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Active and passive PCM walls simulation – a new TRNSYS PCM-Type

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ABSTRACT

Due to modern architectural trends highly glazed surfaces and lightweight materials are widely used in new buildings. This brings them out to have a lack of thermal inertia and couldleadto high cooling and heating loads. Phase change materials (PCMs) are able to provide effective thermal mass to this kind of buildings enhancing their thermal properties. Nevertheless, prior to the building construction process, the designer needs to compute the effect of the PCM over the energy consumption of the building and the occupant comfort. For the purpose of achieving this, a new PCM Type for TRNSYS 17 simulation software has been designed. This new PCM-Type is able to model a wall with a PCM layer inside, which can be located in any place within the wall, and includes the possibility to simulate active systems, based on both capillary pipes and TABS, in the modelled walls. The developed PCM-Type uses a temperature dependent heat capacity approach which takes into account the hysteresis phenomena. A comparison between the new developed PCM-Type and other existing TRNSYS Types is carried through.

Keywords: phase change materials ; TRNSYS ; building simulation

1 INTRODUCTION

In modern architecture buildings trend to be designed by using lightweight materials. This makes that some of them have a lack of thermal mass which may lead to low comfort and energy efficiency levels. On the other hand, the rising cost of fossil fuels and the environmental regulations in Europe [1] make necessary to improve the energy efficiency of new and existing buildings. In this context, phase change materials (PCMs) could be employed to enlarge the thermal mass of buildings reducing the temperature swings and shifting the HVAC loads to off peak electricity periods, at the same time the thermal comfort of the occupants is enhanced [2].

In order to properly design the ambient conditioning systems and evaluate the effect of PCMs for a specific building, energy efficiency computer simulations need to be performed. Thus, from a practical point of view, a reliable tool to assess the effect of active and passive PCM systems, considering the building and the HVAC associated facilities, would be of great utility to the designer.

2 TYPE DEVELOPMENT

TRNSYS is a validated and well-known software tool for energy buildings simulations [3]. It is based on the link between different elements, formerly called Types, which results very appropriate in order to develop new elements that can be later coupled to the building and its energy facilities (HVAC, solar thermal panels, photovoltaic panels, etc.) by properly connecting the corresponding Types.

One of the most used Types in TRNSYS is the Multizone building model (Type 56) which makes use of the Conduction Transfer Function (CTF) method [4] to model the transient heat conduction equation through walls considering a one dimensional approach. The method is based on the calculation of certain coefficients, which are calculated only once before the simulation internal process, and characterizes the thermal behaviour of the wall. Because of the calculated coefficients depend on the wall layer properties, they usually remain unaltered along the simulation process which improve the time-efficiency of the simulation, but it becomes an issue for applications in which the properties of the wall do not remain constant, as in the case of a wall containing embedded PCM [5].

On the other hand, the combined use of PCMs associated to passive and active systems can contribute to the improvement of comfort level in buildings [6]. Therefore, a Type which utilises a different model method is needed to adequately simulate PCMs in TRNSYS. To overcome this issue, a new PCM-Type for TRNSYS 17,based on an earlier experimentally validated version [7], has been developed.

2.1 Mathematical modelling

In the developed PCM-Type (Type 399) walls are modelled by finite difference method. The heat conduction equation is solved by using Crank-Nicolson method(Figure 1) and the gained equations are solved by an elimination method. A one-dimensional approach, where the number of used nodes for each layer depends on its thickness to fulfil the stability criteria, has been considered in order to achieve efficient simulation times [8].

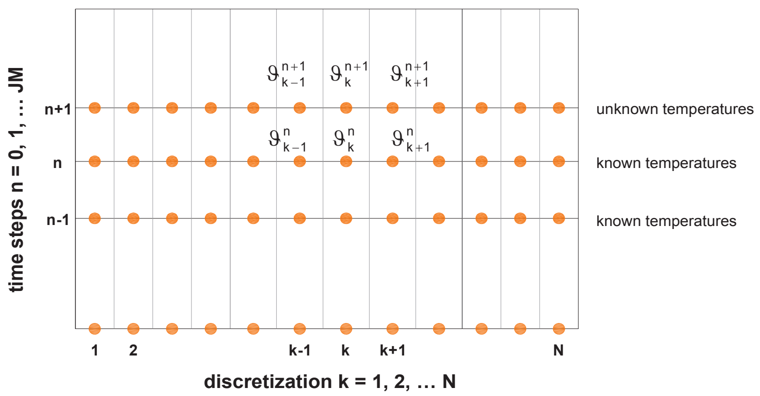

Figure 1. One-dimensional Crank-Nicolson scheme

2.1.1 Phase change modelling

The programmed algorithm does take specific note of the physical phase of the PCM (solid, partly melted or fully melted) and the energy flow (heating up or cooling down) in every time step, so as to reduce inaccuracies in the simulation results. Consequently, the chosen calculation method uses enthalpy as an invertible function of the temperature and, since experimental DSC heating and cooling data are used, the PCM-Type is able to take into account the hysteresis phenomena of PCMs[9].

2.1.2 Piping system modelling

The new developed PCM-Type is capable to model active systems based on both capillary and thermally activated building systems (TABS),like chilled ceiling systems, with any desired active layer location with in the wall. The algorithm of modelling embedded pipes in walls (floors, ceilings or vertical walls)has been taken from Koschenz et. al [10] who made use of a resistances network to model a capillary tube system (Figure 2). The total resistance ($\boldsymbol{R_t}$)between the supply temperature of the capillary tubes (or the TABS)and the core temperature is a serial coupling of the single resistances. Each of these single resistances encompasses the influence and characteristics of the capillary tubes or TABS system: the panel depth($\boldsymbol{R_z}$), the pipe and water resistances($\boldsymbol{R_w}$, $\boldsymbol{R_r}$)and the pipe spacing resistance ($\boldsymbol{R_x}$). On the other hand, the relation between the supply temperature ($\boldsymbol{\vartheta_{VL}}$), the active layer core temperature ($\boldsymbol{\vartheta_K}$), the temperatures of the rooms which surround the active layer ($\boldsymbol{\vartheta_1}, \boldsymbol{\vartheta_2}$),the resistances of the whole piping system($\boldsymbol{R_t}$)and the walls resistances (U_1 and U_2)are shown in Figure 2.

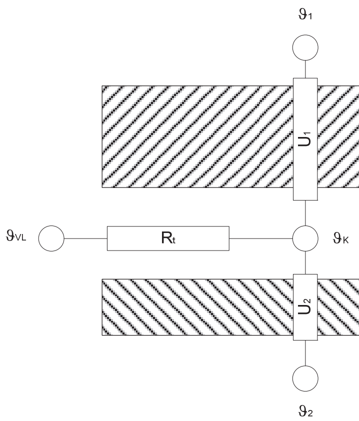

Figure 2. Resistances network model

Furthermore, by calculating the Reynolds number (Re), the PCM-Type makes an automatic distinction between a capillary tube system and a TABS, which is integrated into the flow condition by using the corresponding equations shown in Table 1.

Capillary Tubes (Re ≤ 2300)	TABS (Re > 2300)
$R_t = R_z + R_w + R_r + R_x$ (1)	
$R_z = \frac{1}{2 \cdot \dot{m} \cdot Cp_w}$ (2)	
$R_r = \frac{d_x \cdot ln\left(\frac{\sigma}{\sigma - 2 \cdot d_r}\right)}{2 \cdot \lambda_r \cdot \pi}$ (3)	
$R_w = \frac{d_x}{\pi \cdot \lambda_w}\left(49{,}03 + 4{,}14 \cdot \frac{4}{\pi} \cdot \frac{\dot{m} \cdot Cp_w \cdot d_x}{\lambda_w}\right)^{\frac{1}{3}}$ (4)	$R_w = d_x^{\frac{0{,}13}{8\pi}} \left(\frac{\sigma - 2 \cdot d_r}{\dot{m}}\right)^{0{,}87}$ (5)
$R_x = \frac{d_x \cdot \frac{1}{3} \cdot \left(\frac{d_x}{\pi \cdot \sigma}\right)}{2 \cdot \lambda_l \cdot \pi}$ (6)	$R_x = \frac{d_x \cdot \left(\frac{d_x}{\pi \cdot \sigma}\right)}{2 \cdot \lambda_l \cdot \pi}$ (7)

Table 1 Active layer equations implemented in the PCM-Type

It is necessary to highlight that equations from Table **1**are valid only for the relations between pipes diameters, thicknesses and spacing shown in Table 2.

Capillary Tubes	**TABS**	**Both systems**
$d_x < 5{,}8 \cdot \sigma$ (8)	$d_x \geq 5{,}8 \cdot \sigma$ (9)	$\frac{d_l}{d_x} > 0{,}3$ (10) $\frac{\sigma}{d_x} < 0{,}2$ (11)

Table 2 Resistances network equations validity conditions

2.2 Coupling between PCM Type and the Building Type

The coupling between the PCM-Type (Type 399) and the building Type (Type 56) has been implemented using a highly conductive *dummy wall* with and a known boundary condition ($T_{siback\ side}$), which is equal to the inside surface temperature. The developed PCM-Type uses the $T_{star\text{-}front\ side}$ and $T_{star\text{-}back\ side}$ temperature sand the heat flow-rates calculated by Type 56 [11] as inputs, while the superficial internal and external temperatures ($T_{si\text{-}front\ side}$ and $T_{si\text{-}back\ side}$) are outputs, calculated by the PCM-Type, connected to Type 56 as depicted in Figure 3. An equivalent dynamic heat coefficient (H_{eqv})for the PCM wall is also calculated by the PCM-Type from the equivalent resistance calculated by Type 56in every simulation step.

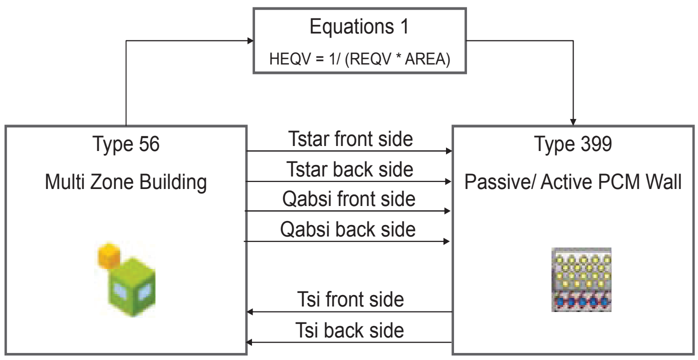

Figure 3. Coupling between PCM-Type (Type 399)and Building Type (Type 56).

3 DISCUSSION

Although several approaches have been carried out regarding PCMs simulation in TRNSYS,for practical reasons only those developed for TRNSYS 15 and later versions have been considered in the present paper. In 2004 Koschenz et al. [6] developed a Type for the study of a thermally activated ceiling panel which included an active layer feature. Nonetheless it was a specific research-oriented Type and it was designed only for embedded capillary systems. Later, Ibáñez et al. [12] considered a different approach in order to evaluate PCM effect in a room by creating a Type (Type 222) that acted as a phase state controller over the PCM, and made use of the active layer feature included in the Multizone building Type of TRNSYS 15. Nevertheless, in this approach the real heat transfer processes inside the materials in which the PCM were added was not taken into consideration. Another PCM-Type (Type 241) for passive PCM walls was developed by Schranzhofer et al. [13], nonetheless this PCM-Type was not able to simulate active PCM systems neither was validated. Finally, Kuznik and Virgone[14] developed a Type for passive PCM walls in TRNSYS (Type 260), which is based on finite difference method and was validated, but only using literature data.

Neither of the mentioned PCM-Types is able to simulate a TABS embedded in a PCM wall selecting the location of both, active and PCM layers. In contrast, the developed PCM-Typeis able to simulate passive and active PCM systems based on capillary systems and TABS. The proposed PCM-Type makes use of a temperature dependent heat capacity of the PCM and includes the possibility to model the PCM-hysteresis effect, which must be considered to improve the model accuracy [15].In addition to that, it calculates a dynamic convective heat coefficient for every simulation time step which takes into account the phase change material state, thus it offers the designer the possibility of evaluate the optimal place inside the wall for taking advantage of the PCM properties [16].Furthermore, the Type provides also information about the energy absorbed or released by the PCM and the phase state of the material along the simulated time period.

4 CONCLUSIONS

A new Type for PCMs simulation in TRNSYS 17, based on a previously experimentally validated version, is presented. The new developed PCM-Type uses a Crank-Nicolson method for to model the PCM and a resistances network based algorithm to model the piping system. It is able to simulate passive PCM wallboards and active PCMs systems, taking into account PCMs hysteresis phenomena. The location of the PCM-layer and the active layer can be selected, and therefore the PCM layer location and the active layer effect regarding the PCM location in the wall can be evaluated. The PCM-Type offers also information about the energy absorbed or released by the PCM and the phase state of the material along the simulated period, which eases the PCM selection task for a specific climatic environment. Due to the aforementioned features, the proposed PCM-Type overtakes the existing ones and it is proposed as a valuable tool for evaluating PCMs application in buildings.

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6 NOMENCLATURE

R_t	Total resistance	Cp_w	Water specific heat capacity
R_z	Panel depth resistance	d_x	Pipe spacing
R_w	Water resistance	σ	Pipe wall thickness
R_r	Pipe resistance	d_r	Pipe diameter
R_x	Pipe spacing resistance	d_l	Depth of active layer
		λ_r	Pipe thermal conductivity
		λ_w	Water thermal conductivity
		λ_l	Wall layer thermal conductivity
		$\dot{m}$	Fluid mass flow-rate

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