Assessing the Effects of Glazing Type on Optimum Dimension of Windows in Office Buildings

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One of the most effective methods to reduce energy loss through the building envelope is to optimize the thermal performance, area, and layout of the transparent components in the facade in order to obtain minimal heat losses and optimal solar gains. When considering the thermal performance of these transparent components, one should consider not only heat loss (or gains) caused by thermal transmission, but also the beneficial effects of incident solar radiation and hence reduced demand for heating and artificial lighting.

Design of efficient fenestration is one of the several design approaches that has potential to reduce energy consumption in commercial buildings. Therefore, in this study the effect of using different types of glazing including single-glazed, simple double-glazed (air filled) and double-glazed with low-e coating (argon filled) on optimized window dimensions and layout in an office room is investigated. EnergyPlus software is used to calculate the required heating and cooling load for different types of window glazing. In addition, Genetic Algorithm and Simulated Annealing Algorithm are used to determine the optimal size and layout of the windows. A typical office room located in Dallas, Texas is selected as a case study. The results of optimization reveal that the obtained optimum area of glazing is very small in comparison with the area of the external wall (between 6.4 to 18%). In addition, at different room orientation, the optimum area of the double-glazed window with low-e coating is larger than double and single-glazed window. Results indicate that the glazing type and room orientation has a larger effect on heating load than cooling load and lighting.

Keywords: Window area, Heating-cooling load, Commercial buildings, EnergyPlus, Genetic Algorithm and Simulated Annealing Algorithm

Introduction

The construction of new commercial buildings in the United States has increased significantly in recent years. In 2003, there were approximately 4.9 million office buildings in the U.S with an average size of 14,700 square feet. The U.S. adds about 1.6 billion square feet per year — nearly 110,000 buildings annually at the mean size, or roughly half a million buildings every five years. Commercial buildings consumed 19% of the total energy used in the United States with associated carbon dioxide emissions totaling 1.0 billion metric tons. The majority of energy use in commercial buildings is related to lighting and space heating/cooling which is approximately 52.8% of their total energy used. Internal sources (electrical lighting, building equipment, and people) and external sources (solar radiation, air temperature, and wind) have considerable effects on the heat gain and loss through facades. Transparent parts of building envelopes, or fenestration, are particularly vulnerable to large heat gain and loss in buildings since they are made from highly conductive materials and exposed to the direct heat gain from solar radiation. Therefore, properly oriented and energy efficient windows are one of the crucial elements both for newly built and retrofitted buildings (Kaklauskas, Zavadskas et al. 2006).

A rich volume of existing publications attests the importance of windows and glazing types in reducing energy consumption in buildings (Ghisi and Tinker 2005; Motuziene and Juodis 2010; Tian, Chen et al. 2010; Ihm, Park et al. 2012; Karabay and Arıcı 2012; Chaiwiwatworakul and Chirarattananon 2013; Grynning, Gustavsen et al. 2013). With the increase of studies on low energy buildings, the effect of the fenestration on this kind of construction has been assessed (Persson, Roos et al. 2006; Gasparella, Pernigotto et al. 2011), both for heating-dominated climates (Persson, Roos et al. 2006) and for cooling-dominated climates (Gasparella, Pernigotto et al. 2011). Also available, are a variety of methodologies for the analysis of energy consumption associated with fenestration in buildings (Motuziene and Juodis 2010; Gasparella, Pernigotto et al. 2011; Tsagarakis, Karyotakis et al. 2012). Johnson et al. (JOHNSON 1984) and Choi et al. (CHOI 1984) examined the effect of fenestration parameters and relevant factors on energy consumption in a typical office building by hourly simulations using DOE-2.1 B. They carried out the sensitivity analysis to study the effect of orientation, window area, glazing properties (U-value, shading coefficient and light transmittance), installed lighting power, and lighting control strategy on fenestration energy performance. Later, Ghisi and Tinker (Ghisi and Tinker 2005) applied an ideal window area concept to develop a methodology to estimate potentials for lighting energy savings from daylighting. They examined different window-to-wall ratios to find an ideal one that can save the maximum amount of lighting energy as well as different ratios of room width and depth. Thermal energy consumption was taken into account; yet, the thermal properties of external walls and glazing transmittance were kept as constant in their parametric study. In another study by Jaber and Ajib(Jaber and Ajib 2011), the thermal performance and economic benefit of different windows including single, double and triple glazing and their orientation in different climate zones was investigated. Similar studies were carried out by Kim et al. (Kim 2004) and Mun et al. (Mun 2006) to assess thermal performance of low-e glazing for office buildings. Particularly, Kim et al. have proposed the application of clear low-e glazing in mixed heating and cooling climates and tinted low-e glazing in cooling dominated climates.

In this study in this study the effect of using different types of glazing including single-glazed, simple double-glazed (air filled) and double-glazed with low-e coating (argon filled) on optimized window dimensions and layout in an office room is investigated. EnergyPlus software is used to calculate the required heating and cooling load for different types of window glazing. In addition, Genetic Algorithm and Simulated Annealing Algorithm are used to determine the optimal size and layout of the windows. The results of a detailed analysis are analyzed to evaluate the impact of a proper window selection and an optimal glazing area in a typical commercial building in Dallas, Texas and to minimize the energy impact of windows.

Description of the Referenced Room

A room with the area of 20 m^2 which located in Dallas, Texas (32.7° N latitude; 96.7° W longitude) is selected as a case study. Dallas is located in hot-Humid climate with four distinct seasons (winter, spring, summer, and autumn). Figure 1 shows the schematic design of the house. The weather file used in the simulation is obtained from TMY3 database provided by the National Renewable Energy Laboratory (NREL 2005).

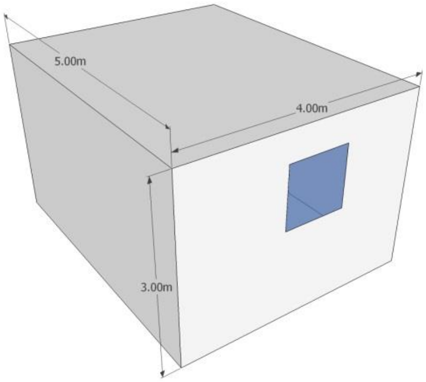


Figure 1. Schematic design of the house

The dimension of studied room is 5 m long, 4 m wide and a height of 3m. This model has one window placed on external wall. For the analysis, all opaque building components of the reference room, with the exception of one of wall surfaces are considered as adiabatic. The external wall is designed based on the ASHRAE 90.1 2007 standard(ASHRAE 2007). Three types of windows including single glazed, simple double glazed (air filled) and double glazed with low-e coating (argon filled) are considered in this study. Thickness of glazing layer is 3 mm while thickness of gas layer is 13mm. The length and height of windows varies from 0 to 3.8m and 0 to 2.8m respectively with 0.1m increment. Four orientations including south, east, north, and west are considered and the whole building is rotated toward the desired orientation. The optical properties of glazing are shown in Table 1.

Table 1

Optical Properties of glazing materials

	Optical properties	Single-glazed	Double-glazed	Low-e
	Visible Transmittance at Normal Incidence	0.881	0.898	0.82
	Front Side Visible Reflectance at Normal Incidence	0.08	0.081	0.11
	Back Side Visible Reflectance at Normal Incidence	0.08	0.081	0.12
	Solar Transmittance at Normal Incidence	0.775	0.837	0.74
	Front Side Solar Reflectance at Normal Incidence	0.071	0.075	0.09
	Back Side Solar Reflectance at Normal Incidence	0.071	0.075	0.1
	Front Side Infrared Hemispherical Emissivity	0.84	0.84	0.84
	Back Side Infrared Hemispherical Emissivity	0.84	0.84	0.2
	Visible Transmittance at Normal Incidence	-	0.898	0.898
	Front Side Visible Reflectance at Normal Incidence	-	0.81	0.081
	Back Side Visible Reflectance at Normal Incidence	-	0.081	0.081
	Solar Transmittance at Normal Incidence	-	0.837	0.837
	Front Side Solar Reflectance at Normal Incidence	-	0.075	0.075
	Back Side Solar Reflectance at Normal Incidence	-	0.075	0.075
	Front Side Infrared Hemispherical Emissivity	-	0.84	0.84
	Back Side Infrared Hemispherical Emissivity	-	0.84	0.84

In this study, the heating and cooling set points are considered equal to 22ºC and 26.6ºC respectively. The internal gains due to people, lighting and electric appliances are estimated according to annual values narrowed down by the ASHRAE[18] and taken into the calculations as a profile with monthly values. The "Ideal Loads Air System" is used in order to study the performance of a building without modeling a full HVAC system. Furthermore, the coefficient of performance (COP) of the heating and cooling system is defined at 0.8 and 3 respectively. In addition to daylighting illuminance, artificial lighting of 300 lux is considered in this study. The adopted design parameters and operation conditions are listed below:

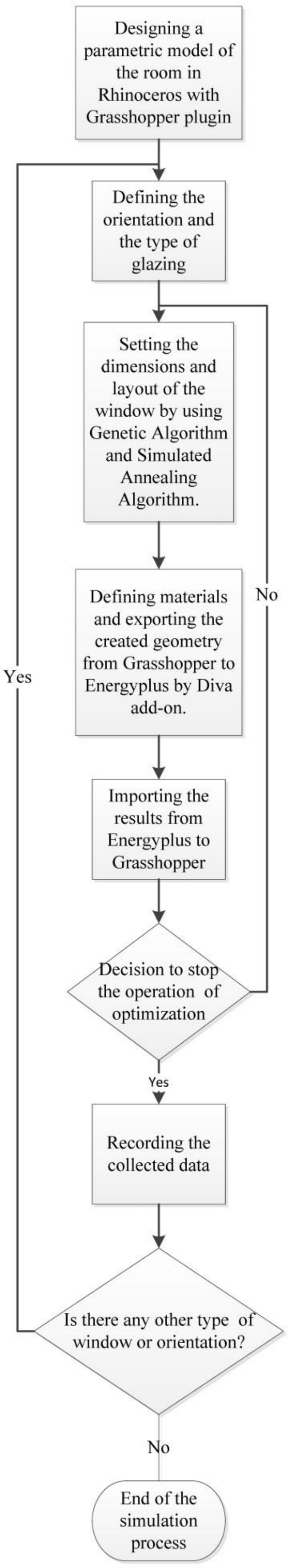
- Occupancy density: 0.1 m^2 per person.
- Installed power of the artificial lighting system: 11.74 W/m^2.
- Working schedule: from 8:00 to 18:00 on Monday–Friday, from 8:00 to 13:00 on Saturday.
- Design illuminance: 300 lux.
- Sensible heat gain from equipment: 4 W/m^2.
- Ventilation rate for fresh air: 0.00944 m^3/s /person.
- Infiltration: 0.5 air changes per hour.

Methodology

The flowchart of solution methodology used in this work is illustrated in Figure 2. After defining building geometry, weather data, HVAC system, lighting and occupant schedule, the optimum values of window dimension for each glazing type is obtained separately for each room orientation (i.e., south, north, east, and west). Then the obtained results are compared together in order to find the optimum dimension of windows based on the glazing type and room orientation. EnergyPlus (Crawley 2000), which is a whole building dynamic energy simulation software, is employed to model energy use in buildings. EnergyPlus models heating, cooling, lighting, and ventilation. It can model multi-zone airflow, thermal comfort, and natural ventilation systems.

In this study a parametric model of the room is developed in Rhinoceros modeling software with Grasshopper plugin. Diva add-on is used to define building materials and to export the developed geometry to Energyplus. Galapagos tool in Grasshopper is set to minimize the total required energy for heating, cooling and lighting of the developed model (mathematically named cost function). In order to minimize the cost function, Glalapagos changes the demonstrations of the window and its layout.

Two optimization methods including Genetic Algorithm and Simulated Annealing algorithm are used in this study to determine the optimum dimension and type of glazing. As optimization process proceeds, little by little, the stored solutions become better and approach the optimum solution. The process is continued until the difference between the obtained results is less than 1%.



Results and Discussion

This study evaluates the influence of using single-glazed, simple double-glazed (air filled) and double-glazed with low-e coating (argon filled) on optimized window dimensions and layout in an office room. Table 2 shows the optimum dimension of three different types of glazing at different room orientation. As it can be observed, the obtained optimum area of glazing is very small in comparison with the area of the external wall (between 6.4 to 18%). In addition, at different room orientation, as expected, the optimum area of the double-glazed with low-e coating is larger than double and single- glazed window. It is obvious that if other cooling system such as evaporative cooler uses in a building, the optimum dimension will increase and the effect of the glazing type will be significant. This can be attributed to the lower effect of cooling load in this case. Also, it should be noticed that in order to compare the therm al performance of three different types of glazing the optimum dimension of windows is considered in this study. This means that if the area of window becomes larger than the optimum dimension, the effect of using double pane and double pane with low-e coating glazing will increase.

Table 2

Figure 2. Schematic structure of the proposed methodology

Optimum glazing dimension

Orientation	Glazing Type	Optimum Dimension		
		Width (m)	Height (m)	Area (m)
South	Single-glazed	0.7	1.2	0.84
	Double-glazed	1.22	0.92	1.12
	Low-e	1.2	1.0	1.2
East	Single-glazed	0.8	1.2	0.96
	Double-glazed	1.22	1.12	1.36
	Low-e	1.4	1.1	1.54
West	Single-glazed	0.7	1.1	0.77
	Double-glazed	1.02	1.02	1.04
	Low-e	1.2	1.0	1.2
North	Single-glazed	1.1	1.2	1.32
	Double-glazed	1.53	1.22	1.86
	Low-e	1.8	1.2	2.16

In the next step of the current study, the obtained optimum dimension for each glazing type and orientation (seen in Table 2) is used to calculate the total energy consumption in a typical office room. Figure 3 shows the total energy consumption including heating, cooling, and lighting in a year for three types of glazing at different room orientation. Results show that the glazing type and room orientation have a larger effect on heating load than cooling load and lighting when optimum dimension of glazing is considered. Besides, changing the glazing type from single to double, double to low-e, and single to low-e reduces the total energy consumption respectively by 6, 9 and 10 % at the north room orientation which represents the highest energy saving. However, if only heating energy consumption is considered, then the energy saving can increase up to 16% depending on the glazing type and room orientation. The application of simple double-glazed and double-glazed with low-e coating window in building increases the overall R-value. Increase in R-value decreases the required heating load both in day and night time in winter. However, higher R-value increases the required cooling load in night time and decreases the required cooling load in daytime in summer. This can be attributed to the lower heat loss through double pane and double-pane low-e glazing window in daytime in summer. These results indicate the significant effect of glazing type and orientation on heating energy consumption. In addition, results showed that changing the type of optimum glazing from single-glazed to simple double-glazed and double-glazed with low-e coating will reduce the required heating load and lighting in both heating and cooling seasons, however, the cooling load will increase in the summer.

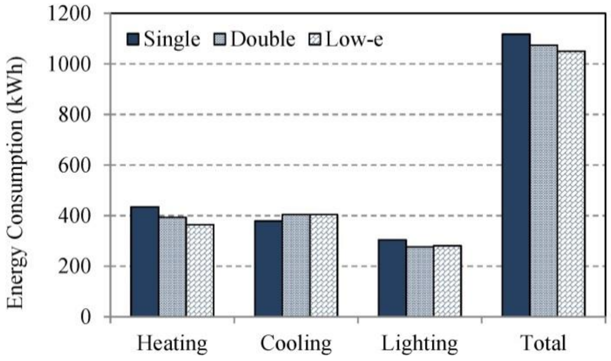


Figure 3.a. South Orientation

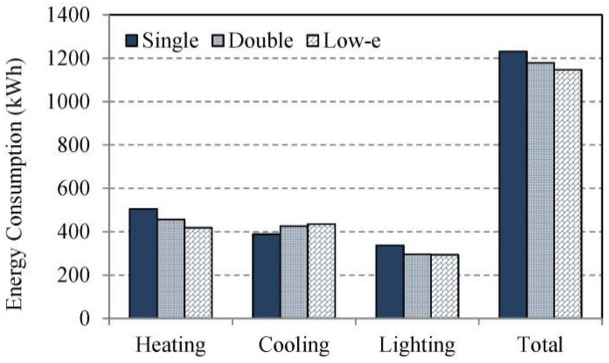


Figure 3.b. East Orientation

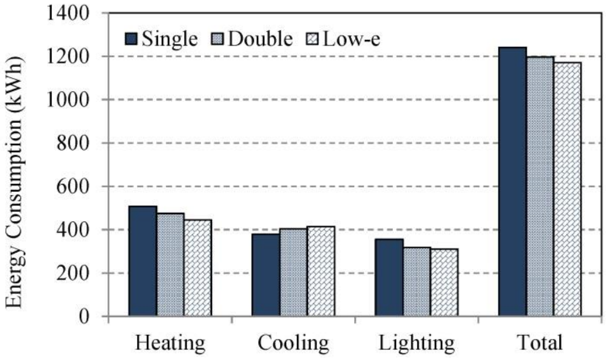


Figure 3.c. West Orientation

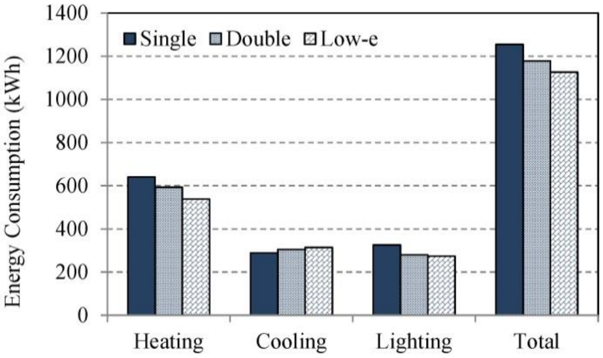


Figure 3.d. North Orientation

Conclusion

This study evaluates the influence of using single-glazed, simple double-glazed (air filled) and double-glazed with low-e coating (argon filled) on optimized window dimensions and layout in an office room. Results show that the obtained optimum area of glazing is very small in comparison with the area of external wall (between 6.4 to 18%). In addition, at different room orientation, the optimum area of the double-glazed with low-e coating window is larger than simple double-glazed and single-glazed window. Results indicate that the glazing type and room orientation has a larger effect on heating load than cooling load and lighting. Besides, changing the glazing type from single to double, double to low-e, and single to low-e reduces the total energy consumption respectively by 6, 9 and 10 % at the north room orientation which represents the highest energy saving. Thus, if the dimensions of windows are optimum, the effect of glazing type on total energy consumption is not very significant. However, if only heating energy consumption is considered, then the energy saving can increase up to 16% depending on the glazing type and room orientation. This result indicates the significant effect of glazing type and orientation on heating energy consumption.

It would be interesting as a future work to find the optimum dimension of glazing in different climate regions in the United States. It remains for future research to study the effect of different type of gas, glazing, and orientation on the optimum designs.

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