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 phase change materials (PCM) in wall constructions. 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 systems (TABS) are 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?**	-
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	-	**Initialization temperature for all temperature nodes**	°C
15	-	**Pipe to pipe distance of the chilled ceiling panel**	m
16	-	**Pipe diameter of the chilled ceiling panel**	m
17	-	**Pipe wall thickness of the chilled ceiling panel**	m
18	-	**Thermal conductivity pipe material of the chilled ceiling panel**	kJ/ (hr K)
19	-	**Heat capacity of the fluid in the pipe**	kJ/ (kg K)
20	-	**Depth of active layer**	m
21	-	**Number of parallel loops**	-
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 m^2 K)
4	h2	**Heat transfer coefficient on side 2** If linked to Type 56 then definition see Input 3 - h1	kJ/(hr m^2 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)**	°C
8	mtot	**Total mass flow rate of thermal active system (tabs)**	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 material.

Note if your workaround is in the TRNSYS-dck:

Please replace your ASSIGN-statement through a DESIGNATE-statement. If the external file is associated with a logical unit number by means of a DESIGNATE statement, the TRNSYS kernel will not open the external file and it is left to the component to do so.

```
*** External files
DESIGNATE "cpPCMData_heat.dat" 99
DESIGNATE "cpPCMData_cool.dat" 100
```

Data file structure:

The data files containing the temperature dependant cp-values of the pcm material

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: the type will not be able to extrapolate beyond the range of data given in the external file.

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.

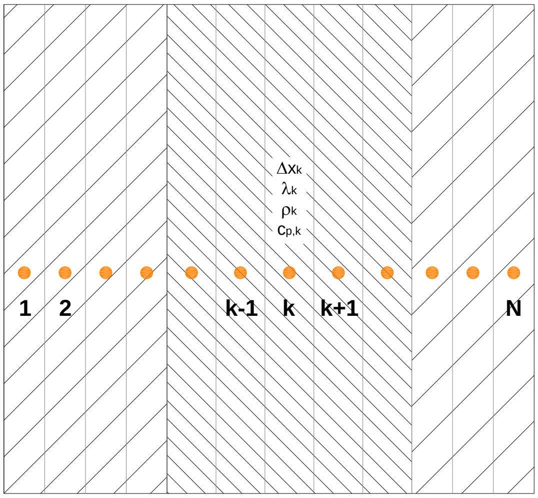


Figure 1: One dimensional model of a wall with 3 different wall layers and N sublayers

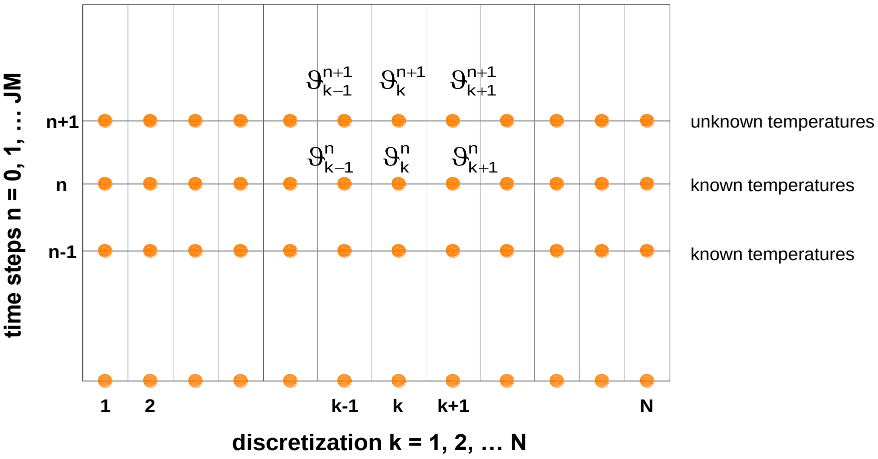


Figure 2: One dimensional Crank-Nicolson scheme

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:

$$\begin{aligned} h &= h(T) \\ T &= T(h) \end{aligned} \qquad \textbf{(1)}$$

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.

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

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

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

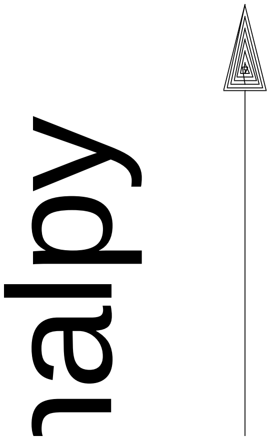


Figure 3: Specific enthalpy h(T) as a function of the material temperature

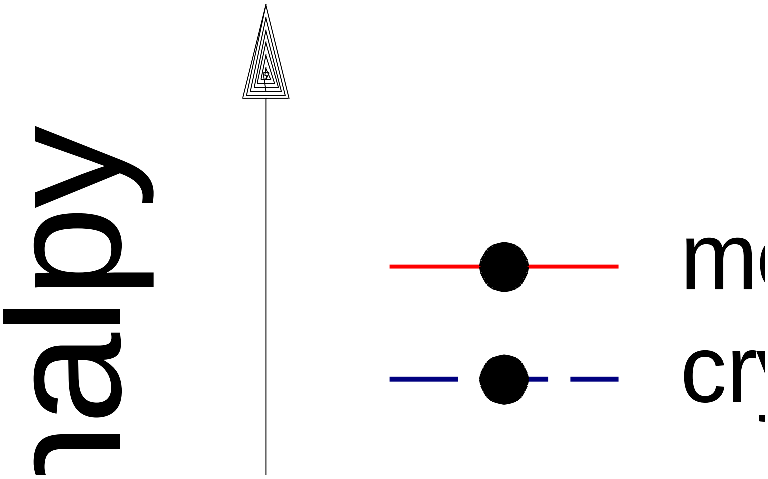


Figure 4: Specific enthalpy h(T) as a function of the material temperature for the melting and crystallization process

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

The algorithm of modeling embedded pipes in a floor, ceiling or wall is carried out from the work of Koschenz et. al (2000). He describes an algorithm to model capillary tube systems through a resistance network. The total resistance (Rt) between the supply temperature of the chilled ceiling panel 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 panel depth (Rz), the heat flux between pipe and water (Rw, Rr) and the pipe spacing and diameter (Rx). **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the correlation between the supply temperature and the core tem-perature of the chilled ceiling layer.

$$R_t = R_z + R_w + R_r + R_x \tag{5}$$

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

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

The type makes an automatic distinction between a capillary tube and a TABS system. Also a distinction is integrated for the flow condition.

R_w for Re < 2300 (laminar flow):

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

R_w for Re > 2300:

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

R_x for capillary tubes:

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

R_x for TABS:

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

Please note that the constraints for the resistance network model are valid.

for capillary tubes:

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

for TABS systems:

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

for both systems:

$$\frac{d_1}{d_x} > 0.3 \qquad (14)$$

$$\frac{\sigma}{d_x} < 0.2 \qquad (15)$$

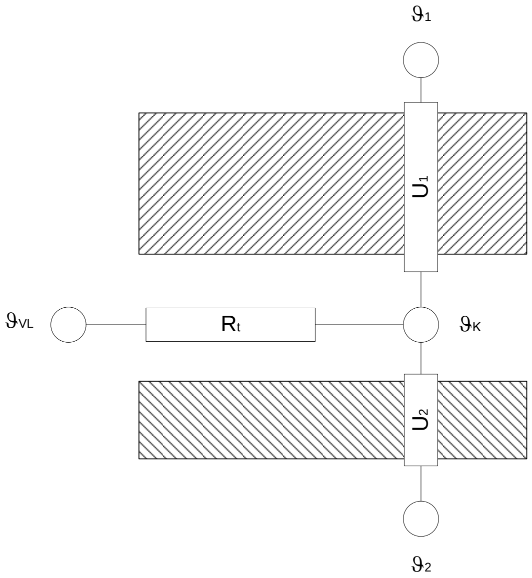


Figure 5: Resistance network

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.

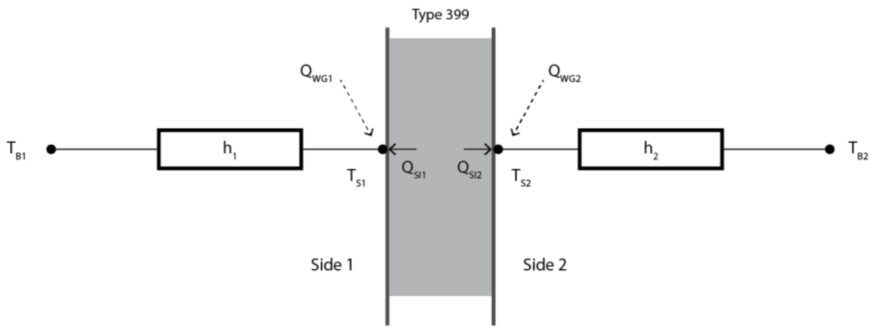


Figure 6: Energy balance of the surface mode sides 1 and side 2 of Type 399

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”.

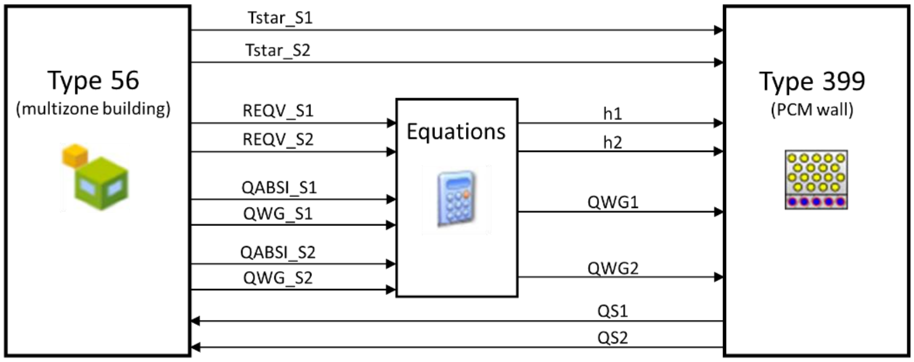
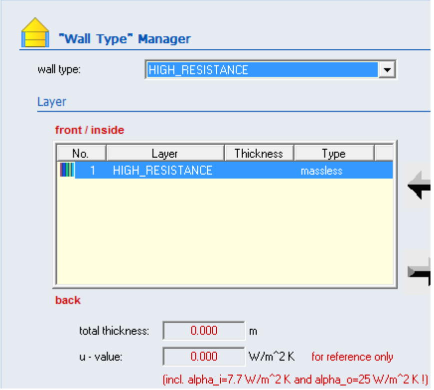


Figure 7: Coupling Type 399 with Type 56 for an “adjacent” surface

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)



"Wall Type" Manager

wall type: HIGH_RESISTANCE

Layer

front / inside

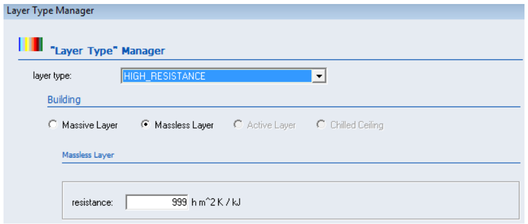
No.	Layer	Thickness	Type
1	HIGH_RESISTANCE		massless

back

total thickness: 0.000 m

u - value: 0.000 W/m^2 K for reference only

(incl. alpha_i=7.7 W/m^2 K and alpha_o=25 W/m^2 K !)



Layer Type Manager

"Layer Type" Manager

layer type: HIGH_RESISTANCE

Building

○ Massive Layer ● Massless Layer ○ Active Layer ○ Chilled Ceiling

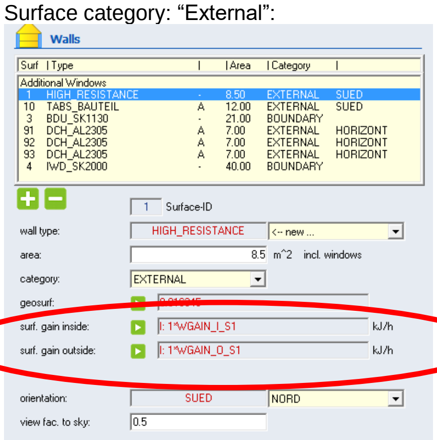
Massless Layer

resistance: 999 h m^2 K / kJ

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 8: Construction Type definition in TRNbuild (for Type56)

Surface category: "External":



Walls

Surf	Type		Area	Category	
Additional Windows					
1	HIGH_RESISTANCE	-	8.50	EXTERNAL	SUED
10	TABS_BAUTEIL	A	12.00	EXTERNAL	SUED
3	BDU_SK1130	-	21.00	BOUNDARY	
91	DCH_AL2305	A	7.00	EXTERNAL	HORIZONT
92	DCH_AL2305	A	7.00	EXTERNAL	HORIZONT
93	DCH_AL2305	A	7.00	EXTERNAL	HORIZONT
4	IWD_SK2000	-	40.00	BOUNDARY	

1 Surface-ID

wall type: HIGH_RESISTANCE <-- new ...

area: 8.5 m^2 incl. windows

category: EXTERNAL

geosurf: [illegible]

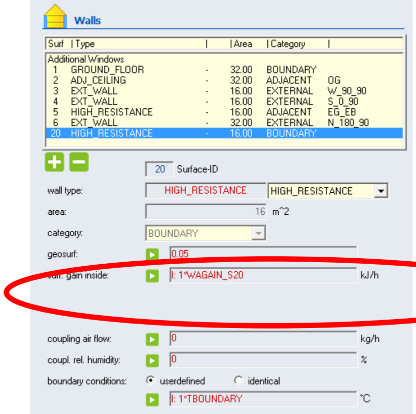
surf. gain inside: I: 1*WGAIN_I_S1 kJ/h

surf. gain outside: I: 1*WGAIN_O_S1 kJ/h

orientation: SUED NORD

view fac. to sky: 0.5

Surface category: "Userdefined Boundary Conditions":



Walls

Surf	Type		Area	Category	
Additional Windows					
1	GROUND_FLOOR	-	32.00	BOUNDARY	
2	ADJ_CEILING	-	32.00	ADJACENT	OG
3	EXT_WALL	-	16.00	EXTERNAL	W_90_90
4	EXT_WALL	-	16.00	EXTERNAL	S_0_90
5	HIGH_RESISTANCE	-	16.00	ADJACENT	EG_EB
6	EXT_WALL	-	32.00	EXTERNAL	N_180_90
20	HIGH_RESISTANCE	-	16.00	BOUNDARY	

20 Surface-ID

wall type: HIGH_RESISTANCE HIGH_RESISTANCE

area: 16 m^2

category: BOUNDARY

geosurf: 0.05

surf. gain inside: I: 1*WAGAIN_S20 kJ/h

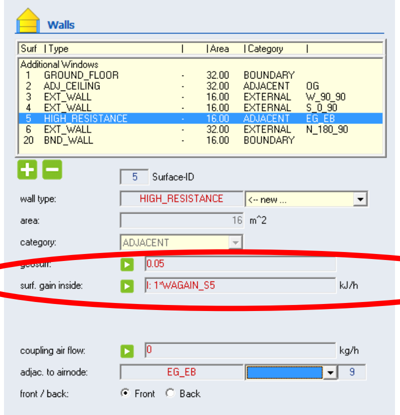
coupling air flow: 0 kg/h

coupl. rel. humidity: 0 %

boundary conditions: ● userdefined ○ identical

I: 1*TBOUNDARY °C

Surface category: "Adjacent":



Walls

Surf	Type		Area	Category	
Additional Windows					
1	GROUND_FLOOR	-	32.00	BOUNDARY	
2	ADJ_CEILING	-	32.00	ADJACENT	OG
3	EXT_WALL	-	16.00	EXTERNAL	W_90_90
4	EXT_WALL	-	16.00	EXTERNAL	S_0_90
5	HIGH_RESISTANCE	-	16.00	ADJACENT	EG_EB
6	EXT_WALL	-	32.00	EXTERNAL	N_180_90
20	BND_WALL	-	16.00	BOUNDARY	

5 Surface-ID

wall type: HIGH_RESISTANCE <-- new ...

area: 16 m^2

category: ADJACENT

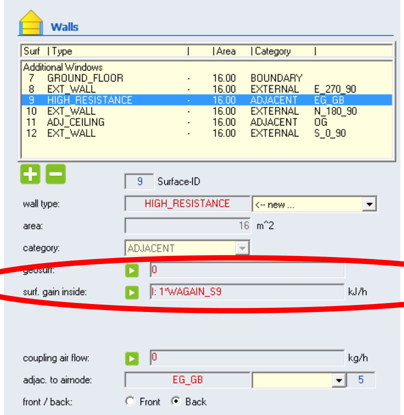
geosurf: 0.05

surf. gain inside: I: 1*WAGAIN_S5 kJ/h

coupling air flow: 0 kg/h

adjac. to airnode: EG_EB 9

front / back: ● Front ○ Back



Walls

Surf	Type		Area	Category	
Additional Windows					
7	GROUND_FLOOR	-	16.00	BOUNDARY	
8	EXT_WALL	-	16.00	EXTERNAL	E_270_90
9	HIGH_RESISTANCE	-	16.00	ADJACENT	EG_GB
10	EXT_WALL	-	16.00	EXTERNAL	N_180_90
11	ADJ_CEILING	-	16.00	ADJACENT	OG
12	EXT_WALL	-	16.00	EXTERNAL	S_0_90

9 Surface-ID

wall type: HIGH_RESISTANCE <-- new ...

area: 16 m^2

category: ADJACENT

geosurf: 0

surf. gain inside: I: 1*WAGAIN_S9 kJ/h

coupling air flow: 0 kg/h

adjac. to airnode: EG_GB 5

front / back: ○ Front ● Back

Figure 9: 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.

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