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Toward multi-functional PV glazing technologies in low/zero carbon buildings: Heat insulation solar glass – Latest developments and future prospects

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ABSTRACT

Heat insulation solar glass (HISG) is a recently developed multi-functional photovoltaic (PV) glazing technology to mitigate energy consumption of buildings and to provide optimum thermal comfort conditions to occupants. In essence, HISG represents an improved transparent amorphous silicon (a-Si) PV module prepared with several optimized coatings and structures. HISG differs from conventional PV glazing products by having some characteristic features such as thermal insulation, sound absorption, self-cleaning and notable energy saving. In addition, HISG has a 100% UV blocking rate and remarkably low shading coefficient, which provides desired lighting related thermal comfort conditions for indoor environments. HISG is also competitive with conventional double glazed products in market in terms of fabrication cost. In this respect, it is highly expected that HISG has a strong potential to dominate the fenestration market in the near future. In this research, a comprehensive review of HISG technology is presented. Power generation, thermal insulation, energy saving, self-cleaning, acoustic and aesthetic features of HISG are evaluated in detail through the state-of-the-art literature survey. Existing research projects on the scope and future prospects are also addressed within the scope of this study.

Contents

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1. Introduction

Energy efficiency is the world's most important fuel according to the latest report of International Energy Agency (IEA) [1] due to limited reserves of energy resources [2], notably soaring energy prices [3] and growing significance of environmental issues such as global warming, ozone layer depletion and climate change [4]. Future predictions regarding environmental health are also not promising as reported by Bolaji and Huan [4]. In this respect, intensive efforts are made on both energy saving [5–7] and clean energy generation [8–13]. There is a promising stimulation into renewable energy technologies [14–18] to reduce total energy consumption of the world and thus to halt greenhouse gas emissions. However, recent works reveal that renewables can supply only about 14% of total world energy demand [19,20]. Cost can be considered one of the most dominant parameters which decelerates the renewables to become widespread as reported by Hasan and Sumathy [20]. Additional definite measures are therefore needed for urgent minimization of total world energy consumption and immediate stabilization of greenhouse gas emissions. International Energy Agency conducts several comprehensive works on accurate and reliable assessment of sectoral energy consumption in the world to determine the target sectors for energy saving [21]. Latest works indicate that building sector plays a significant role in total energy consumption, thus in greenhouse gas emissions. About 40% of global energy use in 2014 is attributed to buildings as highlighted by Baetens et al. [22]. It is also stated by Baetens et al. [23] that building-related carbon emissions are more than 30% of total emissions in most developed countries. This output can be explained by poor thermal insulation performance parameters of conventional building elements notably windows. Windows play a key role in total energy loss from building envelope especially in extreme climatic conditions. Existing traditional window technologies tend to have notably greater overall heat transfer coefficients (*U*-value), therefore they differ from other building elements such as external walls and roof in terms of their role in heating and cooling demand of buildings as emphasized by Grynning et al. [24].

Windows are essential components of building envelope as enabling air ventilation, passive solar gain as well as providing the capability of viewing outside [25]. However, their role in total energy consumed in buildings is unequivocal. Their dramatic role on total energy loss from building envelope becomes much more drastic when window area is large like glass curtain walls [26]. According to the comprehensive review of Jelle et al. on fenestration systems [27], current glazing systems are responsible for about 60% of the energy loss from building envelope. This result is a consequence of insufficient thermal insulation performance of conventional glazing products. Air or Argon filled double glazed windows dominate the current fenestration market owing to their well-documented fabrication process and remarkably better thermal insulation ability in comparison with conventional single glazing. However, current *U*-value range of air or Argon filled double glazed windows is still not at desired level as shown in Table 1 [28]. This is also proved by Pilkington [29] through their latest research on the *U*-values of different glazing products. In this respect, there is a consensus among researchers that additional measures such as developing unique highly thermally resistive and cost-effective glazing technologies are urgently needed to meet the requirements of latest building fabric standards [30]. For instance, windows in UK buildings are required to be in the range of or lower than 1.20–1.40 W/m^2 K according to the fabric energy efficiency standard released by the UK Government [31]. Unfortunately, existing traditional windows are not capable of meeting such high standards.

Considerable attention is given to novel glazing technologies to enhancing existing thermal insulation feature of windows, thus to reduce window related energy loss in buildings. However in most cases, an absolute solution might not be achieved due to some cost, thermal comfort, performance and aesthetic issues. For instance, highly thermally resistive windows can be obtained by multilayer glazing especially when equipped with low-e coatings and suspended films, but this results in remarkably thicker and heavier structures, which are completely undesired by occupants. Vacuum glazing is able to provide attractive thermal insulation performance with slim designs [32], however commercialization is still a challenge for vacuum glazing because of significantly higher fabrication cost compared to conventional glazing products. Aerogel glazing [33–35], PCM glazing [36] and TIM glazing [37] are effective for thermal regulation of building envelope, but they notably deteriorate the visual quality, therefore the thermal comfort of the occupants. Smart vacuum tube windows are also promising in terms of thermal insulation performance, however desired *U*-values require larger tube diameters which cause greater entire thicknesses as reported by Cuce et al. [38]. Adaptive glazing technologies are reasonable, but the overall cost is still not at desired level [39].

1.1. PV glazing

PV glazing is highly preferred in modern architecture due to aesthetic features as well as being able to generate electricity. However, thermal insulation performance of conventional PV glazing products is even worse than ordinary single glazing as also reported by Peng et al. [40] in their recent comprehensive

Table 1
U-values of commercial glazing products.

U-value (W/m^2 K)	Pilkington [29]	Ref. [28]
Air filled double glazed window	2.70	2.53
Air filled double glazed window with low-e	2.00	2.10
Argon filled double glazed window with low-e	1.80	1.90