

# Impacts of Window Frames on Building Energy Consumption

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**Abstract.** *In general, only properties of pure glass are used for windows in building energy calculation. However, past researches showed that properties of window frames could alter overall window system properties by 20-30%. Therefore, this study was set up to investigate the significance of window frames on building energy consumption. First, comparisons of properties obtained from the Window 6.3 software of various combinations of window systems were carried out. Six-mm-thick clear glass was treated as the base case. The combinations of window systems were generated from 3 glass types (6-mm clear glass, 6-mm green glass, 6-mm low-E coating glass), 2 frame materials (aluminum, PVC), and 2 frame configurations (fixed frames, sliding frames). After that, each window system was applied to a sample office building to simulate building energy consumption using the EnergyPlus software. The sample building had 4 floors with a total area of 1,295.91 m<sup>2</sup> and a window-to-wall ratio (WWR) of 37%. The results showed that properties were most different between the base case and the case of low-E glass with PVC sliding frames. Overall heat transfer coefficient (U), solar heat gain coefficient (SHGC), and visible transmittance (Tvis) were found to be different by 58%, 37%, and 26%, respectively. On the contrary, energy consumption between these two cases differed by only 0.67%. It implies that even with as high as 58% deviation, properties of window systems with frames added have insignificant impacts on energy consumption of the building. In turn, building energy calculation may be done by using only properties of glass with no frames for windows as conventionally done without causing significant errors.*

## Keywords:

window system, window frame, thermal property, building energy consumption

## 1. Introduction

Globally, buildings account for around 40% of total energy use [1-4]. In Thailand, 46% of total electrical energy is consumed by the building sector [5]. Half of it is used in

air conditioning systems [6]. Since 20-40% of heat gains into a building are from window systems, properties of window systems and window-to-wall ratio (WWR) become important factors that affect building energy consumption [7]. For WWR, buildings that have less WWR would consume less energy due to less heat gains through windows [4, 8]. It was found that appropriate WWR for buildings in Thailand is approximately 40% [9]. For buildings without external shading devices, WWR should be about 30% [10].

For properties of window systems, the most important three parameters are 1) overall heat transfer coefficient (U) which is related to conduction and convection of window systems, 2) solar heat gain coefficient (SHGC) which is related to solar radiation through window systems, and 3) visible transmittance (Tvis) which characterizes the ability to transmit visible light through window systems important for daylighting application of buildings [1]. Designing window systems to have small U and SHGC values to mitigate incoming heat gains to reduce energy use in air conditioning systems and maintain adequate Tvis value to exploit free daylight and save energy in electrical lighting systems is a crucial concern for building designers. Sekhar and Lim even mentioned that improving window and envelope systems might be the only remaining option for energy saving in buildings associated with building structure [7]. Therefore, having standards for window system properties and knowing impacts of such properties on building energy consumption are necessary.

There is a set of international standards regarding properties and performance of window systems which can be grouped into calculation approach and testing approach [11-26]. In Thailand, there are only standards for categories and dimensions of window systems [27-30] while standards for window system performance are still in progress.

Regarding impacts of window system properties on building energy consumption which is the main point of this article, it is normal to use properties of pure glass without frames for windows in building energy calculation for the sake of convenience. However, past researches showed that properties of frames could alter the overall properties of

window systems by 20-30% [1, 31]. Hence, it was of interest to investigate impacts of properties of window frames on building energy consumption. A sample office building was used as a case study.

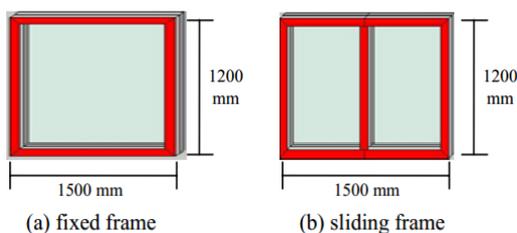
## 2. Methodology

The sample office building had 4 floors with a total area of 1,295.91 m<sup>2</sup> and a WWR of 37%. It was assumed that the building was located in Nakhon Pathom province, Thailand. Brief details of the building are shown in Table 1.

This research was divided into 2 parts. The first part was the analysis of properties of 15 combinations of window systems. The combinations were generated from 3 glass types (6-mm clear glass, 6-mm green glass, 6-mm low-E coating glass), 2 frame materials (aluminum, PVC), and 2 frame configurations (fixed frames, sliding frames) as summarized in Table 2. Relevant properties of glasses and frames are presented in Table 3. Frame configurations are illustrated in Fig. 1. Main properties of window systems comprising U, SHGC, and Tvis of each case were evaluated by using Window 6.3 software [32].

Table 1: Details of sample office building

Building application	Office building
Location	Nakhon Pathom, 13.82°N, 100.05°E
Number of floor	4
Area - conditioned	741.69 m <sup>2</sup>
- unconditioned	554.22 m <sup>2</sup>
- total	1,295.91 m <sup>2</sup>
Material - type	Brick, mortar, concrete, glass, etc.
- number	16 types
Structure - type	Wall, floor, ceiling, roof / window, door
- number	362 / 153 pieces
Window system - type of glass	6-mm clear glass without frames
- window-to-wall ratio	37%
Zone - number	32
- time of use	8:00-17:00, Mon-Sat, 2,808 h/y
Number of occupants	102
Lighting - lamp	- 18-W compact fluorescent - 36-W fluorescent
- fixture	- 274 downlight fixtures, 1 lamp/fix - 29 acrylic cover, 2 lamp/fix
- power	6.75 kW
Equipment - type	Office equipment
- power	7.75 kW
Air conditioning - type	Central system / air-cooled water chiller
- capacity	51 TR
- power	182.2 kW
Form of energy use	Electricity
U value - roof	5.306 W/m <sup>2</sup> -K
- wall	2.057-6.680 W/m <sup>2</sup> -K
- floor	1.774-2.812 W/m <sup>2</sup> -K



Notes: For aluminum frame: frame thickness = 57.2 mm  
For PVC frame: frame thickness = 69.8 mm

Fig 1: Frame configurations

In the second part of this research, each of the 15 combinations of window systems was applied to the sample building and annual electrical energy consumption by air conditioning systems, lighting systems, and building equipment was simulated by using the EnergyPlus software to see the impacts of different window systems on building energy consumption [7, 33, 34]. An uncertainty of ±5% was applied to the property values corresponding to the uncertainty that might occur when using a hot box set to test for the properties of window systems [11].

Table 2: Combinations of window systems

No.	Name	Description
1	clear	6-mm clear glass
2	F clearalu	Clear glass + aluminum + fixed frame
3	F clearPVC	Clear glass + PVC + fixed frame
4	S clearalu	Clear glass + aluminum + sliding frame
5	S clearPVC	Clear glass + PVC + sliding frame
6	green	6-mm green glass
7	F greenalu	Green glass + aluminum + fixed frame
8	F greenPVC	Green glass + PVC + fixed frame
9	S greenalu	Green glass + aluminum + sliding frame
10	S greenPVC	Green + PVC + sliding frame
11	Low-E	6-mm low-E coating glass
12	F low-Ealu	Low-E + aluminum + fixed frame
13	F low-EPVC	Low-E + PVC + fixed frame
14	S low-Ealu	Low-E + aluminum + sliding frame
15	S low-EPVC	Low-E + PVC + sliding frame

Table 3: Properties of glasses and frames

Material	Property		
	U (W/m <sup>2</sup> -K)	SHGC	Tvis
6-mm clear glass	5.381	0.840	0.883
6-mm green glass	5.383	0.618	0.770
6-mm low-E glass	2.507	0.676	0.857
Aluminum frame	5.680	-	-
PVC frame	1.700	-	-

## 3. Results and Discussions

### 3.1 Analysis of Properties of Window Systems

Fig. 2 illustrates comparisons of properties among 3 glass types which were input as windows without frames into the building simulation model. The case of using 6-mm clear glass without frame was treated as the base case. It can be seen that the U value of the green glass is very close to that of the clear glass. On the other hand, SHGC is lower by 26% and Tvis is lower by 13%. This is because the green glass is also clear glass but its tint diminishes the amount of sunlight coming through it so SHGC and Tvis are reduced.

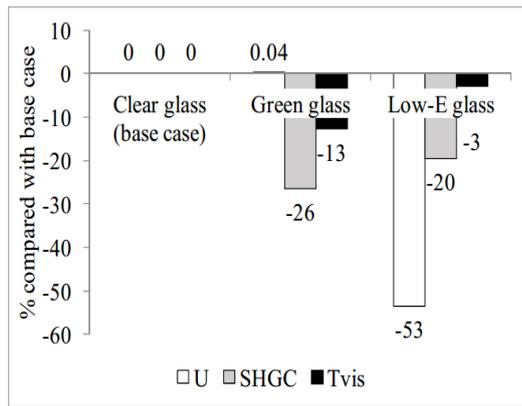


Fig. 2: Comparison of window system properties between different glass types

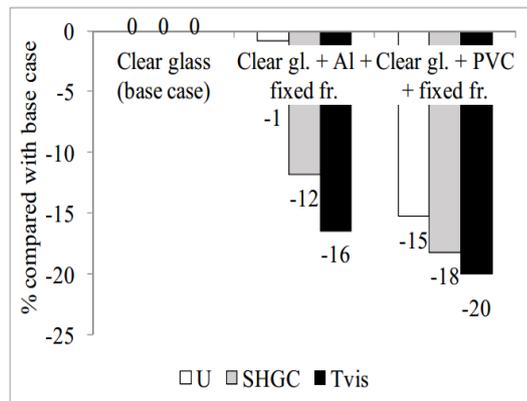


Fig. 3: Comparisons of window system properties between different frame materials

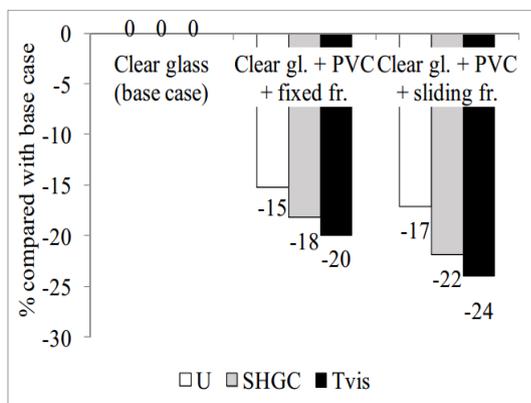


Fig. 4: Comparisons of window system properties between different frame configurations

For the low-E glass, U and SHGC are lower by as high as 53% and 20%, respectively, compared with the base case which agrees well with the literature [33]. The value of Tvis is found to be only 3% lower. The reason that U is decreased relatively much is that the low-E glass is coated by metal substances to prevent heat transfer through the glass and reflect solar radiation. In turn, SHGC and Tvis are reduced but not at the same degree as in the case of the green glass since the low-E glass is clearer corresponding to the findings by Ihm et al. [35].

Fig. 3 shows comparisons of properties of window systems using fixed frames made of 2 materials with the base case to see the effects of the frame material. It can be seen that the clear glass with fixed aluminum frames causes reduction in U, SHGC, and Tvis by 1%, 12%, and 16%, respectively. The small reduction in U is due to the fact that U of aluminum is slightly lower than that of the glass so the overall U value of the window system is a little lower. The reduction in SHGC and Tvis is because the frames decrease the area of solar transmittance through the windows.

For the case of using clear glass with fixed PVC frames, the values of U, SHGC, and Tvis are reduced by 15%, 18%, and 20%, respectively. The reduction in U is due to that U of PVC is lower than that of the glass thus the overall U value of the window system is lower. The reduction in SHGC and Tvis is because the frames decrease the area of the glass portion of the windows. However, SHGC and Tvis in this case are lower than the previous case, especially Tvis that should be equal due to the same frame configuration, because the PVC frames have a little larger area. PVC is categorized as plastic or polymer which has lower strength than aluminum which is metal so the PVC frames need some reinforcement to increase the strength causing a larger area that blocks solar transmittance more than the aluminum frames.

Fig. 4 shows comparisons of properties of window systems using PVC fixed and sliding frames with the base case to see the impacts of the frame pattern. In the case of PVC fixed frames, U, SHGC, and Tvis are decreased by 15%, 18%, and 20%, respectively. In the case of PVC sliding frames, U, SHGC, and Tvis are decreased by 17%, 22%, and 24%, respectively. The sliding frames cause lower values of window system properties compared with the fixed frames because of a larger frame area.

### 3.2 Impacts of Window System Properties on Building Energy Consumption

Annual energy consumption of the sample building when each case of window system combinations was applied is shown in Fig. 5. It can be seen that the energy consumption is less when properties of frames are taken into account. The energy consumption when using PVC frames is less compared with the cases of using aluminum frames. The lowest energy consumption occurs in the case of using low-E coating glass with PVC sliding frames.

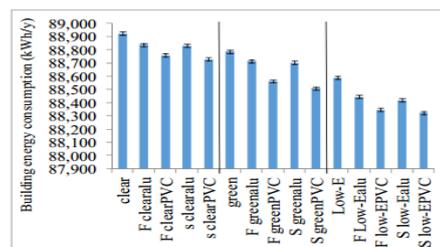


Fig. 5: Annual energy consumption of the sample building when using different window system combinations

When considering the two cases that have the most difference in properties, i.e., the base case of using clear glass without frames and the case of using low-E glass with PVC sliding frames, it was found that the energy consumption differs by only 0.67% even though U, SHGC, and Tvis are different by as much as 58%, 37%, and 26%, respectively. This suggests that applying properties of pure glass without frames for windows when calculating or simulating building energy consumption can be done as usual without causing any significant errors.

Nonetheless, only one sample building with only one WWR is considered in this work. Moreover, the results are not consistent with the work of Sekhar and Lim that mentioned that good window systems could help reduce heat gains into a building thus the size of air conditioning systems while utilizing daylighting and cutting down the number of electric lighting fixtures both of which would lead to a significant decrease in building energy use [7]. Further studies using more number of buildings, more building applications, and more values of WWR should be carried out.

#### 4. Conclusion

This work was to study the impacts of window frames on building energy consumption. The analysis was carried out using 3 glass types, 2 frame materials, and 2 frame configurations applied to a sample office building. It was found that even though when the values of U, SHGC, and Tvis differ the most between the base case of using clear glass without frames for windows and the case of using low-E glass with PVC sliding frames (differ by 58%, 37%, and 26%, respectively), the annual energy consumption from the simulation is different by only 0.67%. Therefore, using properties of pure glass without frames for windows in the building energy consumption calculation or simulation as conventionally done would not cause significant errors in the results. Further studies using more number of buildings, more building applications, and more WWR values should be carried out to gain more solid evidences on the conclusion.

#### 5. Acknowledgement

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