TRNSYS TYPE 399

Phase change materials in passive and active wall constructions

Model description and implementing into TRNSYS

Arno Dentel, M.Eng., Prof. Dr. Wolfram Stephan

Georg Simon Ohm University of Applied Sciences

Institute for Energy and Building

Version 1.5

May, 13st 2013

General description

This component (TYPE 399) models phase change materials (PCM) in wall constructions. The Type allows to model passive and active systems. The wall construction 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. The PCM-layer could be anywhere in the construction. Active systems are modeled with a resistance network for capillary tubes, thus it is possible to simulate chilled ceiling panels. An algorithm to simulate embedded pipes, like TABS, in deeper wall layers is not integrated in this approach. The piping system is fixed coupled to the first node in the first material layer. 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.

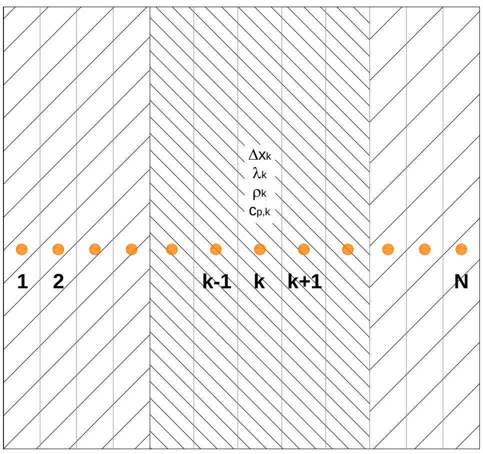

Figure 1: One dimensional model of a wall with 3 different wall layers an N sublayers

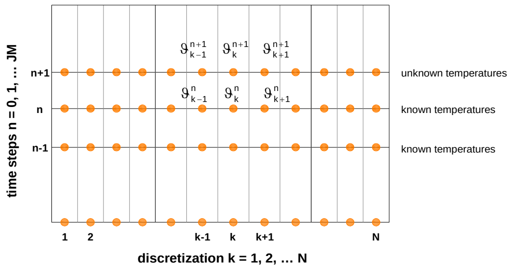

Figure 2: One dimensional Crank-Nicolson scheme

Modeling the phase change

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 inaccuracies 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:

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

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.

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

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

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

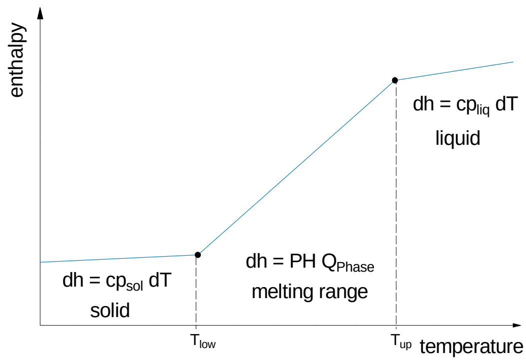

Figure 3: specific enthalpy h(T) as a function of the material temperature

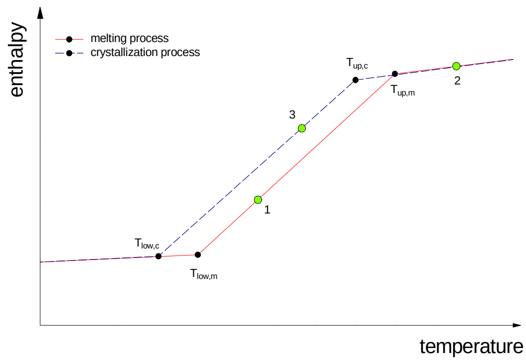

Figure 4: specific enthalpy h(T) as a function of the material temperature for the melting and crystallization process

The TYPE uses two different data files: one for the melting and one for the crystallization 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)

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 (R_t) 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 (R_z), the heat flux between pipe and water (R_w, R_r) and the pipe spacing and diameter (R_x). Figure 5 shows the correlation between the supply temperature and the core temperature of the chilled ceiling layer.

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

$$R_z = \frac{1}{2 \cdot \dot{m} \cdot cp_w} \tag{6}$$

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

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):

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

R_w for Re > 2300:

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

R_x for capillary tubes:

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

R_x for TABS:

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

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

for capillary tubes:

$$d_x < 5.8 \cdot \sigma \tag{12}$$

for TABS systems:

$$d_x \geq 5.8 \cdot \sigma \tag{13}$$

for both systems:

$$\frac{d_1}{d_x} > 0.3 \tag{14}$$

$$\frac{\sigma}{d_x} < 0.2 \tag{15}$$

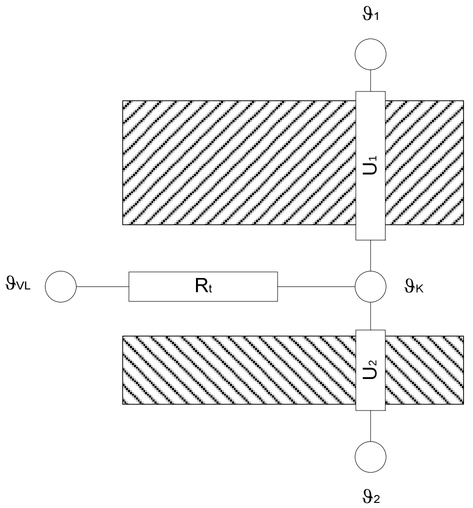

Figure 5: Resistance network

Coupling of Type 399 to Type 56 walls

The general idea is to use a highly conductive dummy wall with known boundary condition such that the given boundary temperature is equal to the inside surface temperature.

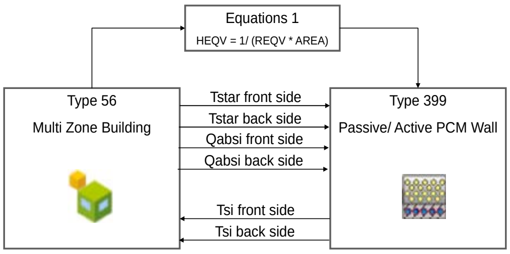

Figure 6: Coupling Type 399 with Type 56 for an adjacent wall and both zones with standard LW radiation mode

Definition of the dummy wall in Type 56:

- Hback < 0.001 (direct contact)
- High conductivity
- Boundary temperature = resulting surface temperature of external wall model (Type 399)

Component configuration

Parameters

1	Number of different material layers [-]
2	Thermal conductivity 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	Internal Timestep of the Type in seconds (360 seconds) [sec]
12	Logical unit for the data file, which contains the dependant cp-values for the pcm material. case heat up
13	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]

Inputs

1	TB1 - boundary temperature on side 1 [°C] If linked to Type 56 then TB1 = Tstar (= NType 23: star node temperature of zone) If surface is facing outside then: TB1 = ambient air temperature or TB1 = equivalent temperature (air and LW radiation)
2	TB2 - boundary temperature on side 2 [°C] If linked to Type 56 then TB2 = Tstar (= NType 23 - star node temperature of zone) If surface is facing outside then: TB2 = ambient air temperature or TB2 = equivalent temperature (air and LW radiation)

3	h1 - heat transfer coefficient on side 1 [kJ/hr m² K]
	
	If linked to Type 56 then
	h1 = 1/ (REQV(=NType 86) * AREA)
	
	If TB1 = air temperature then
	h1 = convective heat transfer coeff.
	
	If TB1 = equiv. temperature then
	h1 - combined heat transfer coeff.

4	h2- heat transfer coefficient on side 2 [kJ/hr m² K]
	
	If linked to Type 56 then
	h2 = 1/ (REQV(=NType86) * AREA)
	
	If TB2 = air temperature then
	h1 = convective heat transfer coeff.
	
	If TB2 = equiv. temperature then
	h1 - combined heat transfer coeff.

5	qWG1 - energy gain on side 1 [kJ/hr] If TB1 = Tstar of Type 56 and LW radiation mode standard: qWG1 = QABSI (= NType 21) If TB1 = Tstar of Type 56 and LW radiation mode detailed: qWG1 = QABSI (= NType 21) + QABSILW (= NType 110) If TB1 = air temperature then qWG1 has to included longwave radiation exchange as well as solar gains and all radiative gains
6	qWG2 - energy gain on side 2 [kJ/hr] If TB2 = Tstar of Type 56 and LW radiation mode standard: qWG2 = QABSI (= NType 21) If TB2 = Tstar of Type 56 and LW radiation mode detailed: qWG2 = QABSI (= NType 21) + QABSILW (= NType 110) If TB2 = air temperature then qWG1 has to included longwave radiation exchange as well as solar gains and all radiative gains
7	supply temperature [°C]
8	total mass flow rate [kg/hr]

Outputs

1	TSI1 - surface temperature on side 1 [°C]
2	TSI2 - surface temperature on side 2 [°C]
3	QSI1 - Heat flux on the surface on side 1 [kJ/hr]
4	QSI2 - Heat flux on the surface on side 2 [kJ/hr]
5	Temperature of the first temperature node, seen form the zone. Also this node will be modified, in case of an active element [°C]
6	Average specific heat capacity of all PCM nodes [kJ/kg K]
7	Input power by the fluid of the integrated pipe system of the total wall area. Negative: cooling Positive: heating [kJ/hr]
8	return temperature of the fluid [°C]
9	average node temperature overall PCM-nodes [°C]
10	phase of the PCM. 0: solid > 0: partly melted >=1: liquid
11	actual amount of energy charged/discharged in the PCM [kJ]
12	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	Specific input power by the fluid of the integrated pipe system of the total wall area. Negative: cooling Positive: heating [kJ/hr m²]
16	actual amount of specific energy charged/discharged in the PCM [kJ/ m²]
17	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]

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 work-around 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.

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 of material layer
ϑ_{Star}	star node temperature
$\vartheta_{w,i}$	surface temperature, inside
ϑ_{VL}	supply temperature
σ	wall thickness pipe

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 wärmephysiologischen Bewertung". Rud. Otto-Meyer Umweltstiftung, Hamburg.

Glück B. 2006 a. „Einheitliches Nährungsverfahren zur Simulation von Latentwärmespeichern", HLH Bd. 57 Nr. 7, pp 25-30.

Koschenz, M. et al. 2000 „Thermoaktive Bauteilsysteme tabs", EMPA.