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Analysis of Heat Charging and Discharging on the Phase Change Energy-Storage Composite Wallboard (PCECW) in Buildings

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Abstract: This research paper combines the phase change material and the basal building material to constitute a kind of new phase change energy- storage composite wallboard (PCECW), applied in a residential building in Beijing. We analyzed the energy-storage characteristics of the PCECW according to phase change energy-storage theory, which is used as the storage-heat body in the "light" inner wallboards, compared to the normal "heavy" inner wallboards. Through computer simulation, we measured the effects on the heating and energy consumption of the room when the enthalpy, thermal coefficient and thickness of the PCECW were changed. The results show that the PCECW the phase change wall could effectively reduce the temperature fluctuation and the winter heating energy consumption in the residential building.

Key words: PCECW; residential building, energy saving; simulation computing

1. INTRODUCTION

On statistics, Beijing has to consume about thirty million tons coal annually at present, quarter of which is used in heating in winter. Energy consumption of building, mainly of which is heat transfer load through building enclosures, has became a much heavier part of the total consumption. In order to implement the policy of energy saving and environment protecting of our country, and achieve the strategic target of sustainable development, "The energy saving design standard in residential building" （DBJ01-602-2004）Promulgated together by the Beijing plan committee and the Beijing construction committee has implemented from July 1, 2004. This design standard has stipulated that the heating design load of ordinary housing in Beijing couldn't surpass 32w/㎡, and further proposed that the winter heating energy consumption of ordinary housing in Beijing should achieve the energy conservation goal of 65%, basing on the norm level of the general design heating energy consumption in 1980.

The heat transfer through building enclosures changes by the time, and the fluctuation of the indoor temperature and the outdoor temperature will impact the room's heat stabilization. Therefore, when considering the measure of heat preservation and heat insulation in building enclosures, besides guaranteeing building enclosures to have enough thermal resistance, we also should enable the building enclosure to have a greater heat capacity, also namely enhancing the heat-charging capacity of the building enclosure, in order to enhance the thermal inertia of the building enclosure and to reduce the influences of the indoor and outdoor temperature fluctuation on the thermal stability of the room.

Recently, domestic and foreign researches on phase change heat charging technology shows that applying the phase change material to the building wall may increase the heat capacity of the wall and enhance the heat-charging capacity of the enclosure, which may realize the uniformization of the any-time load, reduce the first investment of the air conditioning equipment and the operating cost, and at the end achieve the goal of energy conservation in the building.

This research takes the new PCECW as the research object. Considering the affect of the indoor and outdoor disturbance, such as the solar radiation and so on, establish the physical model of the phase change process. And then, through the method of simulation computing, analyze, research and estimate the characteristics of heat charging, heat stability, and energy saving in the room with the phase change wall in winter.

2. APPLICATION CONDITIONS OF THE PCECW IN WINTER

Compared to the south of China, many northern areas in winter have the bright climate characteristic, such as a long sunshine time, the big solar radiation intensity and so on. For example, the winter sunshine rate reaches as high as 76%, and further more the solar elevation angle is smaller, so as to the solar radiation directly entering into the room is intense. Fig.1 is the average solar radiation of easterly wall, westerly wall and southerly wall in Beijing, from which we find that the solar radiation accepting by the southerly wall in winter is higher than that in summer, and also higher than the easterly wall and westerly wall.

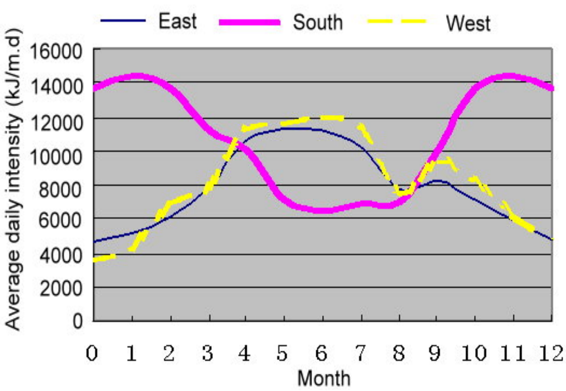

Fig.1 Average daily solar radiation intensity in Beijing

Because the solar energy entering into the room varies in a day, how to use it effectively, enhance the heat comfortableness of the room and achieve energy saving in the building is our goal. Applying the powerfully heat charging and discharging of the PCECW, in the daytime, with the increasing of the solar radiation entering into the room, the indoor temperature begins to rise, and when it is higher than the temperature of the PCECW, the wall begins to absorb the heat energy; In the night, when the indoor temperature falls, the wall begins to release the heat energy saved in the daytime, in order to maintain the stabilization of the indoor temperature. Generally, the steady temperature in the inner surface of the building enclosure is very important to reduce the temperature fluctuation of the room and enhance the heat comfortableness of the room; At the same time it could also realize the uniformization of the any-time load, reduce the first investment of the air conditioning equipment and the operating cost, and at the end achieve the goal of energy conservation in the building.

3. HEAT-CHARGING ANALYSIS OF THE PCECW IN WINTER

The PCECW discussed in this article is a kind of compound, mixed up by the shape-stabilized phase change material and the traditional building material, which is directly daubed on the inner surface of the wall (Fig.2). This kind of phase change wall just makes use of the heat-charging (discharging) characteristic of the phase change material, which is able to absorb (release) plentiful heat energy in the condition of constant temperature. In the heating time in winter, applying the phase change wall together with the climate characteristic of the north we could enhance the heat capacity and the heat-charging capacity of the existing building and achieve the goal of energy saving.

Usually we use the thermal inertia index D to appraise the heat charging and the thermal inertia of the building enclosure. The thermal inertia index D of the ordinary wall is compared with that of the PCECW in Tab.1. Here the thermal inertia index D of the PCECW is computed by the sensible heat capacity method, the enthalpy is assumed to be 80kJ/kg, and the temperature difference is assumed to be 4℃. The computational result shows that in the same thickness situation the thermal inertia index D of the PCECW, which is 1.82, is much bigger than the cement; And this also explains that the phase change material which is thin could achieve the heat-charging function of the thick ordinary wall, testifying the well heat-charging characteristic of the PCECW.

Tab.1 Heat performance parameters of the phase change material layer

Performance / Material	Thickness mm	Thermal conductivity W/m·□	Heat capacity kJ/kg·□	Density Kg/m^3	Thermal inertia D
Concrete grout	20	0.93	0.84	1800	0.41
The PCECW	20	0.5	20	800	1.82

Tab.2 Main heat performance parameters of the building materials

Component	Constitute material	Thickness mm	Thermal conductivity W/(m·K)	Heat capacity kJ/(kg·K)	Density kg/m^3
Outer Wallboard	1 concrete grout	25	0.93	1.05	1800
	2 concrete	200	1.74	1.05	2500
	3 heat preservation layer	40	0.07	1.19	230
	4 concrete grout	20	0.93	1.05	1800
Inner Wallboard	1 concrete grout	20	0.93	1.05	1800
	2 pottery concrete	180	0.465	0.837	1200
	3 PCM wallboard layer	20	0.4	0.43	800
Floor and Ceiling	1 concrete grout	20	0.93	1.05	1800
	2 concrete	80	1.628	0.837	2500
	3 PCM wallboard layer	20	0.4	0.43	800

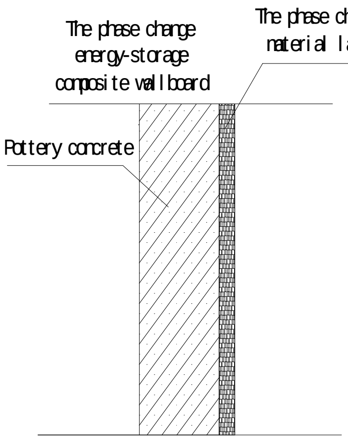

Fig.2 The PCECW

4. MODEL ESTABLISHMENTS

4.1 Computation Object

In order to analyze and research the thermal properties and the energy saving characteristic of the room with the phase change wall in winter, this research takes the typical north-south room 1 as the computation object (fig.3). Here the south wall of the computation room is outside enclosure, the east, west and the north wall are all partition wall, at the same time the upper floor and the nether floor also have their own neighboring rooms.

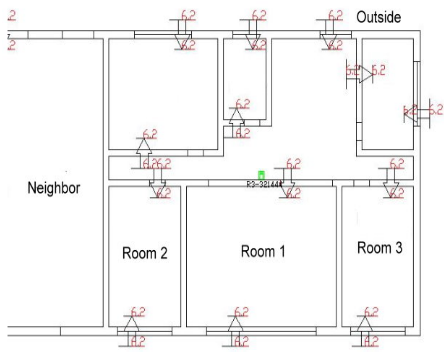

Fig.3 The computation Object

Main heat performance parameters of the building materials in inside and outside enclosures are shown in Tab.2. When the computation room is an ordinary room, replace the phase change material by the cement. In addition, the phase change temperature is 26□, and the temperature difference is 4□.

The outside windows of the computation room all use the single frame double-decked vacuum glass, whose heat transfer coefficient U is 2.7W/(㎡·K),and the total area of the south、east and north outer windows is separately 16, 9, 9 ㎡.

4.2 Establishment of the Computational Model

The numerical model simulating the building thermal process is generally divided into two parts: ① establishing the mathematical physical model of the dynamic thermal process of the enclosure and ② establishing the thermal balance equation of the whole room.

4.2.1 One-Dimensional Heat Transfer Model of the PCECW

The thermal transfer phenomena of the building enclosure is complex, but for the wallboard constituted by several material layers, if along the surface of frame is symmetrical, and the thickness is far less than the surface size, the instability heat transfer in the Wallboard is considered as one-dimensional process. The conductive differential coefficient equation of the inner temperature distribution in the wallboard is shown as follows:

$$\frac{\partial t(x,\tau)}{\partial \tau} = a\frac{\partial t^2(x,\tau)}{\partial x^2} \quad (1)$$

Fourier laws parse equation is:

$$q(x,\tau) = -\lambda\frac{\partial t(x,\tau)}{\partial x} \quad (2)$$

where: a is the thermal diffusivity, ㎡/h;

λ is the thermal conductivity, W/(m·K);

c is the heat capacity of the wallboard material, kJ/(kg·K);

ρ is the density of the wallboard material, kg/m^3.

Considering the heat transfer characteristic of the PCECW, to simplify the computation, some basic assumptions are made as follows: □the heat transfer is only along the direction of the thickness of the wall;□the PCECW is considered as equivalent specific heat in the phase change area, whereas it should be considered as definite nature in the solid and liquid area;□ignore the natural convection when the PCECW is in melted condition, and the over-cold effect when it is in the concretionary state.

For the heat transfer process of the wallboard constituted by several material layers, use the intermediate differential format in space, and use the whole hidden differential format in the time (the retral Euler Format), in order to reach convergence.

4.2.2 Heat Balance Equation of the Room with the PCECW

The transient state heat transfer process satisfies three heat balance equations as follows:

a) Heat balance equation of the outer surface of the wall:

The heat conduction + the heat convection with the air + the solar radiation + the sky radiation + the earth radiation = 0 (3)

b) Heat balance equation of the inner surface of the wall:

The heat conduction + the heat convection with the air + radiant heat =0 (4)

c) Heat balance equation of the air in the room:

$$c_{p\cdot a}\rho_a V_R \frac{d_{t_a}}{d_\tau} = \sum_{k=1}^{N} Q_{w.k} + Q_{s.c} + Q_L \quad (5)$$

where: c_{pa} is the heat capacity of the air, kJ/(kg·K);

ρ_a is the density of the air, kg/m^3;

V_R is the volume of the room, m^3;

Q_{wk} is the heat convection of the inner surface of the room enclosure with the air, W;

Q_{sc} is the heat convection of the illumination, the personnel and the equipment, W;

Q_L is the heat transfer causing by the air seepage or ventilates, W, which is computed by the value of the room ventilation G_L(m^3/s):

$$Q_L = c_{p.a}\cdot\rho_a\cdot G_L\cdot(t_{out} - t_{in}) \quad (6)$$

where: t_{out} is the outdoor air temperature, □;

t_{in} is the indoor air temperature, □.

Disperse and solve the nonlinear equation by the Gauss-Seidel type iterative method. At the same time the unit length is 1cm, and the time step is 1min. According to the outdoor boundary condition and the indoor heat disturbance, in the end we could compute and achieve the temperature of each node[1]~[2].

4.3 Enactment of Computation Condition

(1) The computation object is located in Beijing, and the climate parameters are computed by the

medpha software, established by Tsinghua University. The computation time is the heating time of Beijing: November 15 ~ March 15, altogether 121 days.

(2) Heating when the indoor temperature is lower than 18□; Stop heating when it is higher than 18□.

(3) Assume the ventilative number of the room with the outer air is 0.5, and with the north neighboring room is also 0.5.

(4) Assume the neighboring room temperature of the computation room is 18□, and the range of the phase change temperature Tm is 18～22□.

5. ANALYSIS OF COMPUTATIONAL RESULTS

Introduce “the heating season efficiency of energy saving“ in order to estimate the effect of the PCECW. The computational method of the efficiency of energy saving is shown as follows:

$$\eta = \frac{Q_c - Q_{pcm}}{Q_c} \quad (7)$$

where: η is the heating season efficiency of energy saving;

Q_{pcm} is the total heat consumption of the room with the PCECW in a whole heating time, kW;

Q_c is the total heat consumption of the ordinary room in a whole heating time, kW;

Changing the enthalpy, the thermal conductivity and the thickness of the PCECW, compare the different influence rule of them to the efficiency of energy saving.

Because the enthalpy of the PCECW has an intense influence on reducing the indoor temperature fluctuate and the heating load, increase the enthalpy of the phase change wall as far as possible. But according to Fig.4, we find that when the enthalpy is higher than 64kJ/kg, the increase of efficiency of energy saving becomes slow. In addition, Fig.5 shows that the influences of the thermal conductivity on reducing the indoor temperature fluctuate and the heating load are very small.

Obviously, the thicker of the PCECW is, the bigger of the heat charging will be (Fig.6). When the PCECW is used in the roof, the indoor temperature fluctuate and the heating load fall obviously, which is just because the roof could absorb more solar energy comparing with the inner wall. The best thickness of the phase change material lay in the roof is 25mm, which could make the absorption of the solar radiation more uniform.

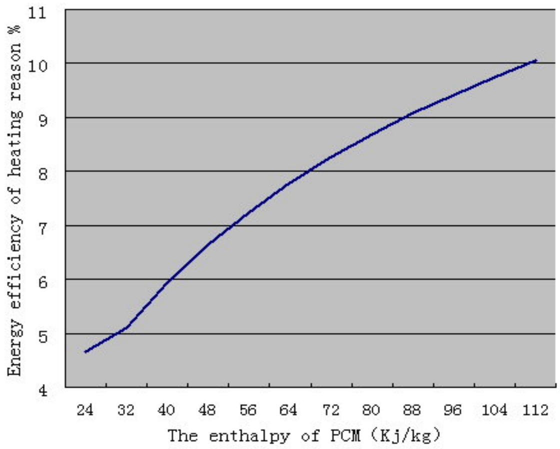

Fig.4 The influence of the enthalpy’s change on the efficiency of energy saving

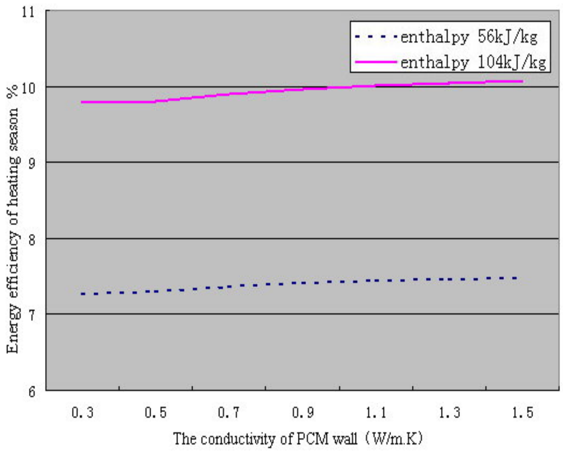

Fig.5 The influence of the thermal conductivity’s change on the efficiency of energy saving

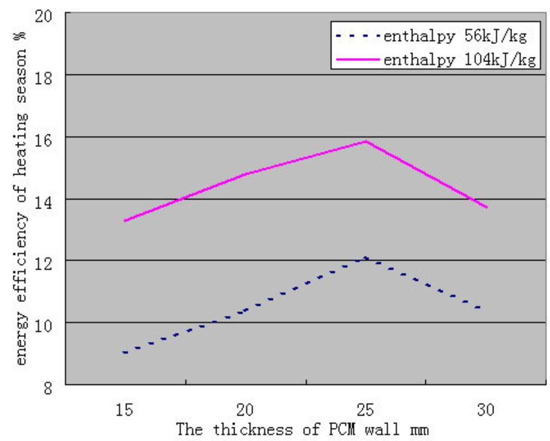

Fig.6 The influence of the thickness’ change on the efficiency of energy saving

For room 1 in Fig.3, when the enthalpy of the PCECW is 64kJ/kg, the thermal conductivity is 0.5W/m·□, the density is 800kg/m^3, the thickness of the phase change wall of the enclosure is 20 ㎜, the thickness of the phase change wall of the roof is 25 ㎜ and the computational time is 12.22～12.25, the temperature-changing rule of the room is shown as Fig.7.

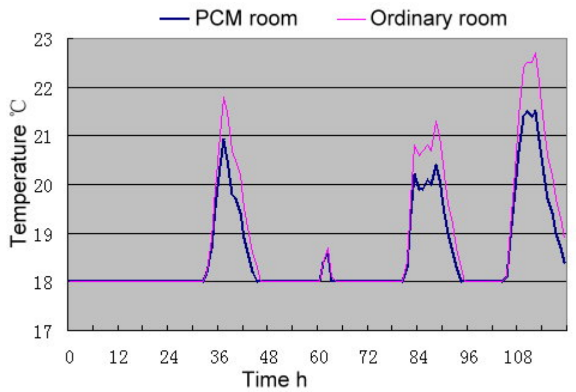

Fig.7 The temperature-changing rule of the room from 12.22 to 12.25

According to Fig.7, we find that the temperature fluctuation of the phase change room is smaller than the ordinary room, which is just because the phase change wall can absorb more solar radiation than the ordinary, after daubing the phase change material. At the same time, the smaller temperature fluctuation of the phase change wall reduces the temperature fluctuation of the room, which greatly enhances the heat comfortableness of the room. In addition, the results also show that the heating season efficiency of energy saving η could reach 12％ in a whole winter.

6. CONCLUSIONS

This paper makes a preliminary simulation analysis to the building thermal process of the room with the PCECW in winter, and the computational results show that: in the area with a long sunshine time and the big solar radiation intensity of Beijing, when there is plentiful solar radiation entering into the room, the phase change wall could effectively reduce the temperature fluctuation and the winter heating energy consumption, applying the characteristic of absorbing (releasing) plentiful heat energy in the condition of constant temperature of the phase change material.

Although this research is quite superficial on the characteristics of heat stability and energy saving of the room with the phase change wall in winter, the results above also show that the research on the phase change wall will give a huge practical and social significance to the construction energy conservation of our country.

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