Impact of Glass Window to Heat Load in Office Building in Different Climates

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Abstract The process of urbanization with the social and economic development in countries, the large and very large building are increasingly serving for administrative, office, commercial, and residential. Nowadays, buildings oriented to meet the aesthetic requirements, also the convenience and fast construction, the covering structure of these buildings is mostly glass. The experiment of heating and cooling loads of reference room has been conducted through the Japanese program for PC Heat load DACCS HkGS (Daikin) with embedded climate data. The raising of thermal load in reference room gets more impact from the values of WWR than the types of glass. In details, the cooling load of reference room increases 35% in Moscow and 40% in Hanoi when raising the WWR. The results show that, the window is a main impact of thermal load of office building with each typical climate. For the window characteristics in the building, the WWR take more impact to the thermal load than the type of glass. Therefore, the using of window into the facade is a major challenger to in the design of high-rise building when balance the aesthetics and energy consumption in the building.

1. Introduction

Nowadays, modern architectural uses glass for envelope of building, to create many good effects in terms of architectural, decorative and aesthetic. Many high-rise buildings around the world have high performance of saving energy by using glass on envelop, such as: Gherkin Tower in London (England), One Angel Square Building in Manchester (England), The Malaysian Energy Commission headquarters in Putrajaya is also known as Diamond Building, Headquarters Court in Los Angeles, California (USA), Shanghai Tower, China, ...[1]. These buildings are often located in cold climates or have a good design to shade the solar radiation.

Vietnam is a developing country with a strong urbanization process, and many high-rise office and administrative buildings have been built with a glass-enclosed architectural style. In the hot and humid climate of Vietnam, the glass envelop makes a strong impact on the microclimate in the building, raises the electricity consumption for the system heat ventilation and air conditioning [2 - 5].

The administrative center of Danang city in Figure 1 is one of the typical building when using glass for envelope in the hot and humid climate of Vietnam. Information about Danang administrative center building: 37 floors with an area of 65,234 m². The project has demanded more than 90 million US dollars. The building operated from September 2014. After two years operation, due to overheating and lack of oxygen by some unreasonable solutions of ventilation and shading the solar radiation, the building should be reconstructed.
From the survey on more than 1400 medium and large building in Vietnam in 2016, the energy consumption of office buildings has a large proportion when compare with the others [6]. In the trend of urbanization and modernization of local administrative centers, the buildings with high percentage of glazing facade are developed and it meets a serious problem of energy consumption and thermal comfort. According to the investigation about the office building of the Institute of Urban-Rural Planning and Construction, Vietnam Ministry of Construction in 2013, the percentage energy consumption is 55% on air-conditioner and 17% on lighting per the total electricity. Moreover, in the rooms have a lot of glasses, the most of them have been covered with drywall or closed blinds to reduce the heat and glare.

Windows should be considered as a fundamental element to regulate the indoor environment because their role in thermal and visual comfort [7, 8]. However, the window functions are contradictory, such as the need to shield the sun-based radiation could contrarily impact the daylighting.

On the other hands, the windows also affect heating and cooling loads. This topic is reflected in many related studies about the impact of glass windows in building and has been given the recommendations about using glass for the building for their location [9 - 23]. Many studies have been conducted in European countries with a trend of nearly zero energy buildings and focused on high insulation materials, large costs, long payback period (for example, more than 20 years) [10, 11, 12, 13, 15]. However, for warm climate, the high wall insulation is not energy efficient [15, 19]. Some studies add some materials/method for enhance the saving energy through the building's envelope such as solar shading, windows’ glazing type, external wall's insulation and air tightness (infiltration) [19, 23].

In this article, we use heat load software, calculate the thermal load of an office room with a structure, which using the local material in location climate condition. Thus, the study conducted calculations in consideration in each climate context: impact on the thermal load from the window to wall ratio (WWR); impact on the thermal load from the glass type of window.

2. Methodology
The study calculated and compared the heat load of various forms of windows in difference values of WWR for reference room in the office building, on the 7th floor. The percentages of the window increased 20%, 40%, 60%, 80% to 100% (Figure 2) and used difference types of glass (Table 3) for the hot and cold climates, in Hanoi and Moscow (Table 2).

2.1. The reference room
The room is rectangular, dimensions are 8.0 m wide, 4.2 m deep and 4.0 m high, windows and outer walls are oriented to the east, Figure 2.

The surrounds structure of the reference room accords to the building standards of the country, Hanoi (Vietnam) and Moscow (Russian Federation) [27 - 29].

In Hanoi, the outer wall is made by hollow brick and the inner wall is made by plaster and the air gap between them; floor is made by reinforced concrete, lined cement mortars and floor tiles.
For Moscow, the outer wall is made by concrete block and rockwool insulation, the inner wall is made by plaster, and an insulated mineral wool between them; floor is made by reinforced concrete, insulated mineral wool, lined cement mortars and floor tiles. Information of opaque of reference room presented in Table 1.

### Table 1. Opaque of reference room.

| Structure       | Thickness b (m) | Hanoi Thermal transmittance U (W/m²K) | Moscow Thermal transmittance U (W/m²K) |
|-----------------|-----------------|---------------------------------------|---------------------------------------|
| Outer wall      | 220             | 0.585                                 | 330                                   | 0.42                                 |
| Inner wall      | 110             | 1.90                                  | 120                                   | 0.53                                 |
| Floor, roof     | 200             | 2.30                                  | 200                                   | 1.17                                 |

2.2. The characteristics of loading
The reference room working from 8:00 to 17:00 daily with 4 people and their laptops, printers, and cool plants, throughout the year. The setting temperature is 26°C for the summer and 20°C for the winter in both study places. The light loading is 10 W/m², with heat recovery and wind leakage.

Thermal loads are calculated for winter (heating), and summer (cooling) based on the characteristic of reference room. Ventilation with fresh air is provided according to the number of people in the room with standard value is 30 m³/h/per.

2.3. Climate reference
In order to provide representative climate data, we have assigned data for hot and cold climates, Hanoi and Moscow. Table 2 is showed the content of the details of climate data, data refer to ASHRAE 2017 document [30, 31].

### Table 2. Geographic and climate data at the study locations.

| Parameter                              | Hanoi     | Moscow     |
|----------------------------------------|-----------|------------|
| Altitude above sea level (m)           | 12        | 157        |
| Latitude (°)                           | 21 02’    | 55 050’    |
| Longitude (°)                          | 105 40’   | 37 37’     |
| Average annual temperature (°C)        | 23.4      | 5.0        |
| The temperature of the coldest month (°C) | 16.6    | -9.3       |
| The temperature of the hottest month (°C) | 28.8    | 18.2       |
| Average relative humidity (%)          | 84        | 76.7       |

2.4. Configure external surfaces with glass windows
External wall of reference room is 32.0 m², window area varies as shown in Figure 3.
Furthermore, we consider the different types of window glass which used in a building, including single or double glass, clear glass or heat absorbing glass, reflective glass (reflective coated glass), tinted reflective coated glass. Specifically, we have 5 types of window glass according to the features as shown in Table 3. For buildings in Hanoi, we used window glass types K1, K3 and K5. For buildings in Moscow, used window glass type K2, K4 and K5. The evaluation calculated for 5 cases of changing WWR with 3 difference types of glass in cold and hot climates. So, we have 15 difference configurations for each reference locations (5 types of window to wall ratio- WWR (Figure 3): 20%, 40%, 60%, 80% and 100%, 5 types of glass: K1, K2, K3, K4 and K5 (Table 3).

Table 3. The thermal and optical properties of glass window are calculated.

| Window                                      | Blind type         | Shading factor | Overall heat transfer coefficient (W/m²K) |
|---------------------------------------------|--------------------|----------------|------------------------------------------|
| K1: Heat absorbing glass 6 mm (single glass) | Bright color       | 0.48           | 4.95                                     |
| K2: Clear glass 6 mm + clear glass 6 mm (double glass) | Bright color | 0.52           | 2.97                                     |
| K3: Heat absorbing glass 6 mm + clear glass 6 mm (double glass) | Bright color | 0.43           | 2.97                                     |
| K4: Clear glass (outside) 6 mm+ low reflective coated glass 6 mm (double glass) | Bright color | 0.46           | 2.20                                     |
| K5: Low reflective coated glass 6 mm + clear glass 6 mm (double glass) | Bright color | 0.34           | 2.20                                     |

3. Results and discussion

3.1. Impact of window area changes

The results are presented in Table 4 and Table 5, with the heating load, cooling load for separate glass windows and the total heating load of the reference room; the ratio of them of the glass window per the total heating load of the reference room. The WWR has a greatly impact to the total heat load of office buildings, especially cooling loads, increasing from 45.6% to 86.3% for Moscow and from 28.6% to 75.8% for Hanoi when they raise from 20% to 100%.

For heating load, the WWR is not much affected in Hanoi because the outdoor air temperature during the cold season in Hanoi is quite high and the amount of heat exchanged through glass window is negligible. For Moscow, the heating load significantly affects the WWR (see Figure 4, Figure 5), due to in the winter outdoor air temperature is low, and the heat loss through glass window.

Table 4. Calculation thermal loads for Moscow.

| K   | WWR (%) | Aw (m²) | By the window (W) | Total (W) | % by window/total |
|-----|---------|---------|-------------------|-----------|-------------------|
|     |         |         | Heating load      | Heating load | Cooling load     | Heating load | Cooling load |
| K2  | 20  | 6.4     | 926               | 1571       | 5425             | 2821         | 17.1         | 55.7         |
|     | 40  | 12.8    | 1852              | 3143       | 6220             | 4393         | 29.8         | 71.5         |
| K4  | 60  | 19.2    | 2778              | 4714       | 7015             | 5694         | 59.6         | 79.0         |
|     | 80  | 25.6    | 3704              | 6285       | 7810             | 7535         | 47.4         | 83.4         |
|     | 100 | 32.0    | 4630              | 7857       | 8605             | 9107         | 53.8         | 86.3         |
|     | 20  | 6.4     | 686               | 1390       | 5185             | 2640         | 13.2         | 52.7         |
|     | 40  | 12.8    | 1372              | 2780       | 5740             | 4030         | 23.9         | 69.0         |
| K5  | 60  | 19.2    | 2058              | 4170       | 6295             | 5420         | 32.7         | 76.9         |
|     | 80  | 25.6    | 2744              | 5560       | 6850             | 6810         | 40.1         | 81.6         |
|     | 100 | 32.0    | 3430              | 6950       | 7405             | 8200         | 46.3         | 84.8         |
|     | 20  | 6.4     | 686               | 1027       | 5185             | 2277         | 13.2         | 45.1         |
|     | 40  | 12.8    | 1372              | 2055       | 5740             | 3305         | 23.9         | 62.2         |
|     | 60  | 19.2    | 2058              | 3082       | 6295             | 4332         | 32.7         | 71.1         |
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Table 5. Calculation thermal loads for Hanoi.

| K | WWR (%) | Aw (m²) | By the window (W) Heating load | By the window (W) Cooling load | Total (W) Heating load | Total (W) Cooling load | % by window/total Heating load | % by window/total Cooling load |
|---|---------|---------|----------------|----------------|----------------------|----------------------|-------------------------|-------------------------------|
| K1 | 20 6.4 | 316 1611 | 2051 | 4362 | 15.4 | 36.9 |
| 40 12.8 | 632 3223 | 2257 | 5930 | 28.0 | 54.4 |
| 60 19.2 | 948 4835 | 2464 | 7497 | 38.5 | 64.5 |
| 80 25.6 | 1264 6446 | 2671 | 9063 | 47.3 | 71.1 |
| 100 32.0 | 1580 8057 | 2878 | 10629 | 54.9 | 75.8 |
| 20 6.4 | 190 1398 | 1925 | 4149 | 9.9 | 33.7 |
| 40 12.8 | 379 2795 | 2004 | 5502 | 18.9 | 50.8 |
| K3 | 60 19.2 | 569 4193 | 2085 | 6855 | 27.3 | 61.2 |
| 80 25.6 | 758 5591 | 2165 | 8208 | 35.0 | 68.1 |
| 100 32.0 | 948 6989 | 2246 | 9561 | 42.2 | 73.1 |
| 20 6.4 | 140 1101 | 1875 | 3852 | 7.5 | 28.6 |
| 40 12.8 | 281 2201 | 1906 | 4908 | 14.7 | 44.8 |
| K5 | 60 19.2 | 421 3302 | 1937 | 5964 | 21.7 | 55.4 |
| 80 25.6 | 562 4402 | 1969 | 7019 | 28.5 | 62.7 |
| 100 32.0 | 702 5503 | 2000 | 8075 | 35.1 | 68.1 |

Figure 4. Cooling and heating load when changing WWR from 20% to 100% for Moscow.

Figure 5. Cooling and heating load when changing WWR from 20% to 100% for Hanoi.

The Figure 4 and 5 showed that, in the type K5 glass, the cooling load and the heating load increases steadily by linear equation, proportional with the increase in the area of glass windows.

3.2. Impact of window features
Evaluating of the impact on the heating load, the trends line of cooling load decreases based on changing the glazing types, lower than based on WWR.
In Winter, the type of glass windows does not affect on heating loads in Hanoi because the outdoor temperature during the cold season in Hanoi is quite high, and the amount of heat exchanged through glass windows is negligible. In contrast, the heating load significantly affects the change of the glass window type in Moscow climate (see Figure 6, Figure 7).

The Figure 6 and 7 showed that the cooling load and the heating load varies by linear equation according to the different types of glass windows, with the WWR is 60%, equations for total cooling load and total heating load is as below.

3.3. Impact of window features and ratio WWR
The change in cooling load and heating load for each type of glass, data is shown in Figures 8 and Figures 9 for Moscow and Hanoi. Based on WWR, each type of glass windows will calculate difference values of thermal loads.

Figure 6. Cooling and heating loads when changing different types of glass for Moscow.  
Figure 7. Cooling and heating loads when changing different types of glass for Hanoi.

Therefore, in hot climates, the effect of glass windows on heating loads is negligible.

Summary: At first, the WWR ratio is the main impact indicator on the total heat load of an office building, especially cooling loads, accounting for from 45.6% to 86.3% for Moscow and from 28.6% to 75.8% for Hanoi when the ratio WWR is from 20% to 100%. In hot climates, ratio WWR was not affect significantly to the total heating load of office. However, it was strongly influenced with regard to cold climate, when the outdoor temperature is low, and the heat loss through the glass has been increased (the slope of the linear equation total heating load of Moscow is 17.7 times the slope of the linear equation of Hanoi). However, considering the combined effect of the ratio WWR and the types of glass used, when using glass for saving – energy, for hot climates the cooling load will increase.
sharply when increasing ratio WWR, and for cold climates both cooling and heating loads are increased.

4. Conclusion
The results show that, the window is a main impact of thermal load of office building with each typical climate. For the window characteristics in the building, the WWR take more impact to the thermal load than the type of glass. Therefore, the using of window into the facade is a major challenger in the design of high-rise building when balance the aesthetics and energy consumption in the building. Moreover, the research about daylighting and energy consumption in the building should be applied for calculate the optimal value of WWR to each local climate.

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