1 Effect of PCM thickness and melting temperature on thermal performance of double
2 glazing units

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6 **Abstract:**

7 The phase change material (PCM) applied in the glazing unit is an effective approach
8 to decrease the building energy consumption and improve the utilization efficiency of
9 solar energy, which makes a better thermal performance of glazing. In the present
10 work, thermal performance of a PCM-filled double glazing unit with different
11 thickness of phase change material in winter was investigated numerically in the cold
12 area of Northeast China with the melting temperature 14-16 °C, 16-18 °C and 18-20 °C.
13 The validation of the calculation model with experimental data was accomplished,
14 and a good agreement of the temperature field between simulations and experimental
15 data can be found. Then effect of thickness and melting temperature of PCM on
16 thermal performance of double glazing units was investigated and the relevant
17 parameters were analyzed. The results show that the interior surface temperature
18 increases by 158.7%, the total transmitted energy decreases by 109.1% and the
19 transmitted solar energy decreases by 86.1% when PCM thickness is 50mm,
20 compared with its thickness 4mm. With the increasing of PCM melting temperature,
21 its utilization decreases. When the thickness increases from 4mm to 30mm, the liquid
22 fraction increases, but the condition is reverse when it continues to increase to 50mm.

23 So considering all parameters, the thickness 12-30mm and the melting temperature
 24 14-16 °C is recommended in Northeast China.

25 **Keywords:** double glazing unit, PCM, thermal performance, PCM thickness

26

Nomenclature			
A_1, A_2, A_3, A_4	solar absorptivity of glass 1 layer, phase 1 layer, phase 2 layer and glass 2, -	Q_L	latent heat of PCM, J/kg
$c_{P,g}, c_{P,p}$	specific heat of glass and PCM, J/(kg·K)	$q_{rad}, q_{rad,air}, q_{rad,sky}, q_{rad,ground}$	radiative heat exchange between exterior surface of outer glass with the outdoor environment, with the air, sky and ground of outer glass, W/m ²
H, h_{out}, h_{in}	specific enthalpy of PCM, J/kg; convective heat transfer coefficient of the exterior surface of outer glass, inner surface of internal glass, W/(m ² ·K)	T_1, T_2, T_3, T_4	solar transmittance of glass 1 layer, phase 1 layer, phase 2 layer and glass 2, -
I_{sol}	solar irradiation, W/m ²	T, T_{ref}, T_s, T_l	temperature, reference temperature, temperature that the phase of PCM starts to change from solid to liquid, PCM completely changed into liquid, K
k	thermal conductivity of glass and PCM, W/(m·K)	$T_g, T_p, T_{p,l}, T_{p,s}$	temperature of outer glass, coupled surface of PCM, liquid PCM near to liquid–solid interface, solid PCM near to liquid–solid interface, K
L_1, L_2, L_3, L_4	thickness of glass 1 layer, phase 1 layer, phase 2 layer and glass 2 layer, m	$T_{out}, T_{a,out}, T_{sky}, T_{in}, T_{a,in}$	temperature of outer glass surface, ambient, sky temperature, internal glass surface, indoor air, K

Greek letters		Subscript	
$\alpha_1, \alpha_2, \alpha_3$	extinction coefficient of glass, phase1 and 2 of PCM, m^{-1}	a	air, -
γ, β	liquid fraction, a factor that splits the heat exchange with the sky dome between sky and air radiation,-	con	Convective,-
ρ	density of glass and PCM, kg/m^3	g, p	glass and PCM, -
$\rho_{i1}, \rho_{i2}, \rho_{i3}, \rho_{i4}$	interface reflectance for surface between air and glass, for surface between phase 1 of PCM and glass, for surface between phase 1 and phase 2 of PCM, for surface between phase 2 of PCM and glass, -	in, out	inner surface and exterior surface, -
τ	time, s	rad	radiative, -
Φ	radiative source term, W/m^3	sol	solar radiation intensity, -
ε	surface emissivity of glass,-	l, s	liquid and solid PCM, -
σ	Stefan–Boltzmann constant, $5.670 \times 10^{-8} W/(m^2 \cdot K^4)$		
φ_s	temperature time lag of the double glazing unit comparing with the outdoor air, minute		

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28

29 1. Introduction

30 The key factor for the increasing CO₂ emission is the burning production of
31 fossil fossil, which contributes to serious global warming [1-3]. Building consumes
32 about 40% of total fossil energy per each year in the last five years [4, 5] due to the
33 energy loss of building envelopment. Energy loss of glazing units is one of important
34 part in the building envelopment because of its poor thermal performance, although

glazing units have an effective way to get air ventilation and enough solar gain [6].

There are two effective ways to improve the thermal performance of glazing units. The one is to increase the thermal mass of glazing structure, and thermal mass is defined as the ability to store heat, and maintains the temperature stability within a building [7]; the other one is to improve thermal resistance, which expresses the ability of heat insulation [8]. There are some methods to improve the thermal performance of glazing units, such as: (1) adding a participating medium in glazing cavity including gas (CO₂, HFC-125) [9], liquid (water, aerogel) [10, 11], and PCM (paraffin, fatty acids) [12]; (2) low emissivity materials coated on the pane surface [13-15]; (3) multilayer glass structure [16-18]. Of all methods stated above, the cavity between glass panes filling with PCM are being attracted much more attention, because the PCM-filled glazing unit is to absorb part of the solar energy for thermal energy storage, without hurting visible light into the indoor environment for daylighting [19, 20].

A variety of numerical and experimental works of thermal energy storage solutions for the integration of PCM into glazing unit have been developed. Some of them paid attention to the effect of thermophysical parameters on the thermal performance [7, 21-26], especially for the optical parameters. For instance, Gowreesunker et al. [7] adopted T-history method and spectrophotometry principles to investigate the thermal performance and optical performance of a PCM-glazing unit, and also calculated the optical properties of PCM layer by the optical constants (i.e. extinction coefficient and refractive index). And there are some researches to study

the effect of PCM thickness on the thermal performance of PCM-filled glazing unit. Goia et al. [27] used a commercial spectrophotometer and a dedicated optical test bed to measure the angular behavior and spectral of glazing units filled with different thicknesses PCM layer, and found that the PCM thickness has a big effect on the absorptivity and transmittance, but has a weak effect on the reflectivity.

The recent studies show that the thickness and the optical parameters of PCM play an important role in the thermal performance of PCM glazing units [21, 23, 28-29], which also have a key effect on the interior heat and light transfer of glazing unit. However, compared with the studies about optical properties effect on the thermal performance of PCM glazing units, there are few studies about the effect of thickness on the thermal performance of PCM glazing units, especially for its applicability analysis in severe cold area. In the present work, the thermal performance of a PCM-filled double glazing unit with different thickness of PCM in Northeast China was investigated numerically, and effect of melting temperature of PCM on thermal performance of double glazing units was also analyzed.

2. Physical and mathematical models

2.1 Geometric description

Fig. 1 shows the model details of glazing unit filled with PCM. As shown in Fig.1, sunlight reaching the glazing unit surface is divided into three parts: transmitted, reflected and absorbed by the two glasses and the PCM layer. Considered three transparent layers (double glazing layers and PCM layer), the effective transmittance, the front and back reflectance are quantified by the result of multiple reflections

79 between the front and back surfaces, plus the effects of absorption through the layers.
 80 With the coupled process of conduction, convection and radiation exchange, the
 81 absorbed heat will transmit inward and/or outward the unit. The exterior and the
 82 interior boundaries have also thermal disturbance containing thermal radiation and
 83 convection.

Fig.1. Double glazing unit filled with PCM

2.2 Governing equations and boundary conditions

Assumptions for the mathematical model have been listed as follows.

(1) The heat transfer in the glazing unit is simplified to one-dimensional unsteady process.

(2) PCM is considered to be purely absorbing medium, and the convection within the PCM layer is neglected too.

(3) The thermal properties of glass and PCM are temperature independent.

(4) The radiation exchange between the two glass surfaces facing the cavity filled with PCM is neglected too. And the PCM of both liquid state and solid state is

highly non-transparent to the long-wave radiation.

As shown in Fig.2, the heat transfer in the double glazing unit filled with PCM is divided into three parts: the outer glass layer, the PCM layer and the internal glass layer.

Fig.2. Layout of double glazing unit filled with PCM

The unsteady energy equation is calculated as

$$\rho \frac{\partial H}{\partial \tau} = k \frac{\partial^2 T}{\partial x^2} + \phi \quad (1)$$

Where, τ is time(s). T is temperature (K). ρ and k are density(kg/m³) and thermal conductivity (W/m K), respectively. H is the specific enthalpy (J/kg). ϕ is radiative source term (W/m³).

In Eq. (1), the specific enthalpy is calculated by the equations below, where equation (2a) is applied to glass region, the others are applied to PCM region.

$$H = c_{p,g} T_g \quad (2a)$$

$$H = \int_{T_{ref}}^T c_{p,p} dT + \gamma Q_L \quad (2b)$$

$$\gamma = 0, T < T_s \quad (2c)$$

$$\gamma = \frac{T - T_s}{T_l - T_s}, T_s \leq T \leq T_l \quad (2d)$$

$$\gamma = 1, T > T_l \quad (2e)$$

Where, T_{ref} is the reference temperature (K). $c_{p,p}$ and $c_{p,g}$ are specific heat of PCM layer and glass layer (J/kg K). T_g is the temperature of glass. Q_L is the absorbed and released latent heat of PCM (J/kg). γ is liquid fraction of PCM. T_s and T_l are the temperatures of initial stage and final stage in the phase transformation of PCM (K), respectively.

The radiation source term of each layer is calculated by

$$\varphi_i = \frac{T_{i-1} A_i I_{\text{sol}}}{L_i} \quad (3)$$

Where, $i=1, 2, 3, 4$ express the glass1 layer, the phase 1 of PCM layer, the phase 2 of PCM layer and the glass2 layer, respectively. T_i and A_i express the transmittance and absorptivity of the layer i , respectively. L_i expresses the thickness of the layer i (m). I_{sol} is solar radiation (W/m²).

The transmittance and absorptivity of each layer are calculated by [30-33]

$$T_i = \frac{(1 - \rho_{i1})(1 - \rho_{i2})\exp(-\alpha_i L_i)}{1 - \rho_{i1}\rho_{i2}\exp(-2\alpha_i L_i)} \quad (4a)$$

$$A_i = 1 - \rho_{i1} - \frac{(1 - \rho_{i1})\rho_{i2}\exp(-2\alpha_i L_i)}{1 - \rho_{i1}\rho_{i2}\exp(-2\alpha_i L_i)} - T_i \quad (4b)$$

Where ρ_{i1} and ρ_{i2} are the reflectance of entrance surface and exit surface of media i , α_i and L_i are the extinction coefficient and the volume of media i , respectively.

The transmittance of glass 2 layer T_4 is related to the indoor daylighting of the

buildings, which should be considered in process of weighing the thermal performance of glazing unit.

The boundary conditions for the calculation domain are given as follows. For the outer glass exposed to solar radiation, the boundary condition at $x=0$ is given as

$$-k_g \frac{\partial T}{\partial x} = q_{\text{rad}} + h_{\text{out}} (T_{\text{out}} - T_{\text{a,out}}) \quad (5)$$

Where, q_{rad} is radiation heat exchange between exterior surfaces of outer glass and the outdoor environment (W/m^2). h_{out} , T_{out} and $T_{\text{a,out}}$ are the convective heat transfer coefficients of the exterior surface of outer glass ($\text{W/m}^2 \cdot \text{K}$), temperature of the exterior surface of outer glass (K), and ambient temperature (K), respectively. The radiation heat exchange with the outdoor environment q_{rad} is given by [24]

$$q_{\text{rad}} = q_{\text{rad, air}} + q_{\text{rad, sky}} + q_{\text{rad, ground}} \quad (6)$$

Where, $q_{\text{rad, air}}$, $q_{\text{rad, sky}}$ and $q_{\text{rad, ground}}$ express radiation heat exchange with the air, sky and ground (W/m^2), respectively.

For the inner glass next to indoor environment, the boundary condition at $x=x_3$ is given as [34]

$$-k_g \frac{\partial T}{\partial x} = h_{\text{in}} (T_{\text{in}} - T_{\text{a,in}}) + \varepsilon \sigma (T_{\text{in}}^4 - T_{\text{a,in}}^4) \quad (7)$$

Where, h_{in} , T_{in} and $T_{\text{a,in}}$ are the convective heat transfer coefficients ($\text{W/m}^2 \cdot \text{K}$), and temperature of the inner surface of internal glass (K), and air temperature indoor (K), respectively.

The average relative value and the max relative value are also key parameters to analyze the thermal performance of the double glazing unit, which is calculated by Eq. (8a) and (8b).

$$\varphi_{ave} = \frac{1}{k} \sum_{i=1}^k \frac{\alpha_i^2 - \alpha_i^1}{\alpha_i^1} \quad (8a)$$

$$\varphi_{max} = \text{Max}_{1 \leq i \leq k} \left\{ \frac{\alpha_i^2 - \alpha_i^1}{\alpha_i^1} \right\} \quad (8b)$$

Where, φ_{ave} and φ_{max} are the average relative value and the max relative value, respectively. i is the node number, α_i^1 and α_i^2 are the compared parameter value and the standard value.

2.3 Method of solution and validation of numerical procedure

In this modeling work, the grid lengths of both the glass and PCM are 1mm. The numerical procedure is validated with the experimental results. The measurements were conducted in the small-scale test facility consisting of glass unit and rooms at Northeast Petroleum University in Daqing city (a typical city of Northeast China). As shown in Fig. 4, the test facility has the south-facing rooms with the internal dimension of 5.66 m × 2.46 m × 1.65 m (Height × Width × Depth), and the glass unit systems have a dimension of 1.5 m × 2 m. The glazing type used in the experiments is composed by four glass panes and PCM layer. The thicknesses of glass and PCM are 4mm and 4.5mm ($b_1=b_3=4\text{mm}, b_2=4.5\text{mm}$). The surrounding external surfaces are built up with 100 mm insulation material, which is mineral wool.

Fig.4. Picture of the small-scale test facility

Temperatures were measured using thermocouples type K, and the solar radiation was measured using Jinzhou Sunshine/TBQ-4-5 solar spectral radiometer. The experimental data were measured in two sunny days on October 10-11, 2015. The solar radiation is depicted in Fig.5 (a), and the outdoor and indoor temperatures of the double glazing facades filled with and without PCM are shown in Fig.5 (b).

Fig.5. Solar radiation and temperatures in the experiment (a: heat flux; b:

temperatures)

Fig.6. Numerical and experimental results of the double glazing unit filled with PCM

In the calculation process, the model was simplified into a one-dimensional one, considering the shape of glazing unit. The thermophysical properties of materials can be attained from reference [30-32], and the simulated results and experimental data are together plotted in the Fig. 6.

As shown in Fig. 6, the curves of the simulated results and experimental data almost keep the same in most regions. Based on the experimental result, the average relative value of the simulation result are 8.2%, and the RMSE of simulation result is approximately 4.8 °C. During the early sunset time the difference between numerical and the experimental results is big, but the numerical results have a good agreement with the experimental results in the sunrise time region. The main reason is that the effect of initial temperature in the double glazing facades filled with PCM is not omitted in the initial stage, when heat conduction plays an important role in the heat transfer process.

3. Results and discussion

The measured average hourly variations of the ambient air temperature and total

radiation on Jan. 7 in Daqing city is depicted as Fig.7. The h_{out} and h_{in} are 19 and 8.7 W/m²·K [5], respectively. The indoor air temperature is 20 °C. According to the different climatic condition and previous experimental results, the thermophysical properties of material are shown in Table 1. The refractive index of liquid and solid PCM is 1.3 and 1.4. And the extinction coefficients of solid and liquid PCM is 50 and 30 m⁻¹. The extinction coefficient and refractive index of glass are 19 m⁻¹ and 1.5 [7], respectively. The emissivity of the glass is 0.88 [22]. The initial temperature of the domain is 18° C. The simulation was kept running until the solution becomes periodic, which needs between two days and four days to reach the periodic condition.

Fig.7. Mean hourly variation of ambient temperature and solar radiation

Table 1 Thermophysical properties of materials

material	Melting temperature(° C)	Density (kg/m ³)	Thermal conductivity (W/(m·K))	Specific heat capacity (J/(kg ·K))	Latent heat (J/kg)
glass	-	2500	0.96	840	-
PCM 1	14-16	850	0.21	2230	205000

PCM 2	16-18	870	0.23	2250	180000
PCM 3	18-20	880	0.24	2240	185000

For investigating the effect of PCM thickness on thermal performance of glazing unit containing PCM, the conditions of seven kinds of thickness of $b_2=4\text{mm}$, $b_2=8\text{mm}$, $b_2=12\text{mm}$, $b_2=16\text{mm}$, $b_2=20\text{mm}$, $b_2=30\text{mm}$ and $b_2=50\text{mm}$ are investigated. Thickness of the glass is 6mm ($b_1=b_3=6\text{mm}$).

Fig.8 illustrates simulated results on the interior surface of double glazing unit with different thickness of PCM1. In Fig.8 (a), with the PCM thickness increasing, the temperature of interior surface of double glazing unit increases due to the improvement of thermal insulation performance. Compared with temperature of the interior surface at PCM thickness 4mm , the average relative value of the thickness 8mm , 12mm , 16mm , 20mm , 30mm and 50mm is 25.3% , 46.8% , 65.4% , 81.6% , 114.1% and 158.7% , respectively. And the max relative values of the thickness 8mm , 12mm , 16mm , 20mm , 30mm and 50mm are 53.7% , 104% , 127% , 141.6% , 166.8% and 242.1% , respectively. These results illustrate that the PCM thickness has a big effect on the interior temperature of the glazing unit filled with PCM.

In Fig.8 (b), we defined that total transmitted energy directed from outdoor to indoor is positive, and the direction from indoor to outdoor is negative. Compared with the total transmitted energy at PCM thickness 4mm , the average relative values at PCM thickness 8mm , 12mm , 16mm , 20mm , 30mm and 50mm are 21.7% , 36.4% , 49.4% , 62.1% , 88.8% and 109.1% , which illustrates the effect of thickness of PCM on total transmitted energy is also big. In Fig.8(c) and (d), with the PCM thickness

increasing, the transmitted solar energy and the solar transmittance reduce. Compared with the transmitted solar energy at PCM thickness 4mm, the average relative values at PCM thickness 8mm, 12mm, 16mm, 20mm, 30mm and 50mm are 16.8%, 29.4%, 40%, 49.1%, 66.6% and 86.1%, and the max relative values at PCM thickness 8mm, 12mm, 16mm, 20mm, 30mm and 50mm are 18.1%, 33%, 45.1%, 55.1%, 72.7% and 89.7%. The result shows the thickness also has a big effect on the transmitted solar energy of the glazing unit filled with PCM.

Besides, the utilization ratio of PCM is also related to its thickness, which is direct to melting situation under solar irradiation. In Fig.8 (e), the liquid fractions of PCM at different thicknesses from 8mm to 50mm are smaller than 0.7, which illustrates that the utilization ratio in the glazing unit is small. The liquid fraction at PCM thickness 4mm is even zero in all day, which results in the poor utilization of latent heat of PCM. There are two main reasons about this phenomenon. Firstly, the thermal insulation of double glazing unit containing PCM at small thickness is weak, which leads to the low temperature of glazing unit as shown in the Fig. 8 (a), and then results in the small liquid fraction of PCM. Secondly, the absorptivity ability of PCM layer at small thickness is weak, which results in poor thermal capacity and the poor utilization of latent heat of PCM. The biggest liquid fraction at PCM thickness 50mm is nearly 0.2 between 0:00 and 6:00, which shows that the stored energy of glazing unit filled with PCM can not consume in whole day when the thickness of PCM is larger, which leads to the poor utilization of latent heat of PCM and weak daylighting. So there is a better range of PCM thickness of glazing unit filled with PCM in Daqing

city. And the PCM can accomplish a melting and solidifying process when the PCM thickness is in the range 12mm-30mm, which results in better utilization of latent heat of PCM as shown in the Fig.8 (a, d, e). Hence, the PCM 1 thickness of 12mm-30mm is recommended considering both the daylighting and thermal performance in Daqing city.

(a)

(b)

(c)

(d)

(e)

Fig.8. Simulation results of the interior surface on double glazing unit with different thickness of PCM1 (a: interior temperature; b: total transmitted energy; c: transmitted solar energy; d: solar transmittance; e: liquid fraction)

Fig.9 shows thermal performance on the interior surface of double glazing unit with different thickness of PCM 2. Compared with glazing unit filled with PCM 1, the effect of PCM thickness on thermal performance of glazing unit filled with PCM 2 is similar, except for the exact time of peak value of the interior surface temperature and total transmitted energy. For example, compared with temperature of the interior surface at PCM 2 thickness 4mm, the average relative value at PCM 2 thickness 8mm, 12mm, 16mm, 20mm, 30mm and 50mm is 27.6%, 43.2%, 60.1%, 80.1%, 108.9% and 143.6%, respectively, which shows that the PCM 2 thickness of 12mm-30mm is also recommended. Then we mainly discuss the difference of the exact time of peak value of the temperature and total transmitted energy between PCM 1 and 2. It is shown in the Fig. 8 (a and b) that the time of peak value of interior surface temperatures at PCM 1 thickness 4mm, 8mm, 12mm, 16mm, 20mm, 30mm and 50mm is 13:15,

263 13:24, 13:25, 13:27, 13:32, 13:50 and 14:30, respectively; The time of peak value of
 264 total transmitted energy at PCM 1 thickness 4mm, 8mm, 12mm, 16mm, 20mm, 30mm
 265 and 50mm is 12:00, 12:24, 13:00, 13:00, 13:01, 13:05 and 13:56, respectively. The
 266 results show that the time of peak values of interior surface temperature and total
 267 transmitted energy decrease with the PCM thickness increasing. From Fig. 9 (a and b),
 268 the time of peak value of interior surface temperatures at PCM 2 thickness 4mm, 8mm,
 269 12mm, 16mm, 20mm, 30mm and 50mm is 13:06, 13:27, 13:28, 13:30, 13:33, 13:50
 270 and 14:28, respectively. The time of peak value of total transmitted energy at PCM 2
 271 thickness 4mm, 8mm, 12mm, 16mm, 20mm, 30mm and 50mm is 12:00, 11:27, 11:04,
 272 10:57, 13:00, 13:01 and 13:53, respectively. The peak value trend of interior surface
 273 temperatures of glazing unit filled with PCM 2 is same with the one of PCM 1,
 274 however for the peak value trend of total transmitted energy of glazing unit filled with
 275 PCM 2 is opposite with the one of PCM 1, when PCM thickness is increasing. The
 276 reason about this phenomenon is that the total transmitted energy of double glazing
 277 unit in the coupled heat transfer process includes transmitted solar energy, radiation
 278 and convective heat transfer between interior and the external surroundings, heat
 279 conduction of double glazing unit, and heat transfer of phase change. The interior
 280 surface temperature is mainly related to the radiation and convective heat transfer
 281 between internal and the external surroundings, heat conduction of double glazing
 282 unit. In addition, the liquid fraction of PCM decreases with the melting temperature
 283 increasing. For example, the average value of liquid fraction at PCM 1 thickness
 284 16mm between 10:00 and 18:00 is 0.46, and the average value of liquid fraction at

PCM 2 thickness 16mm between 10:00 and 18:00 is only 0.37, which illustrates that the utilization of PCM also decreases with the melting temperature increasing. It is concluded that PCM 1 with the melting temperature of 14-16 °C is recommended, compared with PCM 2. It is also found that adding the PCM thickness may lead to the variation trend reversed of total transmitted energy for some PCMs.

Fig.10 illustrates thermal performance on the interior surface of double glazing unit with different thicknesses of PCM 3. It is found that the effect of thickness on thermal performance of glazing unit filled with PCM 3 is also similar with PCM 1 and 2, except for the liquid fraction. And with the PCM thickness increasing from 4mm to 30mm, the liquid fraction increases, but the liquid fraction decreases when the PCM thickness reaches 50mm. The reason is that PCM can not melt for the bigger PCM thickness, though it absorbs more solar energy when the melting temperature of PCM increases. So the thickness of 12mm-30mm is also recommended for the PCM 3. Simultaneously, as shown in Fig.8 (e), Fig.9 (e) and Fig.10 (e), with the melting temperature increasing, the liquid fraction decreases, which illustrates that the utilization ratio of PCM decrease when the PCM of higher melting temperature is selected. For example, the average value of liquid fraction at PCM 3 thickness 16mm between 10:00 and 18:00 is only 0.14, which is even much smaller than the one of PCM 2. Hence, the PCM thickness of 12mm-30mm and the melting temperature 14-16 °C are recommended for the winter of Northeast China, compared with PCM 3.

(a)

(b)

(c)

(d)

(e)

Fig.9. Simulation results of the interior surface on double glazing unit with different thickness of PCM2 (a: interior temperature; b: total transmitted energy; c: transmitted

solar energy; d: solar transmittance; e: liquid fraction)

(a)

(b)

(c)

(d)

(e)

Fig.10. Simulation results of the interior surface on double glazing unit with different

thickness of PCM 3 (a: interior temperature; b: total transmitted energy; c: transmitted solar energy; d: solar transmittance; e: liquid fraction)

4. Conclusions

In present study, the effect of PCM thickness on thermal performance of a PCM-filled double glazing unit in winter in Northeast China was numerically investigated. Three PCMs with different melting temperature were also investigated.

For all three PCMs, the effect of thickness on thermal performance of a PCM-filled double glazing unit is big, including interior temperature, total transmitted energy, transmitted solar energy, and solar transmittance. With the PCM thickness increasing from 4mm to 50mm, the interior surface temperature increases by 158.7%; the total transmitted energy decreases by 109.1%; the transmitted solar energy decreases by 86.1%. However, as the thickness of PCM increases, the variation trend of interior temperature and total transmitted energy are not always consistent, and adding the thickness may lead to the variation trend reversed of total transmitted energy for some PCMs with different melting temperature. The liquid fraction of PCM in winter day is smaller than 0.7 in Northeast China, which shows that the utilization ratio of PCM is small. However, with the increasing of the thickness, the liquid fraction increases. Hence, the PCM thickness 12-30mm and the melting temperature 14-16 °C is recommended in Northeast China.

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