Optimizing Window size of South Facades in Tehran City and the Environmental Impacts

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Abstract

This paper investigates the effects of altering the glazing size of lounge spaces in Tehran city houses. The magnitude of effects is demonstrated through comparing the energy consumption of various models. A great portion of the global energy consumption and resource depletion is dedicated to the construction sector. Considering the low thermal resistance of windows and their role in a building's aesthetic, optimizing window to wall ratio is a key factor in the design process. This research attempts to find the optimum glazing area of lounge spaces while monitoring energy consumption and daylight factor simultaneously. A total of 16 samples with different width to length ratios are studied by exploring the minimum satisfactory daylight factor according to BREEAM regulations. Considering the importance of south facades in Tehran city's urban texture, this paper is concentrated on south façade glazing proportions. Final results indicate that increasing the glazing area of a south façade after meeting the minimum required daylight factor may double the annual energy consumption of a living space. Results also show that altering the window to wall ratio of the south façade has a liner impact on the annual energy consumption of lounge spaces.

1. Introduction

Since the Industrial revolution, the amount of carbon dioxide and nitroxide emitted into the atmosphere has increased by 30% and 15% respectively, and the methane ratio has doubled. It is predicted that by continuing air pollution with current rate, the amount of carbon dioxide in the atmosphere will have increased by about 50% by 2050 (NRC 2008). Studies indicate that the construction sector is responsible for consuming one-third of the earth's resources, i.e. energy, water and materials (Long et al. 2007). It is noteworthy that more than half of the total energy consumed by the construction sector is associated with residential buildings (DoE 2011). Recent studies have noted that about 40% of the global energy consumption and 36% of the total carbon dioxide emissions in the world is linked to the residential sector (IEA 2012). Unfortunately, Iran, with a carbon dioxide emission of 8 tons per capital, is considered the 7th most polluting country per capita in the world. Moreover, an energy consumption rate of 314 kWh per capita, places Iran as the 11th most energy-consuming country globally (EIA 2011). Regarding the fact that windows consist of high thermal conductivity, and are also responsible for a major share of the thermal waste, optimal design of building glazing areas seems inevitable.

2. Research Background

Due to the aesthetic importance of windows in building facades, also considering their role in indoor solar absorption and thermal waste, these components have been carefully studied in energy optimization fields (Bodart and Herde 2002; Stegou-Sagia et al. 2007; Hassouneh, Alshboul and A. Al-Salaymeh. 2010; Ebrahimpour and Maerefat 2011). Among the most significant literature in the field of building glazing optimization is the research conducted by Jonson and his colleagues (Johnson et al. 1982; Johnson et al. 1984). They concluded that it is possible to reduce the electric energy consumption of a building by 31 percent, only via optimizing the Window to Wall Ratio

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(WWR). Yet, the recommendations made in these studies are limited to office buildings. Another study conducted by Inanici & Demirbilek suggests that for hot arid climates, the optimum WWR is 25 percent (Inanici and Demirbilek 2000). Generally, optimizing the window area has a great effect on heating and cooling loads. However, a study reveals that in cold climates, reducing the WWR by 20-50 percent might not affect the heating loads greatly (Presson, Roos and Wall 2006). Therefore, the recommended window area of south façades, while taking into account the Daylight Factor (DF) and visual comfort varies greatly. For the Netherlands, the suggested optimum WWR is 21 percent, whereas for Slovenia the ideal WWR is recommended between 36 and 46 percent (Ochoa et al. 2012; Leskovar and Premrov 2012). By monitoring the relation of glazing size and energy consumption in various Asian cities, Lee and colleagues proposed some recommendations in this field. They suggested that for cities that are categorized under ASHRAE type 3 climates (such as Tehran), a 25% WWR for triple layer windows is optimal. However, they did not discuss the daylight availability (Lee et al. 2013). Khatami and colleagues introduced a method for optimizing the window area in Iran by using EnergyPlus™ software. Yet, the research is solely focused on the relation between solar insolation and energy consumption, while not taking into account the daylight factor (Khatami et al. 2012). Other studies suggested that the optimum window area for low-rise buildings in Tehran city is about 15 percent of the room floor area (Fayyaz 2012). Nevertheless, regulations instructed by authorities have always been the basis for building design. Regarding section 19 of Iran's National Building Regulations, it is suggested that the glazing area in residential buildings should not exceed more than 25% of the façade area (Iran National Building Regulations 2010).

3. Methodology

Considering the regular dimensions used in residential building design, the minimum and maximum width and depth of a living room is considered to be between 3 and 6 meters. Also the living room net height is presumed to be 2.7 meters, as this proportion is very popular and commonly used. Between the smallest possible sample (with a width and depth value of 3 meters) and the largest model (with 6 meters of width and depth), a total of 16 samples (Table 1) are studied. In order to make the comparison conclusive, only the south façade is equipped with a window in this paper. Studies have concluded that for similar climates, the south façade is most energy efficient for installing windows (Lee et al. 2013).

Table 1 - Dimensional properties of samples

Sample	width (m)	depth (m)	height (m)	w/d	d/h
S1	3	3	2.7	1	1.11
S2	3	4	2.7	0.75	1.48
S3	3	5	2.7	0.6	1.85
S4	3	6	2.7	0.5	2.22
S5	4	3	2.7	1.33	1.11
S6	4	4	2.7	1	1.48
S7	4	5	2.7	0.8	1.85
S8	4	6	2.7	0.66	2.22
S9	5	3	2.7	1.66	1.11
S10	5	4	2.7	1.25	1.48
S11	5	5	2.7	1	1.85
S12	5	6	2.7	0.83	2.22
S13	6	3	2.7	2	1.11
S14	6	4	2.7	1.5	1.48
S15	6	5	2.7	1.2	1.85
S16	6	6	2.7	1	2.22

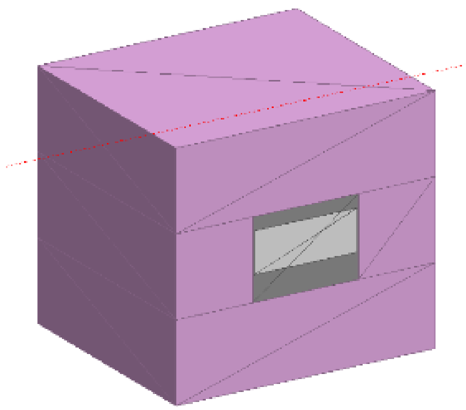

Fig. 1 - Graphical illustration of a modeled sample

3.1 Modelling

Samples are modelled with DesignBuilder software Version 4.2, which runs simulations using an Energyplus™ engine Version 8.1. Except for the south façade, all the vertical surfaces of the lounge zone are modeled as interior walls with no glazing. This approach is utilized in order to minimize the effects of thermal conductivity and solar radiation on non-dominant walls. A similar approach was utilized in some research for studying a room in a cellular office (Gratia and Herde 2003). The composition and layers of the south façade is illustrated in Table 2, where the mean thermal conductivity of the wall is set to 0.249 W/m^2K. Also, the average thermal conductivity of the window with a UPVC frame and the floors are 2.665 W/m^2K and 0.15 W/m^2K respectively. The studied façade has a uniform window which is placed at the center of the wall with no shades. As we attempt to minimize the effects of roof and ceiling, also neutralizing their thermal conductivity and reflections received from the ground, samples are placed one story above the ground level (Fig. 1).

Table 2 - Materials and properties in the south facade

Wall		**Window**	
Materials	**Thickness (mm)**	**Materials**	**Thickness (mm)**
Composite Cladding	6	Clear Glass	6
Polystyrene XPS	128.6	Air	13
Stucco	13	Clear Glass	6

3.2 Climate conditions

Samples are studied in Tehran city weather conditions, which are categorized as 3B in ASHRAE classifications. The city features a semi-arid climate according to Koppen-Geiger classifications with a latitude and longitude of 35.68N and 51.32E respectively at 1190 meters above sea level. Regarding thermal comfort, the climate consists of approximately 2850 Heating Degree Days (HDD) and 2770 Cooling Degree Days (CDD) (ASHRAE 2001; Heidarinejad, Heidarinejad and Delfani 2008; Peel, Finlayson and McMahon 2007). The weather data file used for simulation is supported by the DesignBuilder database. In software settings, the site wind exposure is set to "standard" option, while the orientation is due south and no shading obstacles are defined.

3.3 Variables

The variables studied are width to depth ratio of spaces and the glazing area of the south façade. Samples are simulated for 8760 hours, which is equivalent to one year. Afterwards, the energy and daylight performance are monitored. In this study, the quantity of natural daylight is presented as Daylight Factor (DF). Different environmental assessment methods such as LEED, BREEAM and GreenStar, have diverse requirements for an acceptable daylight. The Building Research Establishment (BRE) in the UK issues one of the strictest standards for acceptable daylight. Two main factors are measured in the BREEAM method. First, at least 80% of the occupied area must have uniform daylight, where the minimum average DF is 2.0%. Second, it is mandatory to have a uniform ratio of 0.4, or a minimum point DF of at least 0.8% (DCLG 2009).

It is notable that in the BREEAM assessment method, both mentioned standards have to be met simultaneously. DesignBuilder software has made it possible to check whether the samples meet with BREEAM daylight regulations. The precision setting for daylight assessment is adjusted to option number five, "Accurate".

Towards finding optimum WWRs, DesignBuilder software is coupled with a trial and error optimizing process. In this method, the WWR of the south façade is increased from zero percent, until BREEAM daylight requirements are met. Meanwhile, the annual energy consumption is measured for the optimum glazing size of each sample (Fig. 2). Afterwards, the WWR is increased until the window covers the whole façade (WWR of 100%). At this time, the annual energy consumption of samples is measured in 10 percent intervals. This approach is adopted to demonstrate the effects of excess glazing area from an energy performance point of view.

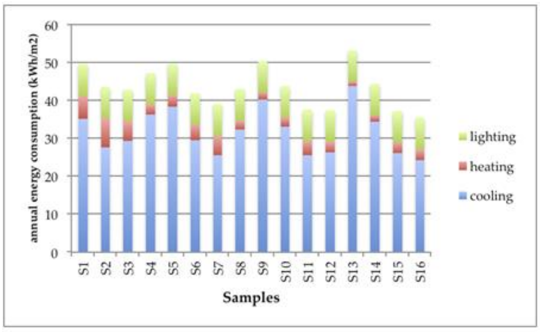

Fig. 2 - HVAC and lighting performance of optimum samples

4. Results and Discussion

Final results indicate that rooms with different width or depth meet their optimum glazing area in various proportions. Sample S1 required a 27% glazing area of the studied façade in order to meet the daylight regulations, while sample S4 required 62% WWR for an acceptable daylight. It is notable that both samples have the same width values which means they consist of similar façade areas. Therefore, it is clear that dictating a certain WWR value for a fixed façade area is not reasonable. The annual energy consumption and WWR of optimum samples is displayed in Table 3. Samples that consist of a small width (S1, S2, S3, and S4) show great variation in their optimum WWR. Meanwhile, the models that have a have greater width (S13, S14, S15, S16) express a smaller difference in their optimum WWR. Similar assumptions could be drawn concerning the depth of samples. Models that have a 3 meters depth (S1, S5, S9, and S13) show little variation between their optimum WWR, while the ideal glazing size in models with greater depth (S4, S8, S12, S16) vary significantly. Therefore, it is obvious that sample S4 consisting of a small width and a great depth, requires the most glazing size.

It may be suggested that optimizing daylight factor is strongly related to a room's width to depth proportion. However, samples with the same w/d factor display various WWRs. Therefore, it can be concluded that another factor that affects the optimal WWR is the relation between a sample's depth and height. When the depth to height ratio (d/h) increases, more glazing area is required in order to obtain a satisfactory daylight level. This is why sample S4 needs more WWR than samples S8, S12 and S16 considering that they all have the same w/d. Sample S4 consists of the least w/d ratio and the greatest d/h ratio simultaneously (as seen in Table 1). Also, this fact explains why sample S1 requires the smallest WWR compared to others. Sample S1 has the greatest w/d and the smallest d/h at the same time.

Table - 3 Energy consumption and WWR of optimum samples

Sample	Floor Area (m)	Energy Consumption ($kWh/m^2.a$)	Window size (WWR)
S1	9	64,59	27
S2	12	55,6	30
S3	15	54,93	42
S4	18	61,28	62
S5	12	64,7	31
S6	16	53,7	34
S7	20	49,55	37
S8	24	55,52	56
S9	15	65,32	33
S10	20	56,69	37
S11	25	47,73	38
S12	30	47,49	49
S13	18	68,71	37
S14	24	57,21	39
S15	30	47,15	40
S16	36	44,75	45

Studying the net energy consumption of samples with optimum WWR reveals that most of the energy utilization is dedicated to cooling loads (Fig. 2). However, the relation between window size and energy consumption is not entirely clear. Sample S13 has the most energy consumption while its WWR is not the greatest. There is a possibility that the energy consumption of optimum samples is related to the window size per floor area. Yet, there are definitely other factors affecting this relation. Figure 3 demonstrates a possible relativity between energy consumption and window to floor ratio of the samples. It seems that this relation is driven from the massive cooling loads which is also related to excessive solar abortion through windows.

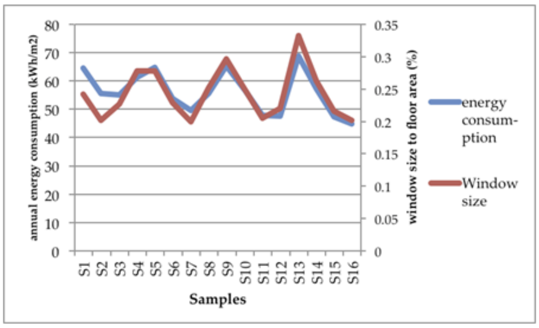

Fig. 3 - Possible relation between energy consumption and window size of optimum samples

Figure 4 shows the effects of increasing window size after reaching a satisfactory daylight level. Samples with a small width seem to be more affected than samples with a greater width. For example, the energy consumption of sample S1 will increase about 16% for each 10 percent extra glazing. This increase rate is much smaller (about 9%) for sample S4. However, models with the same depth, display similar performances regarding excessive glazing size. This fact can be confirmed by analysing the samples presented in figure 5.

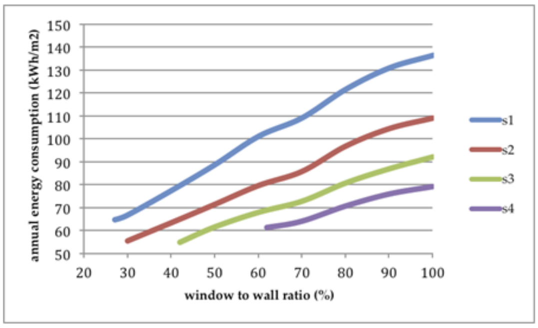

Fig. 4 - The relation between annual energy consumption and WWR of samples with similar width

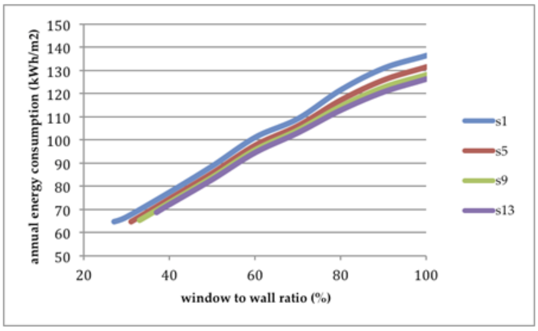

Fig. 5 - The relation between annual energy consumption and WWR of samples with similar depth

Regarding the energy consumption of samples, it can be inferred that increasing the WWR of south façades has a linear impact on a room's environmental performance. This conclusion may be a great aid to architects and designers working at the early stages of design. Therefore, performing numerous simulations will be unnecessary and architects can anticipate the environmental performance of their building by performing only a few simulations. It also reduces the possibility of compromising the design aesthetic, as the glazing area can be modified at early stages of design.

5. Conclusion

Utilizing vast amounts of glass in building façades has gained great popularity between contemporary Iranian architects who practice residential buildings. Applying such façades in some countries, especially those with a cold climate, has been a great benefit from a sustainable point of view. However, due to high solar radiation in most of the major cities in Iran, applying total glazed and frameless glass facades requires a good knowledge of building physics and their environmental performance. Therefore, this paper intends to study the effects of increasing glazing area of south façades in Tehran houses, from an environmental point of view. The results of this study indicate that the optimum glazing area is related to width to depth ratio and depth to height ratio. As the width to depth ratio increases, less glazing area is required for adequate daylight. On the other hand, increasing depth to height ratio has an inverse effect on daylight performance. Also, it is suggested that the relation between the glazing area and energy consumption is mostly related to cooling loads in Tehran's climate. Results show that the relation between window to wall ratio and energy consumption is linear. Yet, the steep of the linear increase is relative to a room's depth and varies between 9% to 16% for each 10% added to the WWR. Finally, it was found that expanding the window size after reaching a satisfactory daylight could increase the annual energy consumption up to twice the minimum necessary amount.

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