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Heat transfer study of building envelopes with phase change materials

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Abstract. The porous foams filled with phase change materials (PCMs) are suitable for insulation and energy storage in building envelopes. This paper presented the physical analysis and computer modeling for heat transfer performance of building envelopes with PCMs. So the building concrete was assumed as phase change concrete. The paper simulated the heat transfer in porous foam building walls by apparent heat capacity method. The phase change concrete was in the center of building envelopes. Some typical parameters were studied in the paper. The results showed that effective thermal conductivity of foamed concrete, phase change latent heat of phase change materials, the PCM phase change temperature radius and phase change concrete thickness have significant effects on the heat transfer performance of building envelopes.

1. Introduction

Phase-change materials are often widely used in building because of their latent –heat. The integration of phase change materials (PCMs) into porous building materials such as porous foamed concrete and gypsum wallboard has low cost and widespread application in buildings [1-3]. Foamed concrete or lightweight concrete has very high porosity, fine pore structure and low density, so phase change of PCM in porous foamed concrete is very valuable to use as building energy storage. Then the PCMs in the building envelopes can achieve the use and conversion of the energy by absorbing and releasing energy in the phase change process, which help to improve insulation and thermal storage in buildings and control the indoor temperature. Many literature reflected theoretical and experimental study on this subject in the past [2, 4]. The phase change heat transfer process has strong nonlinearity, so the dynamic boundary problem is usually numerically solved by enthalpy method and apparent heat capacity method. [5].

This paper researches the phase change energy storage envelopes with PCMs in porous foamed concrete. The paper simulated the heat transfer in porous foam building walls by apparent heat capacity method. The phase change heat transfer was simulated in porous foam building envelopes. The influence of the several significant parameters on the heat transfer process has been analyzed in the paper include effective thermal conductivity of foamed concrete, phase change latent heat of phase change materials, the PCM phase change temperature radius and phase change concrete thickness.

2. Establishment of model

The building envelopes system is presented in Figure1 with porous foamed concrete saturated with PCMs. The foamed concrete is assumed as phase change concrete, which is in the center of building



envelopes. Tables 1 shows thermophysical properties parameter of PCM and building material

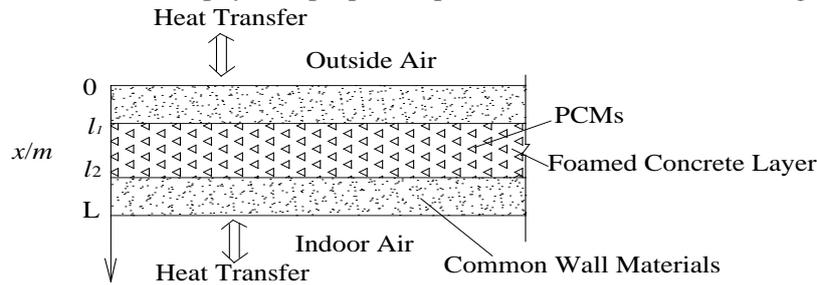


Figure 1. Intergrated building envelopes with PCMS in foamed concrete

Table 1. Thermophysical properties of materials in simulation

Properties units	PCM	Foamed concrete	Wall material
Heat capacity C (KJ·Kg ⁻¹)	2680/2160	2000	2000
Thermal conductivity k(W·m ⁻¹ ·K ⁻¹)	0.35/0.15	0.1(0.5,1)	1
Heat fusion H _f (KJ·Kg ⁻¹)	192(127,250)		
Phase change temperature T(K)	300±2(0.5,1,1.5)		

In simulation, the paper presents the following assumptions: [4]:1) The PCM thermophysical properties are constant in solid or liquid zone except in mush zone; 2) The physical properties of phase change building envelopes are homogeneous and isotropic; 3) the volume change effect of paraffin wax is neglected in phase change process; 4) The initial temperature is the same through the building envelopes.5) there is only heat conduction in the liquid phase ;6) The envelopes thickness is far less than its width and height, so the temperature only changes along the thickness whereas does very little along the height and the width. That is to say, one-dimensional heat transfer will be considered.

Because phase change of paraffin wax occurs within a certain temperature range, there are three status zones in the material, and they are solid zone, mush zone and liquid zone. Based on above assumptions, the paper solves the moving boundary problems by apparent heat capacity [6]. Model will be established in the whole composite envelopes and the energy equation is described by:

$$C_e \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} (k_e \frac{\partial T}{\partial x}) \quad 0 \leq x \leq L \tag{1}$$

$$C_e = C_c, k_e = k_c \quad 0 \leq x \leq l_1 \quad \text{and} \quad l_2 \leq x \leq L \tag{2}$$

$$C_e = \varepsilon C_f + (1 - \varepsilon) C_p, k_e = \varepsilon k_f + (1 - \varepsilon) k_p \quad l_1 \leq x \leq l_2 \tag{3}$$

In three status zones with different properties, thermal conductivity and thermal capacity is described as follow [6]:

$$C_f = \begin{cases} C_s & T < (T_m - \Delta T) \\ \frac{\rho H_f}{2\Delta T} + \frac{C_s + C_l}{2} & (T_m - \Delta T) \leq T \leq (T_m + \Delta T) \\ C_l & T > (T_m + \Delta T) \end{cases} \tag{4}$$

$$k_f = \begin{cases} k_s & T < (T_m - \Delta T) \\ k_s + \frac{k_l - k_s}{2\Delta T} [T - (T_m - \Delta T)] & (T_m - \Delta T) \leq T \leq (T_m + \Delta T) \\ k_l & T > (T_m + \Delta T) \end{cases} \tag{5}$$

Where T is temperature, ΔT phase change temperature radius, T_m phase change temperature, the PCM phase change latent heat, C_e and k_e are the effective heat capacity and thermal conductivity of the building envelopes with PCM in foamed concrete respectively. And the subscript f describes PCM, l liquid, s solid, c ordinary concrete, p foamed concrete,

It assumes an air-conditioned room is in the inside of the building envelopes and makes its constant temperature on 298K in simulation. The outside surface of the envelope receives simultaneously thermal effect of the solar radiation and the outside air temperature, so the outdoor air synthetic temperature $T_{z,\tau}$ is used to simplify the calculation, which is defined as:

$$T_z(t) = T_{air} + \frac{aI}{h_{out}} \quad (6)$$

The outdoor air temperature is 304K. The solar radiation on the south surface and absorptivity of building walls in Nanjing are assumed as 365 W/m² and 0.7, respectively.

$$-\lambda \frac{\partial T}{\partial x} = \alpha_w (T_{z,\tau} - T) \quad x = 0, \quad \tau > 0 \quad (7)$$

$$-\lambda \frac{\partial T}{\partial x} = \alpha_n (T_a - T) \quad x = L, \quad \tau > 0 \quad (8)$$

$$T = T_s \quad 0 \leq x \leq l, \quad \tau = 0 \quad (9)$$

Where T_a is temperature of the room, T_s initial temperature of the building envelopes, L is set as 240mm

3. Numerical Simulation

In the numerical simulation the change rate of PCM from the solid phase to the liquid phase in mushy zone is supposed to be linear between 0-100%. The convective coefficient of the outside and inside wall is respectively 18.6 W/(m·K) and 8.72 W/(m²·K). The temperature of the air-conditioned room is set at 298K and the initial temperature of the wall is also set at 298K. The control equation, boundary conditions and the initial conditions are discretized and numerically solved with the help of the control volume method [7]. Specifically, after adopting the grid algorithm of the inner node, a group of the diagonally dominant tri-diagonal equations will be achieved. Then they are solved by Gauss - Seidel iterative method [6] and all the node temperature will be obtained.

4. Results and Discussions

4.1. The temperature Distribution of Building Envelopes

The temperature distribution of building envelopes for different factors in Figure 2 clearly shows three heat storage processes. The latent heat process in phase change concrete occurred within a certain temperature range. The increase in phase change concrete thickness resulted in dramatic temperature gradient increment in phase change concrete layer. Whereas foamed concrete porosity effect and phase change latent heat effect achieved the same inner temperature variation, and the reduction in porosity and phase change latent heat produced higher inner temperature thus indicating that PCM in foamed concrete play an important role in insulation and in energy storage of buildings. The reduction in foamed concrete thermal conductivity produced slower heat transfer rate in phase change concrete layer. Whereas the difference of the inner surface temperature among three groups is obviously smaller than that of the outside. The thermal conductivity of foamed concrete prevented heat transfer. In other cases, however, it reduced the phase change rate of paraffin wax and the absorbed latent heat which weakened the insulation performance.

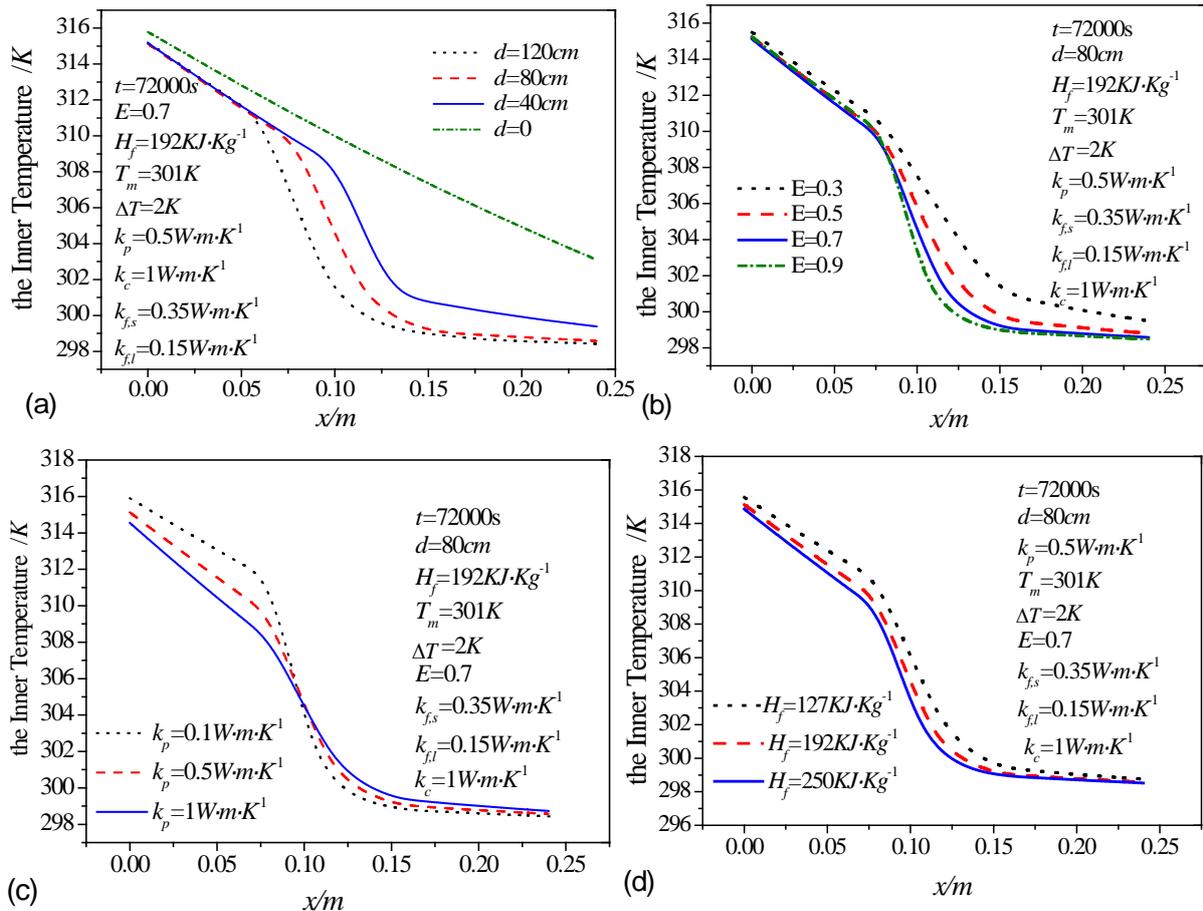
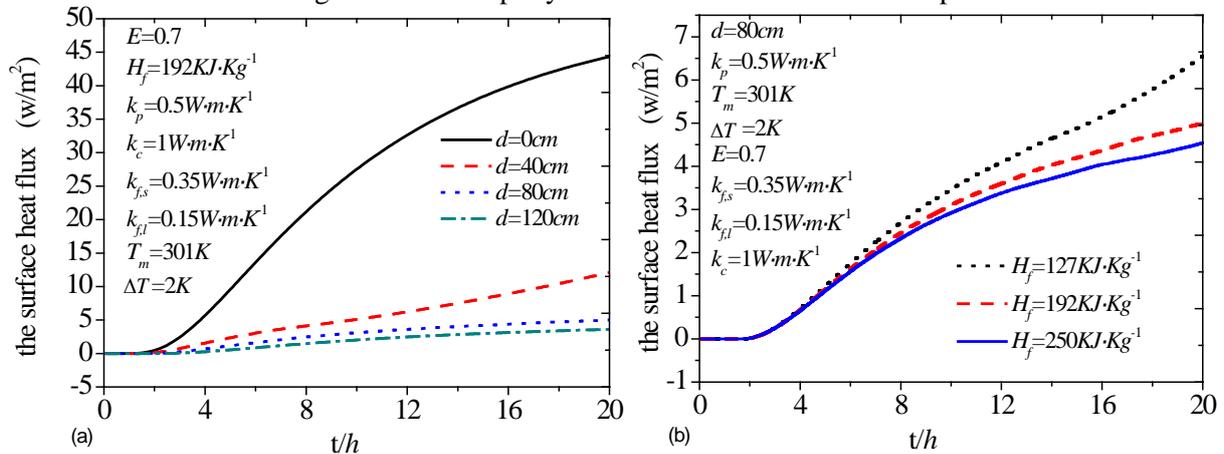


Figure 2. The temperature distribution of building envelopes at different conditions:(a) phase change concrete thickness effect;(b) foamed concrete porosity effect;(c) foamed concrete thermal conductivity effect;(d) PCM phase change latent heat

4.2. Differential Inner Surface heat Flux Variation

Figure 3 shows that the differential inner surface heat flux variation based on several parameters. The differential parameters variation resulted in the surface heat flux decreasing, including the increase of foamed concrete thickness, temperature radius and latent heat and the decreasing of foamed concrete thermal conductivity. From the figure, we can also see that, the heat flux increased with the time for the heat transfer increasing. However, the slower increasing rate happens when phase change begins to start and heat flux didn't again increase rapidly until latent heat transformation process ends.



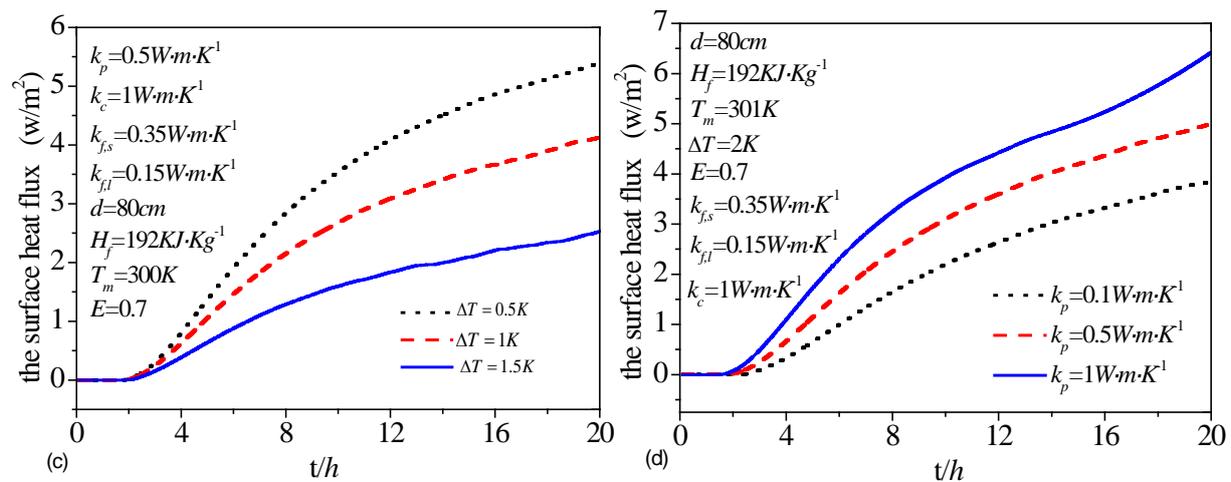


Figure 3. The surface heat flux of building envelopes at different conditions: (a) phase change concrete thickness effect; (b) PCM phase change latent heat (c) PCM phase change temperature radius effect; (d) foamed concrete thermal conductivity effect;

5. Conclusions

This paper presented the physical analysis and computer modeling for heat transfer performance of building envelopes with PCMs in foamed concrete. The phase change heat transfer in porous building envelopes was simulated according to apparent heat capacity method. The results indicated several parameters have important impacts on the heat transfer performance of building envelopes. (1)The thermal conductivity of foamed concrete prevented heat transfer. In other cases, however, it reduced the phase change rate of paraffin wax and the absorbed latent heat, which weakened the insulation performance. (2)The differential parameters variation resulted in the surface heat flux decreasing, including the increase of foamed concrete thickness, temperature radius and latent heat and the decreasing of foamed concrete thermal conductivity. The above conclusions play a great role in energy storage in the buildings.

Acknowledgements

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