TYPE 701: BASEMENT CONDUCTION (INTERFACES WITH TYPE 56)

General Description

This routine models the heat transfer from a basement (typically four walls and a floor, all made of concrete) to the soil surrounding the five surfaces of the basement. The heat transfer is assumed to be conductive only and moisture effects are not accounted for in the model. The model relies on a 3-dimensional finite difference model of the soil and solves the resulting inter-dependent differential equations using a simple iterative method. The user enters the temperature of the zone side surfaces of the floor and walls as well as the U-values of the same. The user is also asked to enter the soil properties, soil grid geometry, and the conditions outside of the basement (near-field). The initial soil conditions may be calculated from the Kasuda correlation [1] or read from a user-supplied data file. The surface conditions for the near-field and far-field soil may be calculated in one of three ways; 1) from the Kasuda correlation, 2) from an energy balance on the surface plane, 3) provided as an input to the model. The near-field soil temperatures are affected by the heat transfer from the basement. The far-field soil temperatures are only affected by the surface conditions (time of year) and depth.

This basement model is intended to be used in conjunction with Type56. If you wish to use this model in conjunction with a simplified building model, you should use Type702 instead.

Nomenclature

m	-	Mass.
C_p	-	Specific heat.
$\dot{Q}_{in}$	-	The rate at which energy enters a fluid, soil or slab node.
$\dot{Q}_{out}$	-	The rate at which energy exits a fluid, soil or slab node.
$T_{x,y,z}$	-	The temperature of a given soil node.
x	-	The distance along the length direction.
y	-	The distance along the width direction.
z	-	The depth dimension (node 1 is at the surface, increasing downwards).
k	-	Thermal conductivity.
dx	-	The x direction dimension of a soil or slab node.
dy	-	The y direction dimension of a soil or slab node.
dz	-	The z direction dimension of a soil or slab node.
$T_{surface}$	-	The surface temperature of a node exposed to ambient conditions.

Detailed Description

1. Appropriate Building Models

Simplified building models such as the lumped capacitance or degree day models (for example Types 660, 80, and 12) lack two concepts on which this version of the basement conduction model depend. First, they do not contain the concept of a boundary wall and second, they do not perform the radiation

exchange calculations that determine interior surface temperatures of all walls, floors and ceilings as does Type56. By defining a wall as a boundary wall in Type56, one assumes that there is either a known temperature on the other (non-zone) side, or that the temperature on the non-zone side is identical to the temperature in the zone. In both cases, the temperature specified for the non-zone side is the surface temperature at the interface between the non-zone side of the wall and its surroundings, as shown for a wall and a floor in Figure 1. In the case of basements, the temperature would typically be at the interface between the wall or floor and the soil.

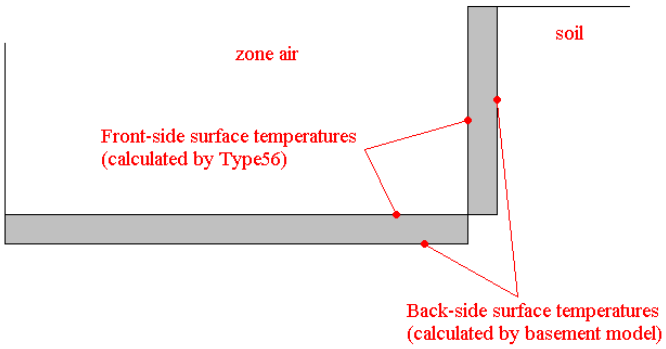


Figure 1: Boundary Wall Definition

Because it is the interface temperature and not the surroundings temperature (provided that h back for the wall is set to zero) taken by Type56 as an input, a special basement model is required. The capacitance effects of the basement must be handled by the building model and the interaction between the basement and its surroundings must be handled by the slab model. Type701 includes such as scheme. Type702 does NOT and should be used in conjunction with other (non Type56) building models.

To use Type701, one defines five basement surfaces in Prebid (a floor and four walls) as boundary walls with a "user defined" temperature as an input (as opposed to as a schedule or a constant value) and with a back-side heat transfer coefficient of zero to indicate that it is a surface temperature and not an air temperature on the back side of the wall. The boundary walls should contain all the layers comprising the wall or floor (carpeting, pad, concrete, drywall, etc.) The user then generates the Type56 files and checks the .inf results, entering the U values of all five surfaces in the appropriate Type701 parameter fields. The U-value entered for the slab model should be for the wall only and should not contain the front or back-side convection coefficients. The user will also have to specify that one of the outputs from Type56 is the inside surface temperature of this boundary wall. The user then connects the appropriate surface temperature outputs from Type56 to this model's inputs and connects the appropriate temperature outputs of this model back to the boundary wall temperatures required by Type56. Note that the basement's thermal properties are not specified in Type701; these are accounted for within Type56 and by the definition of the boundary floor and boundary walls. In essence Type701 does not calculate any of the thermal behavior of the basement, it takes the air/basement surface boundary temperatures and computes the basement surface/soil boundary temperatures required by Type56.

2. Basement Surfaces and Surroundings

Type701 divides the basement and its surroundings into three parts. First is the basement itself, for which the user specifies the dimensions of the floor and four walls as shown in Figure 2.

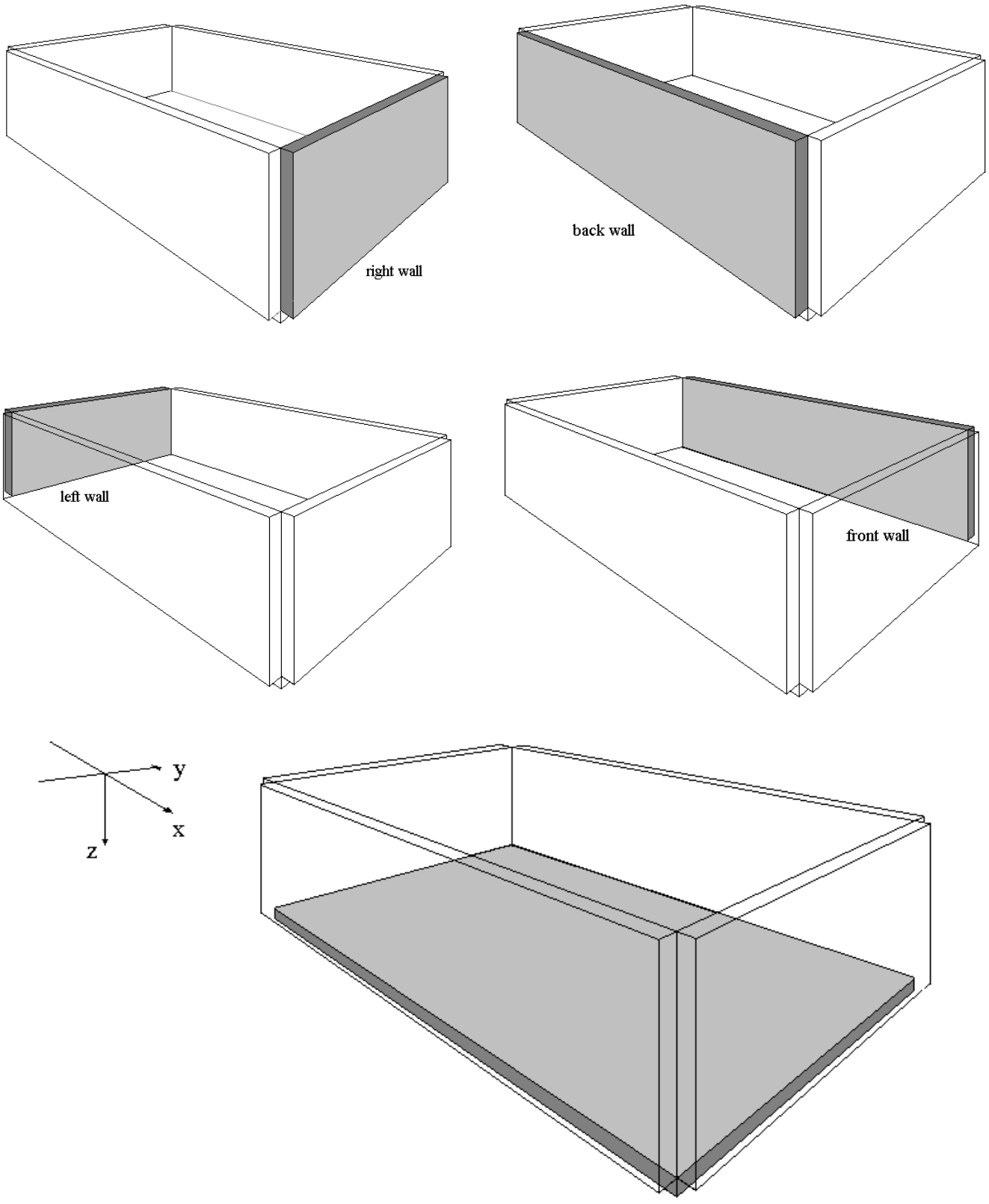


Figure 2: Basement Surface Definitions and Coordinate System

Note that while the user does specify the number of nodes in the x, y, and z directions, these are used ONLY for sizing the soil nodes outside the basement boundaries. This model does not perform any thermal computations on the basement walls and floors but leaves those to the building model to Type56.

The basement is assumed to be embedded in soil, for which the user must specify the thermal properties. It is assumed that the basement walls do not extend above the surface of the surrounding soil, meaning that no radiation is incident on the basement. Walls that extend above the soil grade should be defined as EXTERNAL walls in Prebid. The soil volume surrounding the basement in the x, y and z directions as shown in Figure 3 is referred to as the near-field (light gray area). Nodes contained in the near-field can vary in size in all three dimensions (user-specified), usually becoming larger as they get farther from the basement surfaces, and are included in the basement energy balance. The near-field is in turn surrounded by the far-field, which is assumed to be an infinite energy sink/source. In other words, energy transfer with the far-field does not result in a temperature change of the far-field. Temperatures in the far-field are governed only by depth and time of year. Users have a number of options as to how they wish to treat the soil in both the near and far-fields as discussed in Section 3.

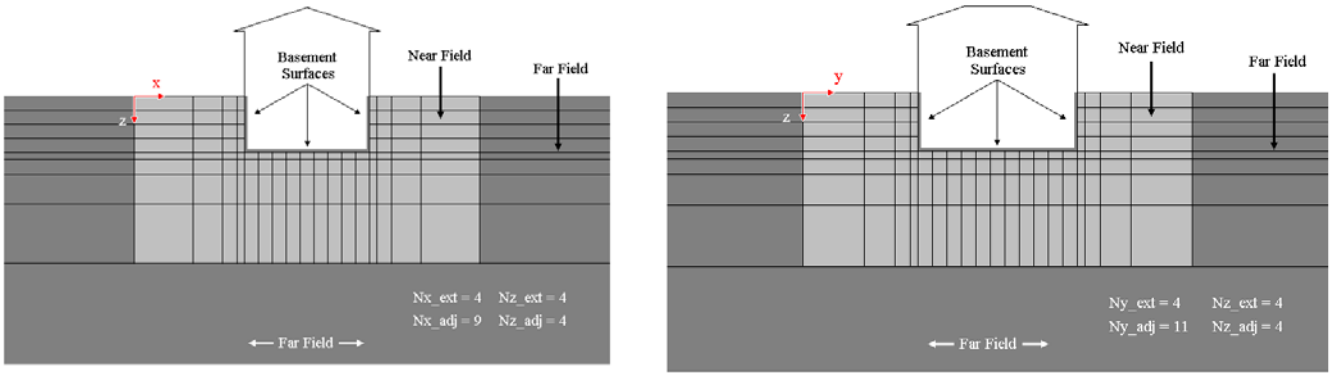


Figure 3: Basement Surface, Near and Far Field Dimensions

The number of and sizes of the soil nodes directly beneath the basement floor, directly outside the basement walls, and in the near-field are specified as PARAMETERS to the model. The x, y, z origin is taken at the corner of the near-field, proceeds towards the basement, through the basement, back into the soil and back towards the far corner of the near-field.

3. Ground Temperature Options

Users are asked to specify one of three ground temperature options using parameter 23. The same assumption is made for both the near and the far-field.

The first option is to employ an energy balance on the soil surface to calculate the surface temperature. In this option, the user provides the ambient temperature, sky temperature, and the amount of incident solar radiation on the soil surface to the model as inputs. An energy balance is applied to the surface to determine the surface temperature. Conduction to the soil nodes provides the heat transfer to the ground from the surface. The Kasuda ground temperature profile [1] (which calculates a depth dependent soil temperature based on the average annual surface temperature, the amplitude of the annual surface temperature, and the day of the year at which the minimum annual surface temperature occurs) sets the initial ground temperature profile for the near-field and for the far-field.

The second option is to use the Kasuda correlation to set the surface temperature as a function of the time of the year. In the near field, the Kasuda correlation is used to set the initial temperature profile in the soil and to obtain a time dependent surface temperature. The temperature of near field soil nodes depends upon conduction effects from neighboring nodes and from the Kasuda calculated surface temperature. In the far field, the Kasuda correlation is used to set the temperature of all nodes. The temperature of these nodes will change, but only as a function of depth and time of year.

The third option is for the user to supply the surface temperature as an INPUT to the model. In both the near and far-fields, the Kasuda correlation is used to set the initial temperature profile in the soil. The near-field nodes then change temperature due to conduction effects from other nodes (vertical direction only in the far-field) influenced by the surface temperature provided by the user. The far-field nodes change temperature as influenced by time of year but not by energy transferred to them by near-field nodes.

4. Energy Balances

The basic energy balance on a node contained in a basement surface or in the soil is shown in Equation 1:

$$mC_p \frac{dT}{dt} = \dot{Q}_{in} - \dot{Q}_{out} \qquad \text{(Eq. 1)}$$

The equations describing Q_{in} and Q_{out} change depending upon the type of node and its location. Three types of nodes exist: internal nodes, boundary nodes (between a basement surface and the near-field or between the near-field and the far-field for example), and surface nodes.

4.1 Internal Near Field Soil Nodes

If a node is contained entirely within the near-field and does not border either the far-field or a basement surface, it's energy balance is made up of purely conductive terms. The equations for Q_{in} and Q_{out} are:

$$\dot{Q}_{in} = \frac{k_{soil}\, dy\, dz}{x_i - x_{i-1}}\left(\overline{T}_{x-1,y,z} - T_{x,y,z}\right) + \frac{k_{soil}\, dx\, dz}{y_i - y_{i-1}}\left(\overline{T}_{x,y-1,z} - T_{x,y,z}\right) + \frac{k_{soil}\, dx\, dy}{z_i - z_{i-1}}\left(\overline{T}_{x,y,z-1} - T_{x,y,z}\right) \qquad \text{(Eq. 2)}$$

$$\dot{Q}_{out} = \frac{k_{soil}\, dy\, dz}{x_{i+1} - x_i}\left(T_{x,y,z} - \overline{T}_{x+1,y,z}\right) + \frac{k_{soil}\, dx\, dz}{y_{i+1} - y_i}\left(T_{x,y,z} - \overline{T}_{x,y+1,z}\right) + \frac{k_{soil}\, dx\, dy}{z_{i+1} - z_i}\left(\overline{T}_{x,y,z} - T_{x,y,z+1}\right) \qquad \text{(Eq. 3)}$$

It should be noted that some internal soil nodes may have an additional resistance term added because Type701 allows insulation on the perimeter of the basement to extend down below the basement floor as far as desired.

4.2 Boundary Nodes

Two types of boundary nodes exist: nodes on the boundary between the near and far-fields, and nodes on the boundary between the basement and the near-field.

Nodes in the near-field on the boundary with the far-field are governed purely by conduction. The far-field temperature to which the node conducts is not affected by energy passing from the node to the far-field, only by time of year and depth as given by the Kasuda correlation (for surface mode 2) or by conduction in the vertical direction (surface modes 1 and 3). Nodes at the bottom corners of the near-field can conduct to two different far-field temperatures while nodes only along the depth of the near-field conduct to a single far-field temperature (along the horizontal plane). The conduction length between the node and the far-field is one-half of the corresponding nodal distance. For example, the conduction length between a node along the bottom of the near-field and the far-field is dz/2.

Conduction between the near and far-fields may be neglected, if desired, by setting parameters 15 and 16 to the appropriate values.

Nodes on the boundary between a basement surface and near-field are also governed by conduction but may have an additional pure resistance built into their energy balance due to the specification of additional insulation beneath the floor or on the outside of the walls.

4.3 Surface Nodes

As stated in Section 1, Type701 does not require that the user specify the thermal properties of the slab itself; these are taken into account by the Type56 building model itself. Type701 takes the temperature of the basement surface-zone interface generated by Type56 and performs a conduction energy balance between that temperature, and the temperature of each soil node outside the basement, which are INPUTS back to the Type56 model)

It is important to remember that the surface temperature ($T_{surface}$ in Figure 4) is the same for calculations to all soil nodes for a given surface but that the temperatures of each soil node (T_{soil} in Figure 4) change. The boundary temperatures for the soil node/basement surface interface are computed assuming that the conductivity of the basement surface material and the conductivity of the soil are the same.

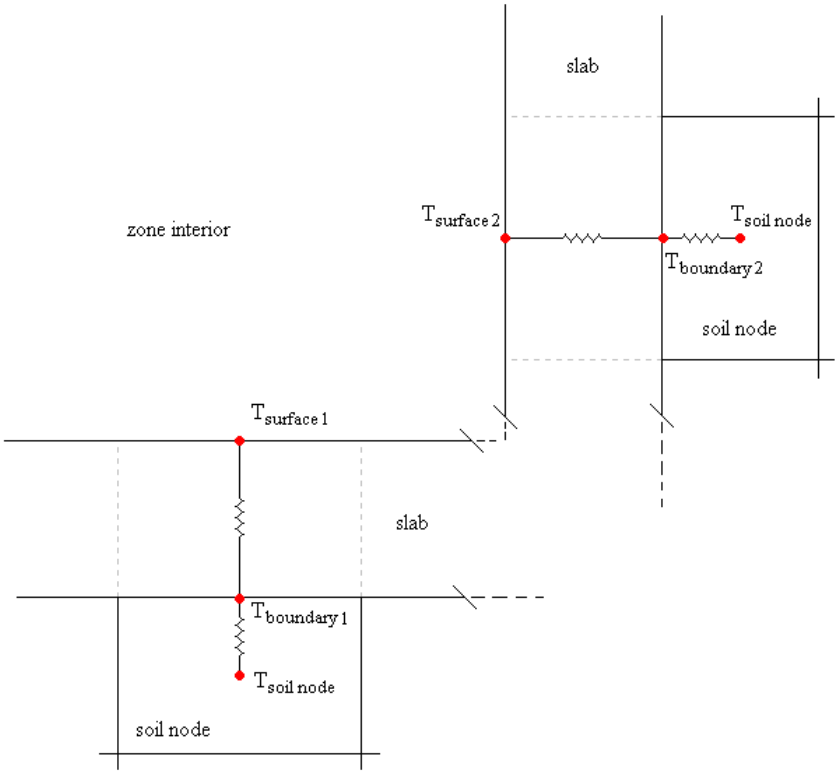


Figure 4: Energy Balance on Surface Nodes

Energy balances on the bottom surface of the floor and the outside of the basement walls are written using the form shown in Equation 1. The Q_{in} and Q_{out} terms in this case are:

$$\dot{Q}_{in} = U_{BoundaryWall}\left(T_{surface} - T_{boundary}\right) \quad \text{(Eq. 4)}$$

$$\dot{Q}_{out} = \frac{k_{soil}\, dx\, dy}{dz/2}\left(T_{boundary} - T_{soil,node}\right) \quad \text{(Eq. 5)}$$

Once the boundary temperatures are know, they are averaged for each of the five basement surfaces individually and are provided as outputs to Type701. These outputs are typically connected back to the Type56 building model as an inputs.

5. Model Execution Speed

Because the near-field volume of soil modeled by this component is broken up into a large number of nodes, model execution speed is often significantly reduced. Execution speed can be increased by reducing the number of nodes in the near field but this in turn sacrifices accuracy. As an alternative, the convergence tolerance on the soil temperatures contained within the near-field is provided as a PARAMETER to this model. Users may plot the energy imbalance output of the model and loosen the tolerances to increase speed while making sure that the energy imbalance does not increase inordinately.

References

[1] Kasuda, T., and Archenbach, P.R. "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States", ASHRAE Transactions, Vol. 71, Part 1, 1965