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ASSESSING THE IMPACT OF BUILDING PARAMETERS ON ENERGY PERFORMANCE IN RESIDENTIAL SETTINGS

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Abstract

The building sector energy use currently accounts for over 40 percent of the world energy use. With respect to such significant influence of the buildings, well-designed buildings on the basis of energy efficiency provide long-term building optimisation, and consequently minimising energy demands. The purpose of the current study is to evaluate the thermal performance of a range of variables such as building orientation and window to wall ratio (WWR) in a residential building in the semi-arid continental climate to find the most appropriate scenarios to reduce energy consumption. The case study is an existing apartment building which is modelled in Design Builder software. The results indicated that the optimum WWR in the study area is 40 percent for all sides of building. The results further revealed that using an overhang with 30 cm in-depth, and 40 percent WWR provide a significant reduction in total energy use up to 26 percent. In terms of orientation, buildings lined longitudinally along an axis of 25° north-east had 3 percent lower energy use as compared to the building longitudinally arranged along east-to-west. The recommendations are given based on the results of simulation to assist designers in designing building layouts for residential buildings in similar climate.

Keywords: Energy efficiency, residential building performance, thermal comfort, simulation, WWR, orientation.

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1. Introduction

Over the past five decades, the increasing consumption of fossil fuels and its consequences problems has become a major challenge in many countries. According to the United Nations, 68 percent of the world population projected to live in urban areas by 2050 (United Nations, 2018). In recent years, rapid urbanisation and the growth of construction industry especially in developing countries such as Iran (Madvar et al., 2018), have increased building energy consumption. Energy plays a significant role in human life (Hou et al., 2019). The building sector energy use currently accounts for over 40% of the world energy use (Delgarm, Sajadi, Azarbad, & Delgarm, 2018; Nejat et al., 2015) and has become the third largest consumer of natural resources after industry and agriculture (Chel & Kaushik, 2018). This amount is expected to increase to 50% by 2050 (Goudarzi & Mostafaeipour, 2017; Yousefi, Gholipour, & Yan, 2017). Considerable amounts of energy consumptions are used in order to provide a pleasant indoor environment and thermal comfort for the building occupants (Yao, Costanzo, Li, Zhang, & Li, 2018). The increasing consumption of fossil fuels leads to severe environmental problems such as CO_2 emissions and global warming (Emadodin, Taravat, & Rajaei, 2016; Hou et al., 2019). Therefore, it is no wonder that greater efforts towards energy efficiency and conservation of natural resources are clearly necessary. The energy conservation through carbon dioxide emissions reduction has acquired prime importance all over the world (Omer, 2018; Zhao, Künzel, & Antretter, 2015). In preserving the environment, a major challenge is to find ways in order to implement new technologies, renewable resources and useful strategies to reduce CO_2 emissions (Shad, Khorrami, & Ghaemi, 2017).

Multiple studies have explored the optimal building design, resulting in more passive solutions to reduce energy and efficiency in building sector. Research has indicated that energy performance of buildings depends on five factors, namely climate, building design, urban geometry, system's efficiency, and occupant behaviour (Sanaieian, Tenpierik, van den Linden, Seraj, & Shemrani, 2014). Evidence suggested that architectural design contributes to a reduction of energy consumption (Alhuwayil, Mujeebu, & Algarny, 2019; Al-Saadi & Shaaban, 2019). The use of these strategies in buildings and architecture is not new (Omer, 2018). Under design and construction zone, passive design strategies and bioclimatic design are among the main solutions for minimising energy demands (Mirrahimi et al., 2016). Passive building design can aid energy conservation efforts as it is directly related to energy use (Schiefelbein et al., 2019; Zhang et al., 2019). Studies have classified building design factor into six parameters, i.e., shape, transparent surface, building orientation, thermal–physical properties of building materials and distances between buildings (Pacheco, Maluf, Almeida, & Landim, 2014; Fernandes, Rodrigues, Gaspar, Costa, & Gomes, 2019).

A well-designed energy efficient building can reduce the amount of energy demand in order to provide thermal comfort. Passive design strategies need to be integrated into a building's overall architectural design from its early stage. As there are various passive techniques with different efficiency levels, the passive techniques related to a particular building by considering the external climate need to be selected on the basis of thermal comfort expectations, site location and building function (Goudarzi & Mostafaeipour, 2017). Utilising natural daylight along with control strategies through architectural aspects are another step forward in providing energy efficient buildings, especially in the areas with high

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potential for solar energy usage. However, recommendations concerning the fenestration of the façade and suitable materials differ, and depend on internal environment and external climate.

Iran has signed as the "world's second largest natural gas reserves and the fourth largest proved oil reserves" (Gorjian, Zadeh, Eltrop, Shamshiri, & Amanlou, 2019). In Iran, fossil fuel energy consumptions have considered as main energy supply chain as compared to renewable energies due to huge amount of fossil fuels. Evidence suggested that the residential buildings consume the largest amount of energy, followed by industrial and transportation sectors in developing nations (Madvar et al., 2018). A same trend can be observed in Iran, where residential sector consumes the largest amount of energy, accounting for one-third of total fuel consumption (Goudarzi & Mostafaeipour, 2017). Accordingly, in order to decrease energy demands, the energy efficiency of buildings plays a significant role as compared to other sectors such as industry and transportation (Goudarzi & Mostafaeipour, 2017). A number of studies have been conducted on residential energy consumption and GHG emissions to understand their demand and feasible mitigation measures through passive strategies. The current study seeks to investigate the impact of building orientation on energy performance in a medium-rise residential building in Tehran, Iran.

2. Problem Statement

Referring to global warming issues and increasing greenhouse emissions (GHGs), although previous attempts at reducing energy demands have not always been successful (Sorrell, 2015), various attempts have been made to reduce cooling and heating demands in different scales. Due to the crises of the growing natural resources shortages and continued environmental degradation, building energy performance is of growing importance all over the world. One of the most sustainable energy techniques is to conserve natural resources of energy as much as possible and the use of renewable resources (Goudarzi & Mostafaeipour, 2017). The use of passive techniques is one of the most effective approaches to reduce heating and cooling energy loads in buildings (Valladares-Rendón, Schmid, & Lo, 2017). These techniques contribute to reduce energy consumption, greenhouse gas emissions and indoor air temperature fluctuations, and at the same time to increase thermal comfort in buildings (Karunathilake, Halwatura, & Pathirana, 2018; Mirrahimi et al., 2016; Omer, 2018; Yao et al., 2018).

3. Research Questions

There is a research question in the study that needs to be addressed:

- Do the level of energy consumptions in order to provide thermal comfort vary across different building orientation and WWR ratios?

4. Purpose of the Study

Passive building design can aid energy conservation efforts as it is directly related to energy use. Therefore, passive strategies have always been a matter of interest. In order to propose the potential effective strategies, simulation is required based on the real data. Studies have reported shape and orientation of a building, window-to-wall ratio and shading devices are effective design strategies that contribute to energy consumption (Sari & Chiou, 2019). It is vital to consider various design strategies to

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provide appropriate shadings, especially for apertures. The purpose of this study is to investigate the thermal performance of a range of variables such as external wall structure, building orientation, window-to-wall-ratio (WWR) and external shading in a real residential building in the semi-arid continental climate of Tehran in order to find optimal or near optimal building design solutions to reduce energy consumption. Few studies took real case buildings to investigate the impact of aforementioned parameters on energy consumption. This study fills the gap by investigating the most effective design parameters of a building envelope in Design-Builder software based on the building's real specifications.

5. Research Methods

In order to achieve the study objectives, four phases were conducted: secondary data collection (verification), design strategies (simulation conceptual model), analysis (simulation) and results (comparison to other models). The case study is an existing apartment building located in Tehran which is modelled in Design Builder software as it comes with extensive data templates for a variety range of building simulation inputs such as typical envelope, glazing and shading devices. Calculations were performed for the case study at the residential building block level. To study and evaluate the best scenarios, the thermal simulation was performed using real climate data in the simulation model, in this case for the city of Tehran. The case study is a residential building located in Tehran, Iran. The present study emphasizes energy efficiency optimization focusing on orientation of the building, and the amount of openings (WWR).

6. Findings

The results of simulation indicated that WWR and building orientation play significant roles on energy performance in the study area. In the simulation process, the window size differed from WWR=20% to 60% for all sides. According to the study findings, the optimum window to wall ratio in Tehran is 40%. The results further revealed that using an overhang with 30 cm in-depth, and 40% WWR provide a huge reduction in total energy consumption up to 26%. As shown in Table 1, in terms of orientation, buildings lined longitudinally along an axis of 25° north-east had 3% less energy use as compared to the building longitudinally arranged along east-to-west. Although the results indicated a small impact of orientation on building energy use, but there was a significant improvement in the average daylight factor (up to 17%). To improve thermal performance, the findings of this study could be of assistance to make energy-wise decisions in the early stage of the design process.

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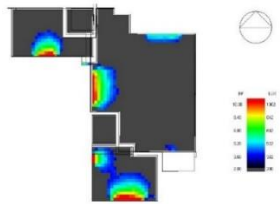
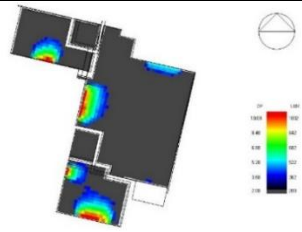
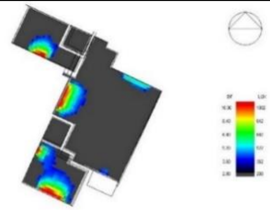
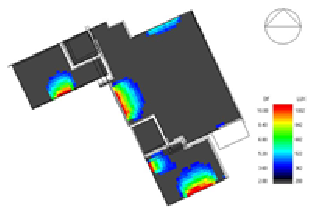
Table 01. The results of simulation in different orientations

Orientation	Total energy requirement [kWh/m^2]	Average daylight factor (%)	Daylight Map
0° (E-W)	314.41	1.58	
13° (E) current situation	319.20	1.39	
25° (W)	324.19	1.57	
25° (E) Best result	305.00	1.90	

7. Conclusion

Residential buildings are the major consumers of energy and GHG emissions (Geng et al., 2017). Population growth is one of the main causes of increasing demand for fossil fuels in the building sector all over the world which has critical consequences such as air pollution, global warming and GHG emissions (Motealleh, Zolfaghari, & Parsaee, 2018). One of the best strategies to reduce energy demands and costs in buildings is climatic design, where the design is shaped according to the climate in order to facilitate energy efficiency enhancement (Omer, 2008). The first step of defence against the climate is an appropriate design where largely influenced by climatic factors. When buildings design according to the climate, the need to achieve thermal comfort using mechanical heating or cooling will reduce. Maximum renewable energy usage can then be applied for creating an internal pleasant environment (Omer, 2018). As the design parameters, shape and orientation of a building, WWR, and shading are the most effective parameters to reduce energy consumption.

The current study focused on two main parameters of design strategies (i.e., building orientation and WWR) in order to underrated the best scenarios in creating more efficient buildings. The study employed DesignBuilder software in order to analyse the climatic data of the study area. According to the study findings, it was verified that energy consumption is strongly depends on design strategies including

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WWR and building orientation. It can be concluded that passive design strategies play a significant role in heating and cooling loads in buildings. Although, WWR has a significant effect on reducing energy use, building orientation also plays a role to create more efficient buildings. Reduction of energy use in buildings using passive strategies has a major role in achieving sustainable development due to its huge contribution in reducing greenhouse gas emissions. Therefore, the study suggests that professional and those who are involved in design process need to wide their focus on both internal and external conditions of buildings such as climatic features.

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