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# TEMPERATURE MODERATION IN A STRUCTURE BY SOLIDIFICATION OF A PHASE-CHANGE MATERIAL

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## ABSTRACT

The current numerical study focuses on the feasibility of temperature moderation in a structure located at mid-storey in a multi-storey building, by using a phase-changing paraffin wax stored on an aluminum tray under the floor tile. Inside the building, at each level, walls are exposed to the ambient. In winter the walls are cooled, and the paraffin wax serves as the heat source, by solidifying in day-time, and melting at night. The numerical model relates to day-time temperature variations, outside and inside the structure. The heat conduction from the paraffin wax is coupled with the free convection of air in the space, radiation between the inside surfaces, heat conduction across the walls and accumulation in the walls. The dimensions of the analyzed structure are: 8m long, 8m wide and 2.5m high. Effects of wax layer thickness and of fins along the tray, on the rate of solidification are parametrically investigated. The simulations are performed for the structure using Fluent 6.3 software.

## INTRODUCTION

Often thermal storage systems utilize latent heat of phase-change materials (PCM) for their large storage capacity. The PCM applications in buildings are of interest as heat sources in winter, or heat sinks in summer. For the winter applications the materials have to solidify at temperatures higher than the desired thermal comfort temperature in the structure.

Dincer and Rosen [1] described the applications of phase-change storage, which provide effective use of solar energy in buildings, in particular in wallboards. However the principle of latent heat storage may be applied to any kind of container, to any location in the building, or any kind of heating.

Farid et al. [2] extensively reviewed the phase-change materials and methods of application. Lacroix [3] numerically simulated storage of PCM in shell-and-tube heat exchangers. Pasupathy et al. [4] studied the development of PCMs applications in buildings, and the methods used for space heating and cooling. The authors referred to impregnation in building materials, and to integrated space heating and cooling.

Baetens et al. [5] analyzed the performance of wallboards impregnation, as well as PCM enhanced concrete and clay tiles distributed throughout the building. Farid and Husian [6] have replaced the ceramic bricks in common domestic heaters by paraffin wax encapsulated in metal containers, which were electrically heated, melting the wax within eight hours at night-time. The stored latent heat was then discharged during the non-heating periods.

Farid and Chen [7] numerically simulated storage of a phase-change material placed between an electrically heated surface and floor tiles. Kuznik et al. [8[ presented a wide range of considerations with regard to integrated phase-change materials in buildings, indicating that integration highly depends on the containment. Their review included numerous experimental and numerical studies concerned with the PCM envelope of buildings.

In our previous works we have investigated the performance of paraffin wax as a heat sink in summer, being stored on a tray at the ceiling [9], or encapsulated in aluminum containers at the walls [10]. Our current study focuses on space heating in a structure, on a winter day, by stored paraffin wax under floor tiles. Heating of the wax, up to its complete melting, is accomplished at night. At day-time the latent heat is released into the space above the floor.

## NOMENCLATURE

| | | |
|---|---|---|
| $f_m$ | [-] | PCM melt fraction |
| $T_{out}$ | [°C] | Surroundings temperature |
| $T_{PCM}$ | [°C] | PCM temperature |
| $T_{room\ av}$ | [°C] | Average room temperature |
| $T_{wall\ av}$ | [°C] | Average wall temperature |
| $T_{wallin\ av}$ | [°C] | Average temperature of inside wall surface |
| $X$ | [m] | Horizontal coordinate |
| $Y$ | [m] | Vertical coordinate |

## PHYSICAL MODEL

A structure inside a multi-storey building is considered. Its dimensions are 8m long, 8m wide, and 2.5m high. Heat from the structure to surroundings penetrates the four walls, which are 0.15m thick, and made of construction materials, having a density of 1300 kg/m$^3$, specific heat of 0.9kJ/kgK, and thermal conductivity of 0.45W/mK. In our case temperature moderation in the structure is required, therefore, a heat source in winter, and a heat sink in summer have to be mounted.

In the current study a winter day is chosen, and a paraffin wax, being a phase-change material serves as a heat source. The paraffin wax is stored on an aluminum tray under the floor tile. The tray being horizontal, is 8m long, and 8m wide. It has end walls, which are 2cm higher than the stored wax melt. An aluminum plate closes the tray from above, touching the floor tile. Air fills the 2cm high space between the melt and the plate. An electrical heater is placed between the tray and the 20cm thick concrete, which separates between the analyzed structure and the lower storey. The same relates to the storey above our structure. There, under the floor, the same PCM layer and a heater are installed. The 20cm concrete extends down to the ceiling of the structure dealt with (Figure 1).

The wax properties are based on commercially available paraffins. The one chosen for our study melts at 33ºC. Its latent heat is 100kJ/kg, density of the solid wax is 800kg/m$^3$, density of the liquid wax is 750kg/m$^3$, specific heat is 2.5kJ/kgK, and the thermal conductivity is 0.2W/mK.

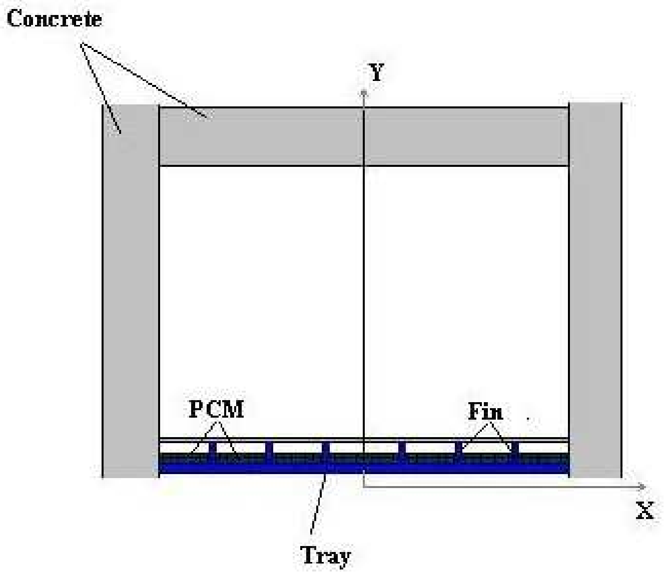


**Figure 1.** Schematic structure

The following processes are expected: Heat from the PCM melt is conducted across the floor and the ceiling, entering the structure. The air inside is cooled at the walls, and moves inside the space by natural convection. Simultaneously heat is transferred by radiation between the inside surfaces. Heat from inside the space is conducted across the walls into the ambient. Part of it accumulates in the walls.

The wax is cooled, and solid is formed in the wax. The heavier solid phase sinks in the liquid phase. When solid-liquid interface becomes perfectly uniform, solid phase would stay on top of its melt. The solid-liquid interface moves down, and the thermal resistance to transfer of heat grows.

At night the wax has to melt, by operating the heater at off-peak hours. Currently, the night heating has not been considered quantitatively.

The end walls of the tray are 8m apart. Longitudinal fins connect the tray and the top aluminum plate. As the fins are constructed between the end walls, they have to be as high as the end walls.

The heat conducted along the fins, essentially contributes to the heat exchange process. The thermal resistance to heat transfer decreases, and the rate of solidification increases. The thermal resistance may vary with the number of fins on the tray.

## NUMERICAL SIMULATIONS

For the computational procedure, the structure was divided by two vertical planes of symmetry. The origin of the coordinate system was taken at the intersection of the two planes. This division yielded a quarter of the original space, namely 4m × 4m × 2.5m, defined as the three-dimensional computational domain. Free convection of air inside was coupled with radiation, with time-dependent accumulation in walls, conduction across the walls, and conduction across the floor and the ceiling. Turbulent free convection of air was modeled, using the k-ε method.

The computational grid consisted of 50×80×80 cells, for height, length and width of the structure respectively. The time step varied along the day. At first it was 1s, and later on, up to 10s. The computation was conducted for 12 hours, from 7:00 till 19:00.

Two wax layers were investigated: 16mm thick, and 12mm thick. Two distances between the fins were studied: fins 0.5 m apart, and fins 1.0m apart from each other. All the numerical calculations were performed using the Fluent 6.3 software.

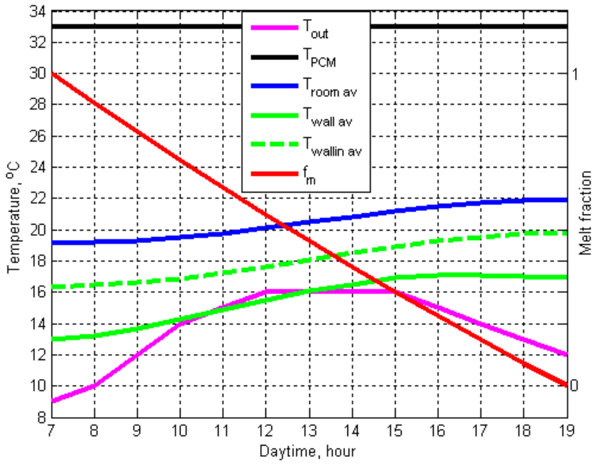
## RESULTS

The simulation starts at 6:00. Till then the calculations are conducted at a steady state mode. From there on, the simulation proceeds in transient state of all the processes. The temperatures and melt fraction are presented in Figures 2-5 from 7:00 till 19:00.

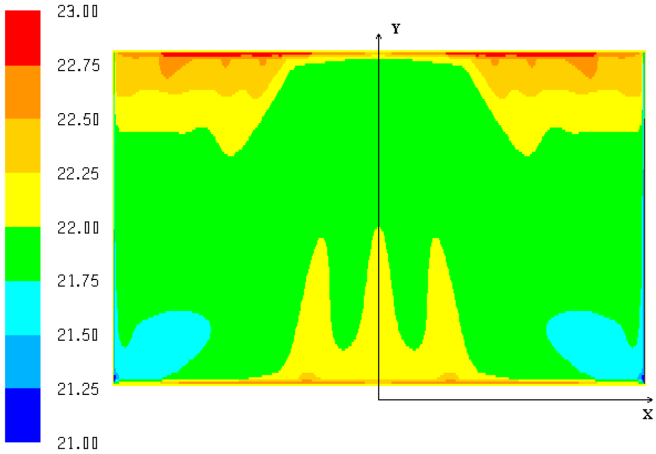
Figure 2 depicts the thermal phenomena taking place on a winter day in the studied structure, located at a mid-storey in a multi-storey building. The PCM layers under the floor tile, 12mm and 16mm thick, exhibit the same thermal performance. The melt fraction refers to the 12mm thick layer only.

Figure 2(a) presents the temperatures variations, and melt fraction along the 12 hours of day-time. Figure 2(b) shows the temperature field at the plane of symmetry at 19:00, and Figure 2(c) exhibits the air streamlines at the same plane of symmetry and at the same hour. Thus, in the absence of fins solidification proceeds all day long, and the space temperature varies from 19ºC to 22ºC, which is almost the thermal comfort temperature.

Figure 3 illustrates the performance of fins, 1.0m apart in the wax layer of 12mm thickness. The inside average air temperature is in the range of 22ºC-24ºC till 17:00. At that time




(a)

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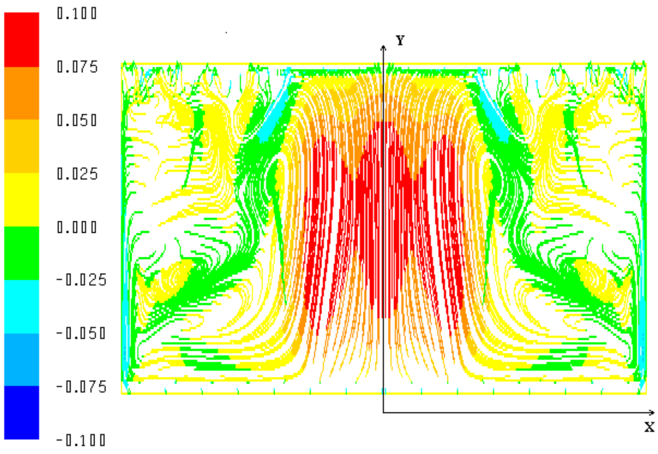
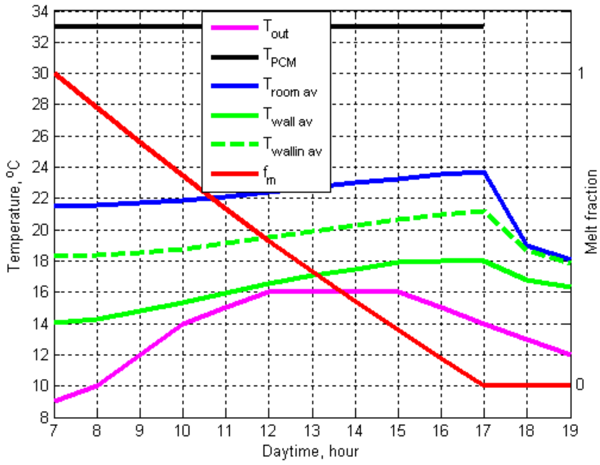
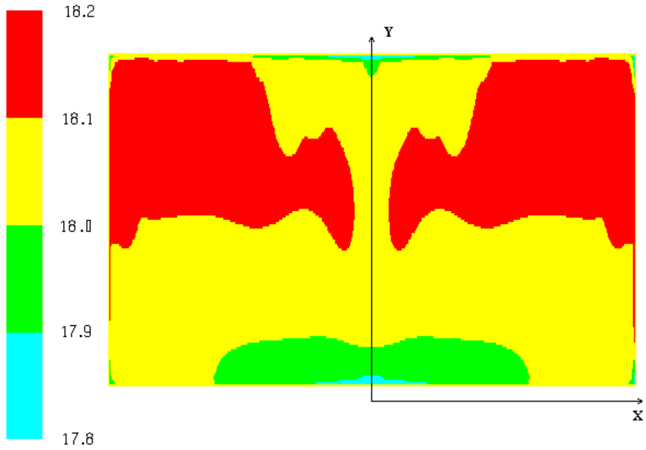



(c)

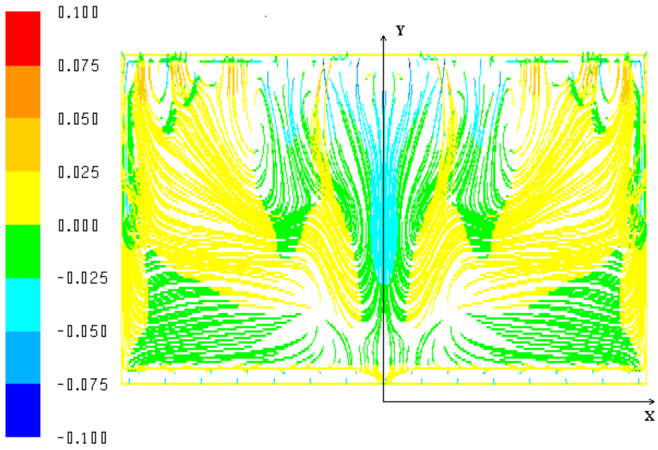
**Figure 2.** PCM layer – 12 or 16 mm thick without fins:
(a) Temperature variation along the day. Melt fraction variation for the 12mm thick layer along the day,
(b) Air temperature field at the plane of symmetry at 19:00,
(c) Air streamlines at the plane of symmetry at 19:00




(a)




(b)




(c)

**Figure 3.** Distance between longitudinal fins of 1.0m, PCM layer – 12mm thick:
(a) Temperature and melt fraction variation along the day,
(b) Air temperature field at the plane of symmetry at 19:00,
(c) Air streamlines at the plane of symmetry at 19:00.

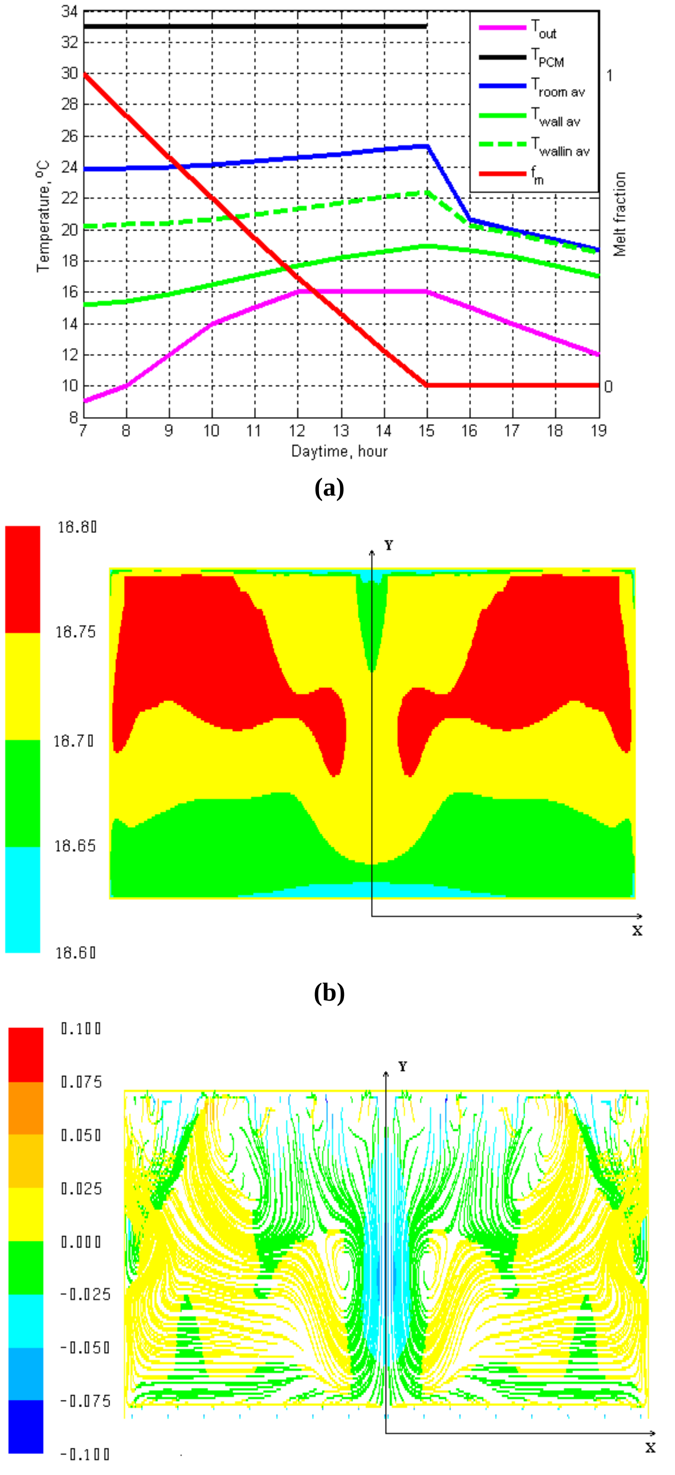



**Figure 4**. Distance between longitudinal fins of 0.5m, PCM layer – 12mm thick:
(a) Temperature and melt fraction variation along the day,
(b) Air temperature field at the plane of symmetry at 19:00,
(c) Air streamlines at the plane of symmetry at 19:00.

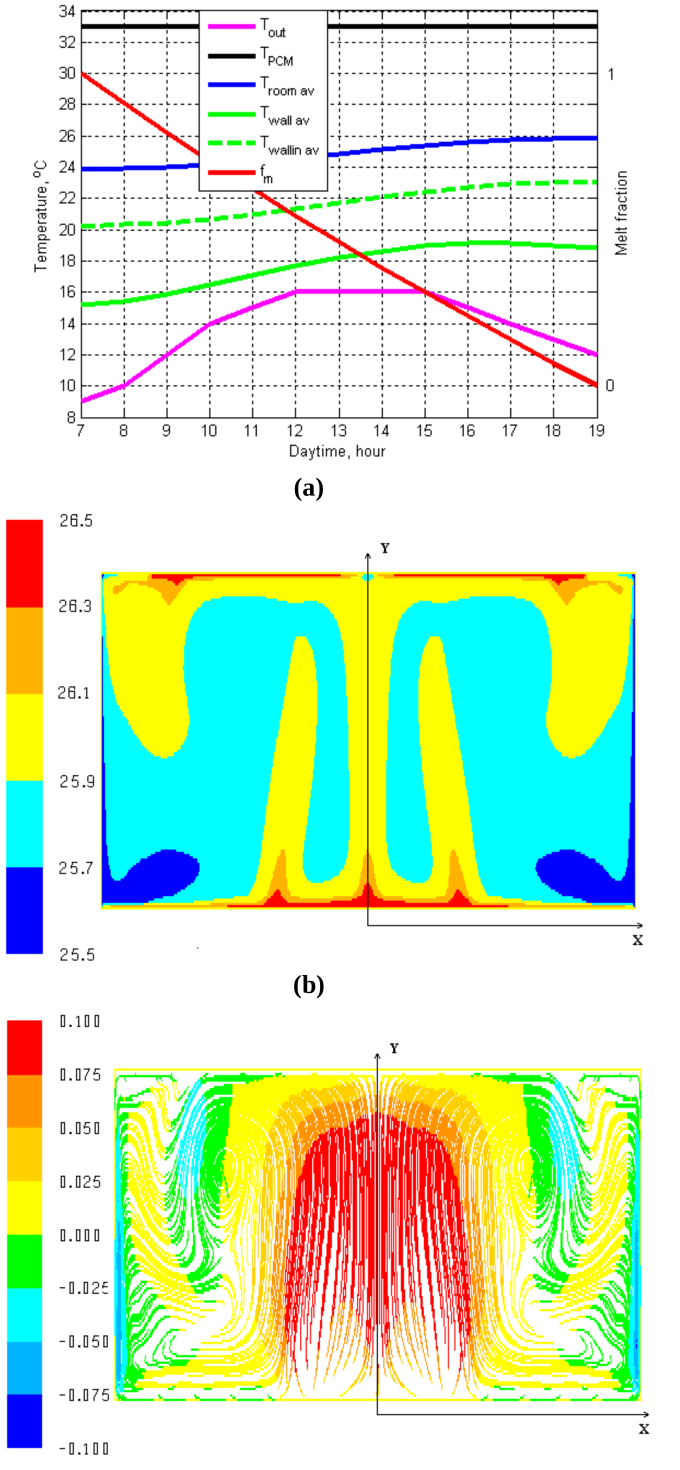



**Figure 5.** Distance between longitudinal fins of 0.5m, PCM layer – 16mm thick:
(a) Temperature and melt fraction variation along the day,
(b) Air temperature field at the plane of symmetry at 19:00,
(c) Air streamlines at the plane of symmetry at 19:00.

all the wax is solidified. However, the temperature up to that hour may be still identified with the thermal comfort temperature. From that hour on, the temperature steeply falls down to 18ºC at 19:00, namely 6ºC below the comfort temperature.

Figures 4 and 5 demonstrate the effect of fins on the inside air temperature by wax layers of 12mm and 16mm, respectively, where the fins are 0.5m apart. The wax layer of 12mm thickness completes its solidification at 15:00. From there on, the inside temperature falls down to 19ºC at 19:00. At that time the wax layer, 16mm thick, reaches its full solidification. In the last case, the space temperature varies from 24ºC to 26ºC. Figures 4(b) and 5(b) show the temperature field at 19:00. In the case of the 12mm layer, the air inside the space stratifies. The coldest air settles to the floor. In the case of the 16mm layer, segregated zones of temperature are apparent. Figures 4(c) and 5(c) illustrate the air streamlines. In the stratified case the air is still in comparison to the segregated case.

The model presented herein demonstrates the effects of the wax mass on the average temperature inside the structure, and the effect of fins on the PCM solidification.

## CONCLUSIONS

PCM stored below the floor tile may heat the inside air of the structure on a winter day.

The temperature moderation in the structure varies with the quantity of the paraffin wax, and the temperature of the ambient.

Fins within the phase-change material enhance its rate of solidification.

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