\text{lat},i} &= H_{\text{evap}} \cdot F_i \cdot (W_a - W_z) \\ Q_{\text{lat},v} &= H_{\text{evap}} \cdot F_v \cdot (W_a - W_z) \\ Q_{\text{lat},f} &= H_{\text{evap}} \cdot F_f \cdot (W_f - W_z) \\ Q_{\text{lat},o} &= Q_{\text{lat}} - Q_{\text{lat},i} - Q_{\text{lat},v} - Q_{\text{lat},f} \end{aligned}$$

where

- $Q_{\text{lat},i}$  = latent load attributed to infiltration and natural ventilation
- $Q_{\text{lat},v}$  = latent load attributed to venting
- $Q_{\text{lat},f}$  = latent load attributed to fan operation
- $Q_{\text{lat},o}$  = latent load attributed to internal moisture release, and all other effects
- $F_i$  = infiltration air flow rate
- $F_v$  = venting air flow rate

$F_f$	= fan air flow rate
$W_a$	= ambient humidity ratio
$W_z$	= zone humidity ratio
$W_f$	= humidity ratio of other zone(s) connected by a fan. For fan source zones, this is a weighted average of the humidity ratios in all sink zones for which fans are operating.

Subroutine WATER also performs an approximate accounting of water flows between zones due to fan operation, water flow to ambient due to infiltration and venting, and internal moisture release as specified by the user. It calculates a new zone humidity ratio hourly, as a function of the previous hour's humidity ratio, and net water flows during the hour.

$$W_z = \frac{\text{Vol} \cdot \rho_{\text{air}} \cdot W_z + F_i \cdot W_a + F_v \cdot W_a + F_f \cdot W_f + F_c \cdot W_c + \frac{\text{LG}}{H_{\text{evap}}}}{\text{Vol} \cdot \rho_{\text{air}} + F_i + F_v + F_f + F_c}$$

where

$\text{Vol}$	= zone air volume
$\text{LG}$	= user-specified latent gain.

The zone humidity ratio calculated above is constrained to that corresponding to 100% relative humidity, by using function HUMID to calculate the humidity ratio of saturated air at the zone's air temperature. If this occurs, some water is lost from the system. Given the zone's humidity ratio,  $W_z$ , and the humidity ratio of saturated air at the same temperature,  $W_s$ , the zone's relative humidity,  $H_{\text{rel}}$ , is calculated as

$$H_{\text{rel}} = \frac{W_z \cdot (W_s + 0.622)}{W_s \cdot (W_z + 0.622)}$$

The humidity ratio of cooler return air,  $W_c$ , is taken as the minimum of that of saturated air at the cooler return temperature and the zone's humidity ratio. The humidity ratio of ambient air,  $W_a$ , is calculated using function HUMID and ambient dewpoint temperature read from the weather data. In this case, HUMID is called from subroutine ENVIR.

#### **4.5.2. Humidity Ratio of Saturated Air**

Function HUMID calculates the humidity ratio of saturated air at a specified temperature and air pressure (ASHRAE 1976). For any location, air pressure,  $P$ , is taken as a constant value given by

$$P = A \cdot e^{B \cdot \text{ELEV}}$$

where

- ELEV = station elevation
- A = standard air pressure = 29.921 in. Hg = 760 mm Hg
- B = value from curve fit
  - =  $-3.71781196 \cdot 10^5/\text{ft}$
  - =  $-1.219755 \cdot 10^4/\text{m}$

The humidity ratio, W, is then calculated by the following, where T is the air temperature in Kelvin.

$$\begin{aligned} \text{If } T \geq 273.16 \quad \text{then } Z &= 373.16/T \\ P_1 &= -7.90298 \cdot (Z - 1.0) \\ P_2 &= 5.02808 \cdot \text{ALOG10}(Z) \\ Z_1 &= 11.344 \cdot (1.0 - (1.0/Z)) \\ P_3 &= -1.3816\text{E-}7 \cdot (10.0^{Z_1} - 1.0) \\ Z_2 &= -3.49149 \cdot (Z - 1.0) \\ P_4 &= 8.1328\text{E-}3 \cdot (10.0^{Z_2} - 1.0) \end{aligned}$$

$$\begin{aligned} \text{else } Z &= 273.16/T \\ P_1 &= -9.09718 \cdot (Z - 1.0) \\ P_2 &= -3.56654 \cdot \text{ALOG10}(Z) \\ P_3 &= 0.876793 \cdot (1.0 - (1.0/Z)) \\ P_4 &= \text{ALOG10}(0.0060273) \end{aligned}$$

$$\text{Let } P_{VS} = 29.921 \cdot (10.0^{**} (P_1 + P_2 + P_3 + P_4))$$

$$\text{Then } W = (0.622 \cdot P_{VS}) / (P - P_{VS}) \text{ for } P \text{ in English units of in Hg}$$

or

$$W = (0.622 \cdot P_{VS}) / (P/25.4 - P_{VS}) \text{ for } P \text{ in metric units of mm Hg}$$

where ALOG10 indicates base 10 logarithm.



## 5. References

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## Appendix A: SUNREL Output

This appendix covers the details of the output pages and explains the meaning of the variables. The output from SUNREL is flexible and should provide most information required by most users. Information from SUNREL may be output at hourly, daily, or monthly increments over any time period during the run. There are two types of output in SUNREL: one with headers for each column and one with no headers for ease of use with data analysis programs.

Output files with headers are the most common because they are easier to read and understand. For reference, output files begin with an echo of the building description from the input file.

The output files without headers are meant to be used as only one output page at a time (see below for a description of each output page). If more than one output page is printed to a file, then the lines from each output page will be mixed together, thus making it difficult to read. The headerless output is obtained by entering "N" for FRMT in the OUTPUT section of the input file. This output will then be written to a file with the extension ".dt1"; each headerless output will have its own file with its own extension up to ".dt9." For example, to print the hourly air temperatures (page 7 of the zone output pages) for the second zone for the day of July 7 (a season for this day would be defined under SEASONS), the following input would be used:

```
&OUTPUT
outtype = 'zones'
period = 'h'
outunits = 'm'
outseason = 'JUL7'
iocomp = 2
iopage = 7
frmt = 'n'
/
```

If the input building description file is named "MYBUILD.BLG," then the headerless output file produced would be named "MYBUILD.DT1." Each line of data begins with numbers corresponding to the output type (AMBIENT, BUILDING, ZONES, WINDOWS, SURFACES, WALLS, FANS, ROCKBINS, or TROMBES), the building component number, the output page number, and the date and hour. The example below is for ZONES output for the second user-defined zone and the seventh zone output page for the tenth hour of July 7 (see the description of the zone output for information on the data listed). Note that all of the information would be on one line, but is too long for the format presented here.

```
3 2 7 JUL 7 10 .000000E+00 .000000E+00 .000000E+00 .000000E+00 .000000E+00 .000000E+00
.270541E+02 .267729E+02 .272929E+02 .000000E+00
```



**Ambient Summary, page 1 of 2**

----- SOLAR RADIATION ----- - AMBIENT TEMPERATURE -

DIRECT NORMAL KBTU/SF MJ/SM	UNSHADED HORIZ. KBTU/SF MJ/SM	DIRECT HORIZ. KBTU/SF MJ/SM	DIFFUSE HORIZ. KBTU/SF MJ/SM	TOTAL HORIZ. KBTU/SF MJ/SM	MEAN F C	MIN F C	MAX F C	RANGE F C
--------------------------------------	--	--------------------------------------	---------------------------------------	-------------------------------------	----------------	---------------	---------------	-----------------

Direct Normal Incident direct normal solar radiation  
 Unshaded Horiz Incident total horizontal before skyline shading  
 Direct Horiz Incident direct horizontal radiation after skyline shading  
 Diffuse Horiz Incident diffuse horizontal radiation after skyline shading  
 Total Horiz Incident total horizontal radiation after skyline shading  
 Ambient Temperature  
     Mean Average hourly ambient temperature  
     Min Minimum hourly ambient temperature  
     Max Maximum hourly ambient temperature  
     Range Average difference between daily maximum and minimum ambient temperatures

**Ambient Summary, page 2 of 2**

--- WIND SPEED ---			-- HUMIDITY --		MEAN	-- DEGREE DAYS --	
MEAN	MIN	MAX	DEWPOINT	RATIO	GROUND	HEATING	COOLING
MPH	MPH	MPH	F	NONE	F	FD	FD
M/S	M/S	M/S	C	NONE	C	CD	CD

Wind Speed  
     Mean Average hourly wind speed  
     Min Minimum hourly wind speed  
     Max Maximum hourly wind speed  
 Dewpoint Average hourly dewpoint temperature  
 Humidity Ratio Average hourly humidity ratio  
 Mean Ground Temperature  
     Average hourly ground temperature  
 Heating Degree Days  
     Heating degree days for the base temperature specified for HddbBase in the PARAMETERS input section  
 Cooling Degree Days  
     Same as Heating Degree Days for cooling

**Building Summary, page 1 of 6 & Zone Summary, page 1 of 7**

----- SOLAR RADIATION -----					
TRANS- MITTED MBTU GJ	INTER- ZONE MBTU GJ	INWARD ABSORBED MBTU GJ	WINDOW LOSS MBTU GJ	CAVITY LOSS MBTU GJ	TOTAL GAIN MBTU GJ
Transmitted	Short-wave solar radiation transmitted through the windows				
Interzone	Net transfer of short-wave solar radiation with other zones through transparent walls				
Inward Absorbed	Inward-flowing portion of the short-wave solar radiation absorbed in the glazing layers before the shading coefficient				
Window Loss	Reduction in solar heat gain due to user-specified shading factors on windows				
Cavity Loss	Short-wave solar radiation reflected back through the windows specified by the SOLLOST (the cavity albedo)				
Total Gain	Total solar heat gain entering the zone; this is the algebraic sum of the above variables				

**Building Summary, page 2 of 6 & Zone Summary, page 2 of 7**

----- HEAT FLOWS -----				
WINDOWS MBTU GJ	AMBIENT MBTU GJ	GROUND MBTU GJ	INTERZONE MBTU GJ	INTERNAL GAINS MBTU GJ
Windows	Heat flow through the windows neglecting short-wave radiation			
Ambient	Sum of all heat flows through walls and user-specified loss coefficients to the ambient			
Ground	Sum of all heat flows through walls and loss coefficients to the ground node			
Interzone	Net heat flow to other zones through walls and loss coefficients			
Internal Gains	Sensible heat gains due to internal heat loads			

Note: All heat flows are positive inward. For accounting purposes, the zone boundary is taken at the internal surfaces of walls and windows.

**Building Summary, page 3 of 6 & Zone Summary, page 3 of 7**

HEAT FLOWS			AIR CHANGES			NAT.
INFILTRATION	NATURAL	VENTILATION	INFILTRATION	NATURAL	VENTILATION	VENT
INTERZONE	AMBIENT		INTZN.	AMB.		ON
MBTU	MBTU	MBTU	ACH	ACH	ACH	HRS
GJ	GJ	GJ	ACH	ACH	ACH	HRS

Heat Flows

Infiltration Interzone

Net heat flow due to infiltration from other zones; this can be negative if there is net exfiltration. This number is meaningless in the whole building summary.

Infiltration Ambient

Heat flow due to infiltration from the ambient

Natural Ventilation

Heat flow due to natural ventilation

Air Changes

Infiltration Intzn

Air changes per hour with other zones

Infiltration Amb

Air changes per hour with the ambient

Natural Ventilation

Air changes per hour due to natural ventilation

Nat Vent On

Number of hours that natural ventilation occurs or is on

**Building Summary, page 4 of 6 & Zone Summary, page 4 of 7**

HEAT FLOWS					
ROCKBIN	ROCKBIN	FANS	TROMBE	INTERNAL	HEAT
ACTIVE	PASSIVE		WALLS	STORAGE	BALANCE
MBTU	MBTU	MBTU	MBTU	MBTU	MBTU
GJ	GJ	GJ	GJ	GJ	GJ

Rockbin Active Net controlled (through fans) heat flows to the zone from rockbins

Rockbin Passive Heat flow to the zone due to passive losses from the rockbins

Fans Net heat flow to the zone by fans (not fans to rockbins)

Trombe Wall Sum of heat flow by thermocirculation through Trombe wall vents and transfer from the zone side of the Trombe wall

Internal Storage Net heat-flow from storage elements entirely within zone boundaries

Heat Balance Heat balance on the zone over the reporting period. This is equal to the sum of the Heat Flows on the previous three pages, plus the solar gain, plus the HVAC heating cooling and venting.

**Building Summary, page 5 of 6 & Zone Summary, page 5 of 7**

(This page is only printed if latent loads are calculated.)

INTERNAL	INFIL	NAT. VENT	LATENT FANS	HEAT VENT	TOTAL	ACLOAD	RH	HR
MBTU GJ	MBTU GJ	MBTU GJ	MBTU GJ	MBTU GJ	MBTU GJ	MBTU GJ	NONE NONE	NONE NONE

Internal Internal latent loads specified by the user under GAINLAT in the ZONES input section

Infil Latent loads due to infiltration

Nat. Vent Latent loads due to natural ventilation

Fans Latent loads due to moisture transfer by fans from other zones

Vent Latent loads due to mechanical venting

Total Total latent load

AC Load Sum of sensible and latent cooling loads

RH Mean hourly relative humidity in the zone

HR Mean hourly humidity ratio in the zone

**Building Summary, page 6 of 6 & Zone Summary, page 6 of 7**

EQUIP ENERGY			MAXIMUM LOAD			SETPT FR.	
HEAT	VENT	COOL	HEAT	VENT	COOL	HEAT	COOL
MBTU GJ	MBTU GJ	MBTU GJ	KBTU/H KW	KBTU/H KW	KBTU/H KW	NONE NONE	NONE NONE

Equip Energy  
Heat/Vent/Cool Total sensible heat supplied or removed from conditioned spaces by heating, venting, and cooling equipment

Maximum Loads  
Heat/Vent/Cool Maximum hourly rate of sensible heat addition or extraction required from the equipment

Setpt Fr.  
Heat/Cool Fraction of hours the air temperature is at the heating or cooling setpoints

**Zone Summary, page 7 of 7**

--- FULL LOAD HOURS ---			MEAN DUTY CYCLE			--- AIR TEMPERATURE ---			
HEAT	VENT	COOL	HEAT	VENT	COOL	MEAN	MIN	MAX	RANGE
H	H	H	NONE	NONE	NONE	F	F	F	F
H	H	H	NONE	NONE	NONE	C	C	C	C

**Full Load Hours**

Heat/Vent/Cool

Total hours of operation of equipment at full capacity. May be used to determine operating energy for equipment. Undefined if equipment capacity is not specified.

**Mean Duty Cycle**

Heat/Vent/Cool

Average ratio for period of summary of the actual rate of energy delivery to the maximum capacity rate of delivery in each time increment in which the equipment operates. Undefined if equipment capacity is not entered.

**Air Temperature**

Mean/Max/Min

Mean, minimum, and maximum hourly zone air temperatures over the reporting period

Range

Average temperature difference between daily maximums and minimums



**Window Summary, page 1 of 4 & Trombe wall Summary, page 1 of 6**

--- UNSHADED INCIDENT ---			FRAC. SUNLIT			---- SHADED INCIDENT ----		
DIRECT	DIFFUSE	TOTAL	DIR.	DIF.	TOT.	DIRECT	DIFFUSE	TOTAL
MBTU	MBTU	MBTU	NONE	NONE	NONE	MBTU	MBTU	MBTU
GJ	GJ	GJ	NONE	NONE	NONE	GJ	GJ	GJ

**Unshaded Incident**

- Direct Incident direct solar radiation on the window, which would occur in the absence of shading effects. Shading here refers only to overhangs and sidefins; skyline shading has already been taken into account.
- Diffuse Same as above for diffuse solar radiation
- Total Same as above for the Total solar radiation

**Fraction Sunlit**

- Direct Fraction of direct radiation incident on the window after shading by overhangs and sidefins
- Diffuse Same as above for diffuse solar radiation
- Total Same as above for the Total solar radiation

**Shaded Incident**

- Direct Actual direct solar radiation incident on the window
- Diffuse Actual diffuse solar radiation incident on the window
- Total Actual total solar radiation incident on the window

**Window Summary, page 2 of 4 & Trombe wall Summary, page 2 of 6**

----- TRANSMITTED -----			TRANSMISSIVITY			POTENTIAL	ACTUAL
DIRECT	DIFFUSE	TOTAL	DIR.	DIF.	TOT.	HEAT GAIN	HEAT GAIN
MBTU	MBTU	MBTU	NONE	NONE	NONE	MBTU	MBTU
GJ	GJ	GJ	NONE	NONE	NONE	GJ	GJ

**Transmitted**

- Direct Direct short-wave solar radiation transmitted through the glazings
- Diffuse Same as above for diffuse solar radiation
- Total Same as above for the Total solar radiation

**Transmissivity**

- Direct Fraction of actual direct beam incident short-wave solar radiation transmitted through the glazings
- Diffuse Same as above for diffuse solar radiation
- Total Same as above for the Total solar radiation

**Potential Heat Gain**

Transmitted short-wave solar radiation, plus inward-flowing portion of the short-wave radiation absorbed in the glazings before multiplying by the shading factor

**Actual Heat Gain**

Solar heat gain adjusted by the user specified shading factor

**Window Summary, page 3 of 4 & Trombe wall Summary, page 3 of 6**

HEAT LOSS TO AMBIENT	-- MEAN	INNER GLASS MIN	TEMPERATURE MAX	-- RANGE	LOSS U-VALUE	ADJUSTED U-VALUE
MBTU GJ	F C	F C	F C	F C	BTU/SF-H-F W/SM-C	BTU/SF-H-F W/SM-C

Heat Loss To Ambient

Heat loss to the ambient excluding all short-wave radiation effects

Inner Glass Temperature

Mean/Max/Min

Mean, maximum, and minimum hourly temperatures of the inner glazing layer

Range

Hourly difference between the maximum and minimum temperatures

Loss U-value

Effective U-value ignoring short-wave radiation effects. Calculated as the heat loss to the ambient, divided by the mean zone to ambient temperature difference.

Adjusted U-value

Effective U-value adjusted for solar absorbed in the glazings. Calculated as the heat loss to the ambient, minus inward-flowing absorbed radiation, divided by the mean zone to ambient temperature difference.

**Window Summary, page 4 of 4 & Trombe wall Summary, page 4 of 6**

(This page is only printed if thermochromic switchable glazings are used.)

FRACTION AREA:			----- SWITCHABLE GLAZING TEMPERATURES -----					
CLEAR	OPAQUE	INTER	UNSHADED REGION			SHADED REGION		
			MEAN	MIN	MAX	MEAN	MIN	MAX
NONE	NONE	NONE	F	F	F	F	F	F
NONE	NONE	NONE	C	C	C	C	C	C

**Fraction Area**

**Clear/Opaque/Inter**

Fraction of the switchable glazing area that is clear, opaque, and intermediate (between phase-changes) when reported hourly. Otherwise, it is easier to think of this as the fraction of the reporting period that the switchable glazing is in one of these three states.

**Switchable Glazing Temperatures**

**Unshaded Region**

**Mean/Max/Min**

Hourly mean, maximum, and minimum temperatures of the unshaded portion of the switchable glazing layer

**Shaded Region**

**Mean/Max/Min**

Hourly mean, maximum, and minimum temperatures of the shaded portion of the switchable glazing layer

**Surface Summary, page 1 of 1**

--- UNSHADED INCIDENT ----			FRAC. SUNLIT ----			SHADED INCIDENT ----		
DIRECT	DIFFUSE	TOTAL	DIR.	DIF.	TOT.	DIRECT	DIFFUSE	TOTAL
KBTU/SF	KBTU/SF	KBTU/SF	NONE	NONE	NONE	KBTU/SF	KBTU/SF	KBTU/SF
MJ/SM	MJ/SM	MJ/SM	NONE	NONE	NONE	MJ/SM	MJ/SM	MJ/SM

**Unshaded Incident**

**Direct/Diffuse/Total**

Incident solar radiation on the window that would occur in the absence of shading effects. Shading here refers only to overhangs and sidefins; skyline shading has already been taken into account.

**Fraction Sunlit**

**Direct/Diffuse/Total**

Fraction of direct, diffuse, and total radiation incident on the window after shading by overhangs and sidefins

**Shaded Incident**

**Direct/Diffuse/Total**

Actual incident solar radiation

**Wall Summary, page 1 of 1 & Trombe wall Summary, page 5 of 6**

- SURFACE TEMPERATURE -				SOLAR ABSORBED		--- HEAT FLOW ---		SOL-
FRT/INT	BCK/EXT	FRT/INT	BCK/EXT	FRT/INT	BCK/EXT	FRT/INT	BCK/EXT	AIR
MEAN	RANGE	MEAN	RANGE					TEMP
F	F	F	F	MBTU	MBTU	MBTU	MBTU	F
C	C	C	C	GJ	GJ	GJ	GJ	C

**Surface Temperatures**

- Mean/Range** Mean hourly temperatures and mean daily difference between the maximum and minimum hourly temperatures for the front and back sides of the wall
- Solar Absorbed** Total solar radiation absorbed at the front/interior and back/exterior sides of the wall
- Heat Flow** Net heat flow at each side of the wall taken as positive inwards
- Sol-Air Temp** The mean sol-air temperature. That is, the ambient temperature that would give the same heat exchange with the surface in the absence of all radiation effects and convective heat transfer. Output only for exterior walls.

**Fan Summary, page 1 of 1**

HEAT FLOW	FULL LOAD HOURS	DUTY CYCLE	TEMPERATURE	
			INLET	OUTLET
MBTU	H	NONE	F	F
GJ	H	NONE	C	C

Heat Flow Total sensible heat flow through the fan  
 Full Load Hours Number of hours of fan operation; can be used to estimate fan operating energy  
 Duty Cycle Fraction of time the fan operates averaged over all time increments in which the fan operates  
 Temperature Inlet and Outlet temperatures averaged over all time increments in which the fan operates

**Rockbin Summary, page 1 of 2**

HEAT FLOW		PASSIVE LOSSES			NET	ENERGY
CHARGE	DISCHARGE	AMBIENT	ZONES	GROUND	STORED	BALANCE
MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU
GJ	GJ	GJ	GJ	GJ	GJ	GJ

Heat Flow Heat flow into and out of the rockbin during Charge and Discharge cycles  
 Passive Losses Passive heat losses to the Ambient, Zones, and Ground  
 Net Stored Net heat stored in the rockbin during the reporting time period.  
 Energy Balance Energy balance on the rockbin, calculated as charge energy minus discharge energy minus passive losses minus net stored

**Rockbin Summary, page 2 of 2**

TEMPERATURE						FULL LOAD HRS	DUTY CYCLE		
CHARGE		DISCHARGE		AVG.	CHARGE	DIS-	CHRG	DISCH	
OUTLET	ZONE	DIFF	OUTLET	ZONE	DIFF	CHARGE			
F	F	F	F	F	F	H	H	NONE	NONE
C	C	C	C	C	C	H	H	NONE	NONE

Temperatures  
 Charge Inlet Mean hourly temperature of the node at the charge end of the rockbin  
 Charge Outlet Mean hourly temperature of the node at the discharge end of the rockbin  
 Charge Zone \* Mean hourly temperature of the charge zone air  
 Charge Diff. \* Mean temperature difference between charge zone air and inlet node of the rockbin  
 Discharge Zone\* Mean hourly temperature of the discharge zone air

Discharge Diff. \* Mean temperature difference between discharge zone air and outlet node of the rockbin

Avg Node Average temperature of the rockbin

Full Load Hrs Total full load hours of operation of the charge and discharge fans. Can be used to calculate fan operating energy

Duty Cycle Mean duty cycle of the charge and discharge fans. Calculated as the ratio of actual operating time to length of time increment for each time increment in which the fan operates

\* Only calculated during time increments in which the rockbin operates

**Trombe wall Summary, page 6 of 6**

- AIR GAP TEMPERATURE -	THERMO-	TOTAL	FLOW	HOURS	TOTAL			
MEAN	MIN	MAX	RANGE	SIPHON	GAIN	RATE	OF FLOW	FLOW
F	F	F	F	MBTU	MBTU	CFM	H	MCF
C	C	C	C	GJ	GJ	CMH	H	MCM

**Air Gap Temperature**  
Mean/Max/Min

Hourly mean, maximum, and minimum air temperature in the gap between the outer face of the Trombe wall and the inner glazing layer

Range Daily difference between the maximum and minimum temperatures

Thermosiphon Heat flow through thermocirculation of the Trombe wall vents

Total Gain Sum of thermocirculation transfer and transfer from zone side of the Trombe wall

Flow Rate Average hourly air-flow rate through vents for the hours in which flow occurs

Hours of Flow Number of hours in which thermocirculation occurs.

Total Flow Total volume of air moved by thermocirculation



## Appendix B: Weather File Formats

SUNREL has the ability to read four different weather file formats: TMY (Typical Meteorological Year), TMY2 (updated version of TMY), BLAST (Building Loads Analysis and System Thermodynamics), and a generic format named SUNREL. All of these file types use an ASCII text format. The type of file used is determined by entering one of these names for WEATYPE in the STATIONS section in the input file. SUNREL requires the following weather data inputs: global-horizontal radiation, direct-beam radiation, dry-bulb temperature, dew-point temperature, wind speed, and wind direction (optional, but recommended). If the wind direction is omitted, SUNREL sets the wind direction to 0.0 degrees (North) for all hours of the simulation. In that case, all other data in the TMY, TMY2, and BLAST weather files are ignored.

Variable	Fields			Units
	SUNREL	TMY	TMY2	
Global-horizontal radiation	7-10	55-58	18-21	TMY - kJ/m <sup>2</sup> TMY2 - Wh/m <sup>2</sup>
beam radiation	11-14	25-28	24-27	TMY - kJ/m <sup>2</sup> TMY2 - Wh/m <sup>2</sup>
dry-bulb temperature	15-19	104-107	68-71	C·10 <sup>(a)</sup>
dew-point temperature	20-24	108-111	74-77	C·10
wind speed	25-28	115-118	96-98	(m/s)·10
wind direction (optional, see above)	29-31	112-114	91-93	degrees <sup>(b)</sup>
month (optional, not used)	1-2	8-9	4-5	
day (not used)	3-4	10-11	6-7	
hour (optional, not used)	5-6	16-19	8-9	

<sup>a</sup> 700 to 0600 = -70.0 to +60.0

<sup>b</sup> Wind direction is as follows: 0 = north, 90 = east, 180 = south, 270 = west

The BLAST file format lists the hourly values for each day for each variable on one line (and continues to the next line if necessary). There is one header



line with location information and the data for each day is contained in sets of 24 lines (not one for each hour, it just turned out that way). The information contained on each line of the daily data sets is explained below. The dew-point temperature and total-horizontal radiation are calculated by SUNREL from the information in the BLAST file.

Line 1 contains the year, month, day of month, and rain and snow flags.

Format (I4, 2I2, 1x, 48I1)

Lines 2-4 contain the dry bulb temperatures ( $^{\circ}\text{C}$ ).

Format (2(8F10.6, /), 8F10.6)

Lines 5-7 contain the wet bulb temperatures ( $^{\circ}\text{C}$ ).

Format (2(8F10.6, /), 8F10.6)

Lines 8-11 contain the barometric pressures ( $\text{N/m}^2$ )

Format (3(6F12.5, /), 6F12.5)

Lines 12-13 contain the humidity ratios.

Format (12F6.4, /12F6.4)

Lines 14-16 contain the wind speeds (m/sec).

Format (2(8F10.5, /), 8F10.5)

Lines 17-18 contain the wind directions.

Format (12F6.2, /, 12F6.2)

Lines 19-21 contain the beam radiation ( $\text{W/m}^2$ ).

Format (2(8F10.5, /), 8F10.5)

Lines 22-24 contain the horizontal diffuse radiation ( $\text{W/m}^2$ ).

Format (2(8F10.5, /), 8F10.5)

**Appendix C: Using Window-4.1 with SUNREL**

Window-4.1 is a computer program developed by Lawrence Berkeley Laboratories. It analyzes windows of any construction created from a library of glazing materials, frame types, gas-fill types, and divider styles (Arasteh et al. 1994). This program and its documentation are available free of charge from Lawrence Berkeley Laboratories. Below is an example of the data file as produced by Window-4.1. The information read by SUNREL is highlighted, the remaining lines may be deleted or comments may be added if desired.

The data file is the "Detailed" report from the "Glz Sys Lib" window. To generate this file, follow these steps in Window-4.1:

- Generate the window from the glazing and frame library.
- Go to the "Glz Sys Lib" window by pressing F5.
- Go to the "Optical" window by pressing F9.
- Turn on the "Angle Calcs" by pressing "A" then answer yes.
- Return to the "Glz Sys Lib" window by pressing F5.
- Press Alt-P to print a report, then "D" for the detailed report.
- Enter the name of file, this is the file name entered for GLZFILE under the GLAZING.TYPES input section.

**WINDOW 4.1 Glazing System** Thermal and Optical Properties 11/01/95 15:54:52

ID : 5  
 Name : Dbl,low-e, Ar  
 Tilt : 90.0  
 Glazings : 2  
 KEFF : 0.0150  
 Width : 0.717  
 Uvalue : 0.27  
 SCc : 0.69  
 SHGCc : 0.60  
 Vtc : 0.77  
 RHG : 142.26

ID	Name	D(in)	Tsol	1 Rsol	2	Tvis	1 Rvis	2	Tir	1 Emis	2	Keff
<b>Outside</b>												
400	LoE CLEAR	0.118	.630	.190	.220	.850	.079	.056	.000	.840	.100	.520
2	Argon	0.500										.015
1	CLEAR	0.098	.850	.075	.075	.901	.081	.081	.000	.840	.840	.520
<b>Inside</b>												

Environmental Conditions: 1 NFRC/ASHRAE

Tout	Tin	WndSpd	Wnd Dir	Solar	Tsky	Esky
(F)	(F)	(mph)		(Btu/h-ft2)	(F)	
-----	-----	-----	-----	-----	-----	-----

Uvalue	0.0	70.0	15.00	Windward	0.0	0.0	1.00
Solar	89.0	75.0	7.50	Windward	248.2	89.0	1.00

Optical Properties for Glazing System '5 Dbl,low-e, Ar'

Angle		0	10	20	30	40	50	60	70	80	90	Hemis
Vtc	:	0.769	0.774	0.763	0.749	0.730	0.692	0.605	0.440	0.205	0.000	0.642
Rf	:	0.138	0.131	0.128	0.131	0.143	0.168	0.217	0.323	0.549	0.999	0.197
Rb	:	0.127	0.120	0.119	0.124	0.138	0.168	0.233	0.379	0.650	1.000	0.208
Tsol	:	0.544	0.548	0.539	0.529	0.514	0.486	0.426	0.312	0.145	0.000	0.453
Rf	:	0.220	0.214	0.212	0.214	0.224	0.244	0.282	0.371	0.574	0.999	0.268
Rb	:	0.236	0.231	0.230	0.232	0.241	0.261	0.307	0.414	0.629	1.000	0.291
Abs 1	:	0.187	0.190	0.200	0.207	0.210	0.218	0.242	0.273	0.248	0.001	0.221
Abs 2	:	0.048	0.049	0.049	0.050	0.051	0.052	0.050	0.045	0.033	0.000	0.048
Abs 3	:											
Abs 4	:											
Abs 5	:											
Abs 6	:											
SHGCc	:	0.596	0.600	0.592	0.583	0.569	0.543	0.483	0.366	0.188	0.000	0.507
SCc:	0.69	Color Properties		DomWL	Purity							
Tdw:	N/A	Transmittance		um	%							
Tuv:	N/A	Reflectance		um	%							

Temperature Distribution (degrees F) for '5 Dbl,low-e, Ar'

Env. Conditions:	1 NFRC/ASHRAE	U-value	Condensation RH	Solar
	Outside Air	0.0		89.0
	Outer Surface	3.7	N/A	99.6
Layer 1	Center	3.9		100.0
	Inner Surface	4.1		100.0
	Outer Surface	55.8		87.0
Layer 2	Center	56.0		87.0
	Inner Surface	56.1	61.4%	86.8
	Inside Air	70.0		75.0

**SWITCHABLE GLAZINGS**

Another feature of SUNREL is the ability to model thermochromic switchable glazings. Thermochromic switchable glazings are glazings that have temperature-dependent optical properties. Typically, this type glazing material has a high transmittance at low temperatures and goes through a transition phase to a lower transmittance over a small temperature range. Window-4.1 may be used to create data files, such as the one above, for up to ten temperature/optical property sets over the range of operating temperatures. Usually two sets of data are adequate. To complete the necessary calculations, Window-4.1 requires the transmittance and reflectance at normal incidence as a function of wave length. These files are combined to one file, starting with the lowest temperature and preceding to the highest temperature. Only the

information highlighted in the above file is read by the program; therefore, the other lines of data may be removed. The top of the file should read "SWITCHABLE GLAZING SYSTEM" instead of "WINDOW 4.1 GLAZING SYSTEM." On the next line, list the number of Window-4.1 data files included followed by a comma and the layer in the glazing system that contains the switchable glazing material counting from the outside. On the next line, list the temperatures (in °C) at which the optical properties were measured, separated by commas. For example, the first three lines of a switchable glazing data file should appear as

```
SWITCHABLE GLAZING SYSTEM
2, 3
29.0, 31.0
```

The temperature of the switchable glazing layer is calculated each hour in the subroutine TPROP. The optical and thermal properties of the window are then checked for a change. If a change has occurred, the new properties are determined by linear interpolation. The temperature of the switchable glazing layer is then recalculated, and the process is repeated until the temperature converges to within the percentage declared in the PARAMETERS input section as GLZCONV. The algorithm does take into account partial shading, so one portion of the window might be at a different temperature and different properties than the other portion.



## Appendix D: Sample Building Description Input File

Below is a sample building description input file for SUNREL using the FORTRAN namelist format. A description of each variable and more information on the structure is given in Chapter 3. However, there are some additional items to discuss here.

1. Note that the data in most of the input sections is aligned in columns; this is not necessary and is only done to improve readability. The input items need only be separated by spaces or commas.
2. Remember that each of the variables is an array and that the program reads the inputs into successive elements in the arrays. It starts with the element specified or with the first element, if none is specified. This is evident in the WALLS and SURFACES sections, which include more items than will fit on a normal size sheet of paper. The lines are continued on a new line, starting with the next element in the array; if the next element number is not specified, the program will start over with the first element and write over the information already in place there.
3. Each input section (26 in all) must appear in the input file, even if no input is used. Comments may be placed between the input sections.
4. Each section begins with "&SECTION NAME" and ends with "/"

```

&RUNS
label = 'Sample Building file'
station = 'Denver.CO'
grefl = 0.3
gtemp = 50.
rstrtmn = 'jan'
rstrtdy = 1
rstopmn = 'dec'
rstopdy = 31
runits = 'e'
/

&ZONES
zonename = 'living' 'attic' 'sunroom'
zarea = 1500.0 1500.0 300.0
zhgt = 8.0 2.5 8.0
zonez = 0.0 8.0 0.0
zach = 0.0 2.0 0.0
zleak = 25.0 0.0 10.0
sol2air = 0.05 0.0 0.0
sollost = 0.02 0.0 0.05
/

&INTERZONES
izsrczone = 'sunroom'
izsinkzone = 'living'
izsoltrn = 0.03
/

```

```

&WINDOWS
winzone = 'sunroom' 'living' 'living' 'living' 'living'
glaztype = 'triplelowe' 'triplelowe' 'triplelowe' 'triplelowe' 'triplelowe'
wextsurf = 'southsun' 'south' 'west' 'north' 'east'
winhgt = 4.0 4.0 4.0 4.0 4.0
winlong = 20.0 10.0 6.0 6.0 6.0
winx = 5.0 35.0 10.0 20.0 10.0
winy = 3.5 1.0 3.0 3.0 3.0
/

```

There are too many walls to fit across this page so they are continued on a new line. Be careful not to overwrite the data in the lower array elements. This was only done to improve readability, the computer does not care about line length. Therefore, all of these could have been placed on one long line. Walls 14-18 do not contain all of the variables listed for the walls 1-7. It was decided to use the default values for these walls and save space in the input file by not duplicating their input.

```

&WALLS
walltype = 'stud' 'cavity' 'ext.wall' 'ext.wall' 'inside' 'stud' 'cavity'
wfrntzone = 'sunroom' 'sunroom' 'sunroom' 'sunroom' 'living' 'living' 'living'
wallkind = 'wall' 'wall' 'wall' 'wall' 'wall' 'wall' 'wall'
wfsolabs = 0.0 0.02 0.02 0.02 0.02 0.0 0.01
wbackzone = 'southsun' 'southsun' 'eastsun' 'westsun' 'sunroom' 'south' 'south'
wbsolabs = 0.2 0.2 0.2 0.2 0.03 0.2 0.2
wallhgt = 8.0 8.0 8.0 8.0 8.0 8.0 8.0
wallong = 30.0 30.0 10.0 10.0 20.0 20.0 20.0
wallpercent = 15.0 85.0 100.0 100.0 100.0 15.0 85.0

```

```

walltype(8) = 'ext.wall' 'ext.wall' 'ext.wall' 'sunfloor' 'inside' 'floor'
wfrntzone(8) = 'living' 'living' 'living' 'sunroom' 'living' 'living'
wallkind(8) = 'wall' 'wall' 'wall' 'floor' 'ceiling' 'floor'
wfsolabs(8) = 0.025 0.05 0.025 0.58 0.24 0.56
wbackzone(8) = 'east' 'north' 'west' 'ground' 'attic' 'ground'
wbsolabs(8) = 0.15 0.2 0.15 0.0 -1 0.0
wallhgt(8) = 8.0 30.0 8.0 10.0 30.0 30.0
wallong(8) = 30.0 50.0 30.0 20.0 50.0 50.0

```

```

walltype(14) = 'roof' 'roof' 'ext.wall' 'roof' 'ext.wall'
wfrntzone(14) = 'sunroom' 'attic' 'attic' 'attic' 'attic'
wbackzone(14) = 'ambient' 'roofs' 'atticw' 'roofn' 'attice'
wbsolabs(14) = 0.3 0.3 0.2 0.3 0.2
wallhgt(14) = 10.0 15.811 2.5 15.811 2.5
wallong(14) = 20.0 50.0 30.0 50.0 30.0
/

```

```

&TROMBEWALLS
twinzone = 'sunroom'
twextsurf = 'southsun'
twtype = 'T-wall 1'
twinsolabs = 0.0
twhgt = 3.5
twlong = 20.0
twx = 5.0
twy = 0.0
/

```

```

&FANS
/

```

APPENDIX D: SAMPLE BUILDING DESCRIPTION INPUT FILE

---

```

&ROCKBINS
/

&SURFACES
namesurf = 'southsun' 'eastsun' 'westsun' 'south' 'east' 'north' 'west'
surfazim = 180      90      270      180      90      0      270
surftilt = 90      90      90      90      90      90      90
surfz = 0      0      0      0      0      0      0

namesurf(8) = 'roofs' 'atticw' 'roofn' 'attice'
surfazim(8) = 180      270      0      90
surftilt(8) = 18.435  90      18.435  90
surfz(8) = 0      0      0

/

&HVACTYPES
hvaczone = 'living'
hsetscd = 'setback'
/

&NATURALVENT
ventsurf = 'east'      'west'      'eastsun'      'westsun'
nventscd = 'ventilate' 'ventilate' 'ventilate' 'ventilate'
vmindt = 2.      2.      2.      2.
venty = 3.      3.      3.      3.
venthgt = 3.      3.      3.      3.
ventarea = 4.      4.      2.      2.
/

&TROMBETYPES
nametrmtime = 'T-wall 1'
twwalltype = 'therm mass'
twglztype = 'doublowe'
twabs = 0.9
/

```

The building layers for the first wall type, "stud," is listed under LAYERS1, starting from the inside and going out. The layers for "cavity" are listed under LAYERS2, and so on.

```

&WALLTYPES
namewalltype = 'stud' 'cavity' 'ext.wall' 'roof' 'sunfloor' 'floor'
              'inside' 'therm mass'
wallayer(1,1) = 'drywall' 'wood'      'siding'
wallayer(1,2) = 'drywall' 'insul'     'siding'
wallayer(1,3) = 'drywall' 'r-19'     'siding'
wallayer(1,4) = 'r-30'
wallayer(1,5) = 'concrete' 'dirt'
wallayer(1,6) = 'carpet' 'concrete' 'dirt'
wallayer(1,7) = 'concrete'
wallayer(1,8) = 'concrete'
/

&MASSTYPES
namemasstype = 'wood' 'insul' 'drywall' 'siding' 'concrete' 'dirt' 'carpet'
masscond = 0.0667 0.0225 0.093 0.051 1.16 0.867 0.03
massdens = 32.0 3.0 50. 100. 150. 100 10.0
masscp = 0.33 0.33 0.260 0.279 0.24 0.25 0.34
massthick = 0.5 0.5 0.0417 0.0417 0.5 4.0 0.313
massnodes = 1 1 1 1 3 8 1
/

```



```
&PCMTYPES
/
```

All of the glazing data are contained in the two Window-4.1 files  
"triplowe.win" and "doublowe.win."

```
&GLAZINGTYPES
nameglztype = 'triplelowe' 'doublowe'
glzfile = 'triplowe.win' 'doublowe.win'
/
```

```
&ROCKBINTYPES
/
```

```
&FANTYPES
/
```

```
&OVERHANGTYPES
ohsurface = 'south' 'southsun'
ohx = 0. 0.
ohy = 8. 8.
ohproj = 2.5 2.5
ohlong = 20. 30.
/
```

```
&SIDEFIN TYPES
/
```

```
&SKYLINETYPES
/
```

```
&OUTPUT
outtype = 'all' 'zones' 'windows'
period = 'm' 'h' 'h'
outunits = 'e' 'e' 'e'
outseason = 'year' 'sep3' 'sep3'
iocomp = -1 -1 2
/
```

Each of the schedules are listed twice with different seasons, this allows them  
to have different sets of values for different times of the year.

```
&SCHEDULES
nameschedule = 'setback' 'setback' 'ventilate' 'ventilate'
schdseason = 'winter' 'summer' 'winter' 'summer'
schdl(1,1) = 7*65 15*72 2*65
schdl(1,2) = 24*65.
schdl(1,3) = 24*80.
schdl(1,4) = 24*75.
/
```

```
&SEASONS
nameseason = 'year' 'winter' 'summer' 'sep3'
seastrtmn = 'jan' 'oct' 'may' 'sep'
seastrtdy = 1 1 1 3
seastopmn = 'dec' 'apr' 'sep' 'sep'
seastopyd = 31 30 30 3
/
```

## APPENDIX D: SAMPLE BUILDING DESCRIPTION INPUT FILE

---

```
&PARAMETERS
/

&STATIONS
namestation = 'Denver.CO'
sitelat =      40
sitelong =    105
elev =        5280
weatherfile = 'denver.tmy'
weatype =     'tmy'
wstrtmn =     'jan'
wstrtdy =     1
wstopmn =     'dec'
wstopdy =     31
terrain =     3
shield =      3
/
```

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