Impact of Phase Change Material (PCM) glazing on the energy consumption and solar radiation transmission in an office room located in a semi-arid climate: Analysis of a real-scale experiment

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Abstract. Phase Change Materials (PCMs) are materials with high latent heat. When integrated into the glazing, they arise as an innovative strategy to improve thermal performance and provide thermal inertia in office buildings with a lack of opaque. Climates with high solar radiation and great temperature variation between day and night are especially interesting because PCM glazing can vastly improve these buildings’ energy performance. Then, this paper aims to analyze the energy performance of an office room with PCM glazing compared to a reference room with double-clear glazing, in a semi-arid climate. A real-scale experiment was carried out for a year in two office rooms located in Santiago, Chile. The analyses include energy consumption of the HVAC system to keep the interior temperature of the room in the comfort range and the solar radiation transmitted through the windows. Results are presented for three representative weeks of summer, mid-season and winter. An important reduction of the solar radiation transmitted was achieved in the PCM glazing in respect to the double-clear glazing when the phase change occurs, and a decrease of the energy consumption of cooling and heating mainly for sunny and variable days was found.

1. Introduction

The building sector is responsible for 40% of CO₂ emissions and consumes 36% of end-use energy [1]. Also, the current trend is to build office buildings with fully glazed façades in the whole world. This type of buildings presents a high energy consumption, especially by cooling demand due to the high solar heat gains and low thermal inertia. To solve this, Phase Change Materials (PCMs) integrated into the glazing arise as an innovative strategy to improve the thermal performance and provide thermal inertia in these buildings. PCMs are materials with high latent heat that store a large
amount of heat during the phase change (solid to liquid) during the daytime and are capable of releasing the stored heat during nighttime. PCMs can be integrated into the glazing façades, and the main advantage of PCM glazing is enabling selective optical transmittance of solar radiation, so radiation of the visible range is mainly transmitted, and infrared radiation is absorbed and converted to heat, causing the phase change [2]. PCM glazing also improves thermal comfort and produces a time delay between outdoor and indoor conditions [3]. The review of Fokaides, Kylili and Kalogirou [4] shows that the main benefit of PCM glazing will be in warm-dominated climates reducing overheating. Santiago of Chile has a semi-arid climate (Bsk according to Köppen-Geiger climate classification), characterized by high temperature and solar radiation during more than half of the months of the year, and high fluctuation temperature between day and night; thereby, this type of climate is appropriate to get the maximum potential of PCM glazing.

Current studies show a good understanding of PCM glazing properties [5] and their behavior [6], and the potential to reduce cooling loads in buildings [7]. The studies mentioned above show an important advance in understanding the PCM glazing behavior and the potential to reduce cooling loads. Pomianowski, Heiselberg and Zhang [8] indicate that measurements in real operational conditions are essential to document the performance and potential of PCM, and the development of validated dynamic simulation tools capable of modeling PCM performance is required to quantify the energy savings. Regarding PCM glazing, the development of simulation tools and measurements in real operation conditions are still required, which was recently pointed out by [9].

This paper aims to analyze the impact of PCM glazing on energy performance and solar radiation transmission with respect to double-clear glazing. A real-scale experiment for one year was performed in two offices with an east-oriented façade and a window-to-wall ratio (WWR) of 56%. Test facilities are located in Santiago of Chile at Pontificia Universidad Católica of Chile. Three representative weeks of summer, winter, and autumn were analyzed.

2. Methodology
The real-scale experiment was carried out for a year in the two office rooms located in Santiago of Chile. Measurement campaign was carried out from February 17th, 2020 to February 28th, 2021. The analyses include the solar radiation transmitted to the room and the energy consumption of the HVAC system to keep the interior temperature of the room in 25°C between 09:00 to 18:00 hrs.

2.1. Facilities
Facilities are two office modules (6.52 m (l) x 3.13 m (w) x 2.68 m (h)) located in the School of Engineering of the Pontifical Catholic University of Chile, specifically in the San Agustín Building, 3rd floor. One of the modules will be the reference room with a double-clear glazed window filled with air (labeled AIR), and the other will be the main room with a double-clear glazed window filled with PCM RT25 of Rubitherm® company (labeled PCM). Both rooms have similar conditions and have a glazed façade oriented to the east. Rooms have a 56% or window-to-wall ratio.

Interior walls, ceiling, and floor of the office rooms can be considered adiabatic. Façade is composed of three parts: an opaque part is a concrete wall of 20 cm without insulation; the upper window, which consists of double-clear glazing filled with air for both offices to provide sufficient natural light inside; the main window filled with PCM or air. The main window is composed of two laminated glasses and the gap in the middle (5+4 mm glass + 11.5 mm air/PCM gap + 4+5 mm glass).

It is important to note that double-clear glazed window does not have a good thermal performance (U-value of 3.62 W/m²K) but is a common glazing strategy used in Chile because there is no energy code or requirements regarding the insulation of the envelope of office buildings.

To measure the outdoor conditions, a meteorological station Kipp & Zonen with a Sun Trucker SOLYS 2 and a Humidity and Temperature Probe HMP60 are available on the Campus.
2.2. Experimental set-up

Two current sensors and three pyranometers were used to measure the energy consumption of the HVAC and solar radiation, respectively. The current and voltage sensor is called Multivoies (Multi channel energy consumption Data Logging) and was bought to the OmégaWatt. The measuring range goes from 230 – 400V, and its accuracy is 2%. The pyranometers are secondary standard pyranometers CMP11 of Kipp & Zonen with an accuracy of 1.35%, according to the manufacturer. Each room has a Multivoies and a pyranometer, while the third pyranometer is located in the exterior. The objective is to measure the outdoor irradiance of the window and the transmitted irradiance through the window of each room.

Figure 1 shows a scheme of the window of each room and the location of the sensors. Figure 2 shows the window dimensions. Figure 3 shows fish-eye pictures of the experimental set-up of both offices, where it is possible to see PCM in solid-state and changing their state. Figure 4 shows the partial enthalpy of the paraffin RT25 according to the manufacturer’s specifications.

**Figure 1.** Scheme of the experimental set-up.

**Figure 2.** Window dimensions.

**Figure 3.** Pictures of experimental set-up of both offices and PCM in solid state and changing phase. February 20th, 2020 at local time (UTC-3).
3. Results

Results are presented considering three representative weeks of summer, winter, and autumn (mid-season). Figures 5 and 6 show the outdoor conditions and the results of global vertical irradiance (exterior and transmitted) and energy consumption of HVAC for the summer season, respectively. Figures 7 and 8, and figures 9 and 10, show the same results for autumn and winter week, respectively. Results are presented in local time, UTC-3 for summer week and UTC-4 for autumn and winter week.

Summer week is characterized by sunny days with high solar radiation, around 1150 W/m$^2$ at noon, and great variation of outdoor temperature between day and night. Results of transmitted radiation of summer week show that phase change occurs before 10 AM, and after that, radiation transmitted through both windows is practically the same. The phase change process during summer is very fast because the window is east oriented, and the irradiance on the window during the morning achieves around 800 W/m$^2$. During the first hours of the day, the cooling loads are significantly reduced due to phase change of the PCM, because most of the solar radiation is blocked and the interior temperature of the window surface of the PCM glazing is close to the 25ºC, then, the long-wave radiation emitted from the PCM glazing is less than the emitted by the window of the AIR Room. The cooling energy consumption of HVAC is reduced when the PCM is used in the gap of the double-glazed window. Mean energy saving is 22%.

![Figure 4. Partial enthalpy of paraffin RT25.](image)

![Figure 5. Outdoor climate conditions of representative summer week. (a) Global horizontal irradiance; (b) outdoor dry-bulb temperature.](image)
Figure 6. Results of the representative summer week. (a) Global vertical irradiance of exterior and indoor (AIR & PCM); (b) energy consumption of HVAC (cooling).

Autumn week is characterized by three sunny days with maximum solar radiation of 670 W/m² at noon, two cloudy days, and two variable days. The variation of outdoor temperature between day and night is relevant only during sunny and variable days. Results of transmitted radiation of autumn week show that phase change is one hour delayed during sunny days in respect of the summer days. This is because the phase change is highly dependent on the irradiance on the window instead of the outdoor temperature.

Figure 7. Outdoor climate conditions of the representative autumn week. (a) Global horizontal irradiance; (b) outdoor dry-bulb temperature.
April and May have days with cooling demand but during the autumn selected week (May 16th to May 22nd), only heating demand was necessary because the low temperature during the night causes high heat losses from the envelope due to the lack of thermal insulation. Even when the maximum outdoor temperature during the day is over 25°C, there is no possibility to achieve 25°C inside the room without HVAC.

Figure 8. Results of the representative autumn week. (a) Global vertical irradiance of exterior and indoor (AIR & PCM); (b) energy consumption of HVAC (heating).

Figure 9. Outdoor climate conditions of representative winter week. (a) Global horizontal irradiance; (b) outdoor dry-bulb temperature.
During sunny and variable days, the heating energy consumption is reduced because, after noon, the solidification of the PCM immediately starts; then, the absorbed energy during the morning is released to the indoor environment, decreasing heating demand. During cloudy days, it is possible to show the heating energy savings despite the fact that the PCM is in solid state all day. This is possible because the partial enthalpy of the paraffin RT25, shown in figure 4, is centered at 25°C, but the phase change occurs in a wide range from 20°C to 27°C, so the PCM part located close to the indoor environment presents some phase change. It is important to note that the phase change occurs during sunny and variable days even whether the outdoor temperature is less than 25°C. The heating energy consumption of HVAC is reduced when the PCM is used in the gap of the double-glazed window. The mean energy saving is 45%.

Winter week is characterized by two sunny days with maximum solar radiation of 670 W/m² at noon approximately, one cloudy day, and four variable days. The variation of outdoor temperature between day and night is relevant only during sunny and variable days, as during the autumn week. During the winter week, there is only heating energy consumption.

During sunny and variable days, the phase change occurs partially, so thermal inertia is increased during all the work hours, and it results in heating energy savings. The heating energy consumption of HVAC is reduced when the PCM is used in the gap of the double-glazed window. Mean energy saving is 29%.

During cloudy days, PCM melting does not occur entirely or does not occur at all. It impedes the vision to the exterior, and there is no difference in the thermal behavior of both windows. It could be possible to add some external heat source to the window to produce the phase change, such as a heating foil. In this way, it would be possible to get the maximum potential from the PCM.

![Figure 10](image1.png)

**Figure 10.** Results of representative winter week. (a) Global vertical irradiance of exterior and indoor (AIR & PCM); (b) energy consumption of HVAC (heating).

Paraffin RT25 shows an important potential to reduce the energy consumption in offices because it presents a good energy performance during sunny and variable days all year.

4. Conclusions
A real-scale experiment was carried out to analyze the impact of PCM glazing on energy performance and solar radiation transmission with respect to double-clear glazing. Two offices with an east-
An oriented façade located in Santiago of Chile (semi-arid climate, Bsk according to Köppen-Geiger climate classification) were used as test facilities. Three representative weeks of summer, winter, and autumn (mid-season) were analyzed.

PCM adds thermal inertia to the PCM glazing and improves the energy performance of the PCM glazing in respect to the double-clear glazing on all analyzed days, especially during sunny and variable days because the phase change process wholly or partially occurs. There is an important reduction of the transmitted solar radiation during the phase change and a decrease of energy consumption of heating and cooling between 22% and 45%.

The presented results are valid only for the offices evaluated and their location. Further works are necessary to assess the impact of PCM glazing with respect to other advanced glazing technologies, such as windows filled with inert gases, Low-E windows, tinted glazing, thermochromic and electrochromic windows.

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