Energy Simulation of HVAC Systems with High Performance Windows

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ABSTRACT

The objective of this study is to determine the most energy efficient and cost effective combination of architectural elements and mechanical systems to specify in an office building while maintaining a comfortable and healthy indoor environment for the occupants. A commercial office building located in the Minneapolis area with three heating, ventilating, and air-conditioning (HVAC) systems and three window systems (double clear, double low E and triple low E) has been simulated by Energyplus. The HVAC systems include variable air volume (VAV) with reheat, VAV with baseboard heater, and a radiant floor system. All nine combinations of window and HVAC systems have been compared and studied in terms of energy use and operating costs, while maintaining nearly identical indoor thermal comfort conditions in Minneapolis weather condition. A model for calculating mean radiant temperature (MRT) and temperature asymmetry has been developed to estimate the temperature asymmetry of a perimeter zone of the building.

KEYWORDS

HVAC, Building simulation, Energyplus, Thermal comfort, Windows.

INTRODUCTION

Heating, ventilating, and air-conditioning (HVAC) energy requirements and the corresponding indoor thermal environment are always two major issues for building design. There are several different approaches related to these two issues.

First, different HVAC systems have different energy requirements and provide different indoor environmental conditions for occupants. Zaidi [1] used a commercial energy-analysis computer program to compare several HVAC systems including variable air volume (VAV) system, fan coil system and water-loop heat pump (WLHP) system. Based on the results, he concluded that WLHP is the most energy efficient system for commerial buildings in mild climates.

Second, since the thermal comfort of building occupants is an important parameter of the indoor environment, several models have been developed to evaluate thermal comfort. The most often used model is Fanger's predicted mean vote (PMV) model [2] [3], which is based on human body energy balance and an empirical fit to thermal sensation. Several other models have been developed and are reviewed by Brager and de Dear [4].

Third, the fenestration selection also has great impact on energy requirements and thermal comfort issues. Carmody [5] emphasized the energy impacts of window selections. He compared energy use for different types of commercial building window systems and proposed several factors, such as interior environment and life cycle cost to help make a decision on selecting window systems. Lyons [6] evaluated window performance in terms of thermal comfort. He concluded that windows are not the primary element affecting the comfort of occupants. However, when the occupant is close to the window, a hot or cold window surface can cause discomfort. Therefore, the temperature difference between the window surface and room air is important in evaluating the window's impact on thermal comfort.

The thermal comfort of building occupants, and the HVAC and fenestration systems are always major concerns. However, the previous studies only considered the impact of each of them separately on building performance. There are few studies that consider their interaction. The purpose of this study was to integrate building fenestration and mechanical system design to provide good thermal comfort for occupants. The energy consumption and initial cost were determined for different combinations of window and mechanical systems while maintaining a comfortable thermal environment.

METHODS

In this study, a commercial office building prototype, which was originally developed by Lawrence Berkeley National Laboratory (LBNL) [5], was used. The building includes three stories, each of them has four 140 square meter perimeter zones, and a 30.5 m by 30.5 m square core zone. Each perimeter zone consists of ten 3.0 m by 4.6 m private offices. The total floor area is 4500 square meters. A typical construction was used for the exterior walls, and that consisted of face brick, rigid insulation, concrete block and gypsum board from outside to inside. The roof used in this study consisted of a built-up roof, perlite board, a polyisocyanurate insulation layer and a steel deck.

The building is located in Minneapolis, Minnesota, USA, and therefore the weather data file for Minneapolis was used in the study.

The internal loads in the building have three components including occupants, lighting and office equipment loads. The peak occupant load is 9.3 square meters per person. The peak lighting load is 16 W per square meter and the peak office equipment load is 11 W per square meter. The occupancy and operating conditions of the building were set to be typical for commercial office buildings. The building had daytime operation from 8 a.m. to 5 p.m. and nighttime operation was from 5 p.m. to 8 a.m. for the five working days during the week.

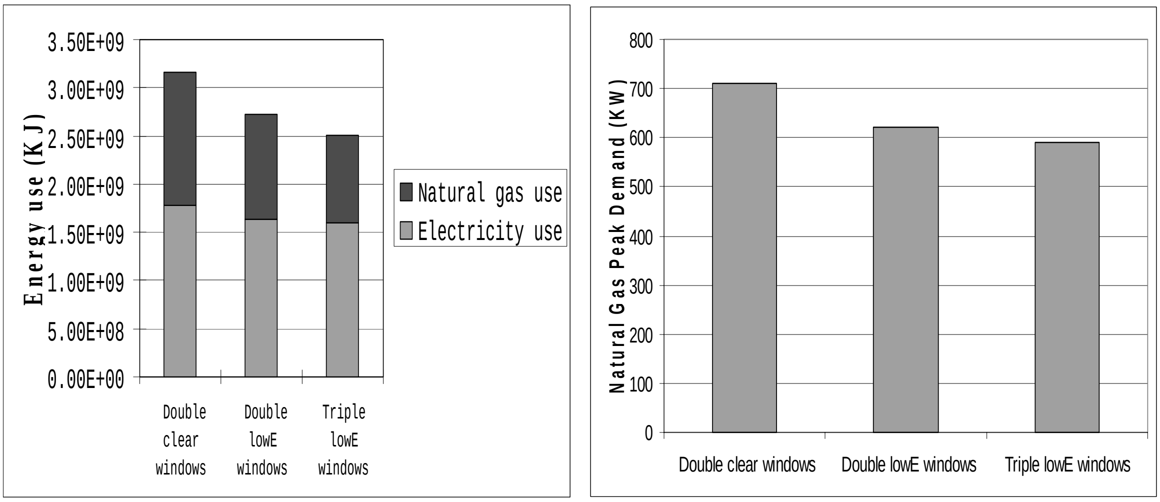
All exterior walls of the perimeter zones have windows. The window-to-wall area ratio (WWR) is 0.6. There is no interior or exterior shading. In order to evaluate the impact of window systems on building energy use, three types of windows were used, double clear, double low E and triple low E window systems. Their U values are 4.33, 3.07 and 1.29 W/m^2K respectively.

The HVAC systems selected for this study are a variable-air-volume (VAV) system with reheat, a variable-air-volume (VAV) system with perimeter baseboard heater and a radiant floor system.

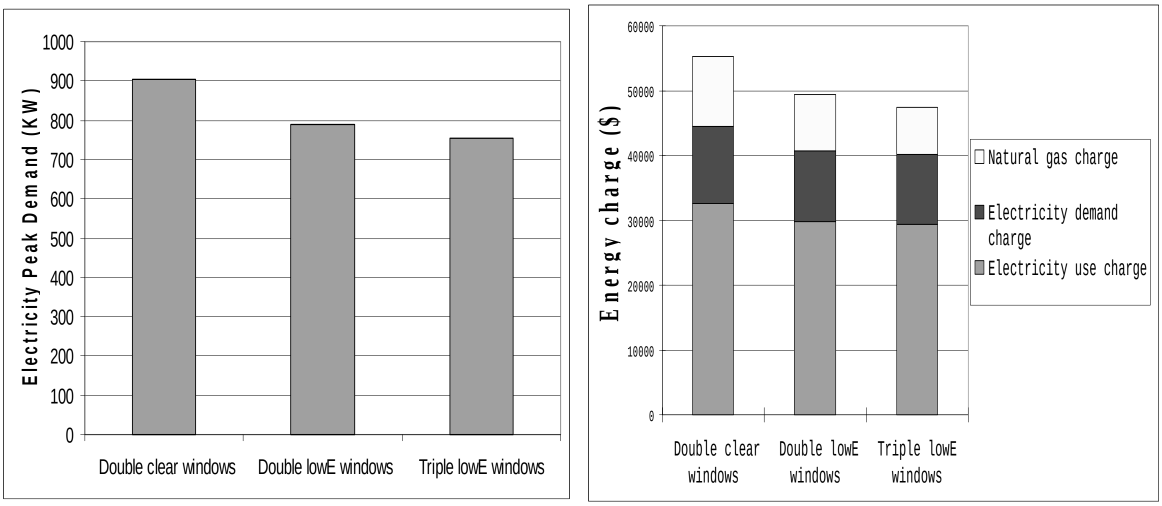
Energyplus [7] and Windows5.0 [8] were used in this study as the main simulation tools.

RESULTS

In this study, for all the HVAC and window system combinations, the PMV values were maintained at 0.8 in summer and -0.8 in winter. In other words, all the systems provided the same level of thermal comfort. Figure 1a shows comparisons of annual energy use for various window systems for a VAV system with reheat. The energy use is the highest for the double clear window system and the lowest for the triple low E window system. The figure implies that the double clear window system consumes 20% more energy than the triple low E window system to provide the same thermal comfort conditions.



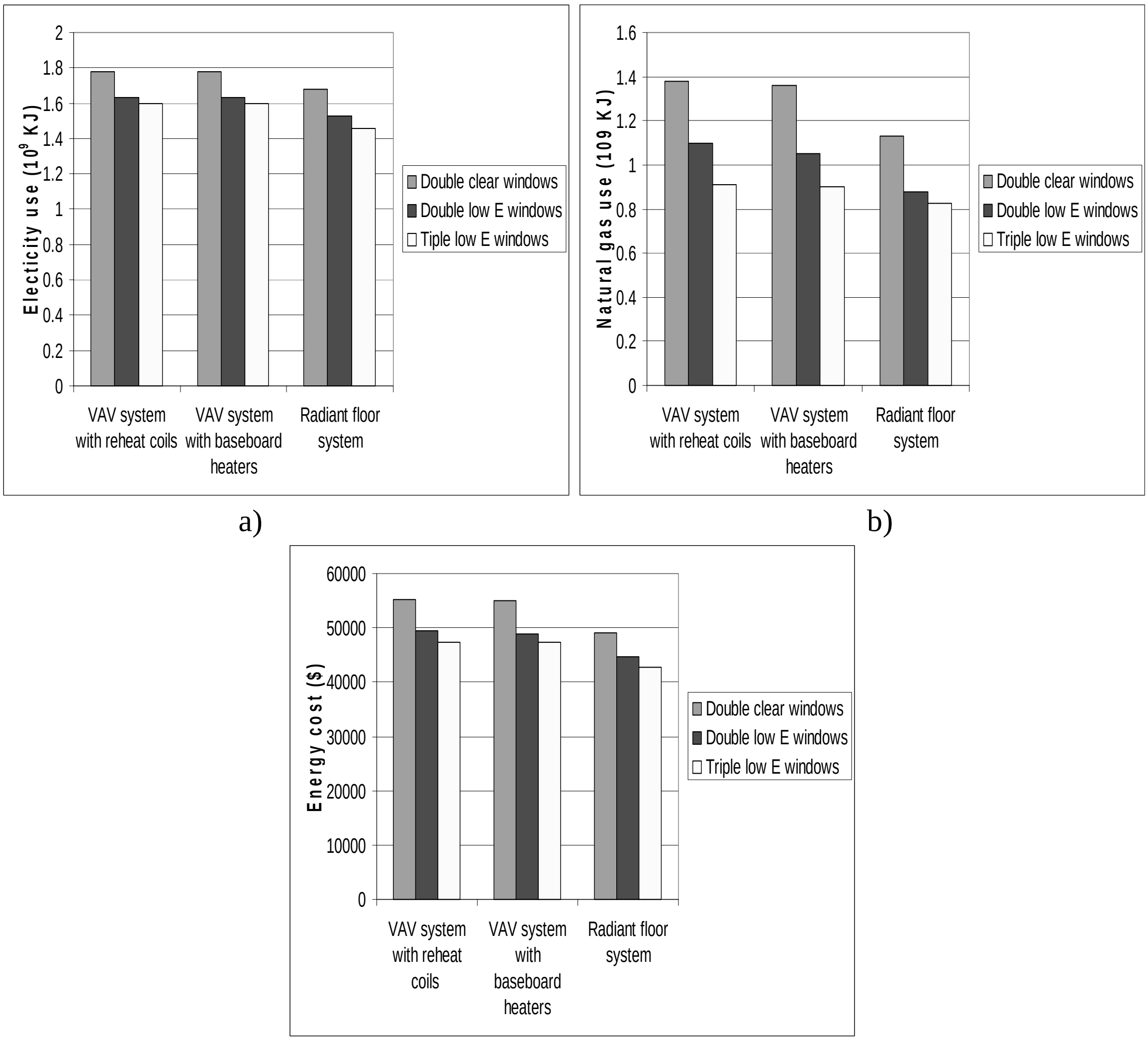
a) b)



c) d)

Figure 1. Comparison of energy use for a VAV system with reheat and three types of windows. a) Annual energy use, b) Natural gas peak demand, c) Electricity peak demand, d) Energy charge.

Figures 1b and 1c show the peak demand for this option. It also can be seen that window selection effects the peak demand of both natural gas and electricity. Figure 1d shows the annual energy cost for the entire building with a VAV system with reheat and different types of windows. The gas and electricity rates used in this study were the average commercial price in Minnesota [9].



a) b)

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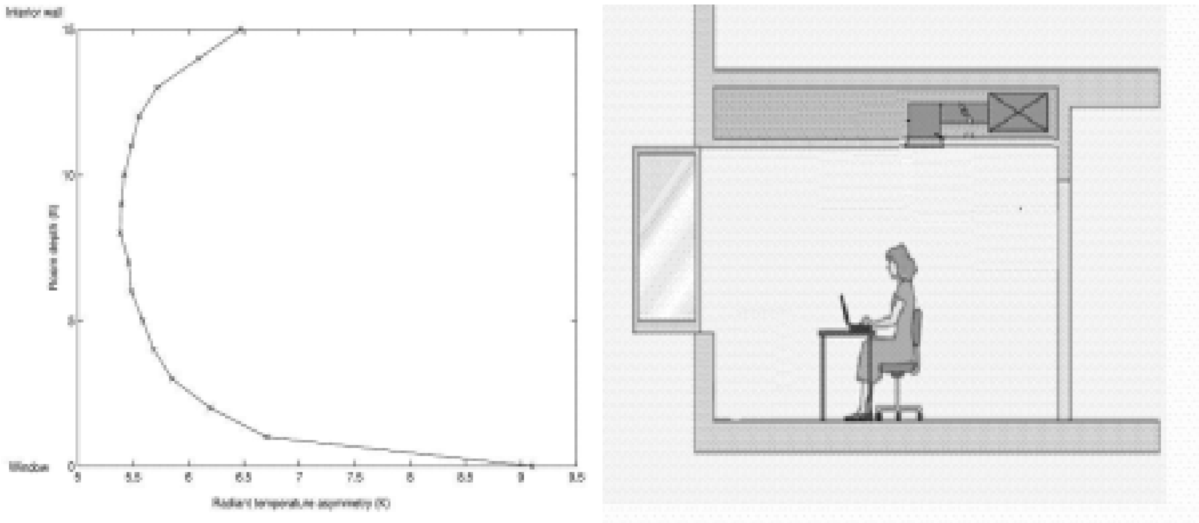
Figure 2. System comparsions. a) Annual electricity use, b) Annual natural gas use, c) Energy cost.

Figures 2a and 2b show the annual natural gas and electricity requirements for all three systems. The annual energy costs are given in Figure 2c. The radiant panel system has a lower annual energy cost compared to the other two HVAC systems when using the same type of window.

A simulation tool based on radiation heat transfer has been developed for predicting the Mean Radiant Temperature (MRT) and radiant temperature asymmetry in the perimeter rooms. The defination of MRT and radiant temperature asymmetry can be found in [2] and [10]. Figure 3a shows the radiant temperature asymmetry for a perimeter room in the simulated building with double low E windows. The x axis gives the radiant temperature asymmetry 0.61 m above the floor, and the y axis gives the room depth, it starts at 0, which represents the window, and ends at 4.57 meters, which represents the interior wall. The 0.61 m height above the floor is chosen because it is typical of people sitting. The weather conditions in this simulation is a Minneapolis winter design day. It has been proven that windows cause radiant temperature asymmetry that leads to occupant discomfort. ASHRAE Standard 55 suggests that radiant asymmetry should be less than 10 K. From the present results, it can be seen that the radiant asymmetry for the double low E window system meets this requirement.



a) b)

Figure 3. a) Radiant temperature asymmetry for the perimeter room with double low E windows, b) Perimeter zone with VAV system.

DISCUSSION

In this study, the impact of different window and mechanial systems on energy and cost with fixed thermal comfort has been evaluated in a Minneapolis climate condition. The triple low E window system has the lowest HVAC energy consumption and the double clear window system has the highest. The results show that the energy requirement for the triple low E window system is lower than that of the double low E window system and the double clear window system. This is because that high performance window has a higher R-value, which provides more insulation to the building in winter, and a lower SHGC, which reduces solar transmittance into the building in summer. In addition, the high performance window has a higher window inside surface temperature in winter and a lower window inside surface temperature in summer. It provides a higher mean radiant temperature in winter and a lower mean radiant temperature in summer, which results in more comfortable conditions at a fixed dry bulb temperature. In this study, the thermal comfort was maintained at a constant value by adjusting the room air temperature set points. Therefore, the energy use was also reduced by modulating the temperature set points when high performance windows were used.

The results show that the radiant floor system requires the lowest energy to maintain the same thermal comfort level. This is because the radiant floor system provides a higher mean radiant temperature in winter and a lower mean radiant temperature in summer. Therefore, the room air temperature setpoint can be decreased in winter and increased in summer while thermal comfort is maintained. Due to the adjustment of the air temperature, the energy use can be reduced.

Designers often use perimeter heating systems to overcome the radiant temperature asymmetry problems in cold climates. However, high-performance windows such as double low E windows, can alleviate thermal discomfort caused by the radiant asymmetry. There is no need to use a perimeter heating system. The VAV system with reheat takes all the heating load. The main advantage of using VAV systems with reheat and double low E windows, instead of the perimeter heating system with double clear windows is that the piping can be reduced. Initial HVAC costs and energy savings can be achieved by reducing the piping.

ACKNOWLEDGEMENTS

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