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Experimental analysis of the energy performance of a full-scale PCM glazing prototype

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Abstract

This paper deals with the development and use of innovative glazing systems that utilize Phase Change Material (PCM) to achieve dynamic and responsive behaviour. The coupling of a PCM and glass panes could be a way of improving the low thermal inertia of fenestrations and could be an effective way of collecting, storing and exploiting solar energy at a building scale.

In the present work, a simple prototype of a PCM glazing system has been proposed and its energy performance has been analysed and compared with a conventional fenestration. The two glazing technologies were installed on an south facing outdoor test cell, in a temperate sub-continental climate. The surface temperatures, transmitted irradiances and heat fluxes of both the PCM glazing and the reference fenestration were measured during an extensive experimental campaign. Summer, Mid-season and Winter days were considered during the analysis, in both sunny and cloudy weather conditions, in order to assess the energy performance of the PCM glazing under different boundary conditions.

The experimental results have highlighted a good ability of the PCM glazing to store solar energy and to smooth and delay peak values of the total heat flux. In summer the PCM prototype allows the energy gain to be lowered by more than 50%, compared to the traditional fenestration. In winter, a suitable reduction in the heat loss during the day can be observed, but the direct solar gain is also drastically reduced and the application of this technology for passive solar heating purpose might not always be effective. The obtained results have pointed out the promising performance of PCM glazing, even though a careful integration of the PCM glazing component with the control strategies of the indoor air temperature (e.g. night cooling) is necessary.

Keywords: PCM; Advanced glazing; Latent heat thermal energy storage; Passive solar heating; Fenestration; Energy performance

1. Introduction

The reduction in the energy demand and an improvement of the exploitation of Renewable Energy Sources at a building scale are key factors in the design and conception of next generation buildings (Directive 2010/31/EU, 2010). A major role in this optimization process could be played by the building envelope, if it is looked at from a new perspective. The building envelope should no longer be considered as a “shelter”, but should be regarded as the simplest and most straightforward “solar energy converter device” that can be integrated in a building. Such a vision requires going beyond the usual design approach that enhances the thermal insulation and the barrier functions of the building envelope, and calls for new, dynamic and responsive technologies that are able to appropriately manage the energy flows (IEA – ECBCS Annex 44, 2007, 2010).

Glazing systems show promising opportunities of development. On one hand, they are one of the weakest elements for the conservation of energy in buildings, because of their

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Nomenclature

E	specific energy (W h/m^2)
Δh	latent heat of fusion (J/g)
H	specific incident daily solar radiation (W h/m^2)
I	specific incident solar irradiance (W/m^2)
$\dot{q}$	specific heat flux (W/m^2)
t	time (h)

Greek symbols

ϑ	temperature (°C)
Σ	percentage difference (%)

Superscripts

$+$	referred to the heat flux/energy gain
$-$	referred to the heat flux/energy loss
CG	referred to the conventional double glazing unit (DGU_CG)
PCM	referred to the double glazing unit with PCM (DGU_PCM)

Subscripts

24 h	referred to the daily energy
air	referred to the air
av	average value
day	referred to the diurnal energy
in	referred to the indoor environment
max	maximum value
min	minimum value
$night$	referred to the nocturnal energy
out	referred to the outdoor environment
$surf$	referred to the specific surface heat flux
t	referred to the transmitted component

poor thermal resistance, low thermal inertia and high transmission of solar radiation. On the other hand, they are one of the elements of the building envelope whose use has exponentially increased over the last decade. Moreover, a glazing system can potentially provide a high degree of dynamicity because of its particular interaction with solar energy.

Considerable improvements have in fact been achieved so far in relation to glazing technologies. For example, thermal insulation performance has been enhanced by reducing the radiative heat transfer between the panes, due to the use of low-emittance coatings (Alvarez et al., 2005; Hammarberg and Roos, 2003; Karlsson and Roos, 2001; Leftheriotis and Yianoulis, 1999), by reducing the convective heat transfer, thanks to vacuum cavities (Eames, 2008; Fang and Eames, 2006; Manz, 2008; Manz et al., 2006; Ng et al., 2007) and by reducing the conductive heat transfer, through the introduction of Transparent Insulation Materials (Kaushika and Sumathy, 2003; Reim et al., 2002; Schultz and Jensen, 2008; Schultz et al., 2005). As far as the dynamic optical properties of the glazing are concerned, great interest has been shown in the improvement and widespread use of the so called “smart windows” (Baetens et al., 2010).

However, further developments are needed as far as thermal inertia is concerned, since its value in existing fenestration systems is still too low. This characteristic is considered a significant shortcoming, because thermal inertia can significantly assist in the exploitation of solar energy through the building envelope.

Finally, there is still a need to improve the capacity to dynamically change the thermo-physical behaviour of glazing, in order to adapt their properties according to different boundary conditions and to tackle the contrasting requirements that can arise in different periods of the day or seasons – e.g. to filter/store solar energy during the day, when it could exceed the heating demand, and to release it during the night.

In order to overcome these limitations, the insertion of Phase Change Materials (PCM) into glazing components has been proposed as a possible solution. The use of PCMs in building are a very up-to-date topic and various research activities are currently on-going. Since the beginning of solar energy research in the building sector in the Forties (Hottel, 1989) different applications adopting PCM have been investigated, and a growing interest in this field can be seen nowadays, with several possible configurations. Examples of applications include: integration into conventional building elements such as exterior walls, partitions walls, floors and ceilings (Carbonari et al., 2006; Koschenz and Lehmann, 2004; Oliver, 2012; Principi and Fioretti, 2012; Silva et al., 2012; Zhang et al., 2011), advanced building façade modules (Diarce et al., 2013; de Gracia et al., 2013, Favoino et al., 2014), PCM-based storage systems (Esen and Ayhan, 1996; Esen et al., 1998; Esen, 2000; Mossaffa et al., 2012; Saman et al., 2005; Tay et al., 2012), PCM-integrating heating/cooling systems (Ansuini et al., 2011; Godarzi et al., 2013; Lin et al., 2005). Among other applications, innovative glazing concepts that adopt PCM have been proposed and studied since the early Nineties too (Ismail and Henríquez, 1998, 2001, 2002; Ismail et al., 2008; Manz et al., 1997; Weinläder et al., 2005); some commercial products based on this last concept are even available on the market (GLASSX, CasaClima, 2013).

1.1. State of the art of PCM glazing systems

PCMs show properties that could potentially improve both thermal inertia and the overall performances of glazed