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Thermal performance investigation of heat insulation solar glass: A comparative experimental study

Erdem Cuce[a,*], Chin-Huai Young[a,b], Saffa B. Riffat[a]

[a] Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, University Park, NG7 2RD Nottingham, UK
[b] Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan

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ABSTRACT

Heat insulation solar glass (HISG) is a multi-functional glazing technology, which has been developed at the University of Nottingham with an ultimate goal of mitigating energy consumed in buildings. HISG is capable of producing electricity when exposed to sunlight. It also differs from a conventional transparent photovoltaic (PV) module by providing some characteristic features such as thermal insulation, sound insulation, self-cleaning and energy saving as well as power generation. In this respect, HISG is very promising for both energy-efficient retrofitting of existing buildings and new-build applications. Therefore in this paper, an experimental attempt is made to investigate thermal performance characteristics of HISG. A test rig is constructed consisting of four different glazing configurations with the same thickness (air filled double glazed window, air filled double glazed window with low-e, argon filled double glazed window with low-e and HISG) and overall heat transfer coefficient (*U*-value) of each sample is determined in an environmental chamber through a standardized co-heating test methodology. The results indicate that HISG is not only a power producer but also a good insulator. *U*-value of HISG is found to be 1.10 W/m^2 K. Maximum temperature difference between internal and external glazing is also achieved by HISG with 12.70 °C.

1. Introduction

Limited reserves of energy resources and growing significance of environmental issues prompt countries to recheck their energy policies for clean and sustainable energy generation [1]. However, fossil fuel based energy resources still have the greatest percentage in global energy consumption, resulting in heavy environmental impacts such as ozone layer depletion, global warming and climate change [2] due to the increasing concentrations of greenhouse gases in the atmosphere [3]. Intensive efforts are made worldwide to narrow the gap between fossil fuels and renewables [4]. Currently, renewables supply about 14% of world energy demand and their future potential is promising [5]. However, there is a consensus among scientists that additional decisive measures are compulsory for mitigation of energy consumption levels and urgent stabilization of greenhouse gas emissions. In this respect, numerous researches are carried out in the world for an accurate evaluation of global energy consumption by sector, and for key solutions to reduce global energy demand. Recent reports reveal that buildings play a crucial role in the world's total energy consumption, and thus in the greenhouse gas emissions [6]. CO_2 emissions from buildings account for more than 30% of the greenhouse gas emissions in many developed countries [7]. Currently, transport sector has the greatest percentage in total primary energy consumption of the world. However, further scenarios of International Energy Agency (IEA) indicate that the domestic sector will lead the total consumption by 2035 [8]. Therefore, there is a great necessity to develop innovative solutions for building elements to minimize heat transfer through the building fabric to its surrounding.

Windows are essential components of buildings which provide passive solar gain, air ventilation and also provide the ability to view the outside [9]. However, they have, in general, poor thermal performance characteristics among the building components, and hence they play an important role in the heating and cooling demand of buildings in winter and summer, respectively [10]. Their influence on energy loss from building envelope becomes much more drastic when the window area is large like patio doors [11]. Current conventional residential windows are responsible for around 47% of the heat loss from building fabric. Due to the significance of windows in reducing the heat requirement and energy consumption of buildings, considerable attention is given to improving their performance. Novel window technologies hold the promise of drastically reducing or eliminating heat gained and lost attributed to windows and in addition increasing the overall

* Corresponding author. Tel.: +44 0115 951 4882.
E-mail address: laxec5@nottingham.ac.uk (E. Cuce).

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energy efficiency of homes [12]. In modern architecture, highly glazed buildings become a worldwide design trend for whatever climate [13]. This gives more concern to the global environmental issue of energy wastage. To be able to cope with the sustainability and conservation needs, window glazing is given revised identities and a wide range of design options [14,15]. The current advanced fenestration systems may have changeable physical configurations as well as optical and thermal properties in response to the weather conditions, occupant preferences and building system requirements [16]. However, they are expected to aim at increasing thermal resistance across the glazing in order to achieve a *U*-value as low as possible to fulfil the requirements for low/zero carbon buildings. For the UK case, windows are required to be in the region of or lower than 1.20–1.40 W/m^2 K in order to meet the latest fabric energy efficiency standard [17]. Unfortunately, conventional window technologies are not able to meet such high thermal standards and this situation results in high energy consumption and consequently increases the CO_2 emissions to the atmosphere. The aforesaid requirements can be achieved via novel window technologies as well-documented in literature. However in most cases, they are unable to provide the definite solution due to some cost, thermal comfort and aesthetic issues. For instance, multilayer glazing gives excellent results in terms of overall thermal performance especially when integrated with suspended films and low-e coatings, but it causes extra thicker and heavier constructions which are totally undesired for occupants in terms of design and aesthetics. Some attempts such as water circulation inside double glazed windows for both thermal regulation and domestic hot water production are promising but cause undesired leakage problems by time [18]. Similarly, aerogel glazing, PCM glazing, TIM glazing are very efficient for thermal regulation of building envelope, but they substantially deteriorate the vision, and hence the thermal comfort of the occupants. Vacuum glazing and smart windows are also good thermal insulators, however commercialization is still challenging for them due to their high cost. Overall, each novel glazing technology is based on a characteristic phenomenon, and there is not a comprehensive attempt to date in literature in order to get benefit from the features of different novel window technologies in a single window like Professor Young's miracle glass (heat insulation solar glass) [19].

HISG is basically a successful application of transparent PV glazing since it provides a very promising *U*-value range whereas the average *U*-values of PV glazing are somewhat high [20]. Besides its ability of power generation, it is a good sound insulator. Also, it has a self-cleaning feature through its special coating on the external glazing [21,22]. In addition to these, HISG has a remarkable potential to reduce energy consumption in buildings as a consequence of its superior thermal insulation property, which constitutes the objective of this paper. Through a standardized environmental chamber and co-heating test methodology, thermal performance characteristics of HISG are obtained and compared with three different conventional glazing technologies shown in Fig. 1, namely, air filled double glazed window, air filled double glazed window with low-e and argon filled double glazed window with low-e. Internal and external glazing temperatures, heat fluxes and *U*-values of the samples are measured and calculated via PVC frame test rig which is illustrated in Fig. 2. In addition to its well-known power generation characteristics, this paper presents the thermal behaviour of HISG under simulated conditions.

2. Description of heat insulation solar glass (HISG)

HISG is a multi-functional glazing technology, which provides power generation, thermal insulation, energy saving, self-cleaning, acoustic and aesthetic features within a single window in a cost-effective way. HISG is basically a transparent amorphous silicon (a-Si) PV module equipped with various coatings and structures. In this section, a brief description of fabrication process and functional theory of HISG is given.

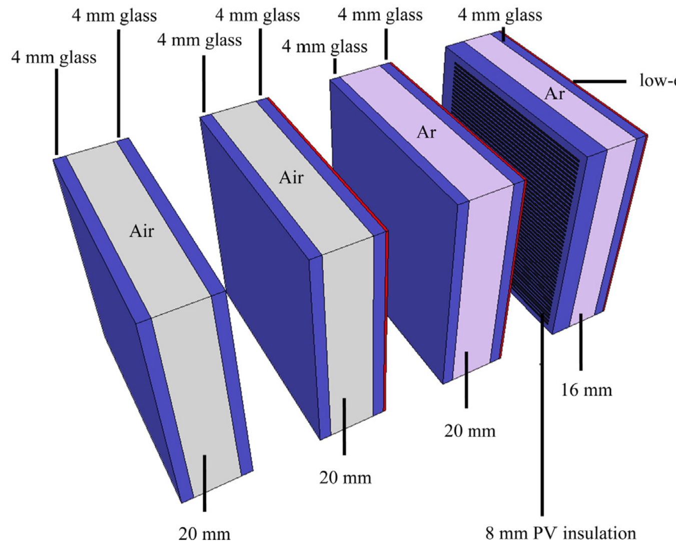

Fig. 1. 3D schematics of the test samples.

2.1. Structural detail of HISG

HISG consists of multiple layers with different structural and thermophysical properties. The core of the unit is transparent a-Si PV module, which is integrated with a nano coating for low reflection and high transmittance as shown in Fig. 3. At the back of the PV module, there is a layer of high reflectivity insulation film located between two layers of spacers. A sheet of rear glass is placed behind the second spacer layer, which forms an air gap on both sides of the insulation film. Driers are utilized between the layers of spacers to provide dry conditions. All materials are fixed and sealed separately via hot-melt adhesive and silicone, respectively. as the final stage,

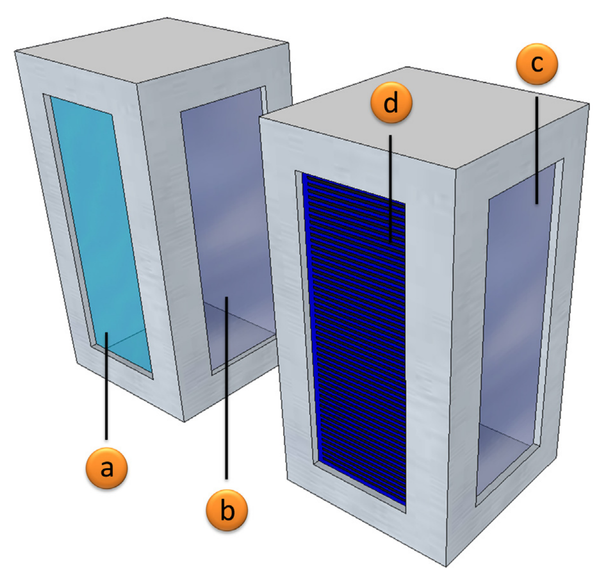

Fig. 2. 3D view of the test rig consisting of four different glazing technologies installed at each face of PVC frame window sample: (a) standard double glazed window (4 mm glass + 20 mm air + 4 mm glass), (b) standard double glazed window with low-e (4 mm glass + 20 mm air + 4 mm low-e glass), (c) Ar filled double glazed window with low-e (4 mm glass + 20 mm Ar + 4 mm low-e glass) and (d) PV insulation glass (8 mm PV glass + 16 mm Ar + 4 mm low-e glass).