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REPORT

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A General Zone Model for HVACSIM^{+}
User's Manual

by

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Abstract

Described herein is a general thermal model of a building zone or room implemented as a module for the HVACSIM$^+$ simulation program. This model differs from other zone models for modular simulators in the level of detail with which thermal processes can be represented. For example, the zone can be represented by an arbitrary number of nodes, among which there can be heat transfer by conduction, convection, and radiation. In particular, the lighting system can be modelled in detail, including the nonlinear power and light output of fluorescent lamps versus lamp wall temperature. Both short and long wavelength diffuse radiation is modelled. If desired, a plenum formed by a suspended ceiling can be included, and air flow can be routed through the zone and plenum in a manner specified by the user. If the need is for a simple zone model, most of these details can be omitted.

From the perspective of the HVACSIM$^+$ user, the model is like other TYPE subroutines, with inputs and outputs that allow it to be connected with other modules, and parameters that allow it to be specialised to particular zone characteristics. These HVACSIM$^+$ interface sets are of reasonable size due to placing the details of the zone definition in a separate file.

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Section 1

Introduction

1.1 Background

Studies of the dynamic operation and control of thermal conditions in building spaces are often carried out with simulation models. Modular simulators such as TRNSYS [Kea88] and HVACSIM$^+$ [Cla85] allow convenient construction of such models by interconnection of software modules that represent the various components of the physical system, e.g., fans, heating and cooling coils, and control elements. This report describes a thermal model of a building space, called a zone, to be used in models of this kind. It is implemented as a TYPE subroutine for the HVACSIM$^+$ program.

There are, of course, other zone models for modular simulators, including several for the HVACSIM$^+$ program. However, many of the previously available models drastically simplify the zone, perhaps representing it as two or three lumped thermal masses and accounting for only the most obvious thermal processes taking place in the space. Such models leave much to be desired. For example, the thermal masses usually represent only the most massive elements such as the floor, and even then may lump the entire floor mass together. Such a model may capture the long period dynamics, i.e., daily cycles, but cannot possibly predict response of the zone to short period disturbances such as fluctuations in solar load caused by rapid cloud movements and the warmup of lamps and housing of the luminaires when lights are switched on. If used for control system design and tuning, such a model may be misleading. The principal aim of the model described here has therefore been to eliminate these deficiencies by representing the space in greater detail, and accounting for all energy transfer mechanisms within the space. Special attention has been given to the artificial lighting system, including nonlinear phenomena in the operation of fluorescent lamps.

1.2 Thermal Processes in Building Spaces

There are complex thermal processes taking place in building spaces that must be understood in order to construct a proper model. These processes can be described in the context of a typical room in a modern, air-conditioned commercial building, Figure 1.1. This room is assumed to be on a mid-floor of a multistory building, so that there are similar rooms above and below. There is a suspended ceiling, forming a plenum space above the room, and recessed fluorescent luminaires. Air-conditioning is provided by a supply air stream to the room which is extracted through slots around the luminaires into the plenum. The air is in turn extracted from the plenum for exhaust to the outside, or conditioning and recirculation. Note that Figure 1.1 is schematic only. Actual supply ducts normally pass through the plenum on their way to ceiling-mounted diffusers which introduce air to the zone.

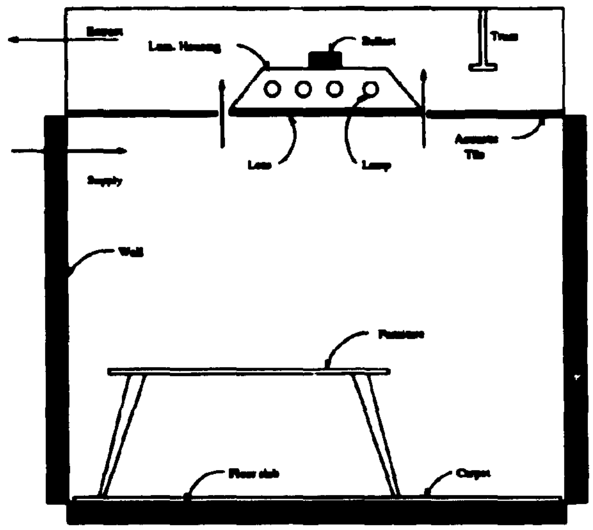

Figure 1.1: Schematic of typical room

There are several sources of heat into such a room, and all of this heat must be eventually removed in order to prevent excessive room temperatures. Among the more important sources are:

- Luminaires and their ballasts
- Equipment such as computers and typewriters
- Occupant metabolism
- Solar radiation through windows
- Transmission through walls and partitions

These are referred to has *heat gain* to the space. Heat is removed from the space by the air stream which is cold upon entry, but leaves at the temperature of the space.

At first thought it would seem that an instantaneous heat balance on the room would require that the heat removed by the air stream should equal the sum of the instantaneous heat gains. However, this analysis does not take into account the radiation and heat storage processes taking place in the space. A portion of each of the above heat gains enters the space as long wave (i.e., thermal) radiation. Because the air absorbs very little of this radiation, nearly all of it falls upon solid surfaces and after a series of interreflections is absorbed by these surfaces. It is only after the surface temperatures rise above space air temperature that this heat can enter the air, becoming then *cooling load*. It is the instantaneous cooling load that must be balanced by heat removed by the air stream. Due to the thermal mass of the solid elements of the space, the surface temperatures change takes place over a period of time, so that the cooling load lags the heat gain. Thus we see that radiant heat transfer, often neglected in simplified models, strongly affects the dynamics of the space.

The importance of radiation suggests that it be considered in more detail. The artificial lighting system (often introducing a significant portion of the room heat gain), the suspended ceiling, and plenum contribute to the complexity of the problem. When the power to the lamps is switched on, a large portion of the input power is emitted from the surface of the lamp as short wavelength (i.e., visible) radiation. This radiation undergoes interreflection within the luminaire, with a portion being absorbed by luminaire surfaces (and the lamp itself), and a portion transmitted through the lens into the occupied space. The portion that does not escape the luminaire by this mechanism causes heating of the lamp, lens, and luminaire housing, which through convection heats the air in the luminaire cavity, the plenum space, and the occupied space. The heated surfaces also emit radiation in the thermal wavelengths (infrared), which also is interreflected and eventually absorbed in the luminaire, plenum, and room. As the walls, floor, and ceilings of the plenum and room absorb radiation (in both wave bands), their temperatures rise, resulting in convective transfer to the adjacent air, and conduction into the solid materials.

A further complication arises in the common case of fluorescent lighting. With fluorescent tubes, both input power and light output are nonlinear functions of minimum lamp wall temperature. A typical lamp characteristic is shown in Figure 1.2. Because the lamp wall temperature is strongly affected by other temperatures in the room, plenum and luminaire, which in turn are determined in part by the lamp input power, there is a cyclic, nonlinear problem of significant complexity.

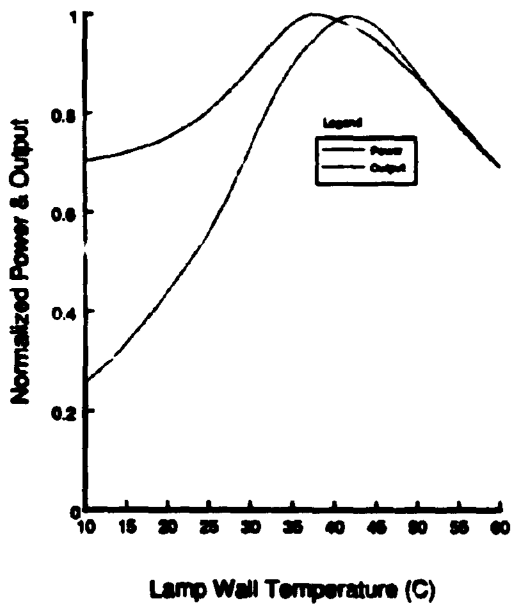

Figure 1.2: Fluorescent Lamp Power and Light Output

1.3 The General Zone Model

The zone model discussed here is based on a general thermal network of the zone as described by Sowell [Sow89, Sow72]. Each surface or volume in the physical zone is represented by a node in this network, as suggested in Figure 1.3. Nodes can be either internal to the zone or at the boundary, and either massive or massless. Conduction, convection, and short and long wave radiative heat transfer can occur between any pair of nodes. An energy balance at each node provides a basis for calculation of unspecified temperatures. A node specified to represent lamps in the artificial lighting system can have a nonlinear characteristic as suggested in Figure 1.2.

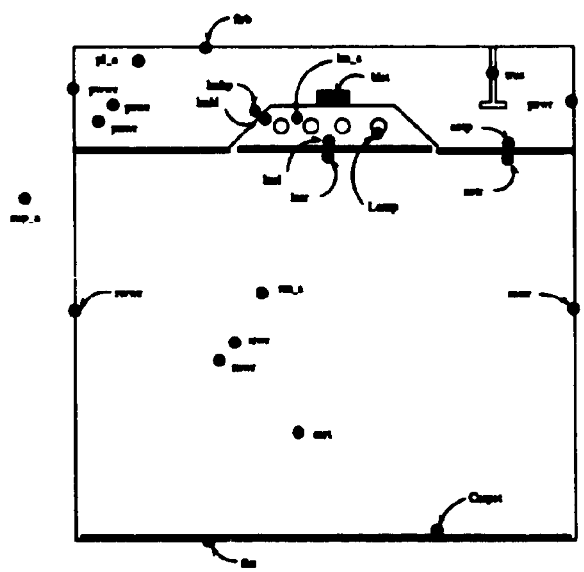

Figure 1.3: Zone with node assignments.

With a model such as this, the room can be represented with as much or as little detail as required by the objectives of the simulation. For example, if only low frequency phenomena are of interest, light weight elements such as lamps and ceilings can be defined as massless. Also, heat transfer paths judged to be of little importance can be omitted. On the other hand, complex phenomena that may have a significant effect can be properly represented.

The relative ease of addition and removal of detail makes it possible to create an appropriate model with a series of "numerical experiments." The zone is first modelled with a great deal of detail to give a baseline "correct" result. Details are then removed one by one, comparing results with the baseline. Those details found to have insignificant effect can be omitted from the final model.

Detailed models of zones do not fit naturally into the modular simulation scheme. For one thing, the amount of descriptive data implied by an highly detailed zone model can create lengthly parameter lists, in contrast to simple components like fans or heating coils. To get get around this problem, the General zone model reads the detailed zone description from a separate file. The HVACSIM$^+$ user therefore sees only a short parameter list including things that are subject to frequent change during a study, such as number of occupants and installed equipment and lighting power. If necessary, a person more familiar with building thermal modeling can be called upon to develop the zone description file.

Another difficulty encountered when embedding a detailed zone model in a modular simulation is providing flexible coupling to other portions of the building and the environment, without an overly complex interface. For example, a perimeter zone needs to be coupled to the outside environment through a wall. If this wall is made part of the zone, environmental variables such as solar irradiation and ambient temperature must be in the interface. If the zone is to allow an arbitrary number of exterior walls, the interface becomes large and complex. Similarly, if the simulation is to have more than one zone and interzone heat transfer is to be considered, there is the problem of partitions and floors between adjacent building levels. If these elements are viewed as belonging to the zone, then temperatures and and heat fluxes at their surfaces must be somehow identified with those of the adjacent space which presumably includes the same element. The approach to modeling these situations becomes much more clear if it is recognised that these shared elements *are not properties of the zone*; they should be represented as separate modules so that they appear only once in the simulation. However, radiation among the surfaces *must be handled within the zone mode*. Otherwise, the interface becomes very complex because each surface can have incident radiant flux from all other surfaces, and its leaving radiant flux might impinge on any other surface.

The General model therefore ascribes to the zone model only those properties and behaviour which clearly belong to the zone only, and likewise for the boundary elements. In this spirit, the zone is an enclosure with behaviour that includes radiant exchange among its bounding surfaces. It also encompasses all elements that do not interact with other portions of the building, such as the lighting system, internal loads such as equipment and occupants, and the ceiling. On the other hand, the conduction in the material of the *bounding elements* is behaviour that cannot belong to any one zone, and therefore must belong to a separate element. Therefore the *material* of the bounding elements is placed in separate modules (i.e., HVACSIM$^+$ TYPEs), while the *surfaces* of these same elements are part of the zone. This is depicted in Figure 1.4 where an imaginary surface is shown conformal to all boundary surfaces. With this division, the only interfaces are temperature and *net* heat rate, i.e., heat unbalance, at each boundary node and at each material element, as shown in Figure 1.5. The temperature of each boundary node is input to the zone module, and the zone calculates the corresponding heat unbalance. The material module receives heat fluxes at each side and calculates corresponding temperatures. This approach is quite flexible, allowing bounding elements to be partitions, outside walls, or floors, either massive or massless and modelled in any desired way. Note that the heat flux at the outside surface of boundary elements can be made adiabatic as demonstrated in the floor of the left zone of Figure 1.5, or symmetric as shown for the right zone. Alternately, a mid-floor zone in a multi-story building can be simulated by connecting the heat flux at the bottom surface of the floor to that of the plenum upper boundary within the zone.

It should also be noted that the zone description is entirely up to the user. For example, Figure 1.3 shows a case where a suspended ceiling forms a plenum above the room, with all of this included in the zone model. If desired, the zone could be described without a plenum. Also, the number of boundary nodes is decided by the user. As shown in Figure 1.5, there is a single wall designated as a boundary node so it can interface with adjacent zones through a partition (as shown), or could be connected to an outside wall. It also has the floor as a boundary node. In this case, *all other surfaces of the enclosure are treated as internal, adiabatic surfaces*. In a more realistic simulation, the zone definition would be changed to allow transfer through additional walls.

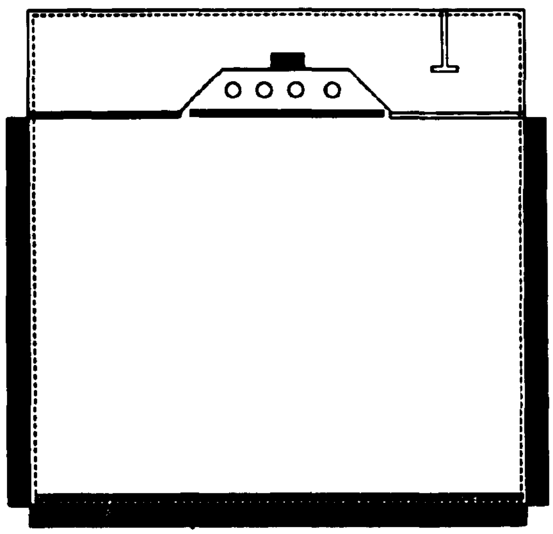

Figure 1.4: Zone boundary

1.4 Limitations

Naturally, the General zone model has restrictions and limitations. Some of these can be easily removed, while others are more fundamental. Discussed below are known limitations; others will no doubt be discovered during use.

Although easily removed, there is currently a limitation in variability among different zone instances in a particular simulation. This is because there is a single zone definition file, where structural things like number of nodes, as well as geometry and surface properties, are specified. A solution would be to have a different HVACSIM$^+$ TYPE for each structurally different instance.

Currently, the underlying nodal network deals with energy only. More generality would be possible if the mass flows and humidity relationships were modelled with separate networks. However, the present *ad hoc* way of dealing with these quantities appears to be adequate for most common situations.

Since the parent program (LIGHTS) calculates lighting, most of the code is in place to provide illumination data at all zone surfaces. However, a little more work is needed to bring this information to the HVACSIM$^+$ interface.

Solar, equipment, and occupant heat gain are input as single values and distributed as *absorbed heat* to zone nodes according to profiles fixed in the zone definition file. Idealy, the solar absorption at each surface should be calculated from *incident direct radiation* and geometric data.

The LIGHTS program upon which the General model is based has an "Equilibrium start" feature, whereby all nodes are temporarily treated as massless with time-zero boundary conditions. This gives initial temperatures for all massive nodes that represent equilibrium. Without such a feature, its almost impossible to specify a set of initial temperatures that is realistic, leading to strange start-up transients. With additional effort, this feature could be provided in

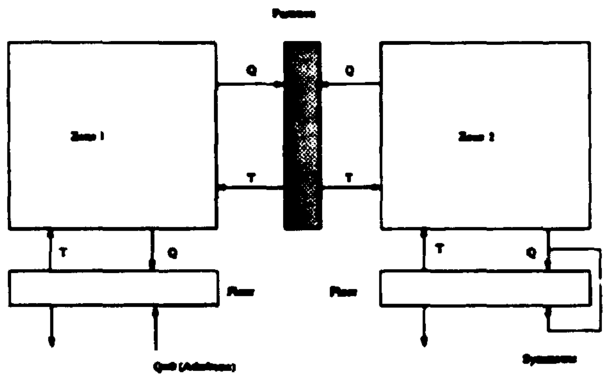

Figure 1.5: Zone interfaces

the HVACSIM$^+$ context.

The input in the zone description file is in terms of model coefficients, rather than physical descriptions of construction elements. This places the burden of calculating these coefficients on the user. Although the work to do so should not be underestimated, one could develop a menu-based interface to help create the zone definition file. One difficulty would be automating view factor computation without limiting flexibility in zone description or compromising accuracy.

The model is based on rigorous models and numerical methods. For example, exact diffuse radiative transfer calculations are performed, using 4th power relationships, and Newton-Raphson iteration is used to force convergence at all massless nodes. A good deal of attention has been given to computational efficiency. For example, the radiative transfer matrices are inverted once only, and short wave distributions are calculated from a precalculated, normalised distribution done at the beginning of the simulation. Nonetheless, the model is not as swift as the simplified, linearised models, especially if a large number of nodes are used. It seems to be fast enough for control studies of relative short duration, e. g., hours. With some profiling and tuning work, it could be fast enough for emulators with 5 second sampling intervals. It probably will not be fast enough for annual calculations.

Section 2

Using the Model

2.1 Overview

This section shows how the General zone model is used in an HVACSIM$^+$ simulation. It assumes that the zone definition file has already been created as explained in Section 3. The example problem is to find the transient temperatures and cooling loads in two identical, adjacent zones when the lights are operated from 8AM to 6PM in one zone only.

2.2 Zone Model

Figure 1.3 shows the zone with node designations. The corresponding HVACSIM$^+$ input, output, and parameter definitions are shown in Tables 2.1 - 2.3. The node labels used in the tables are as defined in Figure 1.3.

Note: The input and output lists depend upon the zone definition file. Those shown in Tables 2.1 - 2.3 are only examples. See Section 3.

The first four inputs refer to the zone heat gains, regardless of the zone definition file. Occupant, equipment, and lighting power are assumed to be normalised by the nominal values given in the parameter list. The solar gain through windows is not normalised. Typically, these inputs come from the HVACSIM$^+$ boundary file, or are calculated by other modules in the simulation.

The fifth input is also always the same, the zone leaving humidity. It is a required input according to the HVACSIM$^+$ protocol because the zone model calculates its derivative.

The remaining inputs will vary depending upon the zone definition file. For the case shown here, there is a single air flow stream into the zone so there is one supply air (mass-flow, humidity-ratio) pair; if there were more inflow streams, there would be an equal number of these pairs at this point in the input list.[1]

After the supply air inputs come the temperatures of the *internal massive nodes*. These are required inputs according to the HVACSIM$^+$ protocol because the zone model calculates their derivatives. In this case there are four such nodes, namely the lamp (lamp), ballast (blst), luminaire housing (lmhp), and the trusses in the plenum space (trus).

[1]The supply air is treated as a boundary node in the zone model, so the supply temperature comes with boundary node temperatures rather than being associated with the flow rate and humidity.

Table 2.1: Input List for Example Zone Model (TYPE 188)

Variable Type	Definition	Units
CONTROL	Fraction of nominal number of occupants	(0-1)
CONTROL	Fraction of nominal equipment power	(0-1)
CONTROL	Fraction of nominal power to lights	(0-1)
POWER	Solar gain through glass	(kW)
HUMIDITY RATIO	Zone leaving humidity ratio	(kg/kg)
FLOW	Supply air flow 1	(kg/s)
HUMIDITY RATIO	Humidity ratio of supply air flow 1	(kg/kg)
TEMPERATURE	lamp Temperature	(C)
TEMPERATURE	blst Temperature	(C)
TEMPERATURE	lmhp Temperature	(C)
TEMPERATURE	trus Temperature	(C)
TEMPERATURE	Temperature of boundary sup_a	(C)
TEMPERATURE	Temperature of boundary rewr	(C)
TEMPERATURE	Temperature of boundary flrr	(C)

The last inputs are the temperatures of the boundary nodes. In this case there are three, namely the supply air (sup_a), the east wall of the room (rewr), and the top surface of the floor slab (flrr).

This example zone model has 14 outputs as seen in Table 2.2. Following the HVACSIM$^+$ protocol, the first five are the zone state variables, i.e., those for which the zone model computes derivatives for integration by HVACSIM$^+$. These are the temperatures of the internal massive nodes, followed by the zone leaving humidity.

The derivative variable outputs are followed by the temperature of the leaving air stream. The zone definition file designates this node from among the air mass nodes in the model, in this case the plenum air, pl_a (See Figure 1.3).

After the leaving air temperature comes the heat fluxes at the boundary nodes, paralleling the boundary temperatures in the input list. Here we see the fluxes at the supply air node, room east wall, and the upper floor surface.

After the boundary heat fluxes come "auxiliary" outputs. These are optional outputs of various quantities at selected nodes in the model, as specified in the zone definition file. In this example we have temperature, and net heat loss from room air (rm, source heat at the lamp and ballast, and the temperature of a "mean radiant temperature node" that has been included in the model.

The parameter list is always the same, independent of the zone definition file. These parameters relate to zone internal loads and lighting level. The first three specify occupant metabolism data. Thus the nominal occupant sensible heat gain is computed internally as the product of the first three parameters. The instantaneous value is this product multiplied by the first input. Equipment heat gain is handled similarly. The moisture addition rate is occupant plus equipment latent gains (the remainders) divided by the heat of vapourisation. Nominal power to the lighting system is given in the sixth parameter. The fraction of this indicated by the seventh parameter is assigned to the ballast node, with the remainder deposited at the lamp node. The nominal light output of all lamps in the zone is the last parameter.

Table 2.2: Output List for Example Zone Model (TYPE 188)

Variable Type	Definition	Units
TEMPERATURE	lamp Temperature	(C)
TEMPERATURE	blst Temperature	(C)
TEMPERATURE	lmhp Temperature	(C)
TEMPERATURE	trus Temperature	(C)
HUMIDITY RATIO	Zone leaving humidity ratio	(kg/kg)
TEMPERATURE	pl_a Temperature	(C)
POWER	Net heat to boundary sup_a	(kW)
POWER	Net heat to boundary rewr	(kW)
POWER	Net heat to boundary flrr	(kW)
TEMPERATURE	Temperature of rm_a	(C)
POWER	Net heat loss from rm_a	(kW)
POWER	Source heat at lamp	(kW)
POWER	Source heat at blst	(kW)
TEMPERATURE	Temperature of mrt	(C)

Table 2.3: Parameter List for Example Zone Model (TYPE 188)

Number	Definition	Units
1	Nominal Number Of Occupants	(-)
2	Total Heat Loss Per Occupant	(kW/person)
3	Occupant sensible fraction	(0-1)
4	Nominal Equipment Power	(kW)
5	Equipment Sensible Fraction	(0-1)
6	Nominal Lighting Power	(kW)
7	Fraction lighting power to ballast	(0-1)
8	Nominal Light output	(Lumens)

It is important to recognise that the lighting power is adjusted in two ways. First, it is multiplied by the (possibly time-varying) normalised lighting power, the third input. Then it is multiplied by the fraction determined from Figure 1.2, using instantaneous lamp wall temperature.[2]

2.3 Partition and Floor Model

To demonstrate the zone model, a model for the partition and floors shown in Figure 1.5 is needed. Although more (or less) elaborate models could be defined, the one shown in Figure 2.1 will do. This model employs three nodes with thermal mass mC_p connected by two conductors of conductance kA/l. Here m is node mass and C_p the specific heat, while k, A, and l are

[2]Actually, a constant 2.78°C is subtracted from the instantaneous lamp wall temperature to get the abscissa for entry to Figure 1.2. This approximates the minimum lamp wall temperature, as the model computes only the average.

Table 2.4: Input List for Three Node Wall Model (TYPE 189)

Variable Type	Definition	Units
POWER	Left heat flux	(kW)
POWER	Right heat flux	(kW)
TEMPERATURE	Left surface temperature	(C)
TEMPERATURE	Middle temperature	(C)
TEMPERATURE	Right surface temperature	(C)

Table 2.5: Output List for Three Node Wall Model (TYPE 189)

Variable Type	Definition	Units
TEMPERATURE	Left surface temperature	(C)
TEMPERATURE	Middle temperature	(C)
TEMPERATURE	Right surface temperature	(C)

thermal conductivity, heat transfer surface area, and transmission length respectively. Tables 2.4 - 2.6 shows input, output, and parameter lists for this model. It is designated TYPE189. Observe that TYPE 189 accepts as inputs the heat fluxes at each of its surfaces and calculates the temperatures of these surfaces. Since the zone model does the opposite, the two models can be interconnected as shown in Figure 1.5.

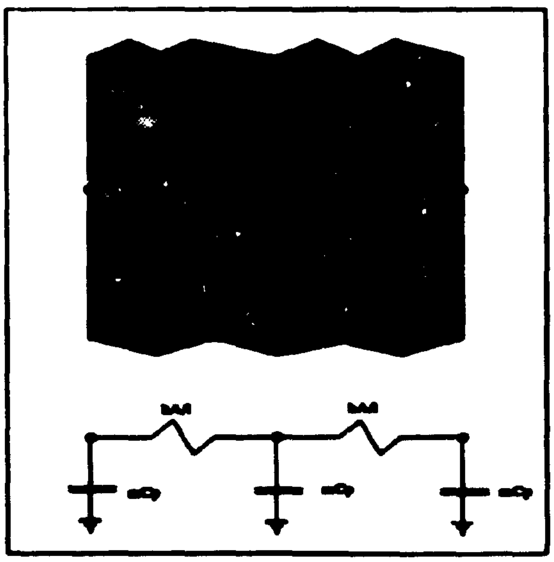

Figure 2.1: Three node wall

Table 2.6: Parameter List for Three Node Wall Model (TYPE 189)

Number	Definition	Units
1	Left conductance	(kW/C)
2	Right conductance	(kW/C)
3	Left thermal mass	(kW·s/C)
4	Middle thermal mass	(kW·s/C)
5	Right thermal mass	(kW·s/C)

2.4 Simulation Definition

Using the zone and wall models, the example problem can be solved with the HVACSIM+ diagram shown in Figure 2.2. As can be seen, there are two instances of the TYPE 188 zone model, referred to as *left* and *right*. Both are identical as described in the zone definition file to be used. However, parameter values can be different. These rooms are connected through a partition represented with TYPE 189 three-node wall model. Each zone has a floor represented by the same model. The variable definitions in this diagram are given in Tables 2.7-2.11.

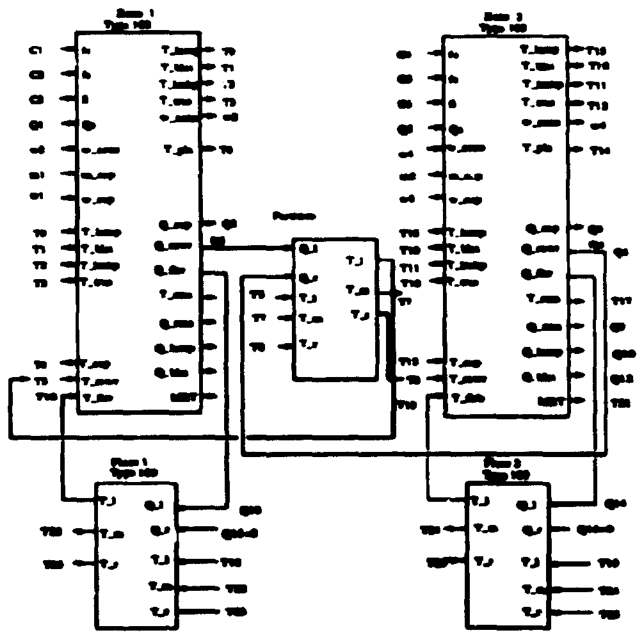

Figure 2.2: HVACSIM+ diagram

Note that the zone definition file for this problem has a single wall defined as a *boundary*. This boundary wall is designated *rewr*, meaning room *east* wall, room side. Figure 2.2 shows this zone model being used for both left and right zones by the device of connecting them through their "east" walls. The geometrically correct formulation, having the east wall of the left zone communicating with the west wall of the right zone, would require two different zone models,

Table 2.7: Simulation Temperature Definitions

Variable Type	Number	Definition	Units
Temperature	1	Left zone ballast	(C)
Temperature	2	Left zone luminaire housing	(C)
Temperature	3	Left zone truss	(C)
Temperature	4	Left zone supply air	(C)
Temperature	5	Left zone room east wall, room side	(C)
Temperature	6	Left zone plenum air	(C)
Temperature	7	Partition, middle node	(C)
Temperature	8	Right zone room east wall, room side	(C)
Temperature	9	Left zone lamp	(C)
Temperature	10	Right zone ballast	(C)
Temperature	11	Right zone luminaire housing	(C)
Temperature	12	Right zone truss	(C)
Temperature	13	Right zone supply air	(C)
Temperature	14	Right zone plenum air	(C)
Temperature	15	Right zone lamp	(C)
Temperature	16	Left zone room air	(C)
Temperature	17	Right zone room air	(C)
Temperature	18	Left zone floor, room side	(C)
Temperature	19	Right zone floor, room side	(C)
Temperature	20	Left zone MRT	(C)
Temperature	21	Right zone MRT	(C)
Temperature	22	Left zone floor, middle node	(C)
Temperature	23	Left zone floor, lower surface	(C)
Temperature	24	Right zone floor, middle node	(C)
Temperature	25	Right zone floor, lower surface	(C)

Table 2.8: Simulation Heat Flux Definitions

Variable Type	Number	Definition	Units
Power	1	Left zone glass solar gain	(kW)
Power	2	Left zone supply air, net	(kW)
Power	3	Left zone room east wall, room side, net	(kW)
Power	4	Right zone room east wall, room side, net	(kW)
Power	5	Left zone glass solar gain	(kW)
Power	6	Right zone supply air, net	(kW)
Power	7	Left zone room air, net loss	(kW)
Power	8	Left zone lamp, source	(kW)
Power	9	Right zone room air, net loss	(kW)
Power	10	Right zone lamp, source	(kW)
Power	11	Left zone ballast, source	(kW)
Power	12	Right zone ballast, source	(kW)
Power	13	Left zone floor, room side, net	(kW)
Power	14	Right zone floor, room side, net	(kW)
Power	15	Left zone floor, lower side, net	(kW)
Power	16	Right zone floor, lower side, net	(kW)

Table 2.9: Simulation Normalised Power Definitions

Variable Type	Number	Definition	Units
Control	1	Left zone normalised occupancy	(-)
Control	2	Left zone normalised equipment usage	(-)
Control	3	Left zone normalised lighting usage	(-)
Control	4	Right zone normalised occupancy	(-)
Control	5	Right zone normalised equipment usage	(-)
Control	6	Right zone normalised lighting usage	(-)

Table 2.10: Simulation Mass Flow Definitions

Variable Type	Number	Definition	Units
Flow	1	Left zone supply air flow rate	(kg/s)
Flow	2	Right zone supply air flow rate	(kg/s)

Table 2.11: Simulation Humidity Ratio Definitions

Variable Type	Number	Definition	Units
Humidity	1	Left zone supply air humidity ratio	(kg/s)
Humidity	2	Left zone extract air humidity ratio	(kg/s)
Humidity	3	Right zone supply air humidity ratio	(kg/s)
Humidity	4	Right zone extract air humidity ratio	(kg/s)

Table 2.12: Problem Inputs

Variable Type	Number	Value
FLOW	1	bnd
FLOW	2	bnd
TEMPERATURE	4	bnd
TEMPERATURE	13	bnd
CONTROL	1	0.0
CONTROL	2	bnd
CONTROL	3	bnd
CONTROL	1	0.0
CONTROL	5	bnd
CONTROL	6	bnd
POWER	1	bnd
POWER	5	bnd
POWER	15	0.0
POWER	16	0.0
HUMIDITY RATIO	1	bnd
HUMIDITY RATIO	3	bnd

one with an east boundary wall and one with a west boundary wall. It should be clear that the formulation used here will give the same thermodynamic results as the correct formulation. On the other hand, a more practical zone definition would have at least two boundary walls so more flexible interconnections could be achieved.

The problem definition requires certain of the variables in Tables 2.7-2.11 to be inputs, allowing all others to be calculated. In this case we specify the inputs as shown in Table 2.12. Those with a given numerical value are held constant at that value, while those marked "bnd" vary with time as given in the HVACSIM$^+$ boundary file.

For this example, all boundary values are to be held constant except the lighting power control for the left zone. This control is 0.0 until 8:00am, at which time it goes to 1.0 , returning to 0.0 at 6:00pm. The lights remain off in the right zone, and all other zone heat gains are maintained at zero for both zones. Recall that the nominal lighting input power is specified as a parameter on the zone model (See Table 2.3). In this example, this nominal power is specified as 1.0 kW, although this is really too high for actual practice. For example, a room of the size defined in the zone definition file would have at most 16 40W lamps which would require about 750W allowing 15% for ballast dissipation.

Both zones receive 0.2 kg/s of supply air at 0.005 kg/kg absolute humidity. That to the left zone is supplied at 17°C, while at the right is delivered at 20°C.

Table 2.13 shows the boundary value table, where at least three values are provided after step changes to support the cubic spline interpolation performed by HVACSIM$^+$.

To complete the problem, the state variables of the problem must be given initial values. In this case, the state variables are the temperatures the lamps, ballasts, luminaire housings, and trusses in each zone; the temperatures of the wall and floor nodes; and the humidity of each zone. All temperatures are assumed to start at 23.889°C, (75°F), and the two zone humidities are assumed to start at 0.005 kg/kg.

Appendix A gives the complete HVACSIM$^+$ zone definition and simulation definition files

Table 2.13: Problem Boundary Variable Variation

Time	$\dot{m}_1$	$\dot{m}_2$	T_4	T_{13}	C_3	C_6	C_2	C_5	Q_1	Q_5	w_1	w_1
0	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
18000	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
21600	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
25200	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
28800	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
28800	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
32400	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
36000	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
39600	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
54000	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
57600	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
61200	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
64800	0.2	0.2	17.0	20.0	1.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
64800	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
68400	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
72000	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
75600	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
86400	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
90000	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
93600	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
97200	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005
100800	0.2	0.2	17.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.005

for this problem.

2.5 Results

Results for the example problem are shown in Figures 2.3 - 2.4. Figure 2.3 shows room air and mean radiant temperatures for both zones. Initially, there is a decay from the initial conditions toward the supply air temperatures in each zone. When the lights come on, there is a rapid rise that can be attributed to the massless adiabatic surfaces in the room which come immediately to equilibrium with the lighting radiant load. There is then a longer exponential rise as the massive elements approach their equilibria. These processes are repeated in reverse when the lights are turned off. As would be expected, the effect of the lights is strongest in the room on the left, but is also evident in the room on the right due to transmission through the partition.

The mean radiant temperature on the left is seen to be about 2.7°C above room air temperature. This is somewhat higher than might be expected in an actual room for two reasons. First, as noted previously, the input power is about 25% too high. Second, the room walls and plenum walls and upper closure are assumed to be massless and adiabatic, meaning that they immediately come to equilibrium temperatures. An actual room would have mass in these surfaces and they would be coupled to adjacent rooms or the outside, so that they may never reach adiabatic equilibrium temperatures.

Figure 2.4 shows heat fluxes for the problem. The solid curve shows the source heat gain due to lighting (lamp plus ballast) in the left zone. The uppermost dashed curve is the cooling load extracted by the air stream passing through the left zone (room and plenum), while the lower one is for the right zone. Again, there is a small but noticeable effect of heat transfer through the partition.

It is interesting to note that cooling load in the left zone reaches 90% of the lighting heat gain within a fraction of the first hour, and reaches nearly 100% before the lights are turned off. This is the response one would expect in a light weight room, rather than the example room which has a 6.35 cm (2.5 in.) concrete slab floor. The explanation is that the carpet specified in the zone definition file shields the concrete from radiation, rendering it ineffective for heat storage. This can be demonstrated by another simulation in which the zone floor slabs are moved to above the plenum where they are fully exposed to the plenum air.[3]. Figures 2.5 - 2.6 show these results. The effect of the slab mass, now better coupled to the air stream, is much more evident. In particular, Figure 2.6 shows that the peak cooling load in the left zone reaches only about 90% before the lights are turned off.

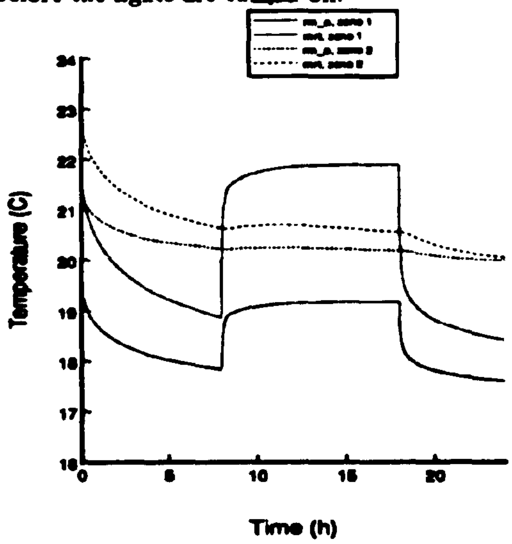

Figure 2.3: Temperatures: floor slab

[3]This is accomplished by a simple change in the zone definition file as explained in the Section 3

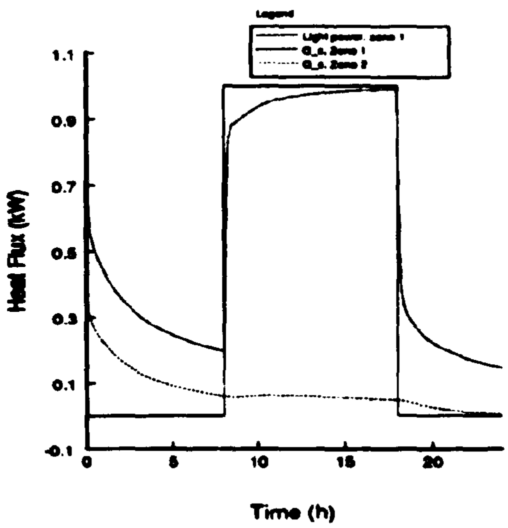

Figure 2.4: Heat: floor slab

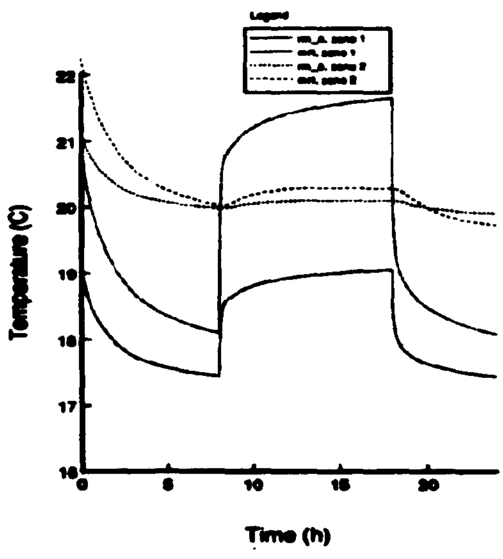

Figure 2.5: Temperatures: slab above plenum

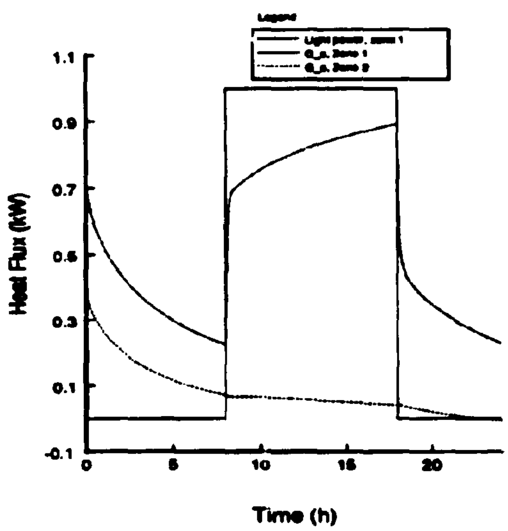

Figure 2.6: Heat: slab above plenum

Section 3

Defining the Zone

3.1 Overview

Thi- section shows how to set up the zone definition file for the General zone model. Following a general discussion of the structure of this file, each piece of data is discussed and example input data are shown. Often, the zone definition file for the example problem of Section 2.2 is referenced. This complete file may be found in Appendix A. Along the way, variations needed to effect certain zone modifications are discussed.

3.2 The Zone Definition File

3.2.1 General Structure of the File

The General zone model reads all input data from a single file called zone188.dat. An example input file for a simple room is given in Appendix A. Some important observations about this file are:

1. The information between /* and */ is commentary to make the input human-readable. These strings are stripped out of the input file by the program before the actual data is read.

2. The input is completely free-format. That is, where an item appears on a line and where line breaks occur are immaterial. Order is all that is important.

3. While some error checking is done, by modern software standards this checking is sparse. Some range checking is done, with error reports that attempt to pinpoint the error. Also, item counts are done on data groups, which will give a message saying that something is wrong with the previous group. In some places, however, a missing item or an extra piece of data will not be trapped until some subsequent item is processed. Detective work is sometimes required to identify the source of these errors. Finally, there probably are yet-to-occur error events waiting to happen with as yet untried input values or combinations. The best advice is to check a new zone definition file very carefully, both from the standpoint of the input rules given here, and physical sense.

4. The program allows the user to specify the number of items in many data input groups, e.g., number of nodes and number of conductors. The maximum allowed values for these counts is determined by array dimensions in the program, which are set at the time the

program is compiled. These limits are given in Appendix B. If larger problems must be run, the limits must be changed and the program recompiled.

For convenience of discussion the input can be divided into the following broad groups of data, given in the required order in the file.

1. Accuracy control information for the solution process
2. Wave band definitions for radiative transfer
3. Nodal data, e.g., label, area, mass, radiative properties and initial temperatures.
4. View factor and other radiative transfer data.
5. Conductive/Convective data.
6. Lamp data.
7. HVACSIM$^+$ interface information.

Each of these groups is discussed in the following subsections.

3.2.2 Accuracy Control

The program uses Newton-Raphson iteration for solving the algebraic equations at each time step. Speed and accuracy of solution can be controlled by specifying control variables. The first control variable, TTOL, determines the degree of accuracy of the solution. The second variable, NRMAX, gives the maximum number of iterations allowed to reach the specified level of accuracy. Typical values are:

```
/* Newton-Raphson controls */
/*TTOL         NRMAX */
 0.000001       20
```

Setting a larger TTOL will speed solution, but accuracy will diminish. If TTOL is too large the accuracy may not be sufficient for HVACSIM$^+$ to calculate correct partial derivatives for the problem Jacobian matrix.

3.2.3 Wave Band Definitions

The model performs radiative emission and interchange calculations in an arbitrary number of short wave and long wave bands. The number of such bands and their limits in microns is required input data. The first item is the number of short wave bands, MS, followed by MS+1 points on the wavelength scale. This sequence is followed by a similar description of the long wave bands. Typical values are:

```
/*  short wave limits (microns)*/
/* MS     1st     last */
   1      0.3      0.8
/* long wave limits (microns)*/
/* ML     1st     last */
   1      1.0     200.0
```

These bands cover the entire spectrum of interest in each range.

Also note that surface properties must be given along with the nodal data for each band. (See Section 3.2.4.) As a practical matter, spectral radiation properties are seldom available, so a single band in each range, as shown above, is almost always used.[1]

3.2.4 Nodal Data

This input group begins with N, the total number of nodes, which is followed by N sets of data for each node. The node data consist of:

1. Node label (up to 6 characters)
2. Thermal mass (kW-s/°C) (0.0 for light-weight nodes)
3. Area (m^2) (0 for air nodes)
4. MS short wave reflectances (1.0 for air nodes)
5. ML long wave reflectances (1.0 for air nodes)
6. MS short wave transmittances (0.0 for opaque nodes)
7. ML long wave transmittances (0.0 for opaque nodes)
8. Initial temperature, used as a starting guess for Newton-Raphson iteration for massless nodes. This value is not used for massive nodes because they get their initial temperatures from HVACSIM+.

The example below shows the nodal data input for various node types.

```
/* Num nodes */
  5
/*node   mass   area    r-sw  r-lw t-sw  t-lw  Init. T   */
/*=====  ====   ====    ====  ==== ====  ====  =====     */
 /* Air node */
 rm_a   0.0     0.0     1.0  1.0   0.0   0.0    24.0
 /* Massive node */
 blst   3.0    0.35     0.2  0.06  0.0   0.0    24.0
 /* Massless node */
 cpt    0.0    15.8     0.50 0.06  0.0   0.0    24.0
 /* Translucent node */
 lnsl   0.0    2.97     0.06 0.06  0.92  0.0    24.0
/* Mean Radiant Node */
 mrt     0.0   0.001    0.37 0.02  0.0   0.0    24.0
```

Note that the easiest modeling technique is to define separate nodes for each side of internal elements such as the the acoustic ceiling. A more efficient solution will result if such elements are collapsed into a single node, but this makes it difficult (but not impossible) to decide what

[1] Because of this, the current limits are set to a single band in each range, so more bands are not possible without recompilation. See Appendix B.

the areas and view factors should be for the composite node. Translucent elements like the lens must have two surfaces to properly represent transmission. (See Sec. 3.2.5 below.).

A fictitious node of negligible area is sometimes defined to calculate mean radiant temperature. It is imagined to have the radiant properties of a clothed human, and to be positioned at the center of the room.

3.2.5 Radiative Transfer Data

This data group consists of view factor information, and indication of the nodes that receive transmitted radiation for each node with nonzero transmittance.

The program employs a method for determining the view factor matrix that minimises required input data. The user inputs at most only n(n-1)/2 factors, and the program calculates the remaining ones from reciprocity and conservation. Moreover, only nonzero factors need be given. The input factors are input as

$$from, to, F(from, to)$$

triplets, preceded by the count of such triplets.

Calculation of view factors is often tedious, and if the model is complex the task can be formidable. The program does not solve this problem, but it makes it a little easier in that relatively few factors have to be given. However, even this can be problematical, since the ones specified are not completely arbitrary. Simply put, the nonzero factors not given must be calculatable from those that are given [SO72].[2]

For example, below we define 2 input factors:

```
/* Number of (from, to, F(from, to)) triplets*/
      2
/* from  to  F(from, to) */
   lamp lamp    0.0304
   lnsr cpt     1.0
```

Note that *from* and *to* are node labels as defined in the nodal input section.

In order to calculate the full matrix the program also needs to know a single factor that will be calculated by conservation in each row. This is given as N (*row*,*column*) pairs, where N is the number of problem nodes. For example:

```
/* row    col to be determined by conservation */
 flrb           lnsp
 lnsp           lamp
 lnsr           lamp
 cpt            lnsp
 lamp           flrb
 flrr           flrr
 flrm           flrm
 rm_a           rm_a
 pl_a           pl_a
 cc_a           cc_a
```

[2]Two separate programs, FACT and VF, are available to aid in calculation of those factors that are to be input to the zone model [Sow89].

Rules for deciding which factors are to be given and which are to be determined by conservation are presented in the References [Sow89].

Some surfaces may have nonzero transmittances, as in the nodal data group. It is necessary to specify the surface to which each such surface transmits. This is indicated by N (*from*, *to*) pairs. For example:

```
/* Radiant transmission coupling vector */

 flrb 0
 lnsp lnsr
 lnsr lnsp
 cpt  0
 flrr 0
 flrm 0
 lamp 0
 rm_a 0
 pl_a 0
 cc_a 0
```

Here we have specified that the two sides of the lens transmit to one another. This is the normal situation. A 0 is given as the *to* node for non-transmitting surfaces. Recall that the transmittance values were given along with nodal data. (See Section 3.2.4.)

It should be observed that when there is a translucent material such as the above lens there should be a proper radiant environment on both sides. Otherwise, the transmitted energy would be lost and there would not be an overall energy balance on the system. Thus if a transparent window is to be modelled, there should be some model of the outside radiant environment. For example, there could be a single node with large area and zero reflectance and transmittance. This would allow lighting short wave radiation to escape through the window in a fairly realistic manner while maintaining overall energy balance.[3]

3.2.6 Conductive/Convective Data

The conductive and convective date defines the way that heat transfer occurs between the nodes. The user supplies this information as a count of number of conductors, followed by data for each conductor in the format below:

from to α β γ δ

Here *from* and *to* are the names of nodes previously defined under nodal data. Other values are:

α: Constant coefficient (kW/°C)

β: Exponent of temperature *difference* factor in correlation

γ: Exponent of temperature *sum* factor in correlation

δ: Factor that correlation film coefficient is to be multiplied by if assumed direction of heat transfer reverses. The assumed direction is *from* $\rightarrow$ *to*.

[3] The window can be made opaque if light loss through the window is to be ignored.

If temperature dependence is to be ignored the input is quite simple:
$\alpha = h_c A$
$\beta = 0.0$
$\gamma = 0.0$
$\delta = 1.0$

Note: α *includes the area* along with the constant factor of the film coefficient.

For vertical free convection (horizontal surfaces) it is necessary to assume a direction of heat flow from the *from* node to the *to* node. The value of δ is then the multiplying factor to be applied if the actual direction of heat flow is the reverse. For example, under steady-state conditions one would assume heat flow up at the carpet, representing a favourable convection situation. Then the input could be:

```
cpt    rm_a    0.047926    0.333    0.0    0.5
```

We have used a high film coefficient in calculating α, and a δ of 0.5 to reduce this coefficient during periods when the heat flow is from the air to the carpet. The same results would obtain if we halved the constant factor α and used δ of 2.0.

Specifying correct natural convection coefficient parameters for rooms is difficult at best. Correlations such as those given in te ASHRAE Handbook of Fundamentals [ASH89, Chapter 3] give coefficients that are significantly different (generally lower) than measured in full-scale test rooms.[4] Design values are also higher than the theoretical correlations. Recently, comparisons between results from the LIGHTS program and test cell data improved considerably when simple constant coefficients (based on the work of Spitler [SPF91]) were used in place of the temperature correlations. All of this suggests that until better natural convection correlations in rooms become available, it is probably best to use constant coefficients in zone models.

Bulk convection, i.e., air flowing between nodes, requires special consideration. This is because when air flows from the room to the plenum, the $mC_pT_{rm\_a}$ term should occur in the energy balance on the plenum air, but the $mC_pT_{pl\_a}$ term should *not* occur in the heat balance on room air. This is modelled as a "one way conductor" with a value of mC_p in a single position in the conductance matrix; i.e., there is no reciprocal entry as there would be for a normal convective or conductive conductor.

To indicate such a conductor in the input, the downstream node must be given first, followed by a *negative* upstream node. Thus for room-to-plenum flow we would write:

```
pl_a -rm_a    0.113989  0.0       0.0     1.0
```

where 0.113989 is the air mass flow rate times the specific heat. Also note that a complete air flow circuit will result in an overall energy balance for the model. This is sometimes desirable for checking purposes, but not essential. (See also the discussion in Section 3.2.8, Flow Paths ans Node Reports.)

3.2.7 Lamp Data

Lamp data in this input group consists of a specification of which surfaces represent the lamp and ballast, the spectral distribution of the lamp, and the lamp power and light output *versus*

[4] According to Prof. Curt Pedersen, Univ. of Illinois.

lamp wall temperature characteristic curves. Note that total nominal lamp power input and light output are parameters of the HVACSIM+ TYPE188 subroutine.

To indicate which node is the lamp, N (*node*, *flag*) pairs are given, with *node* being a defined node label and *flag* being 1 for lamp and 0 otherwise. The same scheme is used to specify which node is the ballast. There can be only one lamp node and one ballast node, with mass and area properties representing a composite of all lamps or ballasts in the zone. Example input is then:

```
 /* Vector indicating
which is lamp surface */

   flrb  0
   lnsp  0
   lnsr  0
   cpt   0
   lamp  1
   blst  0
   rm_a  0
   pl_a  0
   flrb  0
   flrm  0
   cc_a  0

/* Vector indicating which is ballast surface */
   flrb  0
   lnsp  0
   lnsr  0
   cpt   0
   lamp  0
   blst  1
   rm_a  0
   pl_a  0
   flrb  0
   flrm  0
   cc_a  0
```

The model uses the lamp spectral distribution in the short wave length to calculate luminous output in each short wave band specified. This distribution is entered as a count M, followed by M (*wavelength*, *output*) pairs. The units of *wavelength* is microns, and for luminous output W/micron-lumen. The input for standard coolwhite fluorescent lamps is:

```
/* Lamp luminous distribution vs. wavelength */
/* No. of points on the curve */
   39
/* wavelength, output pairs */
           0        0
         .3080      0
         .3081      15e-4
          ..........
```

```
 ..........
 ..........
 .7000    20e-4
 .7500    0
0.9999    0
```

3.2.8 HVACSIM+ Interface Information

Node reporters

Normal outputs of the TYPE188 subroutine include only:

- Internal massive node temperatures[5]
- Extract air absolute humidity
- Extract air temperature (might not be the room air!)
- Heat fluxes at boundary nodes

Often other outputs are wanted, such as room air temperature, mean radiant temperature, and heat fluxes at nodes not normally available outside the zone model. To provide these outputs, the model provides a *node reporter* that allows several quantities of possible interest to be reported at any node. The way this works can best be seen by example:

```
/*      File name          Writing interval   Nodes reported */
          none                   0.0                4
      /*Node     No. items reported at node */
        rm_a     2         -1   -2
        lamp     1         -7
        blst     1         -7
        mrt 1 -1
```

This places into the TYPE188 output list the variables:

1. Room air node temperature
2. Net rate of heat removal from room air node
3. Lamp node source heat
4. Ballast node source heat
5. Temperature of the mean radiant temperature node

The first two items of this input data reflect the history of the node reporter, which was originally created for node output to files. Now, the file name *none* causes the output to be set up in the TYPE188 output array instead of being written to a file. The writing interval then has no meaning, since the values will be set up on each call. Each node to be reported is indicated by its label, and has a count of requested output items followed by a list of codes indicating the specific items requested.

[5] Internally, the TYPE188 subroutine places derivatives in these output locations, but to the user they are treated as the corresponding variables.

In general, the format for the node reporter is structured as follows:
file_name period n_nodes
node n_items item_code item_code ...
node n_items item_code item_code ...
node n_items item_code item_code ...
⋮

Item_code is an integer between 1 and 8 that determines what kind of information is reported. If entered without sign, the value is reported in English units, but if entered as a negative integer, it is reported in SI units. Allowed item_codes and meanings are:

1. Node temperature (F|C)
2. Net rate of energy loss (+) or gain (-) at node due to radiative, conductive, convective heat transfers (Btu/h|kW)
3. Total radiosity from the node (all bands) (Btu/h-ft*2|kW/m*2)
4. Total irradiation to the node (all bands) (Btu/h-ft*2|kW/m*2)
5. Total net radiation from the node (all bands) (Btu/h-ft*2|kW/m*2)
6. Heat transfer rate from node to to_node (Btu/h|kW)
7. Source (+) or sink (-) energy rate at node (Btu/h|kW)
8. Unbalance at node (Btu/h|kW). This is Item 7 minus Item 2. For a massless node, a nonzero value represents unbalance due to numerical solution tolerance. For massive nodes, it represents the rate of release of stored energy (-) or rate of gain in stored energy (+) storage (plus numerical error); division by the node thermal mass gives the rate of change of node temperature.

Observe that several different kinds of node heat flux can be requested. While each of these may be needed at various times, item_codes 2, 6, and 7 are the most commonly used. If there *is not* a bulk flow conductor between the zone extract air node (e. g., the plenum air node) and the supply air node, item_code 2 requested at the supply air node can be used to report zone cooling load.[6] Alternately, room cooling load can be reported by requesting item_code 6 at the supply air with room air as the *to_node*. Item_code 7 is used to report impressed heat source at a node. In the example above, it gives lamp and ballast power for reporting purposes. It could also be used to output the rate of solar, equipment, and occupant sensible heat gain at various nodes in the model. (See also Heat Gain Distribution.)

The node reporter can be used to write information to files also. However, because TYPE188 is under control of the HVACSIM$^+$ executive, synchronisation is difficult . The current implementation writes the *previous* values upon the first call in a new time step. This has proven to be less than satisfactory, and usage is not recommended.[7]

There can be at most two node reporters, and each can request up to 20 items from various nodes. Up to 5 items can be requested at any single node with a single node reporter.

If no additional outputs are required, give 0 for the number of nodes reported.

[6]If there was extract air to supply air conductor there would be a balance between heat added and removed at the supply air and item_code 2 would be zero.

[7]To do this correctly it would be necessary to store several previous values and interpolate to get values at requested write-intervals.

Description string

After the node reporter there is a descriptive string for the zone definition. This is used for the typar.dat file, and is also displayed upon the first instantiation in an HVACSIM$^+$ run.

Fixed Counts

Both HVACSIM$^+$ itself and its generator program *hvacgen* require counts of number of parameters, inputs, outputs, etc. Some of this information, e.g., number of parameters, does not change as the zone definition changes and therefore could have been hard-coded in the program. However, since some of the counts are affected by the zone definition it seemed best to place all such data in the zone definition file. This data, which follows the zone description string, is *always the same* and appears as follows:

```
/* n_misc  n_par  n_saved*/
5  8  4
```

Here n_misc is the number of inputs to TYPE188 that are always the same, regardless of the model structure. Appearing first in the input list, these five inputs are the control signals for occupant, equipment, and lighting power, solar heat gain, and extract humidity ratio. The other two counts are n_par, the number of parameters, and n_saved, the number of items saved between calls to TYPE188. Some of these items are used only by the *build_typar* program.

Massive Nodes

Next in the input comes the internal nodes with significant thermal mass. The input is a count giving the number of such nodes, followed by a list of as many node labels. The order is arbitrary, and will establish the order in which the corresponding temperatures occur in the TYPE188 input list, as well as in its output list. As discussed in Section 2.2, these temperatures follow the supply air humidity input to TYPE188, and are at the very beginning of its output list. An example is shown below:

```
/* n_mass: Number of massive nodes:*/
4
/* Node labels */
 lamp   blst   lmhp   trus
```

Note: The nodes listed here must be those with thermal mass > 0.0, as specified in Section 3.2.4.

Boundary Nodes

After the massive nodes there is a list of boundary nodes following the same style. For example,

```
/*  Boundary nodes. Include enclosing surfaces and supply air nodes.
 *  List in order of TYPE188 input list.
 */

/* n_bound: Number of boundary nodes:*/
3
/* Node labels */
sup_a   rewr   flrr
```

Normally, boundary nodes are those that must communicate with other parts of the simulation. The most obvious examples are walls and floors. Additionally, supply air streams are treated as a boundary nodes. For each of these nodes there will be a temperature input to TYPE188, immediately following the internal massive node temperatures in the input list. In the output list there will be a heat flux for each, immediately following the temperature of the extract air.

Air Flow Paths

Air flow through the zone is specified in terms of input flows, extract flows, and bulk flow conductors. There can be several of each of these, allowing all normal configurations, such as return plenum, static plenum, heat removal luminaires, and so on.

The first input in this group is the number of air flow rates in the TYPE188 input list. It is important to note that this is *not necessarily the number of supply air streams*, but rather the flow rates that are to be used to calculate bulk flow conductors. The example room has only one, which is the most common situation. The input is then:

```
/* nif */
1
```

There can be several bulk flow conductors that are based on each input air flow rate. The input gives the total number of bulk flow conductors, followed by as many triplets of the form:

downstream_node upstream_node input_flow_index

Here *input_flow_index* indicates the input air flow rate upon which the bulk flow conductor between *downstream_node* and *upstream_node* is based.

Figures 3.1 and 3.2 show several example flow paths in zones. Case (a) in Figure 3.1 shows the standard return plenum situation as used in the example problem. The corresponding input is:

```
/* nalf */
3
/* nalf triplets */
rm_a  sup_a 1
pl_a  rm_a  1
sup_a pl_a  1
```

Since there is but one input flow rate, all of the flow indices are 1, and all three bulk flow conductors will have the same value at all times.

Case (b) in Figure 3.1 shows the air-return luminaire situation, in which the air is routed through the luminaire lamp cavity before extraction through the plenum. In this case the model must have an additional air node representing the lamp cavity air, lc_a. The input is:

```
/* nalf */
4
/* nalf triplets */
rm_a  sup_a 1
lc_a  rm_a  1
pl_a  lc_a  1
sup_a pl_a  1
```

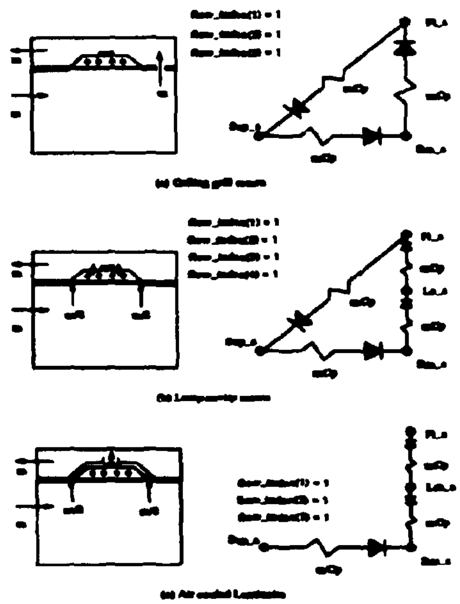

Figure 3.1: Zone Air Flow Paths

In both of these cases we have included the optional return conductor between the extraction node (i.e., the plenum air) and the supply air point. This makes a closed circuit of bulk flow conductors, giving an overall model heat balance. However, exactly the same results are obtained if this conductor is omitted, since the only node heat balance in which this conductor appears is the supply air node which is normally a boundary and therefore of known temperature.

Case (c) in Figure 3.1 shows the air-cooled luminaire situation, in which the air is routed through a cooling jacket on the luminaire housing before extraction through the plenum. The model is exactly the same as case (b) except the additional air node represents average air temperature in the cooling jacket. However, in this case we omit the optional return conductor, so the input is:

```
/* nalf */
3
/* nalf triplets */
rm_a  sup_a 1
lc_a  rm_a  1
pl_a  lc_a  1
```

Case (d) in Figure 3.2 shows the simple case of static plenum without the optional return conductor. The input is obvious.

Cases (e) and (f) show configurations that allow modulation or switching of supply and return air paths. Schemes like these have been suggested for getting better use of structural mass for heat storage [Con91]. For example, in (e) the return air could be routed through the plenum during morning hours in which cooling loads are low. During the afternoon, when cooling loads are approaching their maximum, the air is switched to room extraction (or ducted through the plenum space) so the heat stored in the plenum structural elements (including the

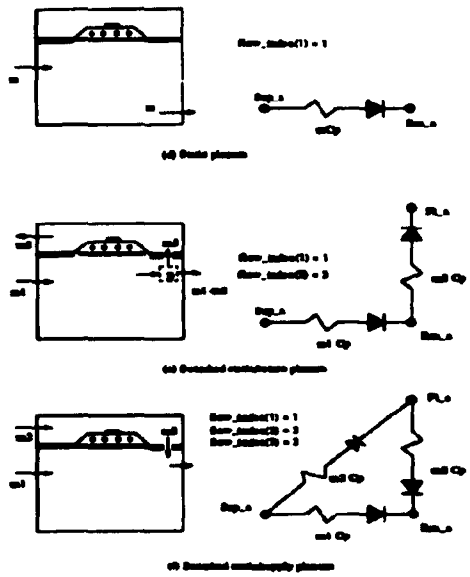

Figure 3.2: Zone Air Flow Paths (concluded)

concrete of the floor slab above) doesn't contribute to the peak cooling load.[8] In both of these cases we need two flow rates as inputs to the model. In case (e) the first flow rate represents the supply air to the room; it is used to calculate the bulk flow conductor between the supply and room air nodes. The second is the flow rate extracted through the plenum; it is used to calculate the conductance between the room air and the plenum air node. The input is:

```
/* nalf */
2
/* nalf triplets */
rm_a  sup_a 1
pl_a  rm_a  2
```

Case (f) is a similar idea except it is the supply air that is switched. The input would be:

```
/* nalf */
2
/* nalf triplets */
rm_a  sup_a  1
pl_a  sup_a  2
rm_a  pl_a   2
```

In cases (e) and (f) the HVACSIM+ TYPE188 would have *two* (supply mass flow rate, supply humidity) pairs in the input list, immediately after the fixed input items. The flow_index indexes into this list to compute the bulk flow conductances according to the above scheme. Also, *two* supply air nodes should be defined as boundary nodes. (See also Boundary Nodes.)

[8] Of course the plenum stored heat would have to be flushed later, perhaps during the night.

Note that the zone model itself merely *uses* these flows. It does not deal at all with mass balance. If the simulation needs the mass flow rate leaving the zone it must be calculated elsewhere.

Output Flow Temperature

Other parts of the simulation often need the temperature of the extract air stream or streams. Because the air flow paths through the zone vary as discussed under Air Flow Paths, the particular node which gives this temperature must be identified in the zone model definition. This is done by giving the number of extract flows followed by a list of node labels. In the case of a return plenum there is a single extract stream and the input is:

```
/*nof: Number of TYPE188 output flows */
1
/* Node labels for temperatures of output flows */
pl_a
```

This input introduces one temperature in the TYPE188 output list immediately after the zone leaving humidity derivative output. See also Air Node List.

Heat Gain Distribution

Zone heat gains are determined from a combination of TYPE188 inputs and parameters as explained in Section 2.2. However, the nodes at which this heat gain is "deposited" is specified in the zone definition file. For each node in the model, a fraction of solar, occupant sensible, and equipment sensible heat gain is specified. Naturally, the sum of these fractions should equal 1.0 for each heat gain component. Lighting heat gain is *not* included here because its distribution is calculated by the model. For the example problem the input might be as shown below:

```
/* node   solar    occupant    equipment */
 rm_a     0.0       0.5         0.5
 pl_a     0.0       0.0         0.0
 lm_a     0.0       0.0         0.0
 lamp     0.0       0.0         0.0
 blst     0.0       0.0         0.0
 lmhl     0.0       0.0         0.0
 lnsr     0.0422    0.0211      0.0211
 cpt      0.2242    0.1121      0.1121
 flrb     0.0       0.0         0.0
 actp     0.0       0.0         0.0
 actr     0.1822    0.0910      0.0910
 rewr     0.1281    0.0641      0.0641
 rswr     0.1476    0.0738      0.0738
 rwwr     0.1281    0.0641      0.0641
 rnwr     0.1476    0.0738      0.0738
 pewp     0.0       0.0         0.0
 pswp     0.0       0.0         0.0
 pwwp     0.0       0.0         0.0
```

```
pnwp    0.0    0.0    0.0
trus    0.0    0.0    0.0
lmhp    0.0    0.0    0.0
lnsl    0.0    0.0    0.0
sup_a   0.0    0.0    0.0
flrr    0.0    0.0    0.0
mrt     0.0    0.0    0.0
```

The fractions are based on judgement and somewhat arbitrary. For the example, it is assumed that 50% of occupant and equipment sensible heat gain goes directly into room air; this is the assumed convective fraction.[9] The remainder is distributed to room surfaces in proportion to area. All of the solar is distributed to room surfaces in proportion to area.

Air Node List

. Ideally, the model should provide for a separate humidity balance on every node in the air flow circuit. At the present it does not; *a single humidity differential equation calculates a single extract humidity.* All input air streams are imagined to mix for calculation of the derivative. The air mass is derived from the composite air thermal mass, calculated as the sum of all designated air node thermal masses. However, since the user may wish to ignor air thermal mass in the heat balance (i.e., assume instantaneous air energy balance), this sum may be zero. To avoid this problem, the air thermal mass for humidity calculation is assumed to be 30.0 (W-s/°C) if the sum is less than 1.e-6. This is the thermal mass of a small office (about 20 m^3).

The input for this data is as follows:

```
/* Number of air nodes */
 3
/* Air node labels  (used to determine air mass for humidity diff eq)*/
rm_a pl_a lm_a

 /* End of Zone model definition */
```

This concludes the zone definition.

3.3 General TYPE188 I/O Lists

Section 2.2 showed a specific example of the TYPE188 input and output list. The general case is shown in Tables 3.1 and 3.2.

[9] In principle it should be possible to define a node representing equipment, convectively and radiatively coupled with other nodes. Then all sensible equipment heat gain could be deposited at this node. This would result in the model calculating radiative and convective portions, rather than having to assume them.

Table 3.1: General TYPE188 Input List

Number	Description	Units
Fixed Inputs		
1	Normalised occupant heat gain	(-)
2	Normalised equipment heat gain	(-)
3	Normalised lighting heat gain	(-)
4	Solar heat gain	(kW)
5	Extract air humidity ratio	(kg/kg-dry-air)
Air Streams		
6	Supply air temperature	(C)
7	Supply air humidity ratio	(kg/kg-dry-air)
⋮	⋮	⋮
4+2*nif	Supply air temperature	(C)
5+2*nif	Supply air humidity ratio	(kg/kg-dry-air)
Temperatures of Internal Mass Nodes		
6+2*nif	Massive node temperature	(C)
⋮	⋮	⋮
5+2*nif+n_mass	Massive node temperature	(C)
Temperatures of Boundary Nodes		
6+2*nif+n_mass	Boundary node temperature	(C)
⋮	⋮	⋮
5+2*nif+n_mass +n_bound	Boundary node temperature	(C)
	Definitions	
nif	Number of air flow inputs	
nof	Number extract air streams	
n_bound	Number of boundary nodes	
n_mass	Number of internal massive nodes	

Table 3.2: General TYPE188 Output list

Number	Description	Units
Derivatives of Internal Massive Nodes		
1	Massive node temperature derivative	(C/s)
⋮	⋮	⋮
n_mass	Massive node temperature derivative	(C/s)
Extract Air Humidity		
1 + n_mass	Extract air humidity ratio derivative	(kg/kg-dry-air/s)
Temperatures of Extract Air Streams		
2 + n_mass	Extract air temperature	(C)
⋮	⋮	⋮
1 + n_mass + nof	Extract air temperature	(C)
Net Heat Gain at Boundary Nodes		
2 + n_mass + nof	Boundary node temperature	(C)
⋮	⋮	⋮
1 + n_mass + nof + n_bound	Boundary node temperature	(C)
Additional Outputs		
2 + n_mass + nof+ n_bound	Node value	(C or kW)
⋮	⋮	⋮
1 + n_mass + nof + n_bound + n_zvars	Node value	(C or kW)
	Definitions	
nof	Number extract air streams	
n_bound	Number of boundary nodes	
n_mass	Number of internal massive nodes	
n_zvars	Number of additional outputs	

References

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[Con91] J. P. Conniff. Strategies for reducing peak air conditioning loads by using heat storage in the building structure. *ASHRAE Transactions*, 97(Pt. 1), 1991.

[Kea88] S. A. Klein and et al. TRNSYS- a transient system simulation program. Technical report, Solar Energy Laboratory, University of Wisconsin, Madison, WI, 1988.

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[Sow89] E. F Sowell. LIGHTS user's guide. Technical report, California State University, Fullerton, Dept. of Computer Science, Fullerton, CA 92634, November 1989. NSF Grant MSM-8614974.

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Appendix A

Example Problem Zone Definition

A.1 The Example Zone

Figure 1.3 shows the zone definition and node designations. Geometry and other pertinent data are shown in Table A.1. This data is from the Lighting/HVAC Interaction Test Cell at the U.S. National Institute of Standards and Technology (NIST)[Tre91]. The geometric data was taken from construction drawings for the test cell. Thermal masses are based on physical dimensions and handbook density and heat capacity data. Radiation properties are estimated.

A.2 Zone Definition File

```
/* General HVACSIM+ zone model        */
/*      4 massive nodes                */
              /*        SI Units                */
       /*       23 July   1991            */
              /*      Edward F. Sowell          */
              /*Acrylic Lens,  ceiling grill return  */
              /*        4 lamp fixtures         */
              /*         Carpets                */
/* Newton-Raphson process controls */
/*eps    max tries */
 0.000001    20

/*Short wave band limits (microns)*/
/* ms     1st    last */
   1     0.3   0.8
/*Long wave band limits (microns)*/
/* ml     1st    last */
   1     0.1   300.0
/* Num nodes */
  26
/*node    mass    area    r-sw  r-lw t-sw  t-lw     t   */
/*=====   ====    ====    ====  ==== ====  ====  ===== */
 /*  Room, plenum and lamp cavity air nodes */
 rm_a   0.0      0.0     1.0  1.0   0.0   0.0  23.8889
```

Table A.1: Zone Geometry

Item	Value	Units
Floor-to-ceiling height	2.44	(m)
East/West wall length	3.70	(m)
North/South wall length	4.27	(m)
Plenum height	2.44	(m)
Luminaires	4	(number)
Lamps per luminaire	4	(number)
Total lamp surface area	2.33	(m^2)
Total lamp mass	1.9	(kW-s/°C)
Luminaire width	0.61	(m)
Luminaire length	1.22	(m)
Luminaire lens thickness	0.32	(cm)
Total ballast surface area	0.35	(m^2)
Total ballast mass	3.8	(kW-s/°C)
Luminaire housing surface area	4.37	(m^2)
Total luminaire mass	13.7	(kW-s/°C)
Acoustic tile ceiling thickness	1.27	(cm)
Truss Surface area	9.29	(m^2)
Truss mass	214.48	(kW-s/°C)

Table A.2: Radiation properties

Surface	SW ref.	LW ref.	SW tran.	LW tran.
Walls	0.80	0.05	0.0	0.0
Carpets	0.50	0.05	0.0	0.0
Lum. housing, plenum	0.80	0.05	0.0	0.0
Lum. housing, inside	0.70	0.05	0.0	0.0
Ballast	0.20	0.05	0.0	0.0
Lamp	0.90	0.05	0.0	0.0
Lum. lens	0.05	0.05	0.92	0.0
Acoustic tile	0.80	0.05	0.0	0.0
Truss	0.10	0.05	0.0	0.0
Mean radiant node	0.37	0.02	0.0	0.0

```
 pl_a   0.0       0.0     1.0  1.0   0.0   0.0  23.8889
 lm_a   0.0       0.0     1.0  1.0   0.0   0.0  23.8889

 /* Luminaire nodes */
 lamp   1.89806 2.33466 0.9  0.05  0.0   0.0  23.8889
 blst   3.79612 0.35117 0.2  0.05  0.0   0.0  23.8889
 lmhl   0.0     4.36645 0.7  0.05  0.0   0.0  23.8889
 lnsr   0.0     2.97290 0.05 0.05  0.92  0.0  23.8889
 lmhp   13.6660 4.36645 0.80 0.05  0.0   0.0  23.8889
 lnsl   0.0     2.97290 0.05 0.05  0.92  0.0  23.8889

 cpt    0.0   15.8028   0.50 0.05  0.0   0.0  23.8889

/* floor slab nodes   -- mass is in HVACSIM+ */
 flrr  0.0       0.0     1.0  1.0   0.0   0.0  23.8889
 flrb  0.0     15.8028   0.50 0.05  0.0   0.0  23.8889

/* acoustic ceiling nodes   */
 actp  0.0    12.8299 0.80 0.05  0.0   0.0    23.8889
 actr  0.0    12.8299 0.80 0.05  0.0   0.0    23.8889

/* Room wall nodes -- mass is in HVACSIM+ */
 rewr  0.0    9.0302  0.80 0.05  0.0   0.0    23.8889
 rswr  0.0    10.405  0.80 0.05  0.0   0.0    23.8889
 rwwr  0.0    9.0302  0.80 0.05  0.0   0.0    23.8889
 rnwr  0.0    10.405  0.80 0.05  0.0   0.0    23.8889


/* Plenum wall  -- mass is in HVACSIM+ */
 pewp  0.0    2.8224  0.80 0.05  0.0   0.0    23.8889
 pswp  0.0    3.2516  0.80 0.05  0.0   0.0    23.8889
 pwwp  0.0    2.8224  0.80 0.05  0.0   0.0    23.8889
 pnwp  0.0    3.2516  0.80 0.05  0.0   0.0    23.8889

/* Truss node --- */
trus 214.4808 9.2903  0.10 0.05  0.0   0.0    23.8889

/* cooling coil leaving air node */
 sup_a   0.0     0.0    1.0  1.0  0.0   0.0    23.8889
/* Mean Radiant Node */

 mrt     0.0     0.001 0.37 0.02  0.0   0.0    23.8889

/*                                                         */
/*              View Factor Data                           */
/*                                                         */
/* number of I,J,F(I,J) triplets*/
   48
```

```
/* I   J       F(I,J) */
lnsr cpt     0.46
cpt  actr    0.25993
cpt  rswr    0.151066
cpt  rnwr    0.151066
rewr actr    0.21463
rewr lnsr    0.04973
rewr rswr    0.17618
rswr actr    0.23286
rswr lnsr    0.03396
rswr rnwr    0.16015
rwwr actr    0.21463
rwwr lnsr    0.04973
rwwr rnwr    0.17618
lamp lamp    0.0872136
lamp lnsl    0.32986
flrb actp    0.4826
flrb pewp    0.058897
flrb pswp    0.068664
flrb pwwp    0.058897
flrb pnwp    0.068664
flrb trus    0.02934
lmhp actp    0.072
lmhp pewp    0.03
lmhp pswp    0.03
lmhp pwwp    0.03
lmhp pnwp    0.03
blst flrb    0.66
blst lmhp    0.15
blst pewp    0.030
blst pswp    0.030
blst pwwp    0.030
blst pnwp    0.030
pewp actp    0.314975
pewp pswp    0.09186
pewp pwwp    0.020119
pewp pnwp    0.09186
pswp actp    0.318739
pswp pwwp    0.07991
pswp pnwp    0.07991
pwwp actp    0.314975
pwwp pnwp    0.09186
pnwp actp    0.318739

mrt actr     0.16635
mrt lnsr     0.02965
mrt rewr     0.098
mrt rswr     0.124
```

```
mrt rwwr     0.098
mrt rnwr     0.124

/* The JJF vector */
/* row  col det. by conservation */
 rm_a  rm_a
 pl_a  pl_a
 lm_a  lm_a
 lamp  lmhl
 blst  trus
 lmhl  lmhl
 lnsr  rnwr
 cpt   rewr
 flrb lmhp
 actp  trus
 actr  rnwr
 rewr  rwwr
 rswr  rwwr
 rwwr  cpt
 rnwr  rewr
 pewp  trus
 pswp  trus
 pwwp  trus
 pnwp  trus
 trus  trus
 lmhp  trus
 lnsl  lmhl
 sup_a  sup_a
 flrr  flrr
 mrt    cpt

/* Radiant transmission coupling vector */
   rm_a  0
   pl_a  0
   lm_a  0
   lamp  0
   blst  0
   lmhl  0
   lnsr  lnsl
   flrr  0
   flrb  0
   actp  0
   actr  0
   rewr  0
   rswr  0
   rwwr  0
   rnwr  0
   pewp  0
```

```
   pswp  0
   pwwp  0
   pnwp  0
   trus  0
   lmhp  0
   lnsl  lnsr
   sup_a  0
   cpt   0
   mrt   0
/*                 Conduction/convection data            */
/* Num. of Conductors  */
   27

/* from  to    alpha    beta     gama    delta          */

/* Convection, Surfaces to air */
    rewr  rm_a    0.022122   0.333    0.0     1.0
    rswr  rm_a    0.025489   0.333    0.0     1.0
    rwwr  rm_a    0.022122   0.333    0.0     1.0
    rnwr  rm_a    0.025489   0.333    0.0     1.0

    actr  rm_a    0.014966   0.333    0.0     2.0
    [illegible]  rm_a    0.003469   0.333    0.0     2.0
    [illegible]  rm_a    0.047926   0.333    0.0     0.5

    pewp  pl_a    0.006912   0.333    0.0     1.0
    pswp  pl_a    0.007964  0.333    0.0    1.0
    pwwp  pl_a    0.006912   0.333    0.0     1.0
    pnwp  pl_a    0.007964   0.333    0.0     1.0

    flrb  pl_a    0.018436   0.333    0.0     2.0
    actp  pl_a    0.038910   0.333    0.0     0.5

    lmhp  pl_a    0.013241   0.333    0.0     0.5
    blst  pl_a    0.001064   0.333    0.0     0.5
    trus  pl_a    0.009638   0.333    0.0     1.0

    lmhl  lm_a    0.005091  0.333    0.0     2.0
    lnsl  lm_a    0.009016 0.333    0.0    0.5
    lamp  lm_a    0.007689 0.25     0.0    1.0


  /* Conduction inside solids */
    flrr  cpt    0.072917    0.0       0.0     1.0

    actp  actr    0.052424   0.0       0.0     1.0
    lnsl  lnsr    0.188858  0.0      0.0     1.0
    lmhl  lmhp    16520.210896    0.0        0.0      1.0
```

```
   blst  lmhp    0.527241     0.0       0.0     1.0

  /* Bulk convection between air nodes -- alpha overwritten by TYPE188 */
   pl_a -rm_a   0.113989  0.0        0.0     1.0
   sup_a -pl_a  0.113989  0.0       0.0     1.0  /* to close the system */
   rm_a -sup_a   0.113989 0.0       0.0     1.0

/* Vector indicating which is lamp surface */

 rm_a  0
 pl_a  0
 lm_a  0
 lamp  1
 blst  0
 lmhl  0
 lnsr  0
 flrr  0
 flrb  0
 actp  0
 actr  0
 rewr  0
 rswr  0
 rwwr  0
 rnwr  0
 pewp  0
 pswp  0
 pwwp  0
 pnwp  0
 trus  0
 lmhp  0
 lnsl  0
 sup_a  0
 cpt   0
 mrt   0
/* Vector indicating which is ballast surface */

 rm_a  0
 pl_a  0
 lm_a  0
 lamp  0
 blst  1
 lmhl  0
 lnsr  0
 flrr  0
 flrb  0
 actp  0
 actr  0
 rewr  0
```

```
rswr  0
rwwr  0
rnwr  0
pewp  0
pswp  0
pwwp  0
pnwp  0
trus  0
lmhp  0
lnsl  0
sup_a  0
cpt   0
mrt   0

/* Lamp luminous distribution vs. wave length */
/* No. of points on the curve */
   39

/* wavelength, output pairs */
     0        0        .3080        0          .3081          15e-4
         .3179   15e-4   .3180         0          .3290          0
         .3291   5e-4    .3389         5e-4       .3390          0
         .3610   10e-4   .3611         40e-4      .3709          40e-4
         .3710   15e-4   .4000         30e-4      .4001          90e-4
         .4099   90e-4   .4100         40e-4      .4310          50e-4
         .4311   195e-4  .4409         195e-4     .4410          65e-4
         .4750   85e-4   .5200         80e-4      .5410          108e-4
         .5411   190e-4  .5509         190e-4     .5510          135e-4
         .5730   175e-4  .5731         225e-4     .5829          225e-4
         .5830   190e-4  .6000         185e-4     .6150          150e-4
         .6250   110e-4  .6500         55e-4      .6750          30e-4
         .7000   20e-4   .7500         0          0.9999         0


/* Lamp relative power and luminous output curves */
/*  From Fig 2.1 of NBS Interim Report  */
/* No. of points */
 /*    20*/
/* Wall Temp (R)  Rel Q      Rel Lumens */
/*
    -27778          0.64          0.039
    255.5556          0.650          0.041
    261.1111          0.660          0.064
    266.6667          0.670          0.091
    272.2222          0.680          0.135
    277.7778          0.690          0.186
    283.3333          0.704          0.259
    288.8889          0.724          0.350
```

```
    294.4444        0.762        0.468
    300.0000        0.832        0.614
    305.5556        0.935        0.818
    308.3333        0.982        0.900
    311.1111        1.000        0.955
    313.8889        0.986        0.991
    316.6667        0.964        0.991
    322.2222        0.886        0.900
    327.7778        0.791        0.782
    333.3333        0.686        0.686
    368.3333        0.000        0.000
    33333.33        -955.0       -955.0
*/
20
    -27778      1.0    1.0
    255.5556    1.0    1.0
    261.1111    1.0    1.0
    266.6667    1.0    1.0
    272.2222    1.0    1.0
    277.7778    1.0    1.0
    283.3333    1.0    1.0
    288.8889    1.0    1.0
    294.4444    1.0    1.0
    300.0000    1.0    1.0
    305.5556    1.0    1.0
    308.3333    1.0    1.0
    311.1111    1.0    1.0
    313.8889    1.0    1.0
    316.6667    1.0    1.0
    322.2222    1.0    1.0
    327.7778    1.0    1.0
    333.3333    1.0    1.0
    368.3333    1.0    1.0
    33333.33    1.0    1.0

 /* Node reporters */
/*  No. of reporters */
      2
/*     File name        Writing interval   Nodes reported */
        out                  0.01              5
/* This one writes to a file.  Doesn't work too well due to lack of
 * synchronisation with  calculation interval. Best we can do is make
 * requested interval small, causing printing at the calculation points.
 */
      /*Node    No. items reported at node */
rm_a    1       -1
        lamp    3       -1   -2  -7
        blst    2       -1   -7
```

```
        sup_a   2       -1   -2
        trus    1       -1

/* This one sets up additional zone variables to pass back for TYPE188 output*/
/*     File name        Writing interval   Nodes reported */
         none                  0.0               4
      /*Node     No. items reported at node */
rm_a    2        -1   -2
        lamp    1       -7
        blst    1       -7
mrt 1 -1
/* HVACSIM+ TYPE188.f interface definition */


/* Description string  (60 char max on a separate line)  */
LIGHTS-based zone model-- 25 nodes, 4 massive, mrt

/* n_misc: Number of miscellaneous inputs to TYPE188 (always 5):*/
5
/* n_par: Number of TYPE188 parameters  (always 8)*/
8
/* n_saved: Number of TYPE188 saved values(always 4) */
4

/*  Massive nodes  in order of TYPE188 input list:. Include every node with
 *  mass greater than  min. recognised mass.
 */
/* n_mass: Number of massive nodes:*/
4
/* Node labels */
 lamp   blst   lmhp   trus

/*  Boundary nodes. Include enclosing surfaces and supply air nodes.
 *  List in order of TYPE188 input list.
 */

/* n_bound: Number of boundary nodes:*/
3
/* Node labels */
/*sup_a   flrr   flrb   rewr   rswr   rwwr   rnwr   pewp  pswp  pwwp  /*pnwp */
sup_a   rewr flrr

/* nif: Number of TYPE 188 input flows (used to set mass flow type conductances */
1

/* nalf = Number of mass flow type conductances -- m_dot*Cp */
3
```

```
/* nalf triplets: {downstream-node upstream-node input-flow-index} */

pl_a rm_a 1
rm_a sup_a 1
sup_a pl_a 1

/*nof: Number of TYPE188 output flows */
1
/* Node labels for temperatures of output flows */
pl_a


/* Distribution of occupant, equipment,  and solar, SENSIBLE heat gains*/
/* node   solar    occupant      equipment        */

 rm_a    0.0       0.5          0.5
 pl_a    0.0       0.0          0.0
 lm_a    0.0       0.0          0.0
 lamp    0.0       0.0          0.0
 blst    0.0       0.0          0.0
 lmhl    0.0       0.0          0.0
 lnsr    0.0422    0.0211     0.0211
 cpt     0.2242    0.1121     0.1121
 flrb    0.0       0.0          0.0
 actp    0.0       0.0          0.0
 actr    0.1822    0.0910     0.0910
 rewr    0.1281    0.0641     0.0641
 rswr    0.1476    0.0738     0.0738
 rwwr    0.1281    0.0641     0.0641
 rnwr    0.1476    0.0738     0.0738
 pewp    0.0       0.0          0.0
 pswp    0.0       0.0          0.0
 pwwp    0.0       0.0          0.0
 pnwp    0.0       0.0          0.0
 trus    0.0       0.0          0.0
 lmhp    0.0       0.0          0.0
 lnsl    0.0       0.0          0.0
 sup_a   0.0       0.0          0.0
 flrr    0.0       0.0          0.0
 mrt     0.0       0.0          0.0
/* Number of air nodes */
 3
/* Air node labels  (used to determine air mass for humidity diff eq)*/
rm_a pl_a lm_a
 /* That's all folks! */
```

A.3 Simulation Definition

```
SUPERBLOCK 1
     BLOCK 1
         UNIT  1     TYPE189 - THREE NODE ZONE WALL
         UNIT  2     TYPE188 - LIGHTS-based zone model-- 25 nodes, 4 massive
         UNIT  3     TYPE188 - LIGHTS-based zone model-- 25 nodes, 4 massive
         UNIT  4     TYPE189 - THREE NODE ZONE WALL
         UNIT  5     TYPE189 - THREE NODE ZONE WALL
---------------------------------------------------

UNIT   1      TYPE 189
THREE NODE ZONE WALL

1     INPUTS:
       POWER             3 - LEFT HEAT FLUX
       POWER             4 - RIGHT HEAT FLUX
       TEMPERATURE       5 - LEFT SURFACE TEMPERATURE
       TEMPERATURE       7 - MIDDLE TEMPERATURE
       TEMPERATURE       8 - RIGHT SURFACE TEMPERATURE

2     OUTPUTS:
       TEMPERATURE       5 - LEFT SURFACE TEMPERATURE
       TEMPERATURE       7 - MIDDLE TEMPERATURE
       TEMPERATURE       8 - RIGHT SURFACE TEMPERATURE

3     PARAMETERS:
         0.100000      LEFT CONDUCTANCE (KW/C)
         0.100000      RIGHT CONDUCTANCE (KW/C)
          264.200      LEFT THERMAL MASS (KW-S/C)
          10.0000      MIDDLE THERMAL MASS (KW-S/C)
          264.200      RIGHT THERMAL MASS (KW-S/C)
---------------------------------------------------

UNIT   2      TYPE 188
LIGHTS-based zone model-- 25 nodes, 4 massive, mrt

1     INPUTS:
       CONTROL           1 - Fraction of nominal number of occupants
       CONTROL           2 - Fraction of nominal equipment power
       CONTROL           3 - Fraction of nominal power to lights
       POWER             1 - Solar gain through glass
       HUMIDITY RATIO    2 - Zone leaving humidity ratio
       FLOW              1 - Supply air flow 1
       HUMIDITY RATIO    1 - Humidity ratio of supply air flow 1
       TEMPERATURE       9 - lamp Temperature
       TEMPERATURE       1 - blst Temperature
```

```
       TEMPERATURE      2 - lmhp Temperature
       TEMPERATURE      3 - trus Temperature
       TEMPERATURE      4 - Temperature of boundary sup_a
       TEMPERATURE      5 - Temperature of boundary rewr
       TEMPERATURE     18 - Temperature of boundary flrr

2     OUTPUTS:
       TEMPERATURE      9 - lamp Temperature
       TEMPERATURE      1 - blst Temperature
       TEMPERATURE      2 - lmhp Temperature
       TEMPERATURE      3 - trus Temperature
       HUMIDITY RATIO   2 - Zone leaving humidity ratio
       TEMPERATURE      6 - pl_a Temperature
       POWER            2   Net heat to boundary sup_a
       POWER            3 - Net heat to boundary rewr
       POWER           13 - Net heat to boundary flrr
       TEMPERATURE     16 - Temperature of rm_a
       POWER            7 - Net heat loss from rm_a
       POWER            8 - Source heat at lamp
       POWER           11 - Source heat at blst
       TEMPERATURE     20 - Temperature of mrt

3     PARAMETERS:
          3.00000     Nominal Number Of Occupants (-)
         0.131900     Total Heat Loss Per Occupant (kW/person)
         0.500000     Occupant  sensible fraction (-)
          1.00000     Nominal Equipment Power (kW)
          1.00000     Equipment Sensible Fraction (-)
          1.00000     Nominal Lighting Power (kW)
         0.150000     Fraction lighting power to ballast (-)
          50000.0     Nominal Light output (Lumens)
---------------------------------------------------

UNIT   3      TYPE 188
LIGHTS-based zone model-- 25 nodes, 4 massive, mrt

1     INPUTS:
       CONTROL          4 - Fraction of nominal number of occupants
       CONTROL          5 - Fraction of nominal equipment power
       CONTROL          6 - Fraction of nominal power to lights
       POWER            5 - Solar gain through glass
       HUMIDITY RATIO   4 - Zone leaving humidity ratio
       FLOW             2 - Supply air flow 1
       HUMIDITY RATIO   3 - Humidity ratio of supply air flow 1
       TEMPERATURE     15 - lamp Temperature
       TEMPERATURE     10 - blst Temperature
       TEMPERATURE     11 - lmhp Temperature
       TEMPERATURE     12 - trus Temperature
```

```
      TEMPERATURE       13 - Temperature of boundary sup_a
      TEMPERATURE        8 - Temperature of boundary rewr
      TEMPERATURE       19 - Temperature of boundary flrr

2     OUTPUTS:
      TEMPERATURE       15 - lamp Temperature
      TEMPERATURE       10 - blst Temperature
      TEMPERATURE       11 - lmhp Temperature
      TEMPERATURE       12 - trus Temperature
      HUMIDITY RATIO     4 - Zone leaving humidity ratio
      TEMPERATURE       14 - pl_a Temperature
      POWER              6 - Net heat to boundary sup_a
      POWER              4 - Net heat to boundary rewr
      POWER             14 - Net heat to boundary flrr
      TEMPERATURE       17 - Temperature of rm_a
      POWER              9 - Net heat loss from rm_a
      POWER             10 - Source heat at lamp
      POWER             12 - Source heat at blst
      TEMPERATURE       21 - Temperature of mrt

3     PARAMETERS:
          3.00000      Nominal Number Of Occupants (-)
          0.131900     Total Heat Loss Per Occupant (kW/person)
          0.500000     Occupant  sensible fraction (-)
          1.00000      Nominal Equipment Power (kW)
          1.00000      Equipment Sensible Fraction (-)
          1.00000      Nominal Lighting Power (kW)
          0.150000     Fraction lighting power to ballast (-)
          50000.0      Nominal Light output (Lumens)
-----------------------------------------------

UNIT   4      TYPE 180
THREE NODE ZONE WALL

1     INPUTS:
      POWER             13 - LEFT HEAT FLUX
      POWER             15 - RIGHT HEAT FLUX
      TEMPERATURE       18 - LEFT SURFACE TEMPERATURE
      TEMPERATURE       22 - MIDDLE TEMPERATURE
      TEMPERATURE       23 - RIGHT SURFACE TEMPERATURE

2     OUTPUTS:
      TEMPERATURE       18 - LEFT SURFACE TEMPERATURE
      TEMPERATURE       22 - MIDDLE TEMPERATURE
      TEMPERATURE       23 - RIGHT SURFACE TEMPERATURE

3     PARAMETERS:
          0.603000     LEFT CONDUCTANCE (KW/C)
```

```
        0.603000     RIGHT CONDUCTANCE (KW/C)
         470.700     LEFT THERMAL MASS (KW-S/C)
         941.500     MIDDLE THERMAL MASS (KW-S/C)
         470.700     RIGHT THERMAL MASS (KW-S/C)
---------------------------------------------------

UNIT   5      TYPE 189
THREE NODE ZONE WALL

1     INPUTS:
       POWER            14 - LEFT HEAT FLUX
       POWER            16 - RIGHT HEAT FLUX
       TEMPERATURE      19 - LEFT SURFACE TEMPERATURE
       TEMPERATURE      24 - MIDDLE TEMPERATURE
       TEMPERATURE      25 - RIGHT SURFACE TEMPERATURE

2     OUTPUTS:
       TEMPERATURE      19 - LEFT SURFACE TEMPERATURE
       TEMPERATURE      24 - MIDDLE TEMPERATURE
       TEMPERATURE      25 - RIGHT SURFACE TEMPERATURE

3     PARAMETERS:
        0.603000     LEFT CONDUCTANCE (KW/C)
        0.603000     RIGHT CONDUCTANCE (KW/C)
         470.700     LEFT THERMAL MASS (KW-S/C)
         941.500     MIDDLE THERMAL MASS (KW-S/C)
         470.700     RIGHT THERMAL MASS (KW-S/C)
---------------------------------------------------
Initial Variable Values:

FLOW             1 ->   0.113400    (kg/s)
FLOW             2 ->   0.113400    (kg/s)
TEMPERATURE      1 ->    23.8889    (C)
TEMPERATURE      2 ->    23.8889    (C)
TEMPERATURE      3 ->    23.8889    (C)
TEMPERATURE      4 ->    17.0000    (C)
TEMPERATURE      5 ->    23.8889    (C)
TEMPERATURE      6 ->    23.8889    (C)
TEMPERATURE      7 ->    23.8889    (C)
TEMPERATURE      8 ->    23.8889    (C)
TEMPERATURE      9 ->    23.8889    (C)
TEMPERATURE     10 ->    23.8889    (C)
TEMPERATURE     11 ->    23.8889    (C)
TEMPERATURE     12 ->    23.8889    (C)
TEMPERATURE     13 ->    20.0000    (C)
TEMPERATURE     14 ->    23.8889    (C)
TEMPERATURE     15 ->    23.8889    (C)
TEMPERATURE     16 ->    23.8889    (C)
```

```
TEMPERATURE      17 ->      23.8889     (C)
TEMPERATURE      18 ->      23.8889     (C)
TEMPERATURE      19 ->      23.8889     (C)
TEMPERATURE      20 ->      23.8889     (C)
TEMPERATURE      21 ->      23.8889     (C)
TEMPERATURE      22 ->      23.8889     (C)
TEMPERATURE      23 ->      23.8889     (C)
TEMPERATURE      24 ->      23.8889     (C)
TEMPERATURE      25 ->      23.8889     (C)
CONTROL           1 ->           0.     (-)
CONTROL           2 ->           0.     (-)
CONTROL           3 ->           0.     (-)
CONTROL           4 ->           0.     (-)
CONTROL           5 ->           0.     (-)
CONTROL           6 ->           0.     (-)
POWER             1 ->           0.     (kW)
POWER             2 ->           0.     (kW)
POWER             3 ->           0.     (kW)
POWER             4 ->           0.     (kW)
POWER             5 ->           0.     (kW)
POWER             6 ->           0.     (kW)
POWER             7 ->           0.     (kW)
POWER             8 ->           0.     (kW)
POWER             9 ->           0.     (kW)
POWER            10 ->           0.     (kW)
POWER            11 ->           0.     (kW)
POWER            12 ->           0.     (kW)
POWER            13 ->           0.     (kW)
POWER            14 ->           0.     (kW)
POWER            15 ->           0.     (kW)
POWER            16 ->           0.     (kW)
HUMIDITY RATIO    1 ->     0.500000E-02(kg/kg)
HUMIDITY RATIO    2 ->     0.100000E-01(kg/kg)
HUMIDITY RATIO    3 ->     0.500000E-02(kg/kg)
HUMIDITY RATIO    4 ->     0.100000E-01(kg/kg)
---------------------------------------------------
Simulation Error Tolerances:

1      RTOLX=    0.100000E-03     ATOLX=    0.100000E-04
       XTOL=     0.200000E-03     TTIME=     1.00000

SUPERBLOCK 1
2      FREEZE OPTION 0       SCAN OPTION 0
---------------------------------------------------
The following are Boundary Variables in the simulation:

FLOW              1
FLOW              2
```

```
TEMPERATURE      4
TEMPERATURE     13
CONTROL          3
CONTROL          6
CONTROL          2
CONTROL          5
POWER            1
POWER            5
HUMIDITY RATIO   1
HUMIDITY RATIO   3
---------------------------------------------------
The following are the reported variables:


SUPERBLOCK 1       REPORTING INTERVAL    60.0000
FLOW             1
FLOW             2
TEMPERATURE      1
TEMPERATURE      2
TEMPERATURE      3
TEMPERATURE      4
TEMPERATURE      5
TEMPERATURE      6
TEMPERATURE      8
TEMPERATURE     10
TEMPERATURE     11
TEMPERATURE     12
TEMPERATURE     13
TEMPERATURE     14
TEMPERATURE      9
TEMPERATURE     15
TEMPERATURE     16
TEMPERATURE     17
TEMPERATURE     20
TEMPERATURE     21
POWER            3
POWER            4
POWER            2
POWER            6
POWER            7
POWER            8
POWER            9
POWER           10
POWER           11
POWER           12
```

Appendix B

Program Implementation and Limits

B.1 About the Implementation

B.1.1 Where Things Are

Most of the General zone model is implemented as a group of functions written in the C programming language. These functions are stored in the following files:

```
chf_h.c
datain.c
dynamic.c
echo.c
evaluate.c
factin.c
genbnd.c
hslights.c
jol.c
jos.c
minv.c
mrt.c
nextt.c
nwrite.c
simul.c
spline.c
stripcom.c
tmod.c
transfer.c
util.c
vcond.c
```

Additionally, the following *include* files are required:

```
lights.h
```

```
lightvar.h
lvar2.h
macros.h
nwrite.h
```

Currently, these files are in the directory:

```
/home/atlas/efs/hlights/source/
```

In this same directory there are several other source files indirectly related to the zone model. These are:

```
build_typar.c    --- Builds the typar.dat fragment for the zone model.
ptypar.c         --- Patches the  new fragment into the typar.dat file
fix.c            --- Fixes a Sunos bug
lookup.c         --- Supports TYPE190
```

The C functions are invoked by an HVACSIM$^+$ FORTRAN subroutine called TYPE188. It is stored in:

```
type188.f
```

which is in the directory:

```
/home/atlas/efs/hlights/hs/
```

In the same directory as the TYPE188 subroutine there are several other files indirectly related to the zone model:

```
Makefile4 --- "make" file for creating executable hsld
type187.f --- Outside surface  model (air film \& radiation)
type189.f --- Three node wall model
type190.f --- Table lookup and variable order interpolation
type98.f  --- Massless wall model
type99.f  --- Null "zone" to test wall models
zone188.dat --- the Example zone definition file
```

The miscellaneous subroutines TYPE187, TYPE189, TYPE98, and TYPE99 are straightforward HVACSIM$^+$ components that are sometimes useful in building complete models. Usage of TYPE189 has been demonstrated in the example problem in this manual. TYPE98 is an alternate wall model, but without mass. TYPE99 is a "null zone," i.e., a component to place between two wall components with heat and temperature inputs and outputs like the zone; it is sometimes useful for testing behaviour of wall models.

The TYPE190 subroutine is a component that can be used to generate time-dependent variables in a simulation, as an alterative to the boundary file. It performs variable order interpolation, with the order read from the input file. Values can be specified to repeat in a cycle. See the type190.f file for usage instructions. A typical data file read by type190 is in:

```
/home/atlas/efs/hlights/hs/pfile.dat
```

After compilation, the executable, called *hsld*, is placed in the directory: /home/atlas/efs/bin

B.1.2 Compilation and Linkage

To compile and link the zone model with HVACSIM+ go to the hs directory and execute:

```
% make -f Makefile4 debug <return>
```

This creates an executable file called *hsld* which is the HVACSIM+ program linked with the zone model and related functions mentioned above. Makefile4 can be examined to see the details.

B.1.3 Revising *typar.dat*

Because the HVACSIM+ interface is determined by the zone definition file (zone188.dat) it is necessary to update the HVACSIM+ typar.dat file when there are any *structural* changes in the zone definition. Structural changes means those that would change the number and meanings of the TYPE188 inputs and outputs. Mere changes to descriptive data such as areas or conductances or mass (other than from nonzero to zero or *vice versa*) do not change typar.dat.

The provided program *build_typar*, found in the same directory as the C source code, may be used to update typar.dat. To execute this program from the *hs* directory type:

```
% ../source/build_typar zone188.dat out_fn 188 <return>
```

where *out_fn* is a chosen output file name to contain the new TYPE188 typar.dat *fragment*. To patch this fragment into the typar.dat file, use the *ptypar* program:

```
% ../source/ptypar typar.dat newtypar.dat out_fn 188 <return>
```

Then, after a visual check of the new file, replace the old with the new:

```
% mv newtypar.dat typar.dat  <return>
```

The HVACSIM+ generator program *hg* will now reflect the new TYPE188 interface.[1]

B.1.4 Using the Model with HVACSIM+

The *hsld* created as in Section B.1.2 is used in the normal HVACSIM+ manner. However, upon the first call to the TYPE188 component model it will expect to find zone188.dat in the same directory. If this file cannot be found, the program will abort with an error message. If found, zone188.dat will be read and the information therein will be stored in internal data structures for use on all subsequent calls.

There can be as many instances of TYPE188 as desired in a simulation. However, since there is but one zone188.dat file, all of the zones will have identical features, differing only in the parameter values. A screen message indicates each instantiation; after the first instantiation, the title string described in Section 3.2.8 is displayed.

B.2 Program limits

Notes:

1. To change any of these limits, locate it in the C header file, set it to the new value, and re-make HVACSIM$^+$.
2. As can be seen, the multiple band feature within short and long wave lengths is disabled by the settings of MS1 and ML1. This saves considerable memory, and it is unlikely that multiband analysis will be of much interest.
3. Arrays are not wildly over dimensioned. In fact, the settings are close to the size of the example problem because it is probably about as detailed as one would want for typical usage.
4. It is believed that all dimension limits are checked at input to avoid exceeding array bounds. However, it would be prudent to check inputs against Table B.1 if larger problems are formulated.

[1] Both *build_typar* and *pltypar* give usage hints if typed without arguments.

Table B.1: Program Limits

Item	Program Constant	Maximum Number
Nodes	N_SIZE	50
Massless nodes (unkn. temperatures)	NT1	50
Convection and conduction conductors	NIC1	50
Lamp spectral curve points	NXY1	39
Short wave bands	MS1	1
Long wave bands	ML1	1
Input view factors	KNOWN_FACTORS	50
Node file writers	MAX_WRITERS	2
Points in lamp temperature curves	NMAX_SPL	20
Node values reported	MAX_VARS	5
Total items reported	MAX_REPORT	20