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ENERGY EFFICIENCY RESEARCH OF HEAT INSULATION SOLAR GLASS ON BUILDINGS

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ABSTRACT

A great deal of interest in photovoltaics (PV) integration into buildings has been developed by heat insulation solar glass (HISG) due to their advantages in terms of energy saving in cold and hot seasons, enhance power generation and self-cleaning, protection from external noise and wind loads. This study aimed to compare energy consumption of heating and cooling in three houses of normal glass (Ordinary house), Low-E glass (Low-E house) and HISG house. Results show that the energy-saving efficiency of the HISG house achieved respective 70.68 and 56.09% for cooling; about 23.53 and 10.34% for heating as compared to those of the Ordinary house and the Low-E house. The energy consumption for heating and cooling of the HISG house significantly reduced with energy efficiency ~19.59–37.07% at outdoor temperature above 30°C compared to that of the Ordinary house. The results also offer a low-cost route to the application of HISG modules on buildings with high energy-saving efficiency, it is able to use for monitoring progression of the greenhouse gas reduction, as well as evaluating their energy efficiency on buildings.

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1 INTRODUCTION

Energy saving has emerged as an important and urgent issue due to soaring energy price and gradual depletion of fossil fuels resources. Therefore, energy saving in buildings has been interested and attracted by many scientists in recent years. Most of the renewable energy resources currently are available, in which solar energy is one of the most abundant, inexhaustible and clean sources (Peng *et al.*, 2011; Tiwari *et al.*, 2011). Thus, a solar cell or photovoltaic (PV) cell is a device that converts solar energy into electricity by the photovoltaic effect, without concern for energy supply or environmental impact. The use of solar energy significantly reduced amount of CO_2 gas emission into the natural environment (e.g., greatly reduced greenhouse gas on buildings), which has been interested too much by scientists in the last decades (European Communities, 2007; Roedern *et al.*, 2008; Strong, 2011; Scognamiglio *et al.*, 2013). Although, commercial PV modules are available and being widely developed, it is essential needed that more research is carried out to improve their cost efficiency. Therefore, building integrated photovoltaics (BIPV) systems potentially have greatly interested due to its lower overall costs compared to PV systems requiring dedicated mounting systems. The cost of BIPV is reduced and their lifecycle cost is improved due to the fact that cost of conventional materials is avoided.

The modern buildings are tall and more energy-consuming, and efforts are made in various areas to reduce energy use of the buildings, which account for 20.4% of the overall energy consumption in Taiwan in 2012 (http://en.wikipedia.org/wiki/Electricity_sector_in_Taiwan, 2012). This leads to an increase in power energy need. Buildings constitute a substantial part of the world's total energy consumption, thus savings within the building sector will be essential for new and existing buildings. The thermal building insulation materials and solutions constitute one of the key fields. Recent studies pointed out that energy efficiency measures were the most cost-effective ones, whereas measures like solar photovoltaics and wind energy are far less cost-effective than insulation retrofit for buildings (McKinsey, 2009).

BIPV is a method to derive energy from the building envelope, which is able to replace conventional building materials in parts of the envelopes or roofs in construction, as a functional part of the building structure or architecturally integrated into the building's design with a primary goal of sustainability by reducing pollution and improving the living standard through on-site energy generation. Moreover, BIPVs can act as shading devices and a semi-transparent material of fenestration. Whereas, other semi-transparent modules can be used in facades or ceilings by using those glass modules to generate various visual effects (Petter Jelle *et al.*, 2012). In addition, the combination between original solar module and other glass types can be used for many goals (e.g., re-protection, low-e insulation, sun protection or bullet-proof) in the buildings (Benemann *et al.,* 2001). In the other hand, these solar glasses were required to provide a large amount of the power energy and to significant decrease emission of CO_2 gas in the environment life. Since, how to design and construct buildings to zero energy, which was not a small challenge for the design of buildings (Gratia *et al.*, 2007; Kylili *et al.,* 2014). Thus, related studies have focused on combination methods, system improvements and developments of photovoltaic cell materials recently. A more clearly comprehensive approach, as well as feasibility study, is needed to explore with wider areas on how to use existing PV cells to reduce annual energy consumed by tall buildings, as well as to save energy for feasibility studies in the green building (Yoo *et al.*, 2002). In addition, the effect factors of the irradiance and PV module temperature should be considered (e.g. their effects to both the electrical efficiency of the BIPV system and the energy performance of buildings where BIPV systems are installed (Tiwari *et al.*, 2011). Moreover, to install BIPV modules on buildings suggested the consideration to other problems such as to avoid energy loss, as well as saving or reducing waste of energy consumption (Pasquay *et al.,* 2004; Yang *et al.,* 2004; Gratia *et al.*, 2007; Jelle *et al.*, 2012).

To overcome the challenges about the reducing of energy consumption and the increasing of power generation from BIPV system used, the HISG module has been developed successfully by Young *et al.* (2014), which possessed multiple functions including power generation enhancement, great heat insulation, high energy-saving efficiency, good self- cleaning capability and significant greenhouse gas reduction on buildings. Herein, heat insulation solar glass (HISG) module was installed on the experimental house in Taiwan to analyse and investigate its energy efficiency in buildings.

2 METHODOLOGIES

2.1 Materials and structure of HISG

The structure of PV module (Tandem type) and HISG module were shown in details in Figure 1. In this work, HISG module was applied on the experimental house for energy efficiency analysis, which was fabricated and described more details in Young *et al.* (2014). And detail parameters about houses' size and materials' characteristics are shown in Tables 1 and 2.

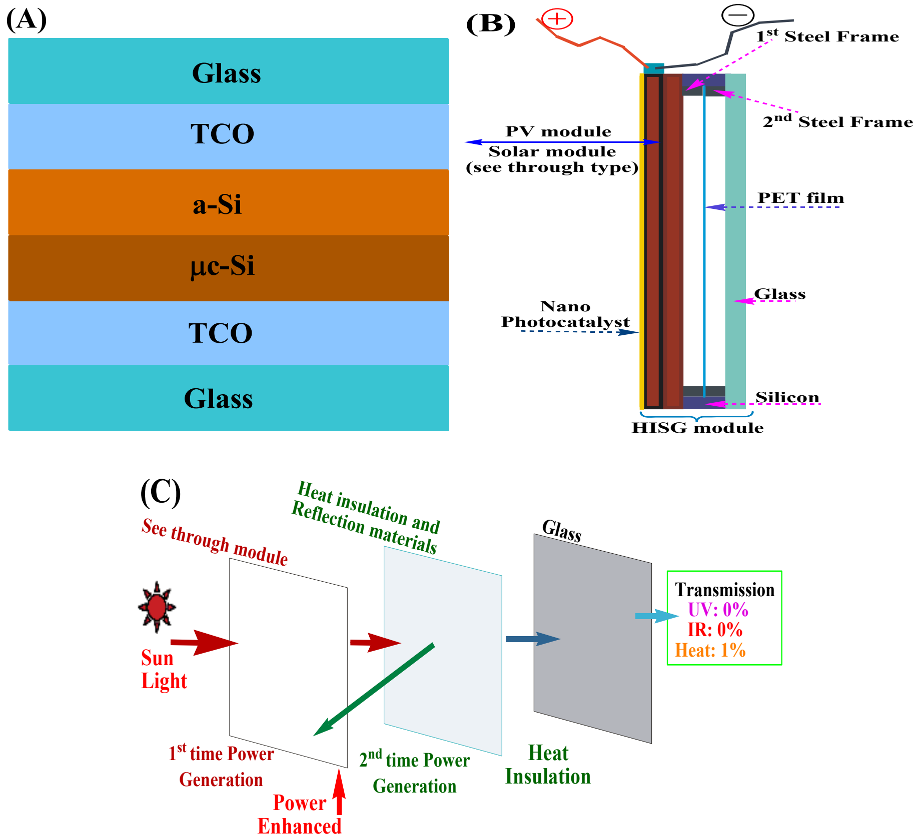


Fig. 1: Structures of (A) original PV module and (B) HISG module (thickness ~28 mm), and (C) Scheme about function theory of HISG

Table 1: Detail parameters of houses

Items	Normal glass	Low-E glass	HISG
Thickness (mm)	10	24	28
Houses' size (m)		Length: 2.59; Width: 2.33; The North (height): 3.17; The South (height): 2.05	
Window area		Vertical: 2 m^2; roof surface: 2 m^2	
Dimension (mm)/panel		1400×1100	
Price of HISG		~700 USD/panel	
Life of HISG		~40 years; after this HISG can be re-used	

Table 2: Detail parameters of materials

Items	Thermal conductivity (W/m.K)	Solar thermal transmittance (%)	Light penetration (%)	Density (kg/m^3)	Specific heat (J/kg.K)	Absorption rate (%)
HISG	0.032	2.6	7.15	1294	765	79.4
Normal glass	1.05	60	87	2300	836	5.75
Low-E glass	0.15		62	1575	787	34
Cement calcium silicate board	0.115		0	950	538	80
XPS board (Expanded styrofoam)	0.037		0	44	1000	5
Concrete	1.13		0	2300	1000	90

Heater and air conditioner devices were used for testing of saving energy consumption (i.e, SAMPO HX-YB12P: 1250W, and TECO LT63FP1-41003), and other materials such as heat insulation film, air, alcohol, aceton, nano photocatalyst were purchased from Acros. All solutions were prepared using de-ionized water from a MilliQ system.

2.2 The experimental houses

Herein, we used two units of normal glass, Low-E glass and HISG, installed on both the south-facing roof and vertical windows of the Ordinary house, the Low-E glass house (Ordinary solar house) and the HISG house, respectively. The three houses faced south to achieve optimal solar radiation. The walls were constructed by heat insulating planks or panels that could effectively block or isolate heat entering into the house through walls. The walls were constructed by a combination of multilayer materials that exhibited exceptional insulating properties. Figure 2 shows the structure and thermal conductivities of these materials. A thermometer, air conditioner, electric heater, and electricity (Watt-hour) meter were installed in the houses to analyze energy-saving. To measure heat insulation functions, the optical and thermal experiments of JIS3106 JIS3107 and JIS A5759 were adopted as test standards (Japanese Industrial Standards, 1998a; Japanese Industrial Standards, 1998b; Japanese Industrial Standards, 1998c).

On the roof and all fadades of the experimental houses were respectively installed by glazing types of normal glass, Low-E glass and HISG (see details in Figure 3).

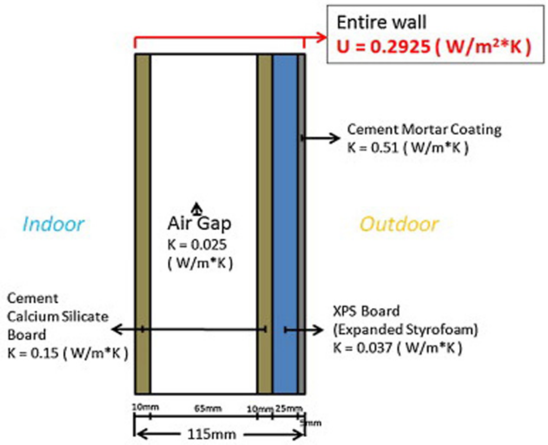


Fig. 2: Thickness and thermal conductivity of all elements of the external envelope of the experimental houses

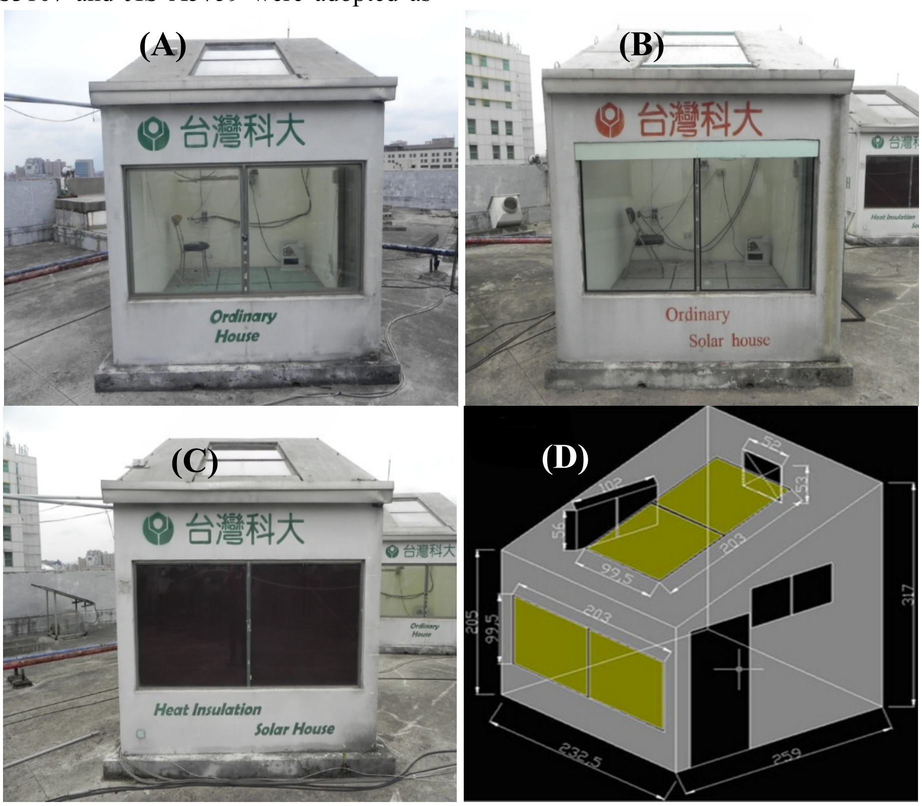


Fig. 3: Outside appearance of experimental houses: (A) Ordinary House, (B) Ordinary Solar House (Low-E house) and (C) HISG House were installed by normal glass, Low-E glass, and HISG; and (D) 3D perspective, respectively

3 RESULTS AND DISCUSSION

3.1 Energy consumption analysis for cooling and heating in the experimental houses in various seasons of summer, winter and spring

Electricity meters (Watt-hour), air conditioners and heaters were installed in three houses to determine the effects of various glazing types in the energy consumption for cooling and heating in the experimental houses during summer, winter and spring, respectively, as shown in Tables (3-5) and Figure 4. Moreover, thermal images of various glazing types on the experimental houses during different seasons of winter, spring and summer are also shown in Table 6.

Table 3: Energy consumption for cooling and heating inside of the Ordinary house, Low-E house, and HISG house per day in summer

Climate (day)	Indoor Temperature (°C)	Ordinary House (kWh)	Low-E house (kWh)	HISG House (kWh)	Energy-saving efficiency of Low-E house (%)	Energy-saving efficiency of HISG house (%)
Sunny	26	8.89	8.92	5.72	0	35.65
Cloudy		2.39	2.16	1.51	9.62	36.82
Sunny	20	0	0	0	0	0
Cloudy		0	0	0	0	0

Table 4: Energy consumption for cooling and heating inside of the Ordinary house, Low-E house, and HISG house per day in winter

Climate (day)	Indoor Temperature (°C)	Ordinary House (kWh)	Low-E house (kWh)	HISG House (kWh)	Energy-saving efficiency of Low-E house (%)	Energy-saving efficiency of HISG house (%)
Sunny	26	3.07	2.05	0.9	33.22	70.68
Cloudy		0	0	0	0	0
Sunny	20	0.34	0.29	0.26	14.08	23.53
Cloudy		4.08	3.81	2.88	6.62	29.41

Table 5: Energy consumption for cooling and heating inside of the Ordinary house, Low-E house, and HISG house per day in spring

Climate (day)	Indoor Temperature (°C)	Ordinary House (kWh)	Low-E house (kWh)	HISG House (kWh)	Energy-saving efficiency of Low-E house (%)	Energy-saving efficiency of HISG house (%)
Sunny	26	1.63	1.09	0.42	33.12	74.23
Cloudy		1.14	0.67	0.03	41.22	97.36
Sunny	20	0	0	0	0	0
Cloudy		0.23	0.04	0.12	82.60	47.83

In this work, the air conditioners were set up at 26°C and performed from 1:00 A.M. to 12:00 P.M. per day. In the sunny day, results show that the Ordinary House and Low-E house consumed 8.89 and 8.98 kWh in summer; about 3.07 and 2.05 kWh in winter; and around 1.63 and 1.09 kWh in spring, respectively; while HISG House consumed only 5.72; 0.9 and 0.42 kWh, see Tables (3-5) and Figure 4(A, C, E), respectively. It indicates that the energy consumption for cooling of the HISG house is greatly reduced with the highest energy saving efficiency per day was obtained at 35.65 and 35.87%; 70.68 and 56.09%; 74.23 and 61.46% during the summer, winter and spring, respectively, as compared to the Ordinary house and Low-E house. And, the effective energy saving of the Low-E house was ~0-33.22% higher than that of the Ordinary house. In the cloudy day, the energy consumption for cooling of all the houses was equivalent to 0 kWh in winter. Whereas, during summer and spring, the energy-saving efficiency for cooling of the Low-E house and HISG house accounted for 9.62-41.22% and 36.82-97.36%, respectively and they were much higher than that of the Ordinary house. The energy consumption reduction of the HISG house could be due to the extremely small shading coefficient of HISG (nano photocatalyst coated on the HISG module's surface) and high solar radiation anti-reflection from sunlight. Consequently, HISG contributed to excellent heat insulation effects and prevented solar radiation entering into the house. Because the U-value of HISG was sequentially much lower than those of Low-E glass and normal glass, cold air could be kept inside and not much lost from the energy consumption for the surrounding environment. So, the energy-saving efficiency was successfully achieved due to the electrical energy consumption for cooling from the activation of air-conditioner being greatly reduced.

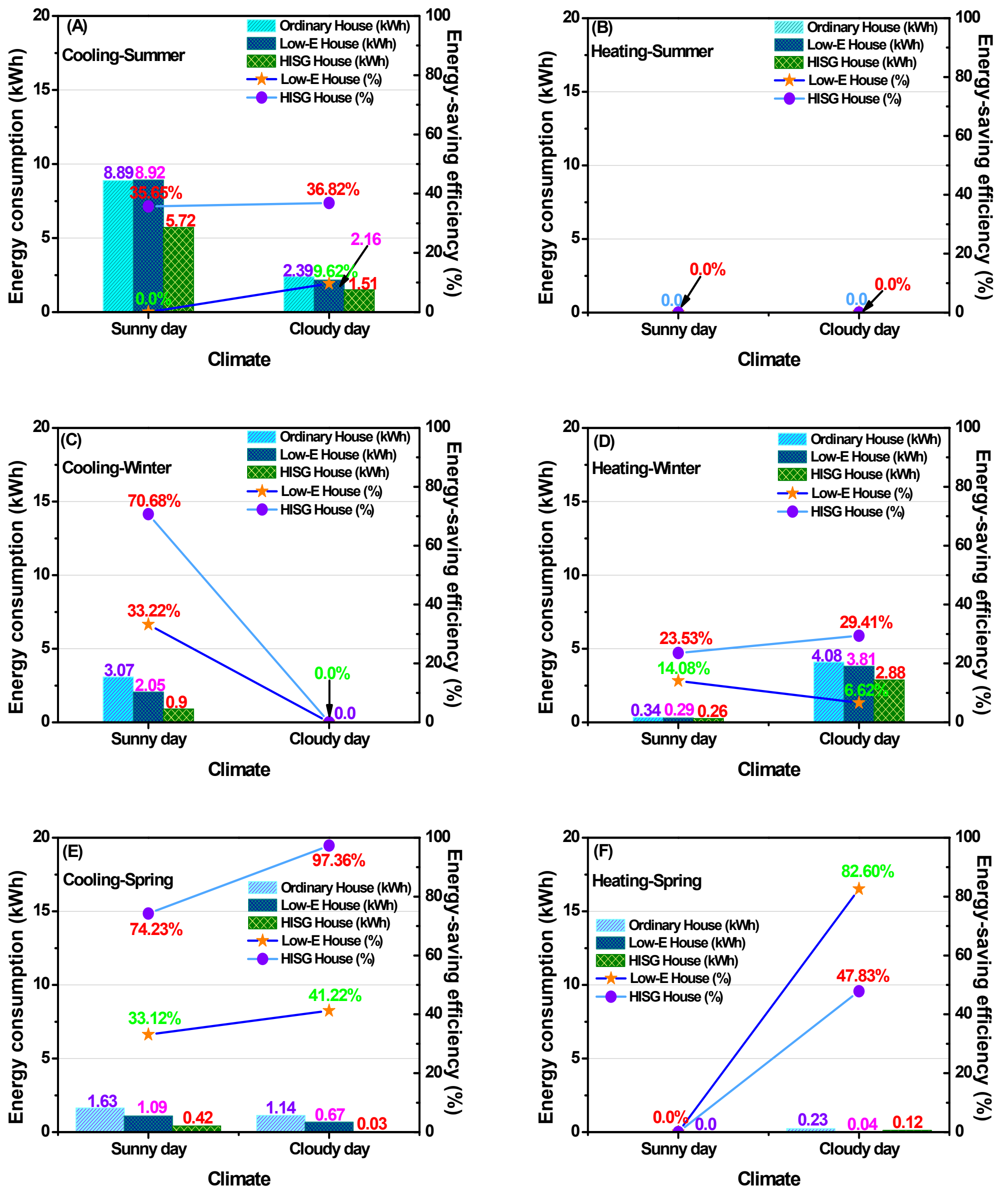
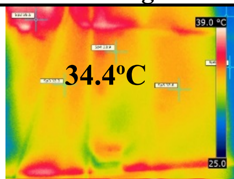
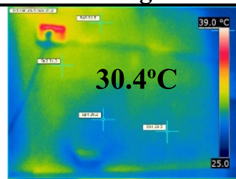
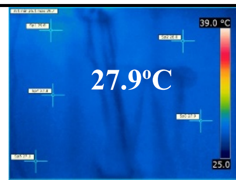
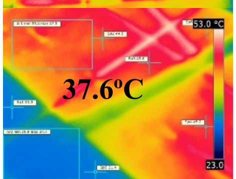
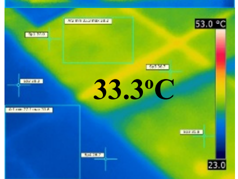
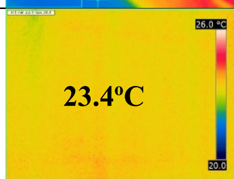
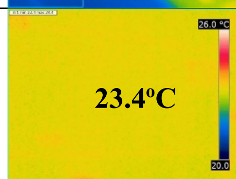
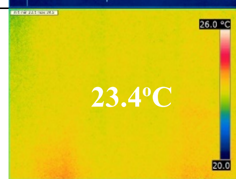
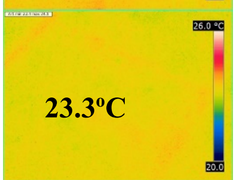
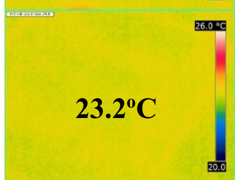
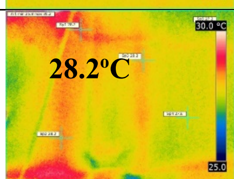
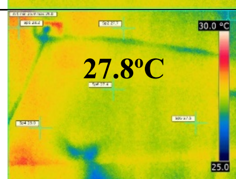
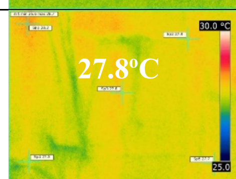
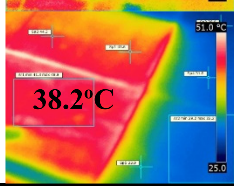
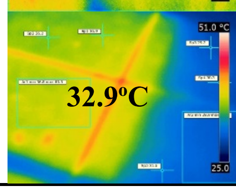
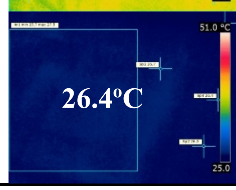


Fig. 4: Electric energy consumption of Ordinary house, Low-E house and HISG house during different seasons of (A, B) Summer; (C, D) Winter; and (E, F) Spring for cooling and heating in sunny and cloudy days, respectively

Herein, the heaters were set up to 20°C and also conducted for 24 h from 1:00 A.M. to 12:00 P.M.. In summer, the effective energy-saving for heating of the Ordinary house, Low-E house and HISG house are equivalent 0% (no energy consumed) in sunny and cloudy days (see Figure 4B). On the other hand, the HISG house is increased the effective energy-saving for heating ~23.53–29.41%, consumed only 0.26–2.88 kWh in winter; and about 0-47.83% equivalent to 0-0.12 kWh of power energy consumed in spring. Whereas, the Ordinary house and Low-E house consumed around 0.34–4.08 kWh and 0.29–3.81 kWh in winter; about ~0-0.23 kWh and 0-0.04 kWh in spring, respectively. The greatest reduction is obtained ~23.53-47.83% of energy-saving efficiency in the HISG house, around 6.62–14.08% in the Low-E house as compared to that of the Ordinary house in winter (Figure 4D, F). Results shown that the energy consumption of the HISG house was significantly reduced as compared to other houses. That could be due to the hot air layer maintained long-term by cool air layers from the inside of HISG module. Moreover, the heat transferred from indoor to outdoor as well as thermal diffusion or radiation of the HISG house were not significant difference and it is very low, whereas the thermal diffusion and radiation of normal glass and low-E are easier and higher for comparisons. Because the HISG has a significant low U-value, which greatly prevented and decreased expense of hot air from diffusing out of the indoor environment through roof and windows. Thus, the energy expense for heating in the HISG house was greatly low and it was the highest energy-saving efficiency as compared to those of the Ordinary house and Low-E house.

Table 6: Thermal images of various glazing types on the experimental houses during winter, spring and summer

Seasons	Climate (day)	Normal glass	Low-E glass	HISG
Winter	Sunny			
	Cloudy			
Spring	Sunny			
	Cloudy			
Summer	Sunny			
	Cloudy			

3.2 Energy consumption analysis for cooling and heating of the experimental houses with different outdoor temperatures

Results in Figure 5(A) showed that the highest effective energy-saving for heating of the HISG house and Low-E house are obtained at average temperature of 24.84°C (~35.53% and 57.89%, respectively) compared to the Ordinary house. When outdoor temperature above 26°C, the energy consumption for heating in the experimental houses are equivalent and there was no electric energy consumption (0 kWh of electricity) (see Figure (A) and Table 7).

As shown in Figure 5(B), the highest effective energy saving for cooling of the HISG house was estimated ~83.19%, consumed only 0.4 kWh, as compared to the Ordinary house (2.38 kWh) at average temperature of 16.24°C; while, the energy-saving efficiency of the Low-E house only obtained ~42.01% and consumed 1.38 kWh of power energy for comparison. When outdoor temperature above 30°C, the highest energy consumption for cooling of the Low-E house was obtained. The lowest energy-saving efficiency was found in the Low-E house at average temperature of ~34.94ºC (consumed 4.95 kWh), while the HISG house and Ordinary house consumed only 2.99 and 4.78 kWh, respectively. Besides, the energy-saving efficiency for cooling of the HISG house and Low-E house was ~38.97–42.45% and 0.98–3.65%, respectively, and they were better than that of the Ordinary house at average temperatures of 33.52 and 32.56ºC, see Table 8 and Figure 5(B). Moreover, the energy-saving efficiency of the HISG house reached 35.66–83.19% and it was higher than that of the Ordinary house at any temperatures of ~15 to ~40°C. This was due to the heat maintenance and storage of HISG very good in long-term, as well as the cold air flow's diffusion to the outdoor environment very slow and low. Thus, the energy consumption for cooling inside the HISG house was greatly reduced.

Table 7: Energy consumption for heating of the Ordinary house, Low-E house and HISG house with different outdoor temperatures per day

Outdoor temperature (°C)	Indoor Temperature (°C)	Ordinary House (kWh)	Low-E house (kWh)	HISG House (kWh)	Energy-saving efficiency of Low-E house (%)	Energy-saving efficiency of HISG house (%)
16.24		5.41	4.8	4.35	11.28	19.59
22.13		2.67	2.19	1.92	17.97	28.09
24.84		0.76	0.32	0.49	57.89	35.53
25.86		0	0	0	0	0
28.37		0	0	0	0	0
30.73		0	0	0	0	0
31.96		0	0	0	0	0
32.56	20	0	0	0	0	0
33.52		0	0	0	0	0
34.94		0	0	0	0	0
35.88		0	0	0	0	0
36.33		0	0	0	0	0
37.26		0	0	0	0	0
38.93		0	0	0	0	0

Table 8: Energy consumption for cooling of the Ordinary house, Low-E house and HISG house with different outdoor temperatures per day

Outdoor temperature (°C)	Indoor Temperature (°C)	Ordinary House (kWh)	Low-E house (kWh)	HISG House (kWh)	Energy-saving efficiency of Low-E house (%)	Energy-saving efficiency of HISG house (%)
16.24		2.38	1.38	0.4	42.01	83.19
22.13		3.08	1.88	0.92	38.96	70.13
24.84		2.71	2.33	1.03	14.02	61.99
25.86		5	4.07	2.42	18.6	51.6
28.37		4.12	3.34	1.64	18.93	60.19
30.73		8.89	8.92	5.72	0	35.66
31.96		3.21	3.26	2.02	-1.56	37.07
32.56	26	3.84	3.7	2.21	3.65	42.45
33.52		4.08	4.04	2.49	0.98	38.97
34.94		4.78	4.95	2.99	-3.56	37.45
35.88		4.91	5	2.9	-1.83	40.94
36.33		5.41	5.48	3.12	-1.29	42.33
37.26		5.65	5.7	3.34	-0.88	40.88
38.93		6.97	6.99	4	-0.29	42.61

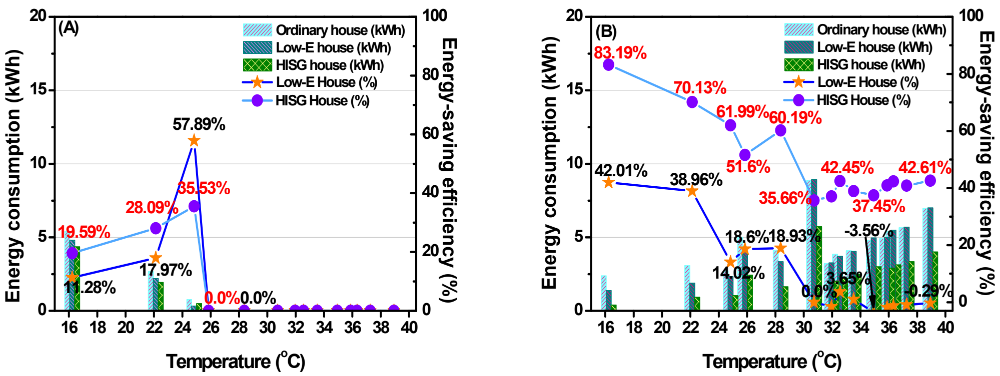


Fig. 5: Energy-saving efficiency for (A) Heating and (B) Cooling of the experimental houses with different temperature

4 CONCLUSIONS

The energy-saving efficiency of using HISG on the HISG house has achieved 70.68 and 56.09% for cooling; around 23.53 and 10.34% for heating as compared to those of the Ordinary house and Low-E house, respectively. Moreover, the energy consumption for heating and cooling of the HISG house has significantly reduced with highly energy efficiencies of 19.59% and 37.07% at outdoor temperature above 30°C (~32~39°C) as compared to those of the Ordinary house. Consequently, HISG can be replaced for the common glass used in buildings because its safety is guaranteed and it possesses a stronger structure, superior fire-resistance and greatly energy-saving, as well as significantly greenhouse gas reducing and gradually suitable trend to the zero energy building for the green buildings in future.

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