The integration of phase change material (PCM) with double skin facades to minimize energy consumption in buildings

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Abstract The rapid increase in world energy consumption caused increased consumption of non-renewable energy sources. Substantially heat losses occur through windows and translucent areas; therefore, it is crucial to mitigate the energy transfer between these boundaries, so emerging technologies based on integration phase change material (PCM) in glazing show the potential to enhance the thermal performance of buildings. This article is studied the thermal performance of integration of the phase change material with a new type of triple glazed window by using numerical methods. The results show that the full case of the triple window (TW) + PCM achieves the maximum insulation from outdoor environment conditions.

Introduction

In recent years, the research activity in the field of building envelope components and building services has led to the identification of numerous solutions able to decrease the energy need in buildings [1]. The building envelope is likely to be one of the most frequently investigated construction elements because of its central role in controlling the mass and energy fluxes that enter/exit from the indoor environment [2]. The highest potential to reduce the energy impact of the building envelope can be related to the transparent components. In this framework, adaptive and dynamic elements are successful strategies to reduce solar heat gains through windows[3].

Among all the activities employing a significant amount of energy, one of the main parts in some countries is related to buildings. According to the International Energy Agency (IEA), the building sector accounts for more than 30% of total energy consumption [4].

In recent years among the large variety of technologies and systems that can be used to increase the energy performance of a building, phase change materials (PCMs) are certainly one of the critical elements in Research and Development (R&D)[5]. The combination of Phase Change Materials (PCMs) in the transparent/translucent envelope [6].

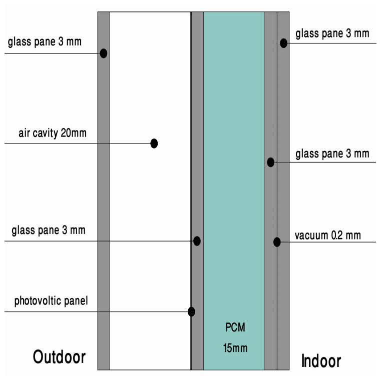
The study by Goia et al. [7] represent one of the efficient way to enhance the thermal capacity of the glazing system, the double glazed window filled with PCM (DW + PCM). Ismail et al. [8] compared two different types of windows, filled with absorbing gases and the other one filled with PCM. The authors calculated the heat transfer through the window, which compared and discussed the total heat gain coefficients. Weinläder et al. studied the excellent capability of DW + PCM to decrease solar gains. The authors investigated the thermal performances of three glazing systems that integrated a plastic container filled with different PCMs and compared them with a DW + PCM through experimental and mathematical methods and analyzed the energy performance of the components. The achieved results present that a PCM configuration can decline heat losses in a south-oriented façade by approximately 30% and solar gains nearly 50% when compared with the DW+ PCM. Zhong et al. [9], conducted experimental and simulation studies to investigate the performance of heat transfer of the DW + PCM and enhance thermophysical parameters of PCM filled inside the windows.

1. Model description

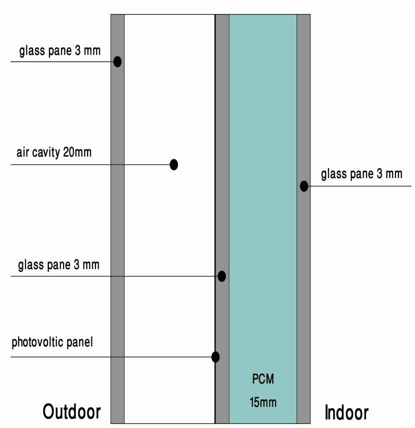
The TW + PCM contained two cavities, of which the outer one is filled with air and the interior one is filled with PCM, this configuration has an vacuum glass in the interior layer of the window, which can increase the holistic thermal resistance of the proposed system. Besides, in order to highlight the merits of the proposed TW + PCM, the mathematical models, the simulation research on the dynamic thermal performance and energy saving performance of the TW + PCM is conducted in hot summer region of Kuwait City.

Figure 1 presents the proposed window component of the different three scenarios. The first one is called the full case which consists of glass, air gap, solar cell, glass, PCM and vacuum glass, at the same time, the second one consist of solar cell, glass, PCM and vacuum glass and finally the third one is consist of glass, air cavity, solar cell, glass, PCM and glass.

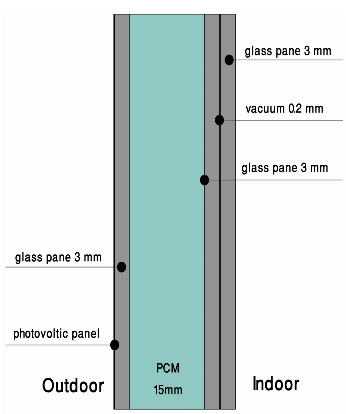
The outer surface of the proposed window is subjected to time-dependent solar radiation and forced convection boundary condition



(a) Structure of full case



(b) Structure of DW + PCM without air cavity



(c) Structure of TW + PCM without vacuum glass

Fig 1: Structure comparison of the three kind of proposed windows

The thickness of the glass is 3 mm, while the air gap and PCM thickness are 20 mm and 15 mm, respectively. Figure 4 indicates the average hourly variations of the ambient air temperature and global radiation in Kuwait City during June because it is one of the hottest months. The thermophysical properties of the different layers were depicted in Table1.

Table 1: Thermo-physical properties of used materials.

Material	Density (Kg/m³)	Specific heat (kJ/kg K)	Latent heat (KJ/Kg K)	Thermal conductivity (W/m K)	Melting temperature ℃
RT35HC	880 solid 770 liquid	2	240	0.2	34-36
Solar cell	2330	0.677	-	130	-
glass	2800	0.750	-	0.7	-

2. Validation and verification

The current model for the PCM domain is validated with the results in the literature of at two different inclination angles of the PCM cavity [10]. Based on the predicted results, the current model for the PCM domain is in a good agreement with the results of [10] as shown in Fig. 2.

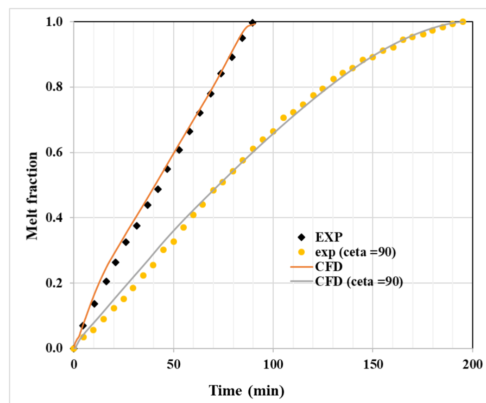


Fig 2: Validation of the current numerical model with experimental work of Kamkari R. et al [10].

3. Result and discussion

The inner wall surface temperature variation with time for each case is calculated and presented in Fig. 3. It increases with the time from sunrise at 5:00 Am until the peak value at 1:00 PM then decreases until sunset at 6:00 PM. The difference is obvious where the full case shows a uniform temperature at 25 ºC during the daytime which equal to the indoor air temperature, this means that the full case achieves the maximum insulation from outdoor environment conditions. Followed by the case without air cavity where the maximum temperature reaches 27.5 ºC at 1:00 PM also it presented an acceptable insulation capability. And the lowest insulation occurs in the case without vacuum glass where the maximum temperature reaches 33.33 ºC at 1:00 PM..

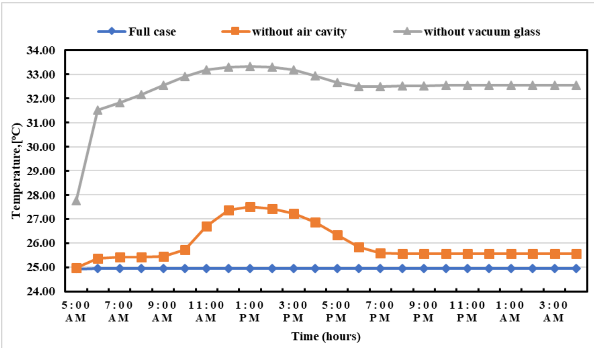


Fig 3: The inner surface temperature for the three cases of windows in typical sunny summer day.

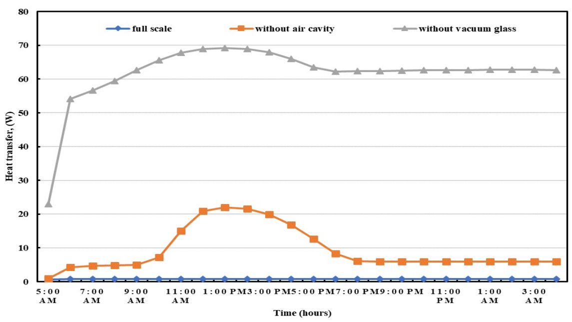


Fig.4 The comparison of the heat transfer rate from the inside ventilated window of the different cases during the whole day.

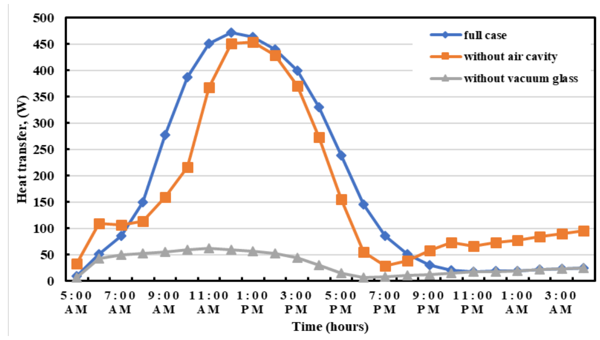


Fig. 5 The comparison of the heat transfer rate from the outside ventilated window of the different cases during the whole day.

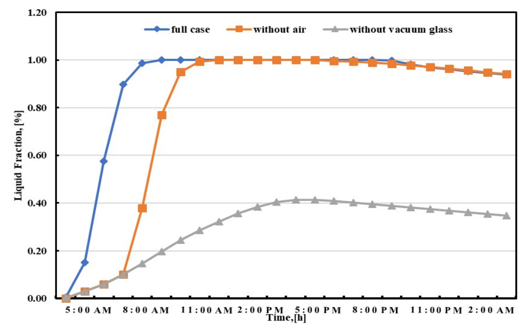


Fig. 6 The liquid fraction of the three different cases of ventilated window.

So, this concluded that the vacuum glass has a significant impact on the heat transferred from the outside ambient to the indoor space.

The amount of heat energy transferred to the indoor is calculated and presented in Fig. 4. The maximum heat Transferred through the window without vacuum glass reaches to 69 W, and 22 W through window without air cavity. While the window loaded with the full case has the best insulation efficiency among the three cases.

However, the better insulation efficiency leads to store heat energy in the air cavity and the PCM volume as shown in Fig.5. Figure 5 illustrates the variation of the heat energy transferred via the outer glass layer through the day and night-time. This heat energy is the net energy from the balance between the total incident energy from the outdoor on the external glass surface and the heat conducted through the window layers to the indoor space. So, it is recorded a higher value when the heat is less conducted to the indoor space equipped with a window with a full loaded options and window without air cavity, while it is the lowest in case of window without vacuum glass layer.

The energy storage in the PCM changes its phase from solid to liquid state as shown in Fig. 6. Figure 6 indicates the liquid fraction changes with time, the melting process is accelerated from sunrise at 5:00 AM until complete melting at 11:00 AM in the cases with fully loaded options and case without air cavity, while it takes longer time without complete melting in the case without vacuum glass. For the first two cases the required melting time was 4 and 7 hours, respectively. The stored latent heat energy will be used at later time to induce the passive ventilation through the air layer.

These results also proved by the time variation of the PCM temperature during the day-cycle as shown in Fig.7. Where the melting temperature was in the range from 34 °C to 36 °C, the sensible heat energy increases the PCM temperature from the 29 °C to the melting lower

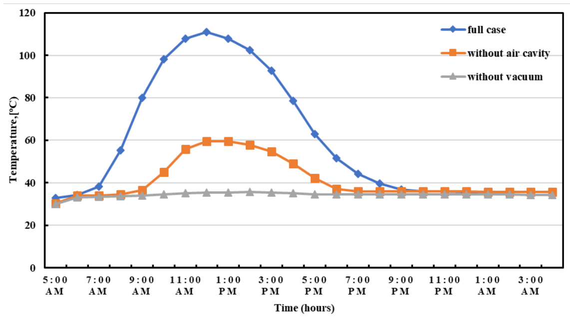


Fig.7 The comparison of the temperature of PCM during the whole day.

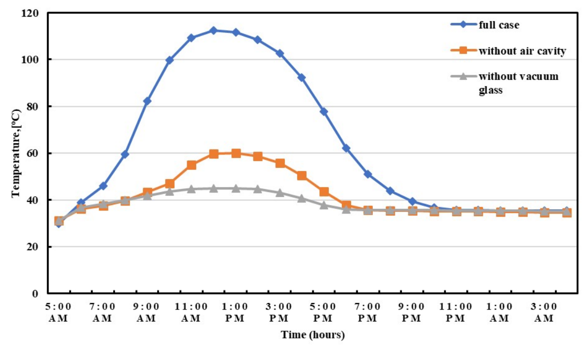


Fig. 8 The temperature surface of the solar cell in the different cases.

limits of 34 oC then the latent heat is changing the phase to liquid at the same temperature continued to the maximum PCM temperature of 110 °C and 60 °C for case with full loaded options and case without air cavity.

Finally, the time variation of the solar cell temperature for 24 hours is shown in Fig.8. The higher solar cell temperature, the lower efficiency and a lower electrical energy production. Despite of the efficient insulation capability of the first two cases, it has a negative impact on the efficiency of the solar cell as indicated in Fig. 8.

4. conclusion

In the present paper, the potential benefits of an innovative of new triple glazed window with PCM

The triple glazed window filled with PCM can avoid overheating phenomenon effectively, consider the thermal insulation of the vacuum glass.

The triple glazed window filled with PCM in full case can reduce the interior surface temperature and the air conditioning peak load, avoid the risk of overheating, significantly reduce the indoor temperature and the save the energy consumption of air conditioning.

PCMs represent an innovative solution that can provide an increase in the energy performance of buildings. A promising recent trend concerns the integration of PCMs into transparent envelope components.

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