Trnsys User Manual
TYPE 399
Phase Change Materials in Passive and Active Wall Constructions

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1. Nomenclature

A_i	Area of the surface
$c_{p,solid}$	Specific heat capacity in the solid phase of the PCM
$c_{p,liquid}$	Specific heat capacity in the liquid phase of the PCM
$c_{p,w}$	Specific heat capacity water
d_1	Depth of cover pipe – side 1
d_r	Pipe diameter
d_x	Pipe spacing
h	Enthalpy
$\dot{m}$	Mass flow rate
Q_{gain}	Energy from heat gains
Q_{PCM}	Latent heat of the PCM material
Q_{Phase}	Latent heat of the PCM material
$R_{t.}$	Overall resistance
$R_{z.}$	Resistance panel depth
$R_{w.}$	Resistance water flow
$R_{r.}$	Resistance pipe
$R_{x.}$	Resistance pipe spacing
T	Material temperature
T_{low}	Lower boundary of the melting range of the PCM material
T_{up}	Upper boundary of the melting range of the PCM material
λ_w	Thermal conductivity water
λ_r	Thermal conductivity pipe material
ϑ_1	Temperature side 1
ϑ_2	Temperature side 2
ϑ_{VL}	Supply temperature
ϑ_{air}	Air temperature
ϑ_K	Core temperature fo material layer
ϑ_{Star}	Star node temperature
$\vartheta_{w,i}$	Surface temperature, inside
ϑ_{VL}	Supply temperature
σ	Wall thickness pipe

2. Introduction

This component (TYPE 399) models a wall constructions where one layer may be a phase change material (PCM). The Type allows to model passive and active systems. The wall con-struction is modeled with a Crank-Nicolson algorithm and an elimination method to solve the heat conduction equation. The discretization scheme is one-dimensional. The amount of nodes depends on the thickness of each layer. The PCM-layer could be any-where in the construction.

Thermal active system (TABS) is modeled with a resistance network for capillary tubes or pipes embedded in the core. The Type has the possibility to model a temperature dependent heat capacity of the PCM. It is also possible to model a hysteresis effect of the PCM. Some PCM materials have different enthalpy curves for heating and cooling.

3. Trnsys Component Configuration

3.1. Description of Parameters

Par. no.	Symbol	Description	Unit
1	-	**Number of different material layers**	-
2	-	**Thermal conductivity of layer n**	kJ/(hr m K)
3	-	**Density of layer n**	kg/m³
4	-	**Heat capacity of layer n**	kJ/(kg K)
5	-	**Thickness of layer n**	m
6	-	**Discretization of layer n**	-
7	-	**Which layer contains the PCM material?** (Set this parameter to 0 if no PCM exits)	-
8	-	**Lower phase change temperature**	°C
9	-	**Upper phase change temperature**	°C
10	-	**Wall area**	m²
11	Tintern	**Internal Timestep of the Type in seconds (360 seconds)**	sec
12	-	**Logical unit cp-data file heat up** Logical unit for the data file, which contains the dependant cp-values for the pcm material, case heat up	-
13	-	**Logical unit cp-data file cool down** Logical unit for the data file, which contains the dependant cp-values for the pcm material, case cool down	-
14	-	**Initial temperature for all temperature nodes**	°C
15	-	**Pipe to pipe distance of thermal active system (tabs)**	m
16	-	**Pipe diameter of thermal active system (tabs)**	m
17	-	**Pipe wall thickness of thermal active system (tabs)**	m
18	-	**Thermal conductivity pipe material of thermal active system (tabs)**	kJ/ (hr K)
19	-	**Heat capacity of the fluid in the pipe of thermal active system (tabs)**	kJ/ (kg K)
20	-	**Depth of active layer of thermal active system (tabs)**	m
21	-	**Number of parallel loops of thermal active system (tabs)** This parameter is used only if a mass flow rate (8th input) > 0 is defined. If no fluid tubes exists, leave the default value and set the mass flow rate (8th input) = 0.	-
22	-	**Number of userdefined wall temperatures**	-
22+i	-	**Depth of temperature n**	m

3.2. Description of Inputs

Input no	Symbol	Description	Unit
1	TB1	**Boundary temperature on side 1** If linked to Type 56 then: If the side1 is facing "the airnode": TB1 = Tstar (= NType 23: star node temperature of zone) If surface is facing outside then: TB1 = ambient air temperature If the side is facing "userdefined boundary condition": TB1 = boundary temperature as defined in Type56	°C
2	TB2	**Boundary temperature on side 2** If linked to Type 56 then definition see Input 1 - TB1	°C
3	h1	**Heat transfer coefficient on side 1** If linked to Type 56 then: If the side1 is facing "the airnode": h1 = 1/ MAX(REQV * AREA ,0.001) (REQV = NType 86; AREA = NTYPE 113) If surface is facing outside then: h1 = HCONVO (= NTYPE 107) If the side is facing "userdefined boundary condition": h1 = HCONVO (= NTYPE 107)	kJ/(hr m² K)
4	h2	**Heat transfer coefficient on side 2** If linked to Type 56 then definition see Input 3 - h1	kJ/(hr m² K)
5	QWG1	**Energy gain on side 1** If linked to Type 56 then: If the side1 is facing "the airnode": LW Mode = STANDARD: QWG1 = QABSI - QWG (QABSI = NType 21; QWG = NTYPE 82) LW Mode = DETAILED: QWG1 = QABSI + QABSILW - QWG (QABSI = NType 21; QWG = NTYPE 82; QABSILW = NTYPE 110;) If surface is facing outside then: QWG1 = HT * ABS-BACK – QSKY (HT = NTYPE 116; ABS-BACK = absorption coefficient as defined in Type 56; QSKY = NTYPE 83) If the side is facing "userdefined boundary condition": QWG1 = 0	kJ/hr
6	QWG2	**Energy gain on side 2** If linked to Type 56 then definition see Input 5 - QWG1	kJ/hr
7	Tsupply	**Supply temperature of thermal active system (tabs)** This input is used only if a mass flow rate (8th input) > 0 is defined.	°C
8	mtot	**Total mass flow rate of thermal active system (tabs)** (If no fluid tubes exists, set the mass flow rate = 0)	kg/hr

3.3. Description of Outputs

Out. no	Symbol	Description	Unit
1	TSI1	**Surface temperature on side 1**	°C
2	TSI1	**Surface temperature on side 2**	°C
3	QSI1	**Heat flux on the surface on side 1** If linked to Type 56 then coupled as surface gain to the dummy surface of Type56	kJ/hr
4	QSI2	**Heat flux on the surface on side 2** If linked to Type 56 then coupled as surface gain to the dummy surface of Type56	kJ/hr
5	-	**Temperature fo the first temperature node** (seen from the zone) Also this node will be modified in case of an active element	°C
6	cp_PCM	**Average specific heat capacity of all PCM nodes**	kJ/ (kg K)
7	Q Fluid	**Input power by the fluid of the integrated pipe system of the total wall area** negative ⇒ cooling positive ⇒ heating	kJ/ hr
8	Treturn	**Return temperature of fluid**	°C
9	-	**Average node temperature overall PCM-nodes**	°C
10	PHASE	**Phase of the PCM** PHASE =0 ⇒ solid PHASE >0 ⇒ partly melted PHASE ≥1 ⇒ liquid	-
11	QPCM	**Actual amount of energy charged/discharged in the PCM**	kJ
12	ePCM	**Cumulated amount of energy charged/discharged in the PCM**	kJ
13	qSI1	**Specific heat flux on the surface on side 1**	kJ/(hr m²)
14	qSI2	**Specific heat flux on the surface on side 2**	kJ/(hr m²)
15	q_Fluid	**Specific input power by the fluid of the integrated pipe system of the total wall area** negative ⇒ cooling positive ⇒ heating	kJ/(hr m²)
16	q_PCM	**Actual amount of specific energy charged/discharged in the PCM**	kJ/m²
17	e_PCM	**Cumulated amount of specific energy charged/ discharged in the PCM**	kJ
18	-	**Indicator which external file is in use:** =1 ⇒ file associated with par12 =2 ⇒file associated with par 13	-
18+i	-	**Userdefined temperature in depth i**	°C

3.4. External Files

The type needs two external files for the cp-values; one for heating up and one for cooling down the PCM material.

Note:

If there is no layer with PCM material (parameter 7 = 0) then Type399 doesn't read the files. However, the Studio proforma writes ASSIGN-statements with default files in the TRNSYS input file, but these files don't have to exist.

Data file structure:

The data files containing the temperature dependant cp-values of the pcm material in J/(kg K), temperatures are given in °C

in the following format:

Line 1: n material temperatures,

blanc separated

Line 2: cp value corresponding to

1st temperature and lower

Line 3: cp values corresponding to

2nd temperature

…

Line 1+n: cp values corresponding to

last temperature in line 1 and

higher

keyword: end (please don't edit!)

next line, after keyword:

number of data points (n) in the file

Note:

This type isn't able to extrapolate beyond the range of data given in the external file. For temperatures outside the given range the boundary values are applied as constant values.

4. Mathematical Description

4.1. Modelling the wall construction

The wall con-struction is modeled with a Crank-Nicolson algorithm (see Figure 2) and an elimination method to solve the heat conduction equation. The discretization scheme is one-dimensional. The amount of nodes depends on the thickness of each layer. A schematic wall construction is represented in Figure 1.

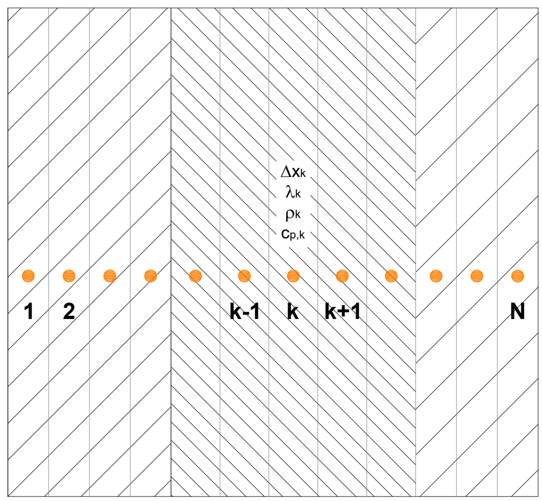


Figure 1: One dimensional model of a wall with 3 different wall layers and N sublayers

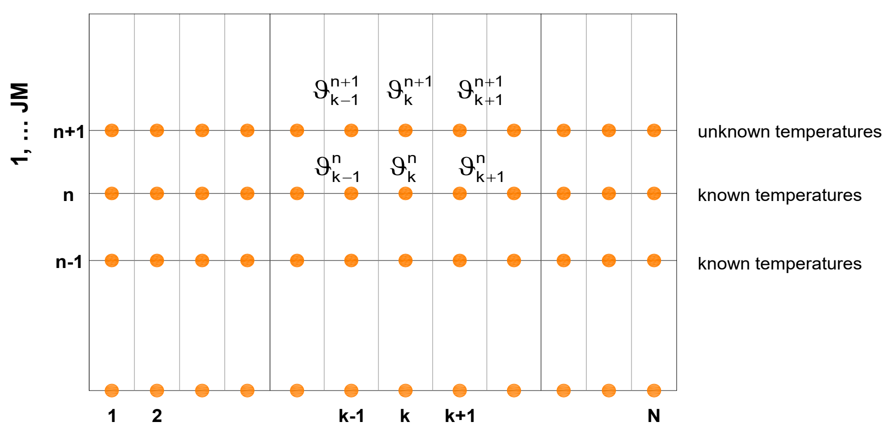


Figure 2: One dimensional Crank-Nicolson scheme

4.2. Modeling the phase change material

To model the phase change of the PCM several methods are possible. To model the PCM material using functions of the specific heat capacity and the material temperature, carried out from experimental DSC measurements can lead to inaccura-cies in the simulation results (Glück, 2006 a), if the algorithm does not pay attention to the phase of the material (solid, partly melted or fully melted) and the energy flow (heating up or cooling down). Another method is to use a rectangular shape of the specific heat capacity over melting temperature range (Ahmad et al. 2006). The calculation method integrated in TYPE 399 uses the enthalpy as an invertible function of the temperature, therefore two different data files with a temperature dependent heat capacity of the PCM is needed:

$$h = h(T) \\ T = T(h) \qquad (1)$$

The approximation of the phase change with a hysteresis was done according to Glück (2006 b). The variation of the enthalpy with the material describes equation 2 – 4 and Figure 3.

$$T < T_{low}: \\ h(T) = c_{p,solid} \cdot T \qquad (2)$$

$$T_{low} \geq T \geq T_{up}: \\ h(T) = c_{p,solid} \cdot T_{low} + PH \cdot Q_{Phase} \\ with: \\ PH = \frac{T - T_{low}}{T_{up} - T_{low}} \qquad (3)$$

$$T > T_{up}: \\ h(T) = c_{p,solid} \cdot T + Q_{Phase} + c_{p,liquid} \cdot (T - T_{up}) \qquad (4)$$

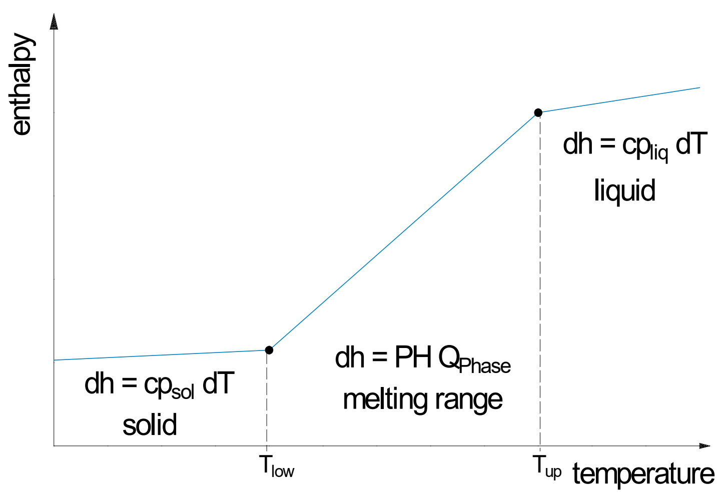


Figure 3: Specific enthalpy h(T) as a function of the material temperature

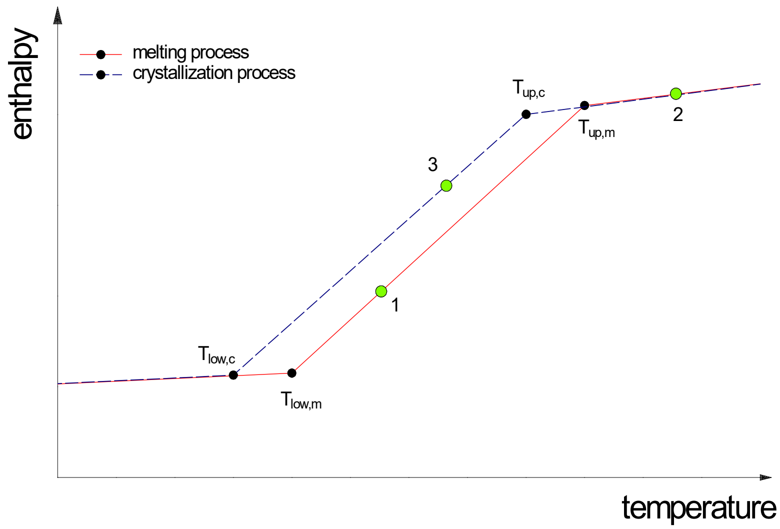


Figure 4: Specific enthalpy h(T) as a function of the material temperature for the melting and crystallization process

The TYPE uses two different data files: one for the melting and one for the crystal-lization process. Thus it is possible to model the temperature dependent behavior of the PCM (see also Figure 4):

$T > T_{low,m} \rightarrow T > T_{up,m} \rightarrow T < T_{up,c} \rightarrow T < T_{low,c}$:

Material consequently heated up (data file for the melting process: solid, melting range and liquid) and then consequently cooled down (data file for the crystallization process: liquid, melting range, solid)

$T > T_{low,m} \rightarrow T < T_{up,m}$:

Material heated up (data file for the melting process: solid, melting range), If material is cooled down in the next time step, but material is still in the melting range (data file for the melting process: melting range, solid)

$T > T_{up,c} \rightarrow T < T_{up,c}$:

Material cooled down (data file for the crystallization process: liquid, melting range).

$T < T_{up,c} \rightarrow T > T_{low,c}$:

Material cooled down (data file for the crystallization process: solid, melting range). If the material is heated up in the next time step, but still in the melting range (data file for the crystallization process: liquid, melting range)

4.3. Modeling the piping system

Thermo-active building elements (slabs or walls of a building) are used to condition buildings by integrating a fluid system into massive parts of the building itself. Examples are radiant floor heat or cooling systems, radiant ceilings or wall heating or cooling systems.

Due to the finite distance between pipes, a two-dimensional temperature field develops in the plane of the thermo-active construction element cross-section. Thermal input or output along piping loops causes a change in the water temperature within the pipe. This change affects the construction element temperature in the z direction. This means that all three dimensions have to be taken into account for the calculation of a thermo active construction element system. Multi-dimensional thermal conduction problems can usually be calculated by a Finite Difference Method (FD) or a Finite Element Method (FEM). Therefore, the region to be examined needs to be transformed into small three-dimensional grid cells. For each cell and for every point in time the required physical variables can be calculated step-by-step in dependency of the adjoining cells. To achieve a sufficiently high level of precision, the grid must be sufficiently dense. This makes calculations complex and usually results in long calculation times. Also, a certain level of experience is required for the collection of geometric data on the construction element and the pipes as well as for the creation of an effective grid design.

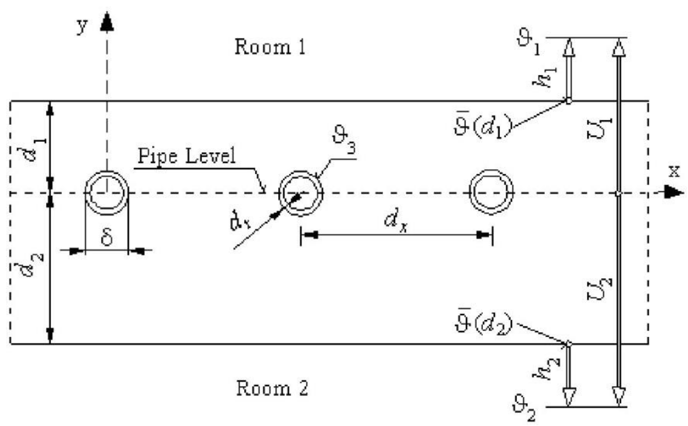


Figure 5: Structure of the thermo active construction element system

For these reasons, a powerful alternative method for the calculation of thermo active construction element systems was developed by Koschenz et. al (2000) and is integrated in Type 399 as well as in Type 56 (multizone building model). The modelling is based on a resistance network approach which is described briefly. A more detailed description is found in maunal of Type 56 (05-MultizoneBuilding.pdf) and Koschenz et. al (2000)

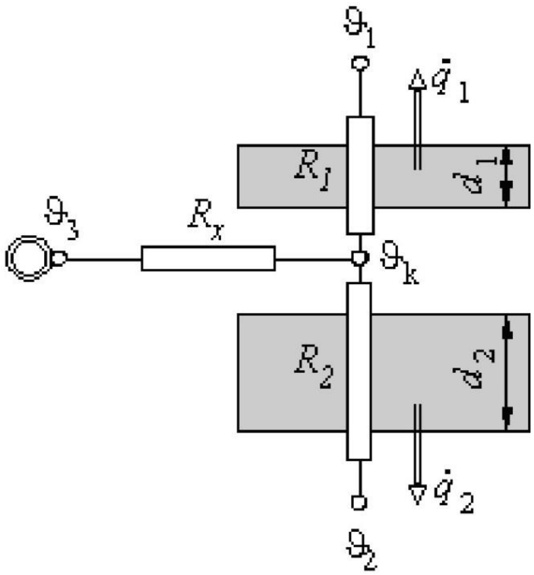


Figure 6: **Network of resistances, star arrangement**

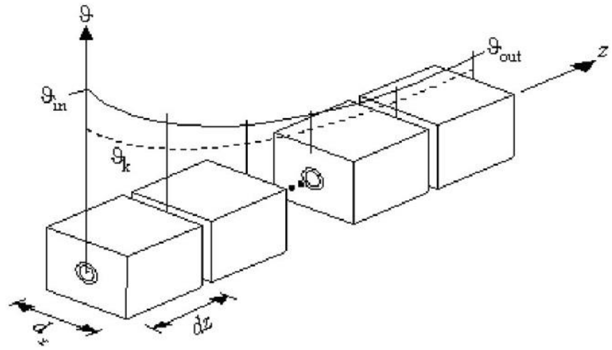


Figure 7: **Change in temperature in the pipe in z direction**

The total resistance (Rt) between the supply temperature of the capillary system or the TABS and the core temperature is a serial coupling of the single resistances. Each of these single resistances models the influences and characteristics of the capillary tube or a TABS system: the thermal resistance in z direction (Rz), the heat flux between pipe and water (Rw, Rr) and the pipe spacing and diameter (Rx).

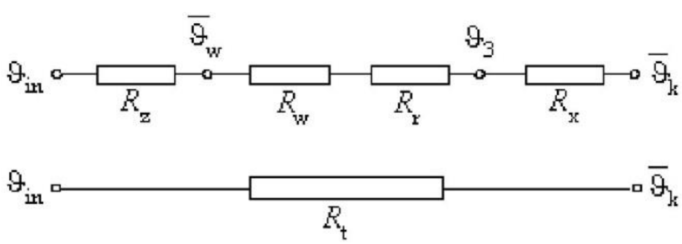


Figure 8: **Total resistance between water inlet temperature and core temperature**

Shows the correlation between the supply temperature and the core temperature of the active layer.

$$R_t = R_z + R_w + R_r + R_x \qquad \textbf{(5)}$$

$$R_z = \frac{1}{2 \cdot \dot{m} \cdot cp_w} \qquad \textbf{(6)}$$

$$R_r = \frac{d_x \cdot \ln\left(\frac{\sigma}{\sigma - 2 \cdot d_r}\right)}{2 \cdot \lambda_r \cdot \pi} \qquad \textbf{(7)}$$

The thermal resistance by convection (R_w) depends on the flow conditions in the tubes and is given by:

R_w for Re < 2300 (laminar flow):

$$R_w = \frac{d_x}{\pi \cdot \lambda_w} \cdot \left(49.03 + 4.14 \cdot \frac{4}{\pi} \cdot \frac{\dot{m} \cdot cp_w \cdot d_x}{\lambda_w} \right)^{-\frac{1}{3}} \quad \textbf{(8)}$$

R_w for Re > 2300:

$$R_w = d_x^{\frac{0.13}{8\pi}} \cdot \left(\frac{\sigma - 2 \cdot d_r}{\dot{m}} \right)^{0.87} \quad \textbf{(9)}$$

Depending on the input data the algorithm automatically detects weather a capillary tube or a TABS system is defined.

R_x for capillary tubes:

$$R_x = \frac{d_x \cdot \frac{1}{3} \cdot \left(\frac{d_x}{\pi \cdot \sigma} \right)}{2 \cdot \lambda_l \cdot \pi} \quad \textbf{(10)}$$

R_x for TABS:

$$R_x = \frac{d_x \cdot \ln\left(\frac{d_x}{\pi \cdot \sigma} \right)}{2 \cdot \lambda_l \cdot \pi} \quad \textbf{(11)}$$

Please note that the constraints for the resistance network model are given by:.

for capillary tubes:

$$d_x < 5.8 \cdot \sigma \quad \textbf{(12)}$$

for TABS systems:

$$d_x \geq 5.8 \cdot \sigma \quad \textbf{(13)}$$

for both systems:

$$\frac{d_i}{d_x} > 0.3 \text{ and } \frac{\sigma}{d_x} < 0.2 \quad \textbf{(14)}$$

In addition, the layer containing the pipe system cannot be the PCM material layer!

5. Example

5.1. Coupling of Type 399 to the multizone building model (Type 56)

The idea is that Type 399 models the construction element completely. The energy balance of the surface sides 1 and 2 is shown in Figure 6.

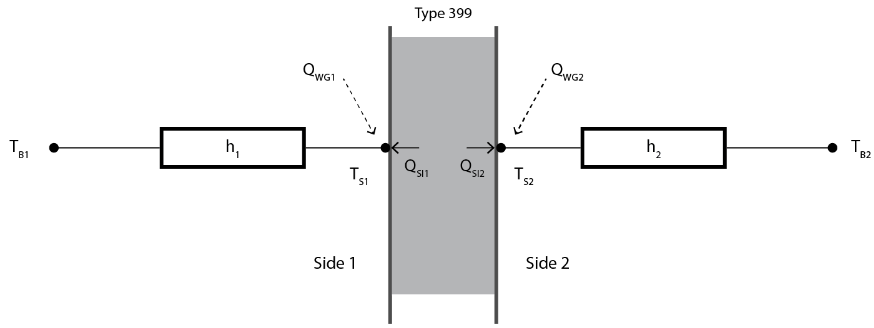


Figure 9: Energy balance of the surface mode sides 1 and side 2 of Type 399

For coupling of Type 399 to the multizone building model (Type 56) the following Inputs needs to be set::

- TB1 - boundary temperature on side 1 [°C]
- TB2 - boundary temperature on side 2 [°C]
- h1 - heat transfer coefficient on side 1 [kJ/(hr m² K)]
- h2 - heat transfer coefficient on side 2 [kJ/(hr m² K]
- QWG1 - energy gain on side 1 [kJ/hr]
- QWG2 - energy gain on side 2 [kJ/hr]

The values of these inputs depend on where the surface sides are facing to (outside, insisde, boundary). The definitions are described in detail in section 3.2. In Figure 7 the coupling of an "adjacent" surface is shown. (Note: An "adjacent" surface is located between two airnodes of the building model).

In the building model (Type56) a dummy surface with a high resistance construction type is defined such that no energy flows through the surface from one side to the other. The heat fluxes from inside the surface to both sides are given as OUTPUTS by the Type 399 (QSI1,QSI2) and passed to the surface in Type 56 by as an INPUT for "surface gains".

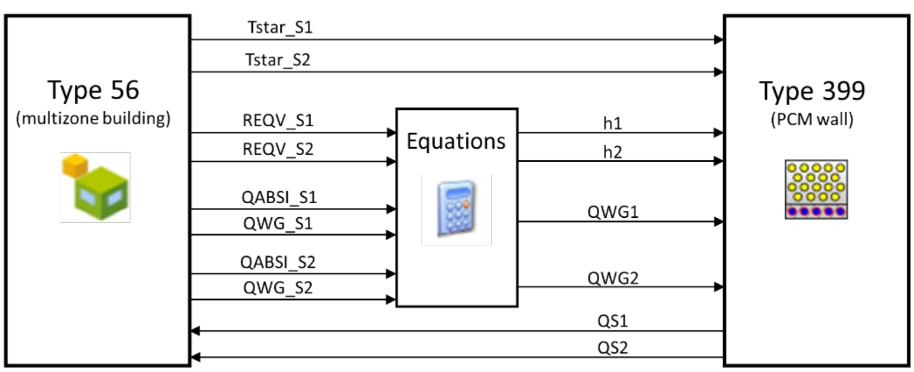
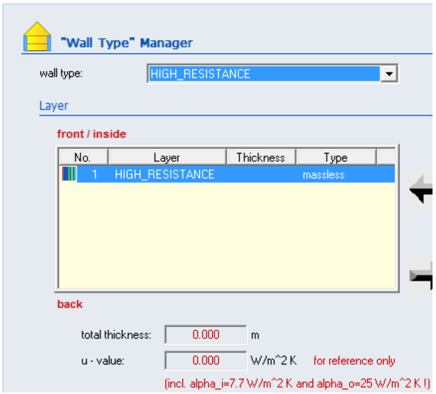
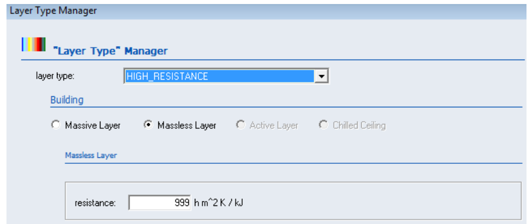


Figure 10: Coupling Type 399 with Type 56 for an "adjacent" surface

The definition of a high resistance construction type in the TRNBuild (GUI of Type 56) is shown in **Figure 8**). The surface definition with the required surface gains in TRNbuild is shown in Figure 9)

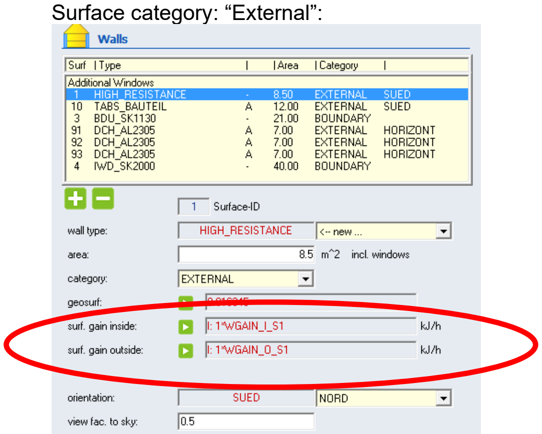




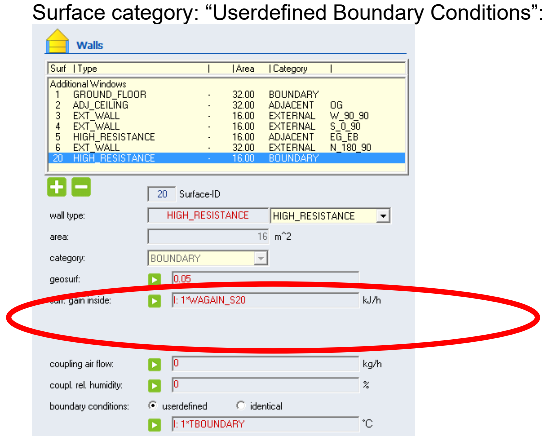
Note: 999 is currently the max. possible value for a resistance. This leads to small error in the energy balance. In general it is neglectable

Figure 11: Construction Type definition in TRNbuild (for Type56)

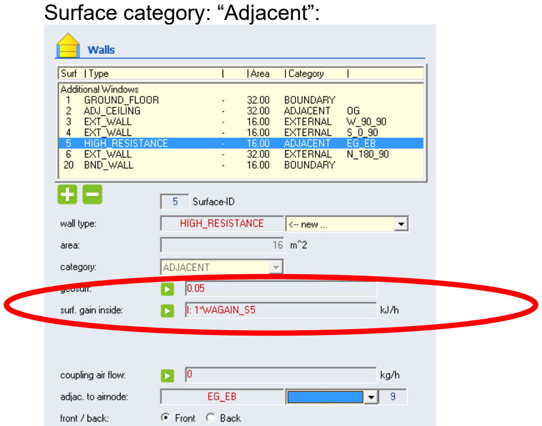
Surface category: "External":



Surface category: "Userdefined Boundary Conditions":



Surface category: "Adjacent":



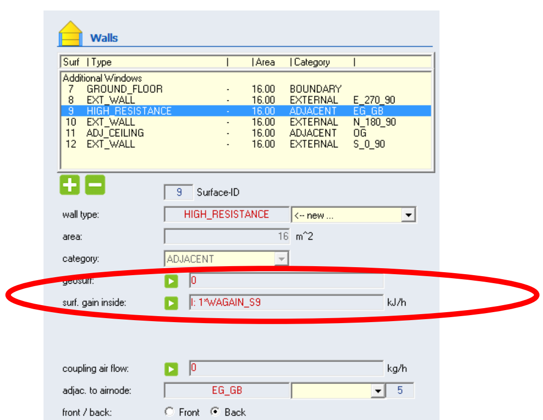


Figure 12: Surface definition with the required surface gains in TRNbuild

6. References

Ahmad A., Bontemps A., Sallèe H., Quenard D. 2006. "Thermal testing and numerical simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material. Energy and Buildings, pp 673-681.

Glück B. 2006 b. „Dynamisches Raummodell zur wärmetechnischen und wär-mephysiologischen Bewertung". Rud. Otto-Meyer Umweltstiftung, Hamburg.

Glück B. 2006 a. „Einheitliches Nährungs-verfahren zur Simulation von Latent-wärmespeichern", HLH Bd. 57 Nr. 7, pp 25-30.

Koschenz, M. et al. 2000 „Thermoakti-ve Bauteilsysteme tabs", EMPA.