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A Feasibility Study of Glass Solar Chimney Wall for Tropical Area, Case Study: Bangkok, Thailand

Jaran Ratanachotinun *[1] and Pithan Pairojn *

Abstract – *This research will study the feasibility of glass solar chimney walls (GSCW) compared with one-layered glass walls (OLGW) for the tropical climate present in Bangkok, Thailand. GSCW uses the concept of indoor natural ventilation operated by heat transfer to air gap of double-layers glass wall. The research methodology is constructed of 2 sample houses and data collection over 3 seasons, data comparison and regression model for forecasting indoor temperature. The result found that GSCW had a lower indoor temperature than OLGW as an average difference in temperature of 1.63-1.30 °C, 2.46-1.80 °C and 1.36-1.28 °C for rainy, winter and summer respectively. The comparisons of energy saving from air conditioning with OLGW were 6-12%, 9-14% and 5-11% for rainy, winter and summer respectively. The reliability of regression models were calculated by R^2 around 0.7 – 0.89 and satisfied when fitted with experimental data. The GSCW concept can be used in office buildings or mini buildings which stand alone outdoor and will be suitable for tropical areas in the world and can help to sustain energy and the environment.*

Keywords – Building for tropical climate, energy saving building, energy saving wall, glass solar chimney wall, solar chimney.

1. INTRODUCTION

The design of the residential building pattern is an important factor that affects comfort condition within buildings in Tropical areas which have a hot-humid climate. Thailand has a tropical climate which generally has three seasons; summer, rainy season and winter (winter is still comparatively warm when compared with European winters), and is the study area for this research. The electricity consumption of Thailand in 2007 from The Ministry of Energy residential sector accounts for 19.61 percent of all the electricity used in the highest third of the Industry sector (41.7%) and Trade sector (23.2%), so the residential building sector is a high energy consumption sector. In the Western zone, researches about glazed trombe wall and glazed solar chimney wall have been widely conducted [5], [17]-[18]. The objective research was about warming the inside of a building and saving energy consumption. In the Asian zone, the experimental investigations of solar chimney by lab scale [11], [13], glazed solar chimney wall research [2]-[3], [19] was studied and adjusted in order to be suitable. The component or shape of a building effects energy performance such as Parasonis *et al.* [14] who studied the relationship between the shape of a building and its energy performance. The focus of this research is building a wall where the main component is to protect from wind, rain and heat. The suitable wall design can reduce indoor temperature and energy consumption. Most designs of the glass wall patterns in Thailand are used in Western countries. It looks beautiful and modern. This building style has been popular, but because of the tropical climate of Thailand, the use of western style glass walls has caused problems to occur. The common solution in Thailand was using wood trip on glass walls or windows in order to protect heat from sun shade show design sample in Figure 1. The disadvantage being, natural light cannot pass inside the building and can be clearly seen outside.

Thermal comfort or the indoor temperature of a building directly effects the consumption of energy from air condition according to Tweed *et al.* [20] who researched thermal comfort practices in the home and the impact on energy consumption. In Thailand, the problem from using glass walls is that heat transfers inside and increases the indoor temperature. Air conditioning is switched on to keep the temperature cool inside the building, so this can easily cause the consumption of electricity to rise. The materials of the glass in the walls of the building are being developed as thermal insulation properties, but the impact on costs of more than regular glass, limit the lifetime and environmental impact. A study and development of energy-saving glass in the solar chimney by Chantawong *et al.* [1] studied the performance of solar ventilation chimney glass in window form in Thailand and results showed that the samples of installed solar ventilation chimney glass had a lower room temperature than the sample when a single glass layer was installed. So this research will study a model of energy-saving glass walls suitable for use in the Tropical climate of Thailand, comparing popular one-layered glass walls (OLGW) with the double-layered walls or glass solar chimney walls (GSCW). A design of GSCW is a glass double-layered wall with space for air ventilation from the inside to the outside of the building. The outputs of this research will be a prototype for the sustainable energy-saving glass wall form suitable for use in the future.

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Fig. 1. The wood strip of glass window for protect sunshade.

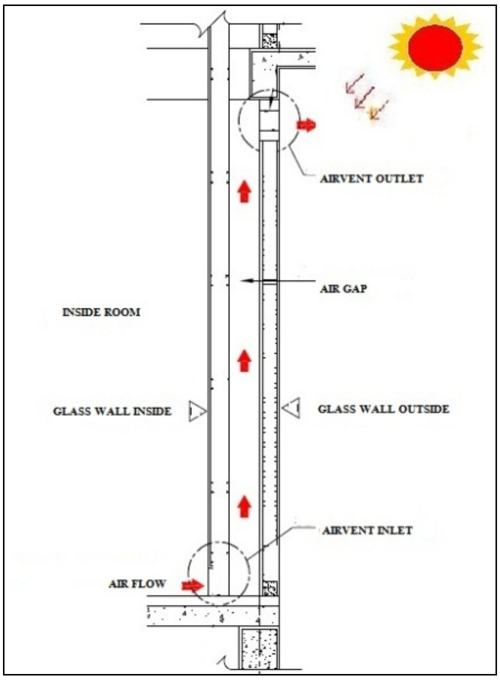

Fig. 2. The section of GSCW model.

Fig. 3. OLGW and GSCW house for testing.

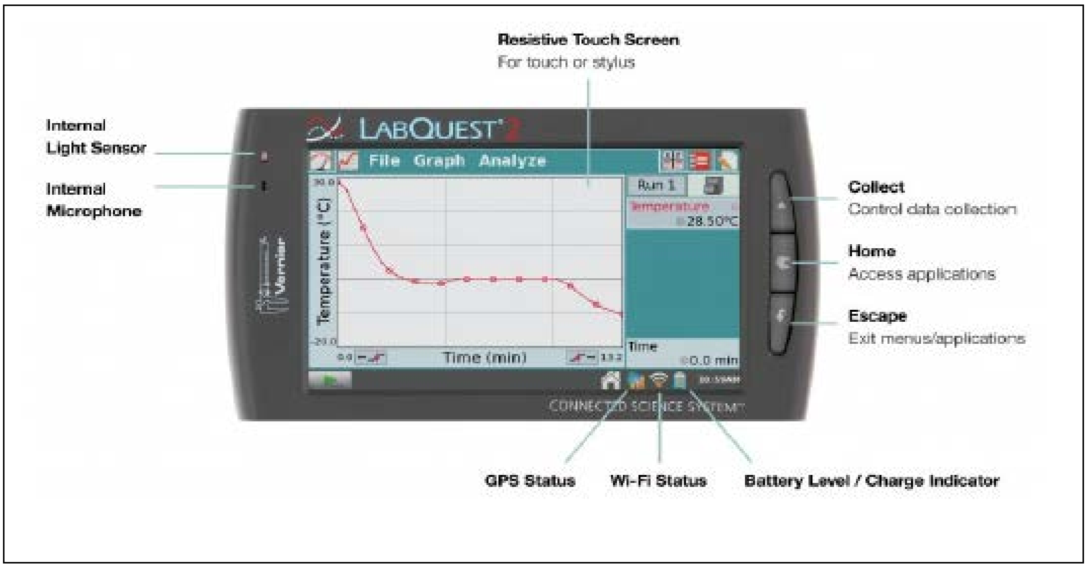

Fig. 4. Data logger for surveying.

2. RESEARCH METHODOLOGY

This research builds an experimental model to compare the performance (indoor temperature and energy saving) of OLGW and GSCW adaptation, for the reference of the solar chimney model research involved in Figure 2 (0.006 m of glass thickness, 14 cm of air gap, 10 cm of airvent outlet), using two sample houses measuring 1.5x1.5x2.5 meters each and shown in Figure 3. Testing took place within Chandrakasem Rajabhat University, during three (3) periods over all seasons; September 2013, December 2013 and March 2014. Both glass wall sides of two samples faced south and the instruments used in the survey was the data logger shown in Figure 4. Factors explored in this research were the indoor and outdoor temperature for two (2) sample houses. Data storage was recorded over 24 hours (15 minutes for each time interval of data collection) using temperature sensors located indoors at the center of the sample houses, and analysis variables were recorded on the regression model. The energy savings from air-conditioning for this analysis is in reference Yamtraipat *et al.* [23], which studied thermal comfort standards for air conditioned buildings in Thailand and found that a temperature difference of one degree Celsius lower can reduce the cooling load of air-conditioning and energy saving by approximately 6.14%. The analysis of the regression model can predict indoor temperature from outdoor temperature. The conclusions and recommendations of the research confirm suitability for all year round usage and development applications that are appropriate for Thailand.

3. RESULT

The data collection and analysis of performance focusing on indoor temperature and energy saving of air-conditioning from the OLGW and GSCW model reported 4 parts; the first data collection and analysis in rainy season, the second in winter season, the third in summer season and the last part the regression model for forecasting indoor temperature.

3.1 Data Collection and Analysis for Rainy Season

Data collections were surveyed 24 hours for OLGW and GSCW during September, 2013 shown in Figure 5. The result found that the average temperature for OLGW was a maximum and minimum temperature of 38.52°C and 27.67°C. The results for GSCW showed a maximum and minimum temperature of 36.46°C and 26.64°C. From Tables 1 and 2, the average indoor temperature of GSCW was lower than OLGW's average indoor temperature of 1.63°C for day time and 1.30°C for night time. The maximum difference of indoor temperature found was 2.06°C between 10.00 to 14.00. The minimum difference of temperature found was 1.03°C during 02.00 to 06.00.

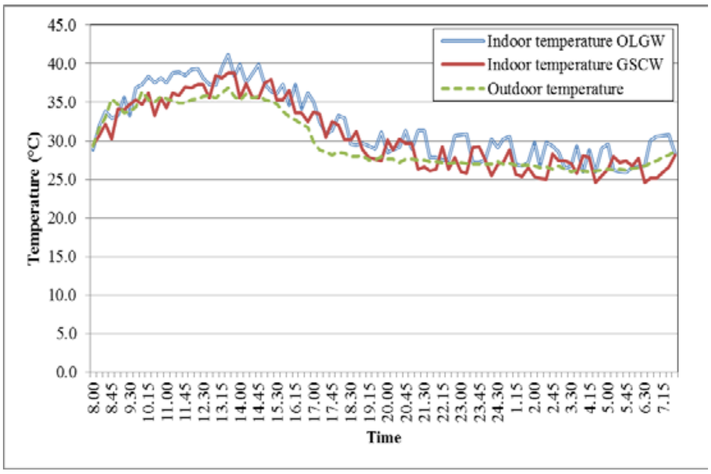

Fig. 5. Compared temperature with all day in each model for rainy season (September, 2013).

Table 1. Average temperature separated by day and night time (September, 2013).

Time			Average temp. outside	Average temp. inside OLGW	Average temp. inside GSCW
	1	06.00-10.00	30.65	31.40	29.71
Day Time	2	10.00-14.00	35.58	38.52	36.46
	3	14.00-18.00	32.68	35.77	34.62
	4	18.00-22.00	27.71	29.96	28.77
Night Time	5	22.00-02.00	27.04	28.68	26.98
	6	02.00-06.00	26.31	27.67	26.64

Table 2. Difference temperature separated by day and night time (September, 2013).

Time			Difference temp. OLGW and GSCW	Average difference temp. OLGW and GSCW
	1	06.00-10.00	1.68	
Day Time	2	10.00-14.00	2.06	1.30
	3	14.00-18.00	1.15	
	4	18.00-22.00	1.19	
Night Time	5	22.00-02.00	1.70	1.63
	6	02.00-06.00	1.03	

Table 3. The analysis of electricity saving for air condition from GSCW model for rainy season (September, 2013).

Time			Difference temp. OLGW and GSCW	Electricity saving (%)
	1	06.00-10.00	1.68	10.35
Day Time	2	10.00-14.00	2.06	12.65
	3	14.00-18.00	1.15	7.08
	4	18.00-22.00	1.19	7.30
Night Time	5	22.00-02.00	1.70	10.44
	6	02.00-06.00	1.03	6.30

In Table 3, which is calculated from the analysis of energy efficiency of N. Yamtraipat *et al.* [23] shows an energy saving of 6.14% each time the temperature lowers by 1 degree Celsius. In rainy season, GSCW can reduce electricity saving of air conditioning by around 6-12% with maximum efficiency during 10.00 to 14.00 (12.65%).

3.2 Data Collection and Analysis for Winter Season

Data collections were surveyed 24 hours for OLGW and GSCW during December, 2013 shown in Figure 6. The result found that the average temperature for OLGW was a maximum and a minimum temperature of 37.76°C and 23.91°C. The results for GSCW showed a maximum and minimum temperature of 33.75°C and 22.33°C. From Tables 4 and 5, the average indoor temperature of GSCW was lower than OLGW's average indoor temperature of 2.46°C for day time and 1.80 °C for night time. The maximum difference of indoor temperature was 2.92°C between 14.00 to 18.00. The minimum difference of temperature was 1.58°C during 02.00-06.00.

Table 6 calculated the analysis of energy efficiency for winter season. GSCW can reduce electricity saving of air conditioning by around 9-14% with a maximum efficiency during 14.00-18.00 (17.95%).

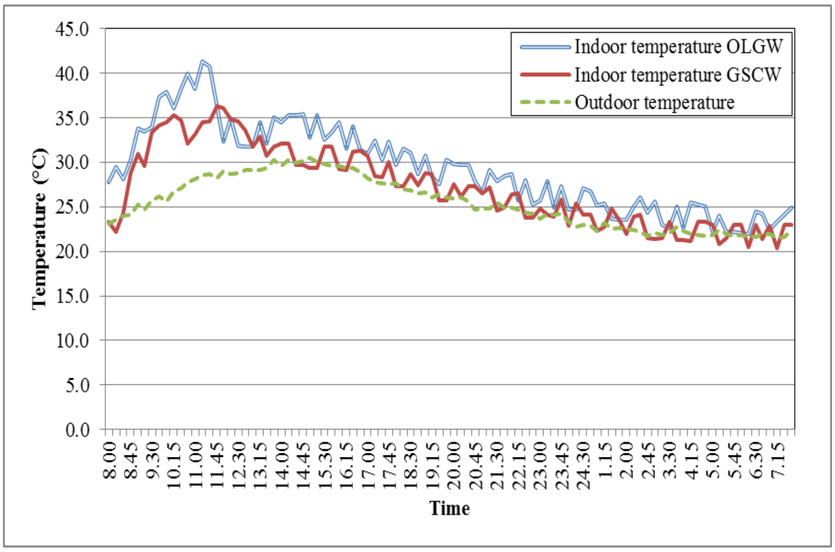

Fig. 6. Compared temperature with all day in each model for winter season (December, 2013).

Table 4. Average temperature separated by day and night time (December, 2013).

Time			Average temp. outside	Average temp. inside OLGW	Average temp. inside GSCW
Day Time	1	06.00-10.00	23.35	28.22	25.78
	2	10.00-14.00	28.46	35.76	33.75
	3	14.00-18.00	29.19	33.04	30.11
Night Time	4	18.00-22.00	25.90	29.17	26.94
	5	22.00-02.00	23.50	25.78	24.19
	6	02.00-06.00	22.08	23.91	22.33

Table 5. Difference temperature separated by day and night time (December, 2013).

Time			Difference temp. OLGW and GSCW	Average difference temp. OLGW and GSCW
Day Time	1	06.00-10.00	2.44	2.46
	2	10.00-14.00	2.01	
	3	14.00-18.00	2.92	
Night Time	4	18.00-22.00	2.23	1.80
	5	22.00-02.00	1.59	
	6	02.00-06.00	1.58	

Table 6. The analysis of electricity saving for air condition from GSCW model for winter season (December, 2013).

Time			Difference temp. OLGW and GSCW	Electricity saving (%)
Day Time	1	06.00-10.00	2.44	14.97
	2	10.00-14.00	2.01	12.35
	3	14.00-18.00	2.92	17.95
Night Time	4	18.00-22.00	2.23	13.72
	5	22.00-02.00	1.59	9.75
	6	02.00-06.00	1.58	9.69

3.3 Data Collection and Analysis for Summer Season

Data collection was surveyed for 24 hours for OLGW and GSCW during March, 2014 shown in Figure 7. The result found that the average temperature of OLGW was a maximum temperature of 38.86°C and a minimum temperature of 29.57°C. GSCW was a maximum temperature of 37.07°C and a minimum temperature of 28.59°C. From Tables 7 and 8, the average indoor temperature of GSCW was lower than OLGW's average indoor temperature of 1.36°C for day time and 1.28°C for night time. The maximum difference of indoor temperature found was 1.79°C between 10.00 to 14.00. The minimum difference of temperature was 0.90°C during 14.00 to 18.00.

Table 9 calculated the analysis of energy efficiency for winter season. GSCW can reduce electricity saving of air conditioning of around 5-11% with maximum efficiency during 10.00 to 14.00 (11.00%).

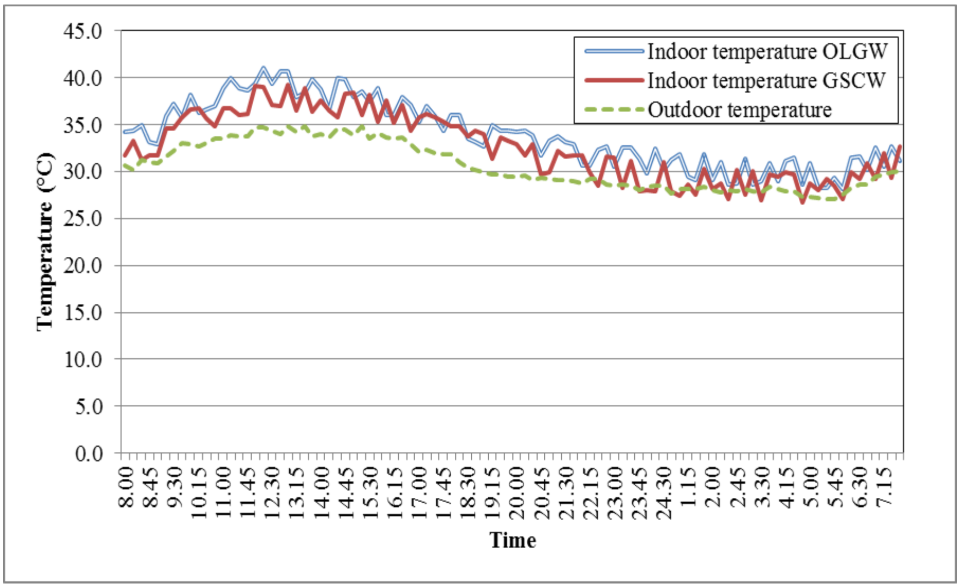

Fig. 7. Compared temperature with all day in each model for summer season (March, 2014).

Table 7. Average temperature separated by day and night time (March, 2013).

Time			**Average temp. outside**	**Average temp. inside OLGW**	**Average temp. inside GSCW**
Day Time	1	06.00-10.00	30.35	33.24	31.86
	2	10.00-14.00	33.92	38.86	37.07
	3	14.00-18.00	33.35	37.28	36.37
Night Time	4	18.00-22.00	29.71	33.71	32.63
	5	22.00-02.00	28.43	31.07	29.28
	6	02.00-06.00	27.74	29.57	28.59

Table 8. Difference temperature separated by day and night time (March, 2013).

Time			Difference temp. OLGW and GSCW	Average difference temp. OLGW and GSCW
Day Time	1	06.00-10.00	1.38	1.36
	2	10.00-14.00	1.79	
	3	14.00-18.00	0.90	
Night Time	4	18.00-22.00	1.08	1.28
	5	22.00-02.00	1.79	
	6	02.00-06.00	0.98	

Table 9. The analysis of electricity saving for air condition from GSCW model for summer season (March, 2013).

Time			Difference temp. OLGW and GSCW	Electricity saving (%)
Day Time	1	06.00-10.00	1.38	8.46
	2	10.00-14.00	1.79	11.00
	3	14.00-18.00	0.90	5.53
Night Time	4	18.00-22.00	1.08	6.64
	5	22.00-02.00	1.79	10.98
	6	02.00-06.00	0.98	6.00

3.4 The Regression Analysis for Forecasting Indoor Temperature

The analysis of the regression model for predicting indoor temperature was separated by rainy season, winter season and summer season. In Figure 8, it is found that GSCW had a lower indoor temperature than OLGW's indoor temperature in every season. The regression model shown in Table 10 can forecast the indoor temperature of OLGW and GSCW when the outdoor temperature is known. R^2 value of models had 0.7 – 0.89 which was a good reliability for forecasting. This model can produce data for energy planning and designing.

The temperature of the regression model was fitted by experimental data which is not calculated in the regression model show in Figures 9 to 14. The result from the model found the same trend and is suitable for predicting indoor temperature of GSCW in all seasons especially in summer.

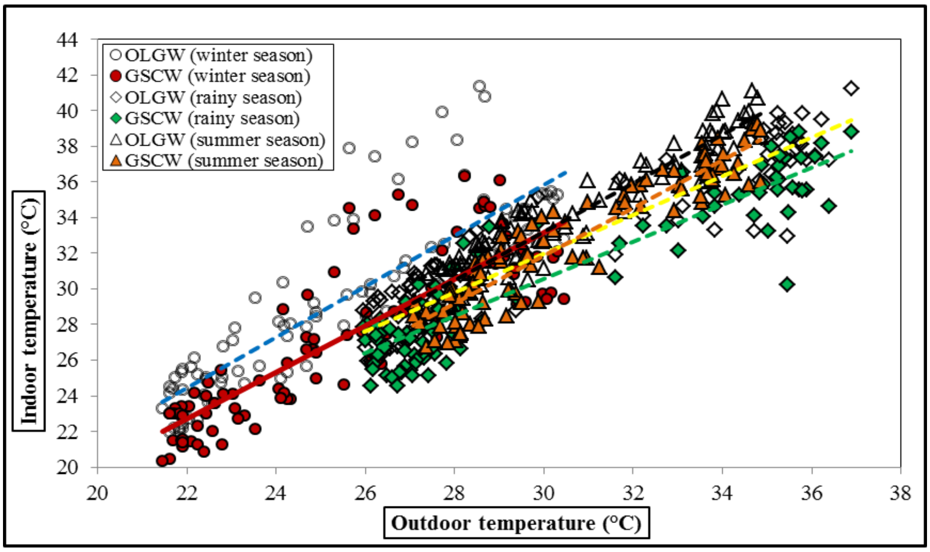

Fig. 8. Compared experimental data of indoor temperature with outdoor temperature during rainy, winter and summer season.

Table 10. The regression for forecasting indoor temperature of GSCW house in case rainy, winter and summer season [x = outdoor temperature (°C)].

Type of wall	Regression of indoor temperature (°C)	R^2
OLGW (winter)	y = 1.423x - 6.8599	0.7063
GSCW (winter)	y = 1.3028x - 5.953	0.7167
OLGW (rainy)	y = 1.0819x - 0.4696	0.8695
GSCW (rainy)	y = 1.0417x - 0.6804	0.8429
OLGW (summer)	y = 1.362x - 7.6761	0.8923
GSCW (summer)	y = 1.3344x - 8.1843	0.8645

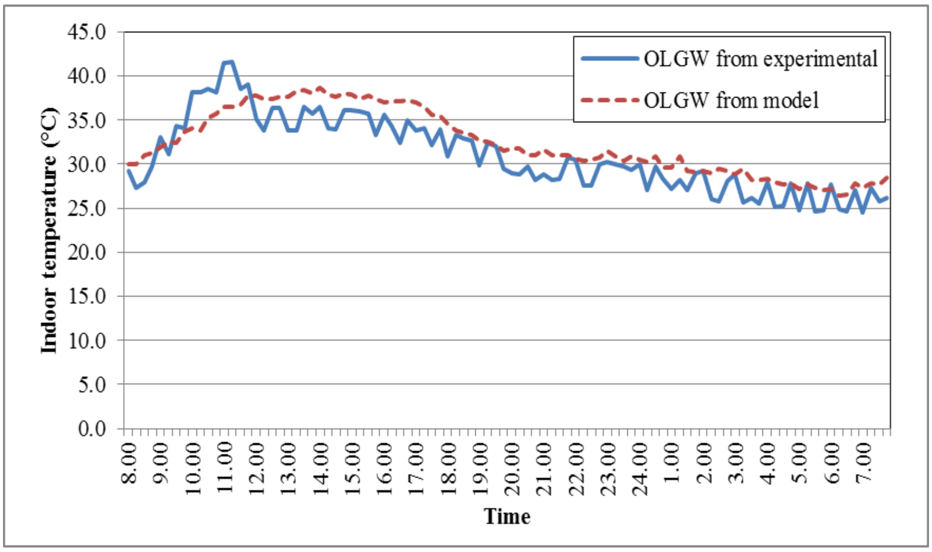

Fig. 9. Compared regression model of OLGW with experimental for winter season.

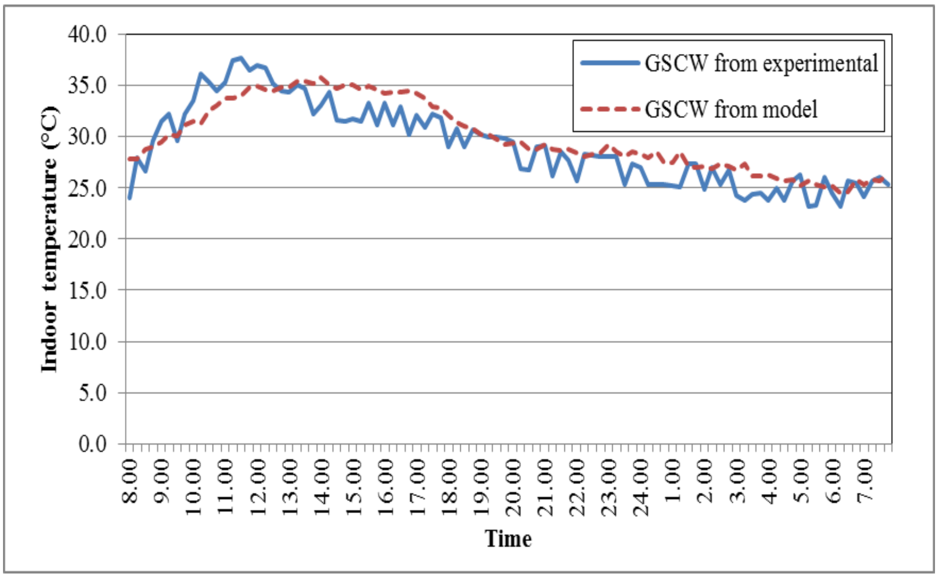

Fig. 10. Compared regression model of GSCW with experimental for winter season.

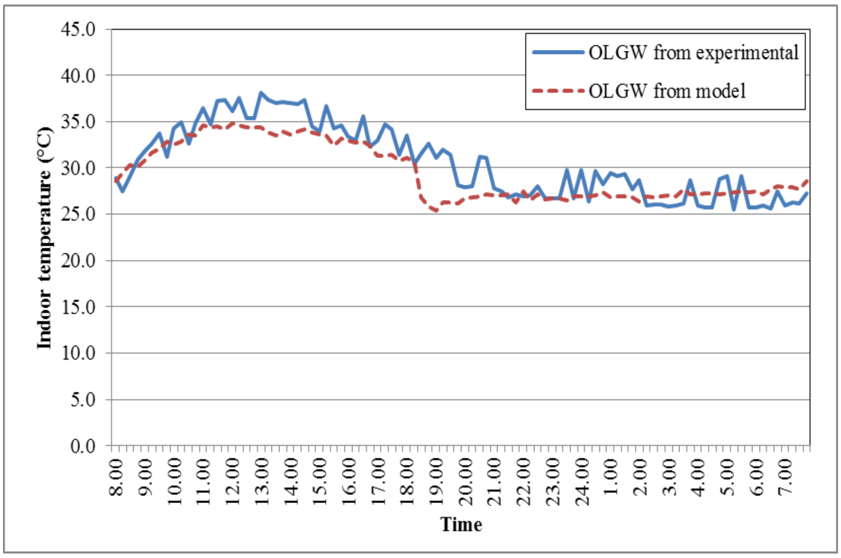

Fig. 11. Compared regression model of OLGW with experimental for rainy season.

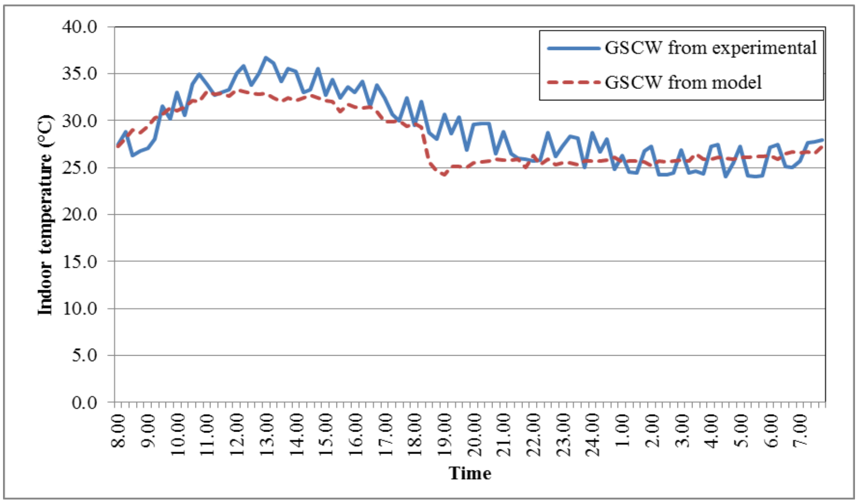

Fig. 12. Compared regression model of GSCW with experimental for rainy season.

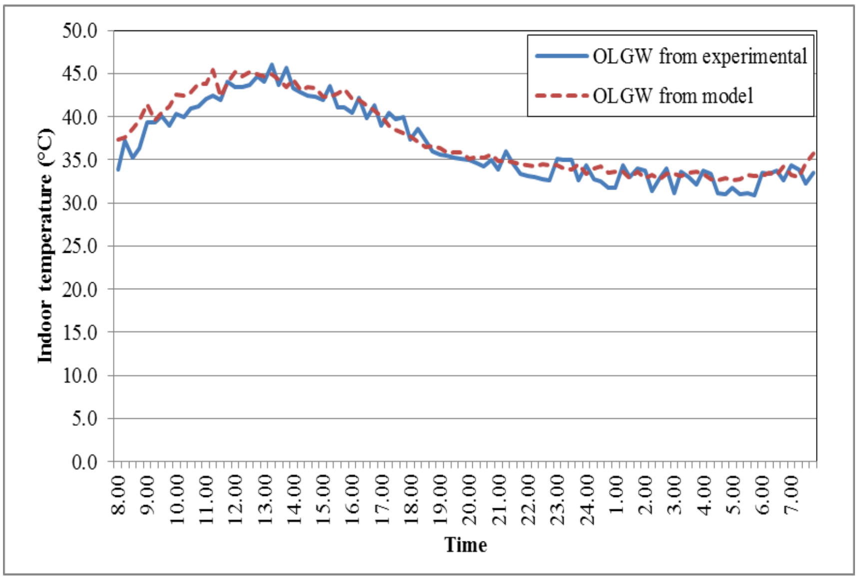

Fig. 13. Compared regression model of OLGW with experimental for summer season.

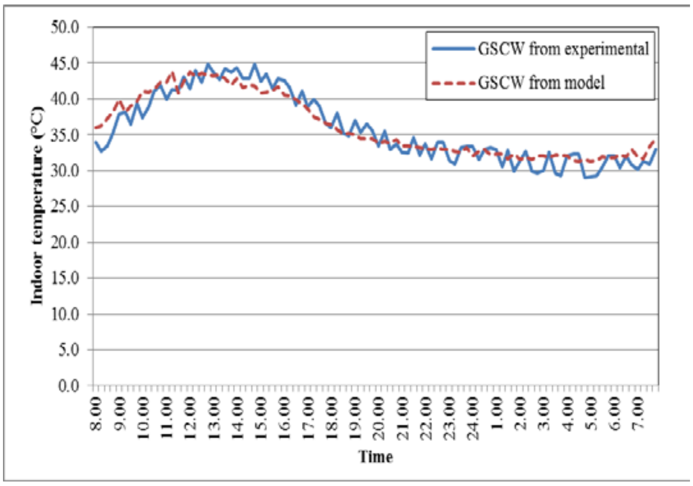

Fig. 14. Compared regression model of GSCW with experimental for summer season.

4. CONCLUSION

The selection of house wall glass design is partly the aesthetic in the design, but also the appropriateness of the design to additional factors. The GSCW concept is an excellent choice for use with the climate in Thailand. This study found that GSCW can reduce the indoor temperature by an average difference of 1.63 – 1.30°C for rainy season, 2.46 – 1.80°C for winter season and 1.36 – 1.28°C for summer season in comparison with the indoor temperature of OLGW. GSCW has good effectiveness for all seasons. The use of GSCW created an energy saving rate of air conditioning electricity of about 6-12%, 9-14% and 5-11% for rainy, winter and summer respectively. It can be used all year round in Thailand. The regression model can forecast the indoor temperature when the outdoor temperature is known, especially the GSCW regression model which produced data for energy building planning. The reliability of models were calculated by R^2 around 0.7 – 0.89 and satisfied when fitted with experimental data. The most effective use of GSCW is during day time or in a lot of sun shade. In future research, GSCW usage could be compared with the use of wood strip. GSCW should be designed within office buildings or mini buildings which stand alone outdoors. It's suitable for tropical climates around the world and can be applied with the green building concept which helps to save energy and the environment.

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