TYPE 460 : HYPOCAUST (AIR-TO-SOIL EXCHANGER)

General Description

This component models an air-to-soil heat exchanger. It accounts for sensible as well as latent exchanges between airflow and tubes, diffusion into surrounding soil, frictional losses and flow of condensed water along the tubes. Local heating from integrated fan motor can be taken into account at tube inlet or outlet. Direction of airflow can be controlled (stratification in case of heat storage) and flexible geometry allows for inhomogeneous soils as well as diverse border conditions.

Nomenclature

List hereafter covers all symbols used in the mathematical description of the model (other symbols are defined directly in the component configuration section). When as here, symbols in text account for currently described node and timestep, while subscripts are used to reference neighbour nodes or previous timestep.

ClatWat	Latent heat of water
CmAir	Mass-specific heat of air
CmVap	Mass-specific heat of vapour
CmWat	Volume-specific heat of water
CvSoil	Volume-specific heat of soil
CvTub	Volume-specific heat of tube
Ctub	Circumference of tube
Dt	Internal timestep
Dl	Node width (along x, y or z)
Dtub	Hydraulic diameter of tube
Fair	Airflow in tube
FairTot	Airflow, total (over tubes and modules)
Hrel	Relative humidity
Hrat	Absolute humidity (vapour pressure)
Hsat	Absolute humidity (vapour pressure) at saturation
Kair	Air/tube exchange coefficient
Kbord	Heat conduction coefficient of border (pondered, including *Rsurf*)
Ksoil	Heat conduction coefficient to neighbour node or surface (including *Rsurf*)
LamSoil	Heat conductivity of soil
LamTub	Heat conductivity of tube
MmolAir	Molar mass of air
MmolWat	Molar mass of water
Mair	Mass of air exchanged between airflow and tube superficial layer
Mwat	Mass of free water
MwatIn	Mass of water flowing into node
MwatInf	Mass of water infiltrating into node

MwatLat	Mass of water cond./evap.
MwatOut	Mass of water flowing or ejected out of node
Pfric	Energy rate of frictional losses
Pint	Energy rate of tube or soil internal gains
Plat	Energy rate of latent air-tube heat exchange
Psbl	Energy rate of sensible air-tube heat exchange
Psoil	Energy rate of heat diffused by neighbour nodes
Pwat	Energy rate of free water internal losses
PrAir	Pressure of air
Rsurf	Surface heat resistance
Rfric	Friction coefficient of tubes
RhoAir	Specific weight of air
Sair	Section of tube
Sbord	Area of border
Ssoil	Lateral area of soil node
Stub	Lateral area of tube node
Tair	Temperature of air
Tbord	Pondered temperature of border
Tsoil	Temperature of soil
Ttub	Temperature of tube
ThTub	Thickness of tube
Vair	Air velocity
Vwat	Velocity of water
VolSoil	Node volume
VolTub	Volume of tube node
Hrat	Humidity ratio

Mathematical Description

Geometry

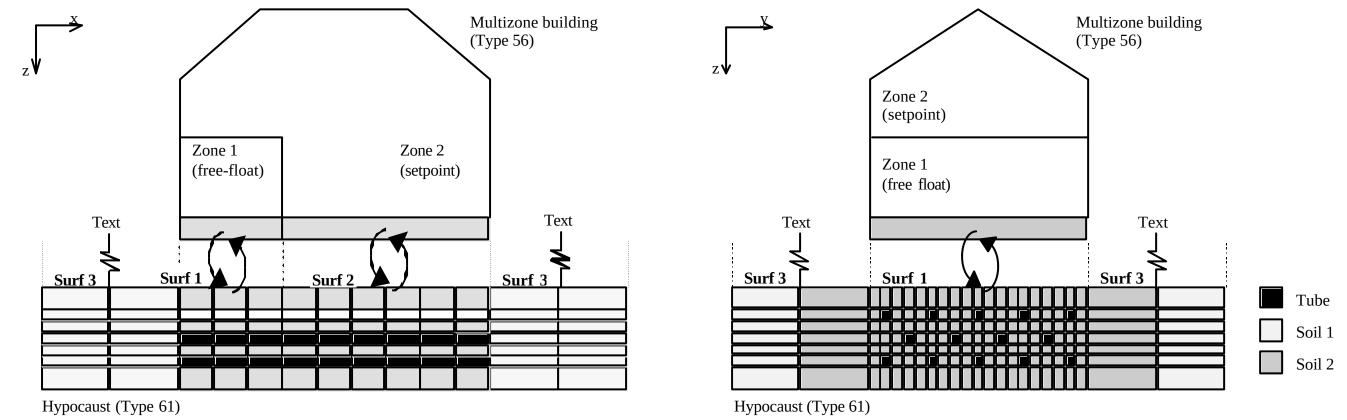
The model describes a block of rectangular soil nodes (which need not all share same physical properties), comprising parallel tubes that run along the x-axis (see figure 1). A correction factor allows to describe non-rectangular tubes. If not adiabatic, surface conditions (which need not expand from edge to edge) can be given in terms of either inflowing energy rate or temperature. An additional surface resistance can be defined, especially for direct coupling with air temperature.

For matter of simplification and run time economy, symmetries in the y-z plane can be used by describing only one module (=relevant part) and specifying the number of times it is used. In this case the symmetry surface(s), which must be subject to adiabatic condition, may if necessary pass through the middle of some tubes (see figure 1).

Parameterisation of chosen geometry occurs in following way (of which best understanding can be taken from figure 1 and example at end) :

- define the occurrence of typical cross-sections along the x-axis, with numbers that refer to them.
- define the typical cross-sections in the y-z plane, with numbers that refer to soil types, respectively surface conditions.
- define two additional cross-sections for frontal and rear surface conditions.

a) longitudinal section **b) cross-section # 2 (through both zones)**



parameterisation :

```
1 1 2 2 2 3 3 3 3 3 3 1 1
```

where
1 : cross-section # 1 (through back and front)
2 : cross-section # 2 (through both zones)
3 : cross-section # 3 (through main zone)

parameterisation (by symmetry only left half) :

```
  3 3 2 2 2 2 2 2 2 2 2 2
0 1 2 2 2 2 2 2 2 2 2 2 2 0
0 1 2 2 0 2 2 2 0 2 2 2 0 0
0 1 2 2 2 2 2 2 2 2 2 2 2 0
0 1 2 2 2 2 0 2 2 2 0 2 2 0
0 1 2 2 2 2 2 2 2 2 2 2 2 0
0 1 2 2 0 2 2 2 0 2 2 2 0 0
0 1 2 2 2 2 2 2 2 2 2 2 2 0
  0 0 0 0 0 0 0 0 0 0 0 0
```

where
0 : tube 0 : adiabatic surface
1 : soil # 1 1 : surface condition # 1 (Zone 1)
2 : soil # 2 3 : surface condition # 3 (Ambient)

Fig.1 : Example of Type460 geometry and coupling to other Type.

<u>Linking</u>

In addition to airflow at inlet/outlet, surface conditions can also be coupled to other Types. One can therefore choose between following two modes :

- If output from other module (=input for Type 460) is the energy rate flowing into hypocaust, Type460 will return equivalent border temperature as output (=input for other Type). Latter is defined as the pondered average node temperature of all nodes comprised in that particular surface :

$$Tbord = \frac{\sum_{i \in bord} Ssoil_i \cdot Ksoil_i \cdot Tsoil_i}{Sbord \cdot Kbord} \tag{1}$$

with

$$Ksoil_i = \frac{1}{\dfrac{Dl_i/2}{LamSoil_i} + Rsurf}$$

$$Sbord = \sum_{i \in bord} Ssoil_i$$

$$Kbord = \frac{\sum_{i \in bord} Ssoil_i \cdot Ksoil_i}{Sbord}$$

One has to take care to use identical border area *Sbord* and heat conduction coefficient *Kbord* in other Type (check these calculated values in parameter control file). The timestep iteration procedure of TRNSYS then will guarantee for proper energy balance (energy rate flowing out of one module = energy rate flowing into other module), which can be checked by plotting inflowing energy rate as optional output of Type 460.

- If on the contrary output from other module is its equivalent border temperature, Type460 will return inflowing energy rate as output. Proper energy balance again is guaranteed by using identical border area and heat conduction coefficient in both Types.

Air flow

Air flow is either positive, negative or zero. If modelling a set of tubes of distinct cross sections, total flow is distributed among the tubes in following way :

$$Fair = FairTot \cdot \frac{Sair \cdot \sqrt{Dtub}}{\sum_{tubes} \left(Sair \cdot \sqrt{Dtub} \right)} \qquad (2)$$

so that according to form of pressure losses (see equation 12 further on) pressure equilibrium at output as well as power and flow integrals are respected.

Water flow

Apart from condensation of airflow (see air-tube heat exchange, further on), water can also enter tubes by infiltration (along part or all of the tube surface). Resultant free water either flows along the tubes or is directly ejected out of hypocaust (flow/ejection occurs in same direction than airflow, in positive direction when airflow is zero). Water flowing/ejected out of a tube node is :

$$MwatOut = \begin{cases} \left(Mwat_{t-1} + \Delta Mwat \right) \dfrac{Vwat \cdot Dt}{Dl} & \text{if water is flowing} \\ \left(Mwat_{t-1} + \Delta Mwat \right) & \text{if water is ejected} \end{cases} \qquad (3)$$

where

$$\Delta Mwat = MwatIn + MwatInf + MwatLat$$

while water flowing from preceeding node (i ±1, depending on flow direction) into actual one is :

$$MwatIn = \begin{cases} MwatOut_{i\pm1} & \text{if water is flowing} \\ 0 & \text{if water is ejected} \end{cases} \qquad (4)$$

Air-tube heat exchange

In each tube node, from inlet towards outlet, following heat exchanges are taken into account :

- **Sensible heat** is characterised by a an exchange coefficient which depends on flowrate. Cutting short on dimensionless analysis, the model uses a linear dependence on air velocity (as derived from experiences on large plane surfaces [3] and confirmed by the author in the frame of an experience on a buried pipe system).

$$Kair = Kair0 + Kair1 \cdot Vair \tag{5}$$

so that

$$Psbl = Stub \cdot Kair \cdot (Tair - Ttub) \tag{6}$$

- **Latent heat** is determined by the Lewis approach [4] which considers proceeding sensible heat exchange to result from an air mass exchange between the airflow and a superficial air layer on the tube surface, at latters temperature and saturated in humidity. Analogy between heat and mass transfer readily give exchanged air mass during timestep *Dt* :

$$Mair = \frac{Psbl \cdot Dt}{CmAir \cdot (Tair - Ttub)} \quad ,$$

that is

$$Mair = \frac{Stub \cdot Kair \cdot Dt}{CmAir} \quad . \tag{7}$$

This air exchange conveys a vapour transfer, which is determined by the difference of humidity ratios of the airflow and the saturated layer :

$$\begin{aligned} MwatLat &= \big(Hrat(Tair, Hrel) - Hrat(Ttub, 100\%)\big) \cdot Mair \\ &= \big(Hrat(Tair, Hrel) - Hrat(Ttub, 100\%)\big) \cdot \frac{Stub \cdot Kair \cdot Dt}{CmAir} \end{aligned} \tag{8}$$

where, from equation of perfect gazes, humidity ratio computes as

$$Hrat(T, Hrel) = \frac{Hsat(Tair) \cdot MmolWat}{PrAir \cdot MmolAir} \tag{9}$$

According to its sign, this vapour transfer corresponds to condensation (*MwatLat* > 0) or evaporation (*MwatLat* < 0). In latter case *MwatLat* is furthermore limited by 1) available free water in node and 2) saturation pressure of air. Latent heat exchange is finally expressed as

$$Plat = Clat \cdot \frac{MwatLat}{Dt} \tag{10}$$

- **Diffused heat** from surrounding nodes (4 soil nodes, 2 tube nodes) is given by

$$Psoil = \sum_{i=1}^{6} Ssoil_i \cdot Ksoil_i \cdot \left(Tsoil_{i,t-1} - Ttub\right) \quad . \tag{11}$$

where

$$Ksoil_i = \begin{cases} \dfrac{1}{\dfrac{ThTub}{LamTub} + \dfrac{Dl_i/2}{LamSoil_i}} & \text{if neighbor is soil} \\ \dfrac{1}{\dfrac{Dl/2}{LamTub} + \dfrac{Dl_i/2}{LamTub}} & \text{if neighbor is tube} \end{cases}$$

- **Heat from frictional losses** relates to pressure drop along the tubes, which commonly writes [5] as

$$\Delta PrAir = Rfric \cdot \frac{Dl}{Dtub} \cdot \frac{RhoAir \cdot Vair^2}{2}$$

or

$$\Delta PrAir = Rfric \cdot \frac{Dl \cdot RhoAir}{2} \cdot \frac{Fair^2}{Sair^2 \cdot Dtub} \tag{12}$$

where the friction coefficient $Rfric$ is here considered to be independent of air velocity, and the hydraulic diameter of the tube writes as

$$Dtub = \frac{4 \cdot Sair}{Ctub} \tag{13}$$

Related energy rate then writes as

$$Pfric = Fair \cdot \Delta PrAir \tag{14}$$

and is supposed to be gained entirely by the airflow (see energy balance further on).

- **Heat lost by free water** computes as

$$Pwat = CmWat \cdot \frac{Mwat_{t-1} \cdot \left(Ttub_{t-1} - Ttub\right) + MwatIn \cdot \left(Ttub_{i \pm i} - Ttub\right)}{Dt} \tag{15}$$

- **Internal heat gain** is the heat gained by the tube :

$$Pint = \frac{CvTub \cdot VolTub \cdot \left(Ttub - Ttub_{t-1}\right)}{Dt} \tag{16}$$

Preceding energy rates allow to calculate new tube temperature and free water content of actual node, as well as air temperature and humidity ratio of next node. Since the saturated humidity in (9) is non-linear in terms of temperature, *Ttub* is determined by numerical resolution of the tube energy balance

$$Pint = Psbl + Plat + Psoil + Pwat \quad , \tag{17}$$

while water balance readily yields

$$Mwat = Mwat_{t-1} + MwatLat + MwatInf + MwatIn - MwatOut \quad . \tag{18}$$

Sensible energy and water balance on air finally yield air conditions of next node (*i±1*) :

$$Tair_{i\pm1} = Tair + \frac{Pfric - Psbl}{\left(CmAir + Hrat \cdot CmVap\right) \cdot RhoAir \cdot Sair \cdot Vair} \quad , \tag{19}$$

$$Hrat_{i\pm1} = Hrat - \frac{MwatLat}{RhoAir \cdot Sair \cdot Vair \cdot Dt} \quad , \tag{20}$$

where calculation can be pursued in same manner.

<u>Soil-soil, soil-tube and soil-surface exchanges</u>
Dynamic of soil nodes relies on diffusive heat from neighbour nodes :

$$Psoil = \sum_{i=1}^{6} Ssoil_i \cdot Ksoil_i \left(T_i - Tsoil_{t-1}\right) \quad , \tag{21}$$

where

$$T_i = \begin{cases} Tsoil_{i,t-1} & \text{if neighbor is soil} \\ Ttub_{i,t} & \text{if neighbor is tube} \\ Tsurf_{i,t} & \text{if neighbor is surface} \end{cases}$$

and

$$Ksoil_i = \begin{cases} \dfrac{1}{\dfrac{Dl/2}{LamSoil} + \dfrac{Dl_i/2}{LamSoil}} & \text{if neighbor is soil} \\ \dfrac{1}{\dfrac{Dl/2}{LamSoil} + \dfrac{ThTub}{LamTub}} & \text{if neighbor is tube} \\ \dfrac{1}{\dfrac{Dl/2}{LamSoil} + Rsurf} & \text{if neighbor is surface} \end{cases}$$

It allows to compute new soil temperature :

$$Tsoil = Tsoil_{t-1} + \frac{Psoil}{CvSoil \cdot VolSoil} \quad . \qquad (22)$$

<u>Initialisation</u>
Hypocaust is initialised with a common initial temperature for all nodes, as well as a common initial water thickness along all tubes. Optionally one may define additional initial temperatures and water thickness for certain nodes or node clusters (see further on, definition of parameter file).

TRNSYS Component Configuration

Source code is separated into two files :

- **Type460.for** contains actual routine and is organised in different subroutines.
- **Type460.inc** is an include file used by the subroutines. It contains definition of variables and their organisation in common blocks, as well as definition of maximum allowed sizes, which are listed hereafter with their default values :

NIMax	max number of nodes along x	40	
NJMax	max number of nodes along y (per module)	100	1)
NKMax	max number of nodes along z (per module)	20	1)
NtubMax	max number of tubes (per module)	20	1)
NsoilMax	max number of soiltypes	10	
NsurfMax	max number of surfaces	6	2)
NoptMax	max number of optional outputs	100	2)
NiniMax	max number of initialisation conditions	20	

1) module = relevant part in y-z plane (see further up, description of geometry).
2) Changing default values for maximum number of surfaces or maximum number of optional outputs will need re-numeration of routine arguments (parameters, inputs and outputs) as defined in information flow diagram.

Input data is separated into three groups, of which two are passed as arguments, the last one read from a file :

- **Parameters** describe fixed data that deal with linking to other modules and with simulation deck.
- **Inputs** describe variable data.
- Parameters which are proper to the model are passed by means of a **Parameter definition file**, which is read by the routine at initialisation. While reading, the data is checked and rewritten to a control file (see below), so that eventual errors can be tracked.

Output data is separated into two groups, of which first one is returned as argument, second one written to a file :

- **Outputs** describe variable data, which can be linked to other modules.
- Parameters which are derived from supplied parameter file or from simulation deck are written to a **Parameter control file**, which can be used to check for proper definition. As pointed out, first part of this file is a formatted and commented copy of Parameter definition file (which it can substitute).

A synoptic view of these data groups is to be found in the information flow diagram (next section), while this section presents each of them in a detailed table (with explanatory notes following last table).

Note, especially in case of debugging, that data is passed to/from the routine with TRNSYS compatible units as defined hereafter, where it is converted to standard SI units.

Parameters

Number	Symbol	Definition and unit	
1	*IparDef*	Logical unit of Parameter definition file [-]	1)
2	*IparCon*	Logical unit of Parameter control file [-]	1)
3	*Dt*	Internal time step [hr]	2)
4	*FairMin*	Minimum airflow [m^3/hr]	3)
5	*DTtubTol*	Temperature tolerance for tube energy balance [K]	4)
6 - 11	*TypSurf*	Linking modes for surfaces 1 - 6 [-]	5)
12 - 17	*Rsurf*	Heat resistance at surfaces 1 - 6 [K m2 hr/kJ]	

Inputs

Number	Symbol	Definition and unit	
1	*FairTot*	Airflow, total over all modules [m3/hr]	6)
2	*TairIn*	Inlet temperature [°C]	
3	*HrelIn*	Inlet relative humidity [%]	
4	*PrAir*	Air pressure [bar]	7)
5	*FwatInfTot*	Water infiltration, total over all modules [m3/hr]	8)
6 - 11	*Xsurf*	Surface conditions for surfaces 1 - 6 [°C] or [kJ/hr]	5)

Parameter definition file

Each data set hereafter is written on one line (exception for *TypSoil* arrays, which take *NK* or *NK*+2 lines). Data within one dataset is separated by commas or blanks. Comments can be entered by using an asterix (*) in first column.

Symbol	Definition and unit	
Nmod,Nsec,Nsoil,Nsurf,NI,NJ, NK	Number of : modules, cross-sections, surfaces, nodes along x-axis, nodes along y-axis, nodes along z-axis [-]	
Dx (1:NI)	Node width along x-axis [m]	9)
Dy (1:NJ)	Node width along y-axis [m]	9)
Dz (1:NK)	Node width along z-axis [m]	9)
TypSec(1:NI)	Type of used cross-sections along x-axis [-]	10)
TypSoil (1:NJ,1:NK)	Type of surfaces on frontal cross-section [-]	11)
TypSoil (0:NJ+1,0:NK+1)	Type of soils/surfaces for typical cross-section in y-z plane [-]	12)
TypSoil (1:NJ,1:NK)	Type of surfaces on rear cross-section [-]	11)
PosInf	Position of water infiltration [-]	8)
Kair0, Kair1	Air-tube exchange coefficients [kJ/hr K m2] and [(kJ/hr K m2)/(m/s)]	13)
LamSoil, CvSoil	Soil conductivity [kJ/hr K m] and capacity [kJ/K m3]	14)
LamTub, CvTub	Tube conductivity [kJ/hr K m] and capacity [kJ/K m3]	
ThTub, CtubCor, Rfric	Tube thickness [m], circumference correction factor [-] and friction coefficient [-]	9) 15)
TypWatFlow (-1:1)	Type of water flow [-]	16)
Vwat (-1:1)	Velocity of water flow [m/hr]	16)
NiniSoil, NiniWat	Number of initial conditions (soil temperatures and water thickness) [-]	17)
TiniSoil, PosIniSoil (1:6)	Initial temperature [°C] and corresponding node position [-]	17)
ThIniWat, PosIniWat (1:6)	Initial water thickness [m] and corresponding node position [-]	17)
Nopt	Number of optional outputs	20)
TypOpt, PosOpt (1:6)	Type of optional output [-] and corresponding node position [-]	20)

Outputs

Number	Symbol	Definition and unit
1	*TairOut*	Outlet temperature [°C]
2	*HrelOut*	Outlet relative humidity [%]
3	*PsblTot*	Sensible energy rate lost by airflow, total over tubes and modules [kJ/hr]
4	*PlatTot*	Latent energy rate lost by airflow, total over tubes and

		modules [kJ/hr]	
5 - 10	*Xbord*	Equivalent border output for surfaces 1 - 6 [°C] or [kJ/hr]	5)
11 - 20	*Xopt*	Optional outputs	20)

Parameter control file

Data hereafter is written at end of file, after formatted copy of Parameter definition file.

Symbol	**Definition and unit**	
Ntub	Number of tubes (per module) [-]	
IflowIni	Node index of tube start along x-axis [-]	
IflowEnd	Node index of tube end along x-axis [-]	
PosTub(1:2)	Node index of tube position along y- and z-axis [-]	18)
Lx	Length of hypocaust [m]	
Ly	Width of hypocaust (total over modules) [m]	
Lz	Depth of hypocaust [m]	
Ltub	Length of tubes [m]	
SairTot	Tube cross-section area (total over all tubes and modules) [m2]	
StubTot	Tube surface (total over all tubes and modules) [m2]	
ZairTot	Normalisation factor for airflow distribution [m5/2]	
SinfTot	Water infiltration surface, total over all modules [m2]	8)
Sbord	Border area (total over all modules) [m2]	19)
Kbord	Equivalent border conduction coefficient [kJ/hr K m2]	19)
DtSoil	Maximum internal timestep for stability of soil temperature [hr]	
DtWat	Maximum internal timestep for consistency of water flow [hr]	
FairMinTub	Minimum air flow for stability of air temperature [m3/hr]	
Dt	Internal timestep effectively used in simulation [hr]	
FairMin	Minimum air effectively flow used in simulation [m3/hr]	

Explanatory notes for proceeding tables

1) Unless assigned in simulation deck with user-defined name, parameter definition and control files must by default be named ParamDef.txt and ParamCon.txt.
2) Since calculation of soil temperature is of explicit type, internal timestep should not exceed a maximum theoretical value *DtSoil*, which is proportional to smallest node volume of soil (problem of temperature oscillation). Consistency of water flow calculation (equation 3) also implies a maximum value *DtWat* for internal timestep, proportional to shortest tube node. Both of these computed values are written to the parameter control file. Type 460 usually takes the smallest of these two values for the internal timestep (which happens by setting the 3rd routine parameter *Dt* to zero). The user may alternatively control soil temperature oscillation by defining a larger or smaller internal timestep himself (which happens by setting the 3rd routine parameter *Dt* to a positive value), in which case the value *DtWat* should not be exceeded though.

3) So as to avoid oscillations of air temperature along the tube, airflow should not exceed a theoretical minimum value *FairMinTub*, which is written to the parameter control file. Type 460 usually takes this value as a lower limit to the airflow (which happens by setting the 4th routine parameter *FairMin* to zero). The user may alternatively control air temperature oscillation by defining a larger or smaller minimum airflow himself (which happens by setting the 4th routine parameter *FairMin* to a positive value). In both cases an airflow smaller than the minimum value will be set to zero (no air-tube exchange, only diffusion within soil).
4) Temperature tolerance (>0) sets precision of numerical resolution of energy balance in tube (equation 17).
5) For each surface, linking mode is one of the following :

0 : corresponding input *Xsurf* is surface temperature, output *Xbord* is inflowing energy rate.

1 : corresponding input *Xsurf* is is inflowing energy rate, output *Xbord* is equivalent border temperature.

6) Airflow direction along x-axis is carried by sign of airflow. If airflow is smaller (in absolute value) than minimum airflow *FairMin* (see parameter control file) it is considered as zero (no air-tube exchange, only diffusion within soil).
7) Air pressure is used to convert volume flow in mass flow as well as to determine humidity ratio from relative humidity (equation 9). In usual cases its dynamic is not known and it is suggested to take standard atmospheric pressure at local altitude, which can be approximated by :

$PrAir = PrAir_0 \exp(-h/h_0)$ with $PrAir_0$ = 1.01325 bar, h_0 = 7656 m.

8) Water infiltration is distributed on a certain tube area *SinfTot*, defined by the rectangular node cluster *PosInf* on which infiltration is to take place.

PosInf(1) and *PosInf(4)* are lower and upper node index along x-axis.
PosInf(2) and *PosInf(5)* are lower and upper node index along y-axis.
PosInf(3) and *PosInf(6)* are lower and upper node index along z-axis.
Only tube nodes within this cluster are considered for water infiltration.

9) Even for non-rectangular tubes, node width must be chosen so that cross-section area is given by *DyDz*. Cross-section perimeter, exchange surfaces and hydraulic diameter will be corrected by tube circumference correction factor *CtubCor*. Latter is defined as the ratio between *real* tube perimeter and *rectangular* tube perimeter 2(*Dy* + *Dz*). For circular tubes node width has to be chosen so that $Dy = Dz = r\sqrt{p} \cong 1.772\,r$ and circumference correction factor becomes $\frac{1}{2}\sqrt{p} \cong 0.8862$. In case of a symmetry plane passing in the middle of some tubes (tube node at hypocaust border, with lateral adiabatic condition) one furthermore has to divide Dy by half.

Generally speaking node widths *Dx*, *Dy* and *Dz* have to be chosen according to given problem, reminding that small soil volumes will lead to small internal timesteps and increase of runtime.Tube thickness *ThTub* may however be set to zero.

10) *TypSec(1:NI)* are positive integer numbers which refer to further on defined typical cross-sections along x-axis.
11) *TypSoil (1:NJ,1:NK)* are integer numbers which refer to given surface conditions for front and rear of hypocaust module (see example at end).
12) *TypSoil (0:NJ+1,0:NK+1)* are integer numbers which refer to further on defined soil types (bulk) or to given surface conditions (border). Exception are the 4 corners *TypSoil (0,0)* , *TypSoil (NJ+1,0)* , *TypSoil (0,NK+1)* , *TypSoil (NJ+1,NK+1)* which have no significance and are not defined (see figure 1 and example at end). This data set has to be repeated for the *Nsec* number of typical cross-sections.

13) Common values for air-tube exchange coefficients [3] are :
Kair0 : 7 - 11 [kJ/hr K m2]
Kair1 : 14 - 18 [(kJ/hr K m2)/(m/s)]
14) This line has to be repeated for the *Nsoil* number of soils.
15) Typical values for Friction coefficient are 0.01 - 0.02 [-].
16) Specification of water flow is given for all 3 airflow directions (negative, zero, positive). *TypWatFlow* indicates whether free water is to flow along the tubes (= 1) or to be ejected out (= 2). *Vwat* (≥ 0) specifies velocity of waterflow (if *TypWatFlow* = 1).
17) Initial temperatures are given for rectangular node clusters, defined by *PosIniSoil* :
PosIniSoil(1) and *PosIniSoil(4)* are lower and upper node index along x-axis,
PosIniSoil(2) and *PosIniSoil(5)* are lower and upper node index along y-axis,
PosIniSoil(3) and *PosIniSoil(6)* are lower and upper node index along z-axis,
except for first initial temperature which is applied to all nodes and thus does not need definition of *PosIniSoil* (see example at end).
Same structure accounts for initial water thickness. In this case only those nodes within the cluster which do effectively corresponds to tube nodes are taken into account though.
18) This line is repeated for the *Ntub* number of tubes.
19) This line is repeated for the Nsurf number of surfaces.
20) *Nopt* defines the number of desired optional outputs. For each one of them *TypOpt* specifies the type of optional output and takes a value from one of the three following tables. *PosOpt* finally defines the rectangular node cluster for which the optional output is to be considered :
PosOpt(1) and *PosOpt(4)* are lower and upper node index along x-axis,
PosOpt(2) and *PosOpt(5)* are lower and upper node index along y-axis,
PosOpt(3) and *PosOpt(6)* are lower and upper node index along z-axis.
If *TypOpt* relates to tube/air nodes, only tube nodes within cluster will be considered.
If *TypOpt* relates to soil nodes, only soil nodes within cluster will be considered.
If *TypOpt* relates to miscellaneous data, *PosOpt* is of no significance and should be set to 1.

Optional outputs for tube nodes :

Type	**Symbol**	**Definition and unit**	
1	*Tair*	Air temperature [°C]	*
2	*Hrel*	Air relative humidity [%]	*
3	*Habs*	Air absolute humidity [bar]	*
4	*Hrat*	Air humidity ratio [kg vapour/kg air]	*
5	*Mwat*	Free water in node [m3]	**
6	*MwatLat/Dt*	Water condensing (>0) or evaporating (<0) [m3/hr]	**
7	*MwatIn/Dt*	Water flowing into node [m3/hr]	**
8	*MwatInf/Dt*	Water infiltrating into node [m3/hr]	**
9	*MwatOut/Dt*	Water flowing out of node [m3/hr]	**
10	*Tsoil*	Tube temperature [°C]	**
11	*Psbl*	Sensible energy rate from air to tube [kJ/hr]	**
12	*Plat*	Latent energy rate from air to tube [kJ/hr]	**
13	*Pwat*	Energy rate lost by free water [kJ/hr]	**
14	*Pfric*	Energy rate from frictional losses [kJ/hr]	**
15	*Psoil(0)*	Energy rate diffused from all 6 neighbour nodes [kJ/hr]	**
16	*Psoil(1)*	Energy rate diffused from previous neighbour node along	**

		x-axis (from surface if border node) [kJ/hr]	
17	*Psoil(2)*	Energy rate diffused from next neighbour node along x-axis (from surface if border node) [kJ/hr]	**
18	*Psoil(3)*	Energy rate diffused from previous neighbour node along y-axis (from surface if border node) [kJ/hr]	**
19	*Psoil(4)*	Energy rate diffused from next neighbour node along y-axis (from surface if border node) [kJ/hr]	**
20	*Psoil(5)*	Energy rate diffused from previous neighbour node along z-axis (from surface if border node) [kJ/hr]	**
21	*Psoil(6)*	Energy rate diffused from next neighbour node along z-axis (from surface if border node) [kJ/hr]	**
22	*Pint*	Energy rate of internal gains [kJ/hr]	**
23	*Fair*	Air flowrate [m3/hr]	*
24	*Vair*	Air velocity [m/s]	*

* averaged over node cluster

** integrated over node cluster and multiplied by number of modules

Optional outputs for soil nodes :

Type	Symbol	Definition and unit	
101	*Tsoil*	Soil temperature [°C]	*
102	*Psoil(0)*	Energy rate diffused from all 6 neighbour nodes [kJ/hr]	**
103	*Psoil(1)*	Energy rate diffused from previous neighbour node along x-axis (from surface if border node) [kJ/hr]	**
104	*Psoil(2)*	Energy rate diffused from next neighbour node along x-axis (from surface if border node) [kJ/hr]	**
105	*Psoil(3)*	Energy rate diffused from previous neighbour node along y-axis (from surface if border node) [kJ/hr]	**
106	*Psoil(4)*	Energy rate diffused from next neighbour node along y-axis (from surface if border node) [kJ/hr]	**
107	*Psoil(5)*	Energy rate diffused from previous neighbour node along z-axis (from surface if border node) [kJ/hr]	**
108	*Psoil(6)*	Energy rate diffused from next neighbour node along z-axis (from surface if border node) [kJ/hr]	**
109	*Pint*	Energy rate of internal gains [kJ/hr]	**

* averaged over node cluster

** integrated over node cluster and multiplied by number of modules

Miscellaneous data for optional output :

Type	Symbol	Definition and unit
201	*PsurfTot*	Total inflowing energy rate through surfaces (over all modules) [kJ/hr]
202	*PwatTot*	Total energy loss of free water (over all modules) [kJ/hr]
203	*PfricTot*	Total frictional losses (over all modules) [kJ/hr]
204	*PintTot*	Total tube and soil capacitive gains (over all modules) [kJ/hr]

Références

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2. Razafinjohany E., *Etude comparative dans les serres agricoles de deux systèmes de stockage de la chaleur influencé de l'humidité de l'air,* Thèse, 1989, Académie de Montpelier, Université de Perpignan.
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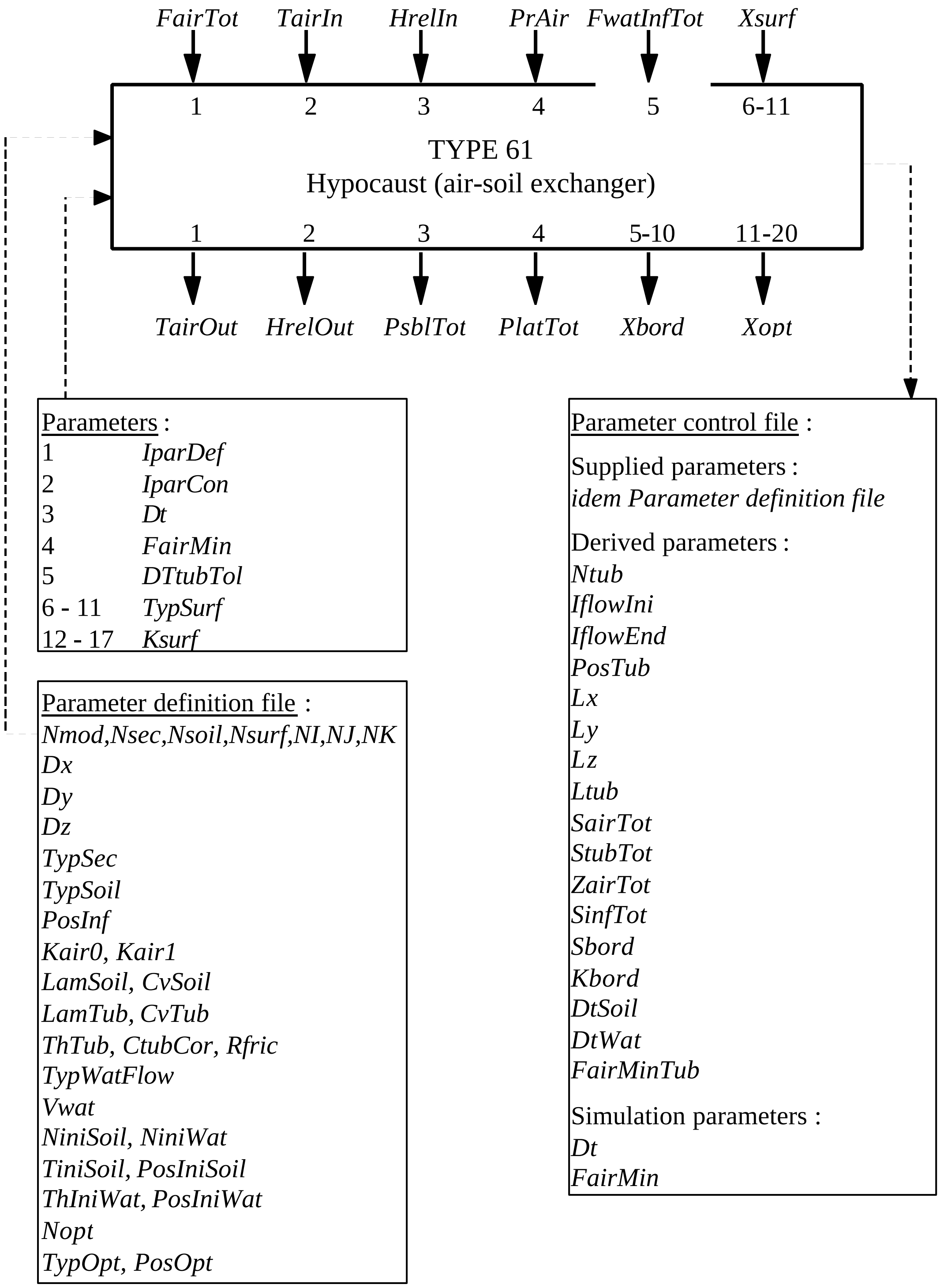
4. Incropera F. P., De Witt D. P., *Fundamentals of heat and mass transfer*, John Wiley & Sons Inc., 1990.
5. *1989 Ashrae Handbook, Fundamentals*, American society of heating, refrigerating and air conditioning engineers inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

Information Flow Diagram



Example

Description

Example is the underground cooling system shown in Fig. 1. It is a mere case study ment to show the possibility of linking Type460 to the multizone building Type 56 and to check consistency of exchanged energy rates as well as of other internal variables. Hence following hypothesis are made :

- Ambient conditions are constant : temperature of 30°C, humidity of 50%, no solar radiation.
- Building is simplified to its uttermost : a first zone (8 m2, 16 m3) with simple brick wall is free-floating and adjoins a second zone (12 m2, 39 m3) with insulated brick wall and at fixed temperature (15°C). No windows are taken into account and no infiltration nor cross-ventilation is considered.
- Pipe system is underneath building and laterally not insulated, wherefore lateral and from hypocaust distinct soil is taken into account.
- Airflow is constant (1000 m^3/hr) and is not injected into building but supposed to be used elsewhere.
- No water infiltration is considered, nor does free water flow along the tubes.
- Initial temperatures are 10°C for hypocaust, 15°C for surrounding soil and building.

Following variables are defined and analysed (some of which, for checking of proper energy and mass balance, are calculated by two alternative ways defined in the deck) :

Psbl	: sensible energy lost by airflow
Plat	: latent energy lost by airflow
Pin	: internal gains of hypocaust and surrounding soil
PinG, PinG#	: internal gains of surrounding soil
PinH, PinH#	: internal gains of hypocaust
PinHt	: internal gains of hypocaust tubes
PinHs	: internal gains of hypocaust soil
Pfree, Pfree#	: energy diffused from free-floating zone into hypocaust
Pfix, Pfix#	: energy diffused from fixed setpoint zone into hypocaust
Pamb	: energy diffused from ambient into surrounding soil
Pfront	: energy diffused from surrounding soil front of the building into hypocaust
Pback	: energy diffused from surrounding soil back of the building into hypocaust
Pside	: energy diffused from surrounding soil to side of the building into hypocaust
Pwat	: energy diffused from free water into hypocaust
Pfric	: friction losses
T1-T4	: temperatures of airflow along tubes (mean value of all tubes)
Tout	: temperature of airflow at outlet
Tfree	: temperature of free-floating zone, air
TgFree	: temperature of free-floating zone, ground
Tfix	: temperature of fixed setpoint zone, air
TgFree	: temperature of fixed setpoint zone, ground
Mwat, Mwat#	: free water within tubes
dMlat	: condensation/evaporation within tubes
dMout	: total outflowing water.

Next pages show files for parameterisation of the system (parameter definition file for Type 460, building definition file for Type 56, simulation deck), after which corresponding simulation results are discussed.

Type460.par : parameter definition file (Type 460)

```
************************************************
* TYPE 460 SUPPLIED PARAMETERS
*===============================================
* Nmod,Nsec,Nsoil,Nsurf,NI,NJ,NK [-]:
  2    3    2     3      13 12  7

* DX [m]:
  1.0000E+00  1.0000E+00
  0.6666E+00  0.6666E+00  0.6666E+00
  0.6666E+00  0.6666E+00  0.6666E+00
  0.6666E+00  0.6666E+00  0.6666E+00
  1.0000E+00  1.0000E+00

* DY [m]:
  1.0000E+00  1.0000E+00  0.3000E+00  0.2000E+00
  0.2000E+00  0.2000E+00  0.2000E+00  0.2000E+00
  0.2000E+00  0.2000E+00  0.2000E+00  0.1000E+00

* DZ [m]:
  0.4000E+00  0.2000E+00  0.2000E+00  0.2000E+00
  0.2000E+00  0.2000E+00  0.4000E+00

* TypSec [-]:
   1   1   2   2   2   3   3   3   3   3   3   1   1

* TypSoil for front surface [-]:
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0   0   0   0   0   0

* TypSoil for sec# 1 (through ambient) [-]:
       3   3   3   3   3   3   3   3   3   3   3   3
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
   0   2   2   2   2   2   2   2   2   2   2   2   2   0
       0   0   0   0   0   0   0   0   0   0   0   0

* TypSoil for sec# 2 (through both zones) [-]:
       3   3   1   1   1   1   1   1   1   1   1   1
   0   2   2   1   1   1   1   1   1   1   1   1   1   0
   0   2   2   1   0   1   1   1   0   1   1   1   0   0
   0   2   2   1   1   1   1   1   1   1   1   1   1   0
```

```
    0   2   2   1   1   1   0   1   1   1   0   1   1   0
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
    0   2   2   1   0   1   1   1   0   1   1   1   0   0
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
        0   0   0   0   0   0   0   0   0   0   0   0

* TypSoil for sec# 3 (through setpoint-zone only) [-]:
        3   3   2   2   2   2   2   2   2   2   2   2
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
    0   2   2   1   0   1   1   1   0   1   1   1   0   0
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
    0   2   2   1   1   1   0   1   1   1   0   1   1   0
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
    0   2   2   1   0   1   1   1   0   1   1   1   0   0
    0   2   2   1   1   1   1   1   1   1   1   1   1   0
        0   0   0   0   0   0   0   0   0   0   0   0

* TypSoil for rear surface [-]:
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0
        0   0   0   0   0   0   0   0   0   0   0   0

* PosInf [-]:
  1   1   1   9  12   7

* Kair0 [kJ/K m2] ,Kair1 [(kJ/K m2)/(m/s)]:
  0.1800E+02  0.1400E+02

* LamSoil [kJ/K m], CvSoil [kJ/K m3]:
  0.7200E+01  0.1000E+04
  0.5400E+01  0.1000E+04

* LamTub [kJ/K m], CvTub [kJ/K m3]:
  0.7200E+01  0.1000E+04

* ThTub [m], CtubCor [-], Cfric [-]:
  5.0000E-03  0.8862E+00  2.0000E-02

* TypWatFlow [-], Vwat [m/h]:
  1   1   1
  0.0000E+00  0.0000E+00  0.0000E+00

* NiniSoil,NiniWat [-]:
  2   1

* TiniSoil [°C], PosIniSoil [-]:
  0.1500E+02
  0.1000E+02  3   3   1  11  12   7

* ThIniWat [m], PosIniWat [-]:
  0.0000E+00

* Nopt [-]:
  17
```

```
* TypOpt [-], PosOpt [-]:
  107   3   3   1   5  12   1 !Pfree#
  107   6   3   1  11  12   1 !Pfix#
  103   3   3   1   3  12   7 !Pfront
  104  11   3   1  11  12   7 !Pback
  105   3   3   1  11   3   7 !Pside
  202   1   1   1   1   1   1 !Pwat
  203   1   1   1   1   1   1 !Pfric
  204   1   1   1   1   1   1 !Pin
   22   3   3   1  11  12   7 !PinHt
  109   3   3   1  11  12   7 !PinHs
    5   3   3   1  11  12   7 !Mwat
    6   3   3   1  11  12   7 !dMlat
    9  11   3   1  11  12   7 !dMout
    1   4   3   1   4  12   7 !T1
    1   6   3   1   6  12   7 !T2
    1   8   3   1   8  12   7 !T3
    1  10   3   1  10  12   7 !T4
************************************************
```

Observations :

- Because of symmetry in the y-z plane, only half of the hypocaust has to be simulated, cutting middle two pipes by half (*Nmod* = 2 and last node width *Dy* is half the width of other ones).

3 cross-sections must be defined, one outside the building, two through the building (one cutting both zones, the other one through fixed zone only), as well as 3 surface conditions (ambient and floor of both zones).

- 2 temperature initialisation are used, for soils surrounding and beneath building respectively.

<u>Building.bui : building definition file (Type 56)</u>

```
************************************************************************
* TYPE 56 DESCRIPTION                                                  *
************************************************************************

PROPERTIES
************************************************************************
DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454 : SIGMA=2.041E-07
RTEMP =293.15

TYPES
************************************************************************

*-- LAYERS -------------------------------------------------------------
LAYER Brick30
THICKNESS=.30 : CONDUCTIVITY=3 : CAPACITY=1 : DENSITY=1800

LAYER Insul10
THICKNESS=.10 : CONDUCTIVITY=0.144 : CAPACITY=0.72 : DENSITY=90

LAYER Soil40
THICKNESS=.40 : CONDUCTIVITY=7.2 : CAPACITY=1 : DENSITY=1000

*-- INPUTS -------------------------------------------------------------
```

```
INPUTS TgFree TgFix

*-- WALLS ---------------------------------------------------------------
WALL Brick
LAYERS Brick30
ABS-FRONT=.8 : ABS-BACK=.8 : HFRONT=15 : HBACK=15

WALL Insul_Brick
LAYERS Insul10 Brick30
ABS-FRONT=.8 : ABS-BACK=.8 : HFRONT=15 : HBACK=15

WALL Soil
LAYERS Soil40
ABS-FRONT=.8 : ABS-BACK=0 : HFRONT=15 : HBACK=36
* rem : HBACK must be equal to Kbord from Type 460 *




WALL Insul_Soil
LAYERS Insul10 Soil40
ABS-FRONT=.8 : ABS-BACK=0 : HFRONT=15 : HBACK=36
* rem : HBACK must be equal to Kbord from Type 460 *

*-- COOLING -------------------------------------------------------------
COOLING CoolFix
ON=15 : POWER=1E6 : HUMIDITY=0

*-- ORIENTATIONS --------------------------------------------------------
ORIENTATIONS Ambient

*-- ZONES ---------------------------------------------------------------
ZONES Free Fix

BUILDING
************************************************************************

*-- ZONE Free -----------------------------------------------------------
ZONE Free

WALL=Insul_Brick : AREA=16 : ADJACENT=Fix : BACK    : COUPLING=0
WALL=Brick       : AREA=16 : EXTERNAL : ORIENTATION=Ambient : FSKY=0.5
WALL=Soil        : AREA=8  : BOUNDARY=INPUT TgFree : COUPLING=0

REGIME
CAPACITANCE=1E+3 : VOLUME=16 : TINITIAL=15 : PHIINITIAL=50.0 : WCAPR=1

*-- ZONE Fix ------------------------------------------------------------
ZONE Fix

WALL=Insul_Brick : AREA=16 : ADJACENT=Free : FRONT  : COUPLING=0
WALL=Insul_Brick : AREA=41 : EXTERNAL : ORIENTATION=Ambient : FSKY=0.5
WALL=Insul_Soil  : AREA=12 : BOUNDARY=INPUT TgFix  : COUPLING=0

REGIME
COOL=CoolFix
CAPACITANCE=1E+3 : VOLUME=39 : TINITIAL=15 : PHIINITIAL=50.0 : WCAPR=1
```

```
OUTPUTS
************************************************************************

*-- TRANSFER -----------------------------------------------------------
TRANSFER : TIMEBASE=1

*-- OUTPUTS ------------------------------------------------------------

ZONES=Free
NTYPES=1 20

ZONES=Fix
NTYPES=1 20

END
************************************************************************
```

Observations :

- Preceding file must be processed by BID program before it can be used by Type 56 (for more details refer to Type56 component description).
- Note that for proper coupling with Type 460 *HBACK* of soil is set to identical value as *Kbord* from hypocaust and ground areas are identical to *Ssurf* from hypocaust (see Parameter control file to check this).

<u>Type460.dck : simulation deck file</u>

```
***************************************************************
* SIMULATION:
***************************************************************

*==============================================================
  ASSIGN  Trnsys.txt      6
  ASSIGN  Out1.txt      101
  ASSIGN  Out2.txt      102
  ASSIGN  Out3.txt      103
  ASSIGN  Type460.par    200
  ASSIGN  Type460.con    201
  ASSIGN  Building.bld  300
  ASSIGN  Building.trn  301
  ASSIGN  Building.win  302
*==============================================================

*==============================================================
  EQUATIONS 37
*--------------------
  DtSim  = 1
  Tamb   = 30
  Hamb   = 50
  Aflow  = 1000
*--------------------
  Tfree = [1,1]
  Tfix  = [1,5]
```

```
  Pfree = -[1,4]
  Pfix  = -[1,8]
*--------------------
  Tout   = [2,1]
  Psbl   = [2,3]
  Plat   = [2,4]
  TgFree = [2,5]
  TgFix  = [2,6]
  Pamb   = [2,7]
  Pfree# = [2,11]
  Pfix#  = [2,12]
  Pfront = [2,13]
  Pback  = [2,14]
  Pside  = [2,15]
  Pwat   = [2,16]
  Pfric  = [2,17]
  Pin    = [2,18]
  PinHt  = [2,19]
  PinHs  = [2,20]
  Mwat   = [2,21]*1000
  dMlat  = [2,22]*1000
  dMout  = [2,23]*1000
  T1     = [2,24]
  T2     = [2,25]
  T3     = [2,26]
  T4     = [2,27]
*--------------------
  PinH  = PinHt+PinHs
  PinG  = Pin-PinHt-PinHs
  PinH# = Psbl+Plat+Pfree+Pfix+Pfront+Pback+Pside+Pwat
  PinG# = Pamb-Pfront-Pback-Pside
  dMwat = dMlat-dMout
  Mwat# = GT(TIME,1)*[3,1]+LT(TIME,2)*dMwat
* Mwat# = [3,1] replaced by preceding line because of bug in
*                integrator Type55
*==============================================================

*==============================================================
  SIMULATION    1           100         DtSim
  TOLERANCES    -0.0001     -0.0001
*==============================================================

***************************************************************
* COMPONENTS:
***************************************************************

*==============================================================
* Multizone Building
*--------------------------------------------------------------
UNIT 1   TYPE 56

PARAMETERS 5
*--------------------
* 01) Logical unit of building description file
* 02) Logical unit of transfer coefficient file
* 03) Logical unit of window library file
* 04) Mode of calculation for star network
* 05) Weighting factor for operative romm temperature
```

```
  300         301         302         0           0.5

INPUTS 8
*---------------------
* 01) Ambient temperature [°C]
* 02) Ambient humidity ratio [kg water / kg air]
* 03) Fictive sky temperature [°C]
* 04) Incident radiation for orientation ambient [kJ/hr]
* 05) Incident beam radiation for orientation ambient [kJ/hr]
* 06) Incident angle for orientation ambient [deg]
* 07) Ground temperature zone "Free" [deg C]
* 08) Ground temperature zone "Fix" [deg C]

  Tamb        0,0         Tamb        0,0         0,0
  0,0         TgFree      TgFix

  0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00
  0.000E+00   0.100E+02   0.100E+02

* OUPUTS 8
*---------------------
* 01) Temperature of zone "Free" [°C]
* 02) Energy rate from zone "Free" to zone "Fix" [kJ/hr]
* 03) Energy rate from zone "Free" to "Ambient"  [kJ/hr]
* 04) Energy rate from zone "Free" to "Ground"  [kJ/hr]
* 05) Temperature of zone "Fix" [°C]
* 06) Energy rate from zone "Fix" to zone "Free" [kJ/hr]
* 07) Energy rate from zone "Fix" to "Ambient"  [kJ/hr]
* 08) Energy rate from zone "Fix" to "Ground"  [kJ/hr]
*===============================================================

*===============================================================
* Hypocaust
*---------------------------------------------------------------
UNIT 2   TYPE 460

PARAMETERS 17
*---------------------
* 01) Logical unit parameter definition file
* 02) Logical unit parameter control file
* 03) Internal timestep [hr]
* 04) Minimum airflow [m3/hr]
* 05) Tolerance on tube temperature [K]
* 06-11) Surface types
* 12-17) Resistance at surface [K m2 hr/kJ]

  2.000E+02   2.010E+02   0.000E+00   0.000E+00   1.000E-02
  1.000E+00   1.000E+00   0.000E+00   0.000E+00   0.000E+00
  0.000E+00   0.000E+00   0.000E+00   0.150E-01   0.000E+00
  0.000E+00   0.000E+00

INPUTS 11
*---------------------
* 01) Air flow [m3/h]
* 02) Air inlet temperature [°C]
* 03) Air inlet humidity [%]
* 04) Air pressure [bar]
```

```
* 05) Water infiltration [m3/h]
* 06-11) Surface conditions [°C or W]

  Aflow         Tamb          Hamb          0,0           0,0
  Pfree         Pfix          Tamb          0,0           0,0
  0,0

  0.000E+00     0.000E+00     0.000E+00     1.000E+00     0.000E-03
  0.000E+00     0.000E+00     Tamb          0.000E+00     0.000E+00
  0.000E+00

* OUPUTS 30
*---------------------
* 01) Temperature of air outlet [°C]
* 02) Humidity of air outlet [%]
* 03) Sensible energy rate delivered to ground [kJ/hr]
* 04) Latent energy rate delivered to ground [kJ/hr]
* 05-10) Equivalent border conditions [°C or kJ/hr]
* 11-30) Optional outputs [fct of output type]
*===============================================================

*===============================================================
* Integrator
*---------------------------------------------------------------
  UNIT 3   TYPE 55
  PARAMETERS 7
  1  1  1  1  1E5  1  1E5
  INPUTS 1
  dMwat
  0
*===============================================================

*===============================================================
* Printers
*---------------------------------------------------------------
* PARAMETERS
*---------------------
* 01) Print time interval (>0=hours <0=months)
* 02) Time for start of printer (>0=hours <0=months)
* 03) Time for stop of printer (>0=hours <0=months)
* 04) Logical unit (<=0 for std Line Printer)
*---------------------------------------------------------------
* Printer 1
  UNIT 11   TYPE 25
*---------------------
  PARAMETERS 4
  1.000E+00     0.000E+00     1.000E+05     1.010E+02
  INPUTS 10
  Psbl          Plat          Pfree         Pfix          Pamb
  Pfront        Pback         Pside         Pwat          Pfric
  Psbl          Plat          Pfree         Pfix          Pamb
  Pfront        Pback         Pside         Pwat          Pfric
*---------------------------------------------------------------
* Printer 2
  UNIT 12   TYPE 25
*---------------------
  PARAMETERS 4
  1.000E+00     0.000E+00     1.000E+05     1.020E+02
```

```
  INPUTS 10
  PinH          PinG          PinH#         PinG#         Pfree#
  Pfix#         Mwat          Mwat#         dMlat         dMout
  PinH          PinG          PinH#         PinG#         Pfree#
  Pfix#         Mwat          Mwat#         dMlat         dMout
*---------------------------------------------------------------
* Printer 3
  UNIT 13   TYPE 25
*--------------------
  PARAMETERS 4
  1.000E+00     0.000E+00     1.000E+05     1.030E+02
  INPUTS 10
  Tfree         Tfix          TgFree        TgFix        Tamb
  T1            T2            T3            T4           Tout
  Tfree         Tfix          TgFree        TgFix        Tamb
  T1            T2            T3            T4           Tout
*===============================================================

****************************************************************
  END
****************************************************************
```

Observations :

- Linking is done by feeding upper hypocaust surfaces with outflowing energy rates (*Pfree* and *Pfix*) from the two zones and reciprocally feeding building with upper border temperatures (*Tfree* and *Tfix*) from hypocaust.
- Internal energy gains of hypocaust (*PinH*, *PinH#*) and surrounding ground (*PinG*, *PinG#*) are each defined by two alternative ways, so as to check for proper energy balance. Same is done for total free water within tubes (*Mwat*, *Mwat#*) and energy diffused from zones to hypocaust (*Pfree*, *Pfree#*, *Pfix*, *Pfix#*).

<u>Results of simulation</u>

Parameters defined further up and printed in output files are plotted hereafter and show following, expected dynamic :

- Airflow heats up hypocaust (see Fig. 3, *Psbl*). During first hours, energy diffuses from building and surrounding soil into colder hypocaust and as latter warms up diffusion reverses (see Fig. 4, *Pfront*, *Pback*, *Pside*, *Pfree*, *Pfix*).
- As airflow heats up hypocaust it cools down along the tubes (see Fig. 2, stratification of *Tamb*, *T1-T4*, *Tout*) and with time tends to reach equilibrium temperature.
- Warm and humid airflow condenses during first hours (see Fig. 3, *Plat* and Fig. 5, *dMlat*, *Mlat*). As ground temperature rises, all free water within tubes then evaporates again, after which no latent exchanges take place any more.
- Within Type 460 energy balance is correct (see Fig. 3, *PinH*, *PinH#*, *PinG*, *PinG#*), as is mass balance (see Fig. 5, *Mwat*, *Mwat#*). Consistency of energy flows between modules is also respected (see Fig. 4, *Pfree*, *Pfree#*, *Pfix*, *Pfix#*).

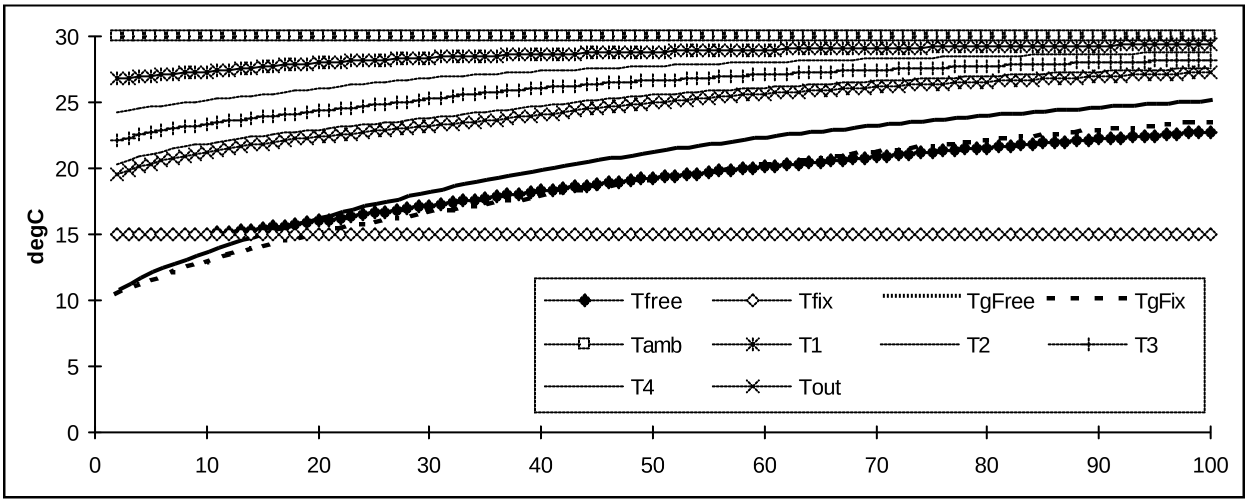


Fig. 2 : Temperature of air (Tfree, Tfix) and ground (TgFree, TgFix) of both zones as well as of airflow along the tubes (T1-T4) and at inlet and outlet (Tamb, Tout).

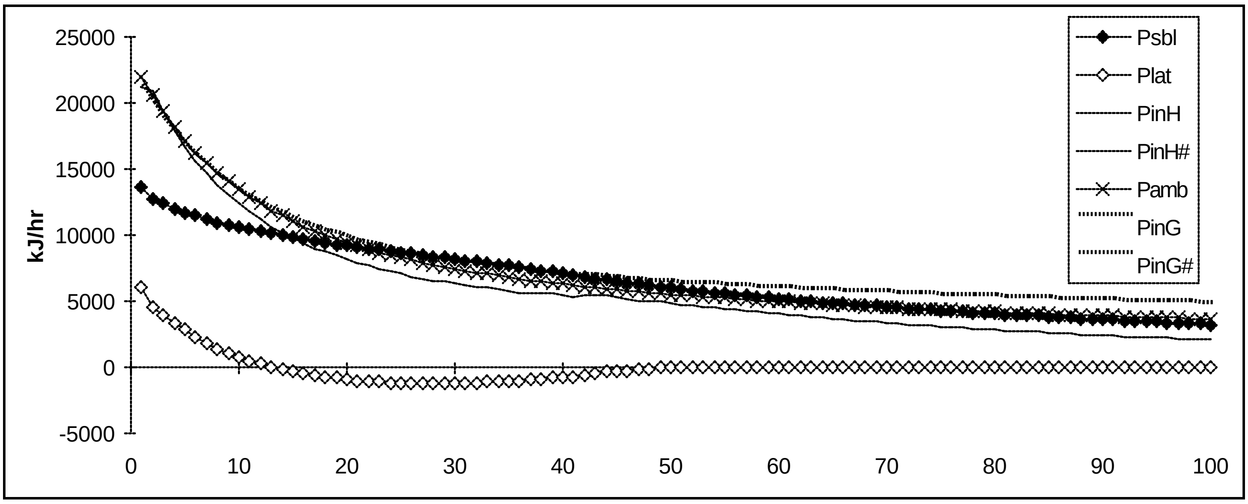


Fig. 3 : Internal heat gains of hypocaust (PinH, PinH#) and surrounding soil (PinG, PinG#), as well as energy entering hypocaust by airflow (Psbl, Plat) and diffused from ambient into surrounding soil (Pamb).

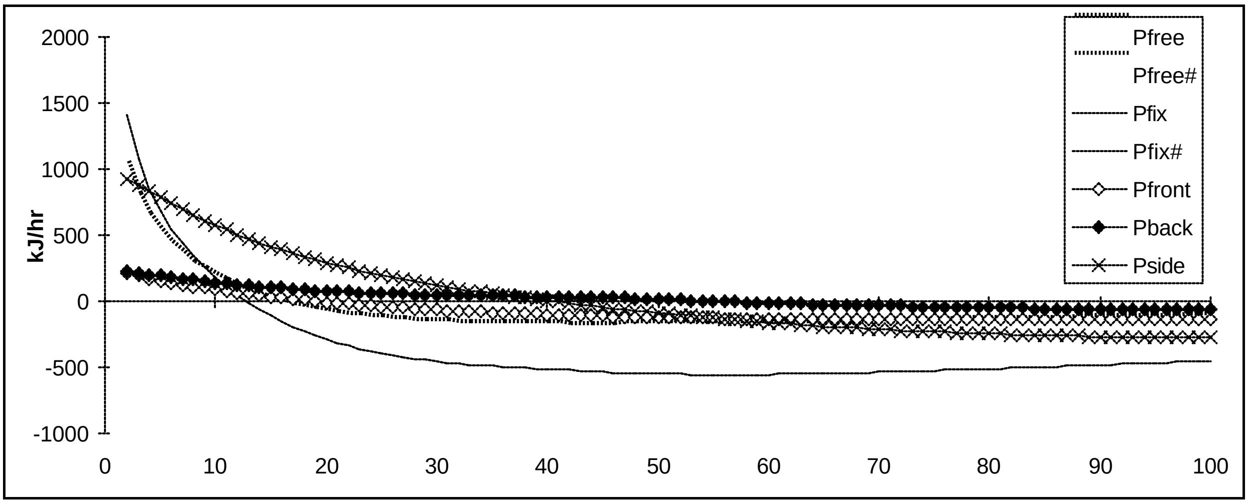


Fig. 4 : Energy entering hypocaust from building (Pfree, Pfree#, Pfix, Pfix#) and from surrounding soil (Pfront, Pback, Pside).

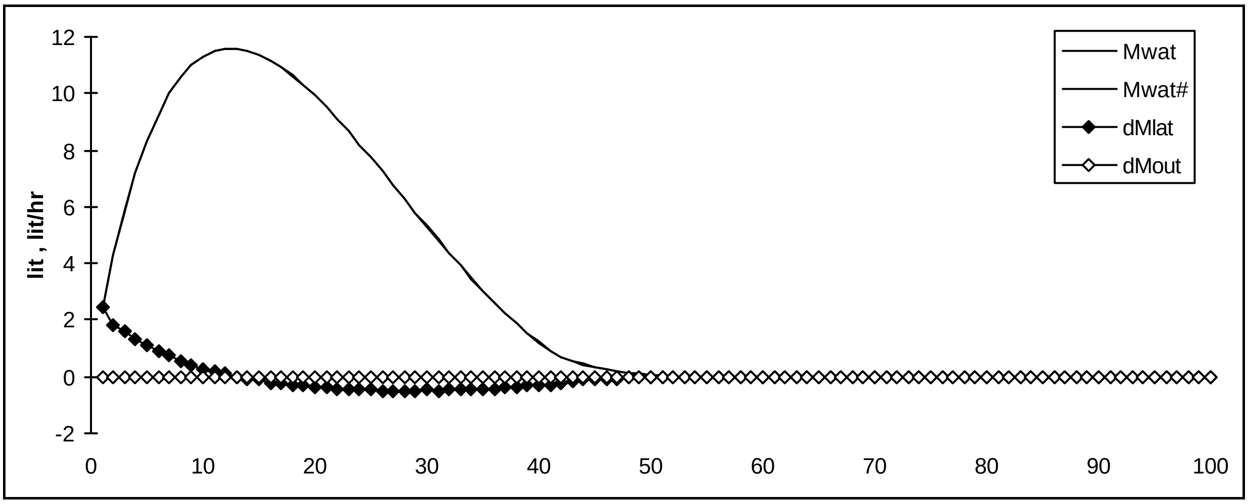


Fig. 5 : Free water in tubes (Mwat, Mwat#) as well as water condensation (dMlat) and flux out of tubes (dMout).