Study of thermal performance of building using glass curtain wall with phase change material (PCM)

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Abstract: Glass curtain wall has received widespread attention because of architectural aesthetics that people persistent pursuit. But using glass curtain wall can bring the sharp increase of building energy consumption. For today's situation of energy scarcity, it is important to find a way to improve energy efficiency. Exploring the energy-saving effect for using phase change material (PCM) in glass curtain wall is the fundamental purpose of this paper. In this paper, the thermoregulation ability and energy-saving efficiency differences between PCM27 using in different building envelopes are studied using simulation methods.

Introduction

Glass curtain wall has been widely used in modern buildings because of its unique visual effects and superior performance. However, using large glass may reduce indoor thermal comfort resulting from great heat in and out easily. In order to maintain indoor thermal comfort, large amounts of energy have to be consumed. With increasingly exhausted fossil energy and rising energy price, energy conservation has received unprecedented attention[1]. A report[2] published by International Energy Agency in 2013 brought out that building energy consumption occupies 22% of the whole energy consumption in China. One of the reasons should be the low thermal insulation capabilities of building external envelope and windows, especially for glass curtain wall building. Many researchers carried out researches to deal with this phenomenon. Manz[3] using glass double façades with insulation in it in experiment and found that the temperature of interlayer could still rise to 80℃ even though the insulation can insulate from heat, and much heat transfer to the roof as a result. Jitka Mohelnikova[4] discovered that low-E glass can prevent not only the infrared radiation but also the far-infrared radiation. Nevertheless, low-E glass has some weakness such as high requirements for manufacturing process and high cost. The integral aesthetics of the glass curtain wall would be destroyed if using shadings. Phase change materials (PCMs) with a huge latent heat storage can absorbing energy when outdoor temperature higher than phase change temperature to cooling the surrounding environments and releasing energy when temperature lower than phase change temperature to achieve the purpose of heating. Integrated PCM into building can maintain indoor temperature at comfortability temperature range for a longer time, achieving the aims of delaying temperature peak and reducing energy consumption[5].

This paper used PCM integrated into building envelop to study its thermal performance.

Simulation Details

Weather Data

Beijing, the capital of China is placed in the north region of China. Beijing is a typical city which has the climate type of hot summer and cold winter. In order to have a better reflection of the local weather, Hourly weather data of TMY (Typical Meteorological Year) developed for Beijing was chosen for simulation, which is provided by ASHRAE.

Building Description

Recently, the pursuit of people for the office building is not only for comfort, but also for the aesthetics. As a result, the number of buildings with glass curtain wall increasing. This paper used a typical glass curtain wall building as building model, as shown inFig.1. It is a 3 layers of office building of 1506m2 with offices, meeting rooms, tea rooms etc. The office in the simulation opened from 8:00 to 20:00 everyday. For a good match to the real building, the parameters of building materials using in the simulation are coincident with the fact. The external wall is composed of a 5 mm cement mortar (outer layer), 20 mm insulation, 20 mm reinforced concrete and 8 mm cement mortar (inner layer). The floor is 10 mm reinforced concrete. The roof consists of 40 mm reinforced concrete (outer layer), 30 mm insulation, 12 mm reinforced concrete and 10 mm cement mortar (inner layer). The thermos-physical properties of building materials are present inTable.1. The windows use 2.5mm ordinary glass with thermal conductivity = 0.00875 W/m·k, shading coefficient = 0.348 and visible transmittance = 0.4. The details of the parameters in the simulation are given in Table.2.

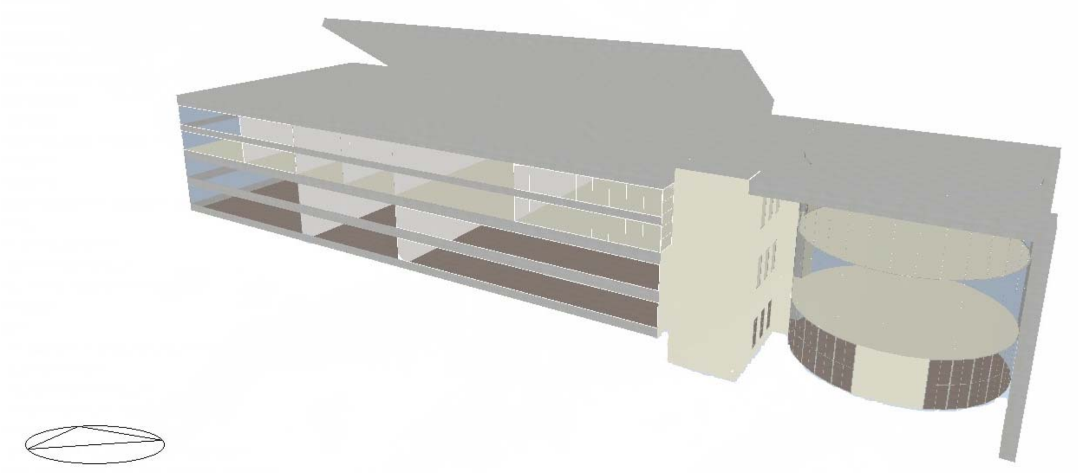

Fig.1.Building model for the simulation

Table.1 Thermo-physical properties of building materials

Name	Density (kg/m3)	Thermal conductivity W/(m·K)	Specific heat	Resistance (m2·K)/W
Reinforced concrete	2500	1.74	0.92	0.02
Insulation (roof)		0.033		0.76
Cement mortar	1800	0.93	1.05	0.01
Insulation (wall)		0.085		0.2

Table.2. Main operating conditions of the base case

Parameters	Value	Schedule
Time step	5min	
Cooling temperature（℃）	26	6.1-9.30 8:00－20:00
Efficiency of equipment	1.67	
Infiltration	0.7	

The cooling energy consumption were calculated using VAV system which is a module of EnergyPlus. VAV system improves indoor temperature to meet the indoor thermal comfort by changing the supplied air temperature[6].

Simulation were carried out using PCM27 with melting range from 26 to 28℃. The latent heat of the PCM was 231 KJ/Kg. The enthalpy-temperature graph of PCM27 is given in Fig.2.. For the purpose of finding out the optimal position that PCM integrated with, three building envelops: walls, floor and roof combined with PCM were started to simulation. The structure of each envelop is shown in Fig.3. The simulated results were analyzed to compare the thermal and energy performance of the office building without PCM (base case) versus the cases with PCM integrated each facade.

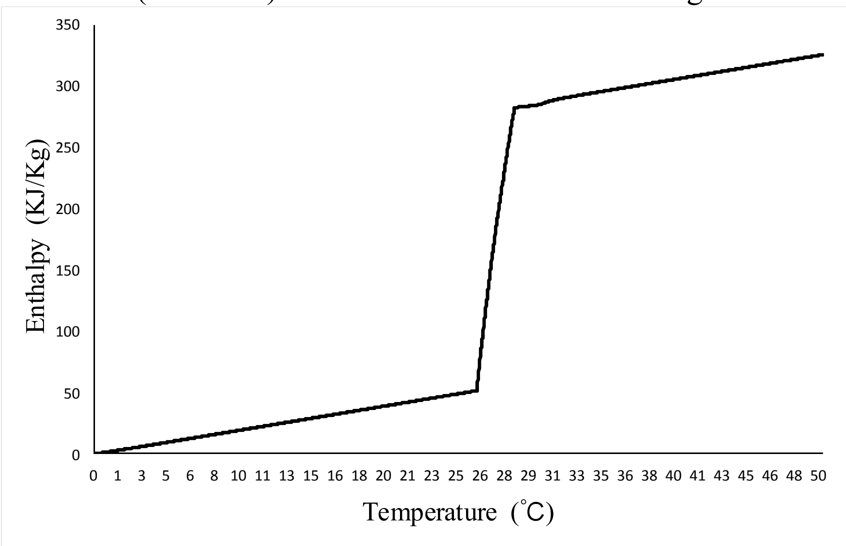

Fig.2. Enthalpy-temperature graph of PCM27

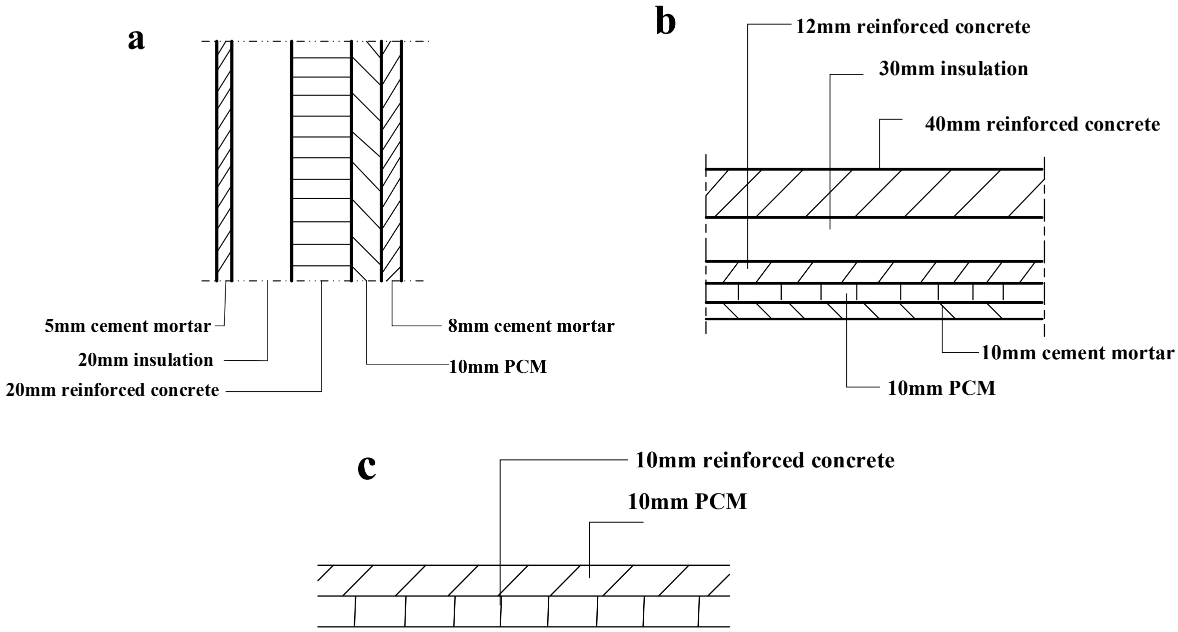

Fig.3. (a) Structure of external (b) Structure of roof (c) Structure of floor

Simulation

Because of the PCM should be simulated , DesignBuilder was employed as the simulation tool, which own EnergyPlus as computation kernel. EnergyPlus can calculate the performance of PCM using the finite difference algorithm, as given by Eq.1. Before simulations for thermal performance were carried out, a validation need to be done.

$$\frac{\rho C_p \Delta x(T_{i,new}-T_{i,old})}{\Delta t}=\frac{k_{\mathrm{w}}(T_{i-1,new}-T_{i,new})}{\Delta t}+\frac{k_E(T_{i+1,new}-T_{i,new})}{\Delta t} \quad (1)$$

Where, ρ=density (kg/m3)
Cp = specific heat capacity (kJ/kg·K)
∆x = layer thickness (m)
T = node temperature (k)
new = new time step
old = previous time step
i = node being modeled
i+1 = adjacent node to interior of construction
i-1 = adjacent node to exterior of construction
k = thermal conductivity (kW/mK)
∆x = calculation time step (s)

Results and Discussions

Effect of PCM integrated into walls, floor and roof on thermal performance

As shown in current results that the effect of PCM on the thermal performance can be obtained just by choosing a few typical days from summer. According to it, the difference among four cases mentioned above were simulated using the weather data of seven typical days, as shown in Fig.4. It can be observed that wherever integrated with PCM, temperature fluctuations were reduced clearly. As for the three building envelopes, PCM added into external wall obtained the optimal performance with the value that peak temperature reducing up to 5℃. However, PCM contained in roof can only change the peak temperature about 3℃. Fig.5 shows the overheating hours for four cases using whole summer weather data for simulation. As ruled by ASHRAE55-1992, the temperature range for indoor thermal comfortable is 22.8-26.1℃. Because only summer days were chosen to discuss the property of PCM, the overheating time assumed to be the time when indoor temperature higher than 26.1℃. The results acquired in Fig.5 is in consist with those of Fig 4. Integrated PCM into wall can maintain the indoor temperature within comfortable temperature range for longer time. The overheating time for the PCM-wall case is less than half of that for no PCM case. Contrasting with the conclusions from published literature[7], there is a little different. The building model used in the literature is 500mmx500mmx500mm, with no windows on it. The result appeared to be like that the case PCM added into floor is similar to the case have no PCM. Ignoring the effect of ambient temperature, the main reason must be the area of windows. The larger area of windows is, the better performance PCM integrated with floor get.

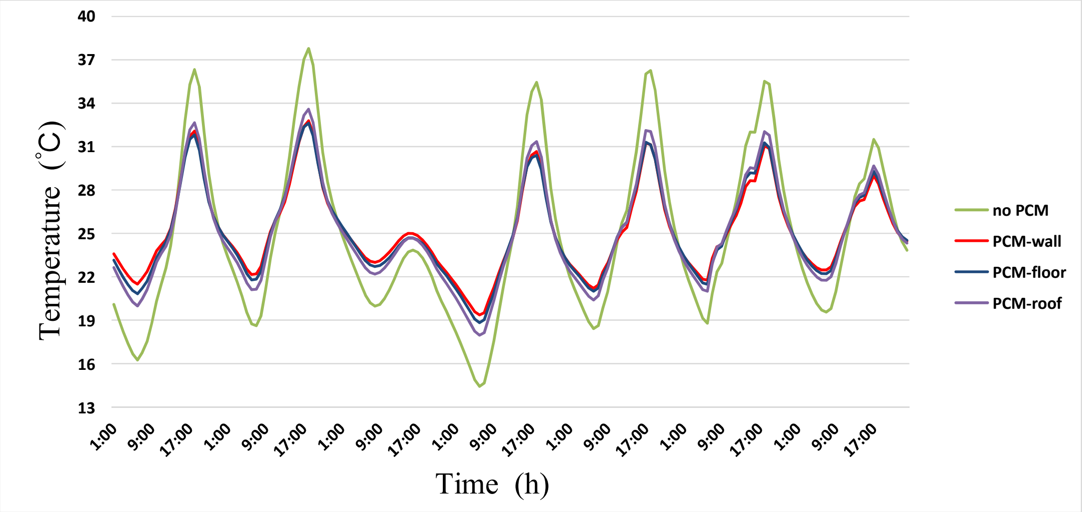

Fig.4. Indoor temperature of four cases

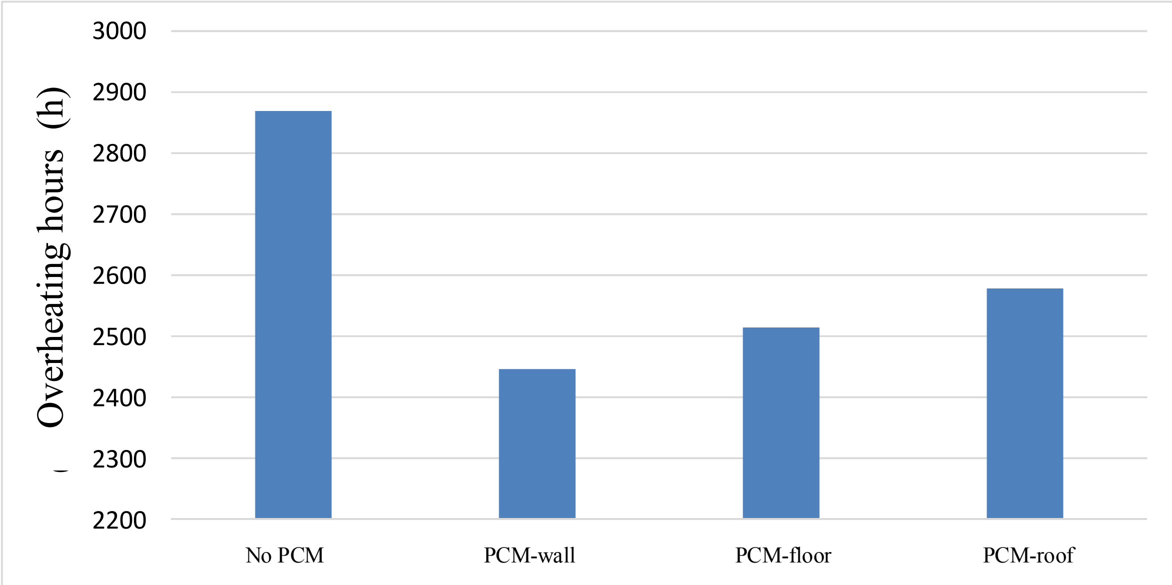

Fig.5. Overheating hours for four cases in whole summer

PCM can shift peak load. Preventing the peak temperature appearing at the peak energy demand time can saving money for the resident using multi-step electricity pricing. It can also saving fund for others by using the natural cold source to reduce indoor temperature when ambient temperature is lower. Table.3 summarized peak load shift for three building envelops. PCM integrated with floor has a better performance of peak load shift, especially in September. Delaying peak load for 17h in a month means that the peak load can be shift at least half an hour for everyday in a month, which can save a lot of money. Although the performance of the case PCM contained into roof not very well compared to others, it also improve the peak load obviously.

Table.3 Peak load shift for PCM integrated with different envelop

	Peak Load Shift (h)		
	Wall-PCM	**Floor-PCM**	**Roof-PCM**
Jun	3	12	-6
Jul	12	14	7
Aug	13	16	10
Sept	17	17	13

Energy saving efficiency of PCM integrated into walls, floor and roof

The simulation mentioned above were carried out without HVAC. From this section, the HVAC was used to simulate. Fig.6 shows the energy saving efficiency for three cases. The result shows a great agreement with the overheating hours in last section. A long overheating time leads to a lower energy saving efficiency. The energy saving efficiency is calculated in Eq.2.

$$\text{energy saving efficiency\%}=\frac{E_{noPCM}-E_{PCM}}{E_{noPCM}}\times 100\% \quad (2)$$

Where E_{noPCM}= energy consumption for the case have no PCM, E_{PCM}=energy consumption for the cases have PCM

PCM added into external wall have a better property for energy saving efficiency, which reach up to 37% in September. However, the efficiency of PCM integrated with roof only reach 24%. During July and August, the efficiency are all low because of the high ambient temperature which could not solidify the PCM. In this time, PCM remained in liquid state for a long time and cannot be used. In order to improve the efficiency during this period, PCM with a high melting temperature should be chosen.

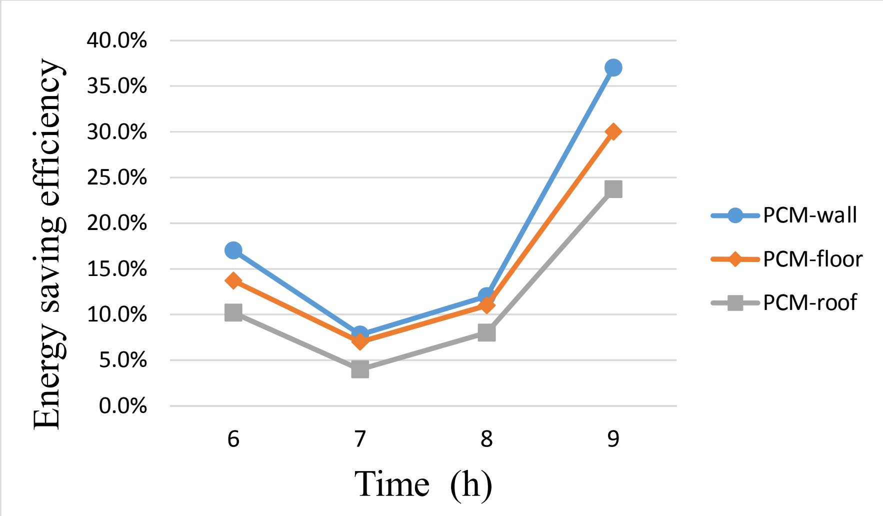

Fig.6.Efficiency of energy saving of PCM integrated into different envelop

Conclusion

This paper aims to research the optimal position for PCM integrated with in glass curtain wall building in Beijing during the summer days that can achieved a best performant of thermoregulation and energy saving efficiency. Following conclusions have been reached from the simulation:

- PCM integrated with external wall observed a better performance to maintain a comfortable indoor temperature and to reducing energy consumption. PCM contained in roof did not play better.
- Compared to other building types, PCM integrated with floor using in glass curtain wall building can improve the indoor temperature and energy consumption apparently by reason of the large area of windows.
- Adding PCM into floor can delay peak load for a longer time, which makes for saving fund.
- The range of ambient temperature plays an important role in energy saving efficiency. In order to improve the energy saving efficiency in summer, a PCM with high melting temperature had better be chosen.
- For glass curtain wall building, PCM integrated with external wall has a better performance on thermoregulation and energy saving. PCM contained with floor plays well on peak load shift. So they should be integrated into account to find the best one.

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