Investigation and modeling of energy consumption of tall office buildings in Iran’s ‘hot-arid’ and ‘cold’ climate conditions

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Abstract

The construction of high-rise buildings has attracted human attention at the beginning of human civilizations’ formation. Presently, making tall buildings is considered as a necessary requirement due to the succeeding reasons: the population increase, the tendency to live in urban centers, the land utilization in the most populated centers of the cities, the need to decrease the cost of horizontal development of cities and technological advances. During the last century, issues related to environmental pollution and high energy use have affected these tall buildings. So, it is crucial to apply appropriate methods and patterns in order to adjust their environmental impacts as much as possible. In addition, the building industry accounts for a significant amount of energy consumption in the world. Therefore, energy-saving and efficiency can be mentioned as a significant issue due to the limitation of fossil resources. The importance of this issue has been increased by eliminating subsidies and realizing the price of fuels in Iran. Efforts in the field of high-rise buildings in Iran are chiefly based on general criteria regarding the location and characteristics of urban imagery and the field of urban design knowledge. The efforts contributed to the energy consumption have not been carried out. The present study provides patterns for the aim of designing high-rise buildings with official use in Tabriz and Yazd. The solutions for the opening design of tall buildings with regular forms to reduce energy consumption are proposed in this study.

Keywords: environmental pollution; energy consumption; energy efficiency; tall office building

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1. INTRODUCTION

In the past few years, increasing the efficiency of energy use in different sectors has been a crucial concept in various investigations [1, 2]. Recent studies into characteristics of external shell of buildings and energy consumption in tall buildings have considered some aspects and almost there is not a perfect study. Considering the effect of one or two parts of external shell parts contributed to high-rise buildings and its relation with energy consumption is the main study in this subject. Bojic et al. [3] studied the effect of thermal insulation position as one of the external shell parts of building on the space cooling of high-rise residential buildings in Hong Kong. Moreover, he considered the energy performance of windows in high-rise residential buildings in Hong Kong [4].

Many researchers investigated the effect of conditions and characteristics of the external shell of the high-rise buildings. They evaluated the energy consumption of studied buildings with existing standards and proposed general solutions related to characteristics of external shell. Yang et al. [5] conducted a research entitled ‘Energy performance of building envelopes in different...
climate zones in China. Some high-rise buildings in the climate conditions of China have been selected and their consumption with the existing standards of China and ASHRAE standard have been compared. Also, the role of building in decreasing the energy consumption of buildings and general solutions have been determined and presented.

Many researchers investigated the role of building shell in high-rise buildings and the effects of shell properties on energy consumptions [6–8]. These researches are more comprehensive. Studies conducted on the shell of high-rise buildings and the relationship between shell and energy consumption are mainly in hot and wet climate zones of Hong Kong. Moreover, these studies are mainly in residential high-rise buildings [9–11]. Bojic et al. [12] considered the effects of shell and thermal insulation position on the space cooling of high-rise buildings in the climate conditions of Hong Kong. Yu et al. [7] performed a study on the design characteristics of residential buildings in China. Cheung [6] studied the design of work energy shells for high-rise buildings in Hong Kong. Additionally, [13] investigated the energy consumption of public buildings in China. Based on the results, the energy consumption per building area is 26.34 kgcE/m²a. Also, the highest energy consumption belongs to hospital buildings among school, hospital and office buildings. Furthermore, the characteristics of energy consumption associated with school buildings have been studied by [14], and according to the results the average comprehensive energy consumption per unit area is 121.81 kWh/m²a, which is lower than the energy consumption of public buildings. Also, the structural systems of tall buildings and their environmental behavior have been investigated by [15]. Additionally, [16] evaluated the performance of different facade systems in tall buildings in five various climate zones. Moreover, residential buildings’ influences on the energy consumption on the condition of hot and arid regions have been determined by [17], and as indicated in the results the significant effect of orientation on the energy consumption cannot be neglected. In another study, some large buildings have been selected by [18] for the aim of investigating the energy consumption of large public buildings in China. In addition, [19] modeled the energy consumption of office buildings with the help of neural network and occupancy profile. Furthermore, building variables that affect the energy consumption of office buildings have been determined by [20].

The present study considers the relationship between energy consumption and window-to-wall ratio (W.W.R) in official high-rise buildings. Based on the literature, some studies have been carried out about the effects of different influential parameters such as various locations, different types of buildings, etc. However, to the best of the authors’ knowledge, this is the first study in which the effect of W.W.R on energy consumption of tall buildings is investigated. Recent studies have investigated only a kind of energy. Bojic et al. [4] considered cooling load as an effective agent for energy consumption. In order to recognize the relation of shell and energy consumption, [7, 8] investigated the heating, cooling and both of them as energy consumption processes. The present study considers the shell direction and its effect on energy consumption.

Two major cities, Yazd and Tabriz, were selected for this study as indicators of two major climate groups in Iran. Based on Köppen–Geiger climate classification, BWh, BSk, CSa and BSh are important climatic groups of Iran, each part covers a large part of the country and other climatic groups comprise a very small part of the country area (Figure 1).

2. CLIMATE SUMMARY

2.1. Tabriz climate summary

The Tabriz lies on 1385 m above sea level, which is influenced by the local steppe climate. In Tabriz, there is little rainfall through-
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Table 1. Tabriz climate data [22].

| Month      | Avg. temperature, °C | Min. temperature, °C | Max. temperature, °C | Avg. temperature, °F | Min. temperature, °F | Precipitation/rainfall, mm |
|------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------------|
| January    | 10.8                 | 9.2                  | 33.5                 | 51.4                 | 37.2                 | 318                         |
| February   | 15.6                 | 12.7                 | 42.2                 | 54.5                 | 39.6                 | 180                         |
| March      | 20.2                 | 17.8                 | 49.4                 | 68.3                 | 45.0                 | 120                         |
| April      | 24.1                 | 21.8                 | 54.6                 | 71.8                 | 51.8                 | 80                          |
| May        | 23.9                 | 20.3                 | 54.2                 | 71.6                 | 51.6                 | 60                          |
| June       | 20.3                 | 17.6                 | 52.5                 | 70.7                 | 50.0                 | 40                          |
| July       | 17.3                 | 15.2                 | 50.1                 | 71.1                 | 49.0                 | 20                          |
| August     | 14.3                 | 12.2                 | 45.8                 | 69.6                 | 47.0                 | 10                          |
| September  | 12.7                 | 10.5                 | 43.9                 | 60.0                 | 45.0                 | 5                           |
| October    | 10.9                 | 8.7                  | 42.0                 | 54.2                 | 43.0                 | 0                           |
| November   | 9.0                  | 6.9                  | 40.1                 | 52.8                 | 41.0                 | 0                           |
| December   | 6.9                  | 4.8                  | 39.0                 | 52.2                 | 40.0                 | 0                           |

Table 2. Yazd climate data [22].

| Month      | Avg. temperature, °C | Min. temperature, °C | Max. temperature, °C | Avg. temperature, °F | Min. temperature, °F | Precipitation/rainfall, mm |
|------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------------|
| January    | 13.8                 | 7.7                  | 27.6                 | 54.6                 | 35.6                 | 5                           |
| February   | 18.7                 | 11.5                 | 33.4                 | 62.0                 | 37.5                 | 10                          |
| March      | 24.5                 | 16.8                 | 49.8                 | 74.6                 | 45.0                 | 40                          |
| April      | 29.4                 | 21.7                 | 55.9                 | 71.5                 | 49.0                 | 120                         |
| May        | 31.7                 | 23.8                 | 59.0                 | 78.8                 | 55.0                 | 180                         |
| June       | 29.9                 | 21.8                 | 55.8                 | 71.4                 | 52.0                 | 240                         |
| July       | 25.4                 | 16.9                 | 51.3                 | 71.7                 | 49.0                 | 300                         |
| August     | 19.3                 | 16.0                 | 46.7                 | 68.6                 | 45.0                 | 260                         |
| September  | 11.7                 | 10.5                 | 52.0                 | 71.6                 | 49.0                 | 200                         |
| October    | 6.9                  | 4.8                  | 40.1                 | 52.2                 | 41.0                 | 0                           |
| November   | 5.2                  | 3.4                  | 41.1                 | 92.8                 | 45.0                 | 0                           |
| December   | 3.1                  | 2.0                  | 52.0                 | 71.6                 | 49.0                 | 0                           |

2.2. Yazd climate summary

Yazd lies on 1216 m above sea level, which is considered to have a desert climate. In Yazd, there is virtually no rainfall during the year. The Köppen–Geiger climate classification is BWk. The average temperature in Tabriz is 11.6 °C/52.9 °F. The annual rainfall is 318 mm/12.5 inch (Figure 2; Table 1) [22].

3. METHODOLOGY

The present study takes various steps in order to achieve the result and uses a strategy in each step. This study is a quantitative research in order to find the relationship between energy consumption and WWR in official high-rise buildings. In this research, which has correlation approach, interpretive-historical strategies were used in the literature review step, a simulation was used in the variable test step and descriptive statistics was used in the variable test analysis. Figure 4 shows the proposed research process.

3.1. Energy and its consumption in high-rise buildings

Economic advances, population growth, globalization and improvement of living standards in developing countries have led to more use of energy resources [24, 25]. Energy international agency statistics show that the energy consumption has increased by about 50% during the past two decades and has increased by about 70% since the 1970s. According to current trends, the energy consumption in developing countries like the Middle East will increase by 32% until 2020 [26].

Energy consumption in the world is used in different fields like industry, transportation and building. Based on the statistics, the major share of energy consumption belongs to buildings [27]. The shares of energy consumption in industrial, transport and building sectors are ∼30%, 28% and 42%, respectively. Moreover, building use has a significant effect on energy consumption. The share of official use in the building sector is 20% [26].

Various researches have been carried out on high-rise buildings, including performance, architectural style and instrumental strategies. Nonetheless, factors affecting energy consumption including form, style, use of natural light and ventilation ducts

Figure 3. Yazd climate graph (average temperature and precipitation) [22].

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have not been considered. Oldfield et al. [28] classified high-rise buildings in five periods based on characteristics and performances of energy consumption.

First period: from 1885 (the beginning of the formation of high-rise buildings) until 1916. In this period, constructional forms were designed with a minimum surface area in order to create a comfortable condition in winter and appropriate use of natural light.

Second period: from 1916 (the beginning of New York law until developing of glass views) until 1915. In this period, due to the technological advances in plant systems and artificial lighting production, the use of pyramidal forms for buildings increased thermal energy consumption and energy consumed by the building.

Third period: from 1915 until 1973 (the start of energy crisis). High-rise buildings were cubic blocks with a high range of work space on the floors. Due to the use of single-walled glass views on a wide surface, absorption and dissipation of thermal energy increased. Therefore, the consumed energy of building was increased.

Fourth period: from 1973 until now. High use of single-walled glass views was affected by an energy crisis. Therefore, laws were adopted by developing countries in order to save energy, which recommended the use of double-walled windows in buildings. Moreover, the use of artificial lighting standards changed and decreased.

Fifth period: from 1997 (the beginning of environmental and sustainability perspectives) until now. According to the principals of the fourth period, a new perspective in high-rise buildings was made. In addition, numerous high-rise buildings were designed and built in order to reach a maximum decrease in energy consumption.

3.2. Simulation of energy consumption in the building and application software

Among the tools that are available to individuals and experts involved in the design process, energy simulation software is the most efficient software in evaluating the energy behavior. This software simulates the building approximately really by providing the virtual design [29].

According to technical advances in various fields, in the fields of quality enhancement and increasing the quantity, a growing development in the simulation software is observed [30]. The eQUEST is used as the simulation tools in this study.
Table 3. *The characteristics of research base model [23].*

| Plan geometry: rectangle                                      | General characteristics | Structural-architectural characteristics |
|----------------------------------------------------------------|-------------------------|------------------------------------------|
| Plan proportion: 1:1.35                                        |                         |                                          |
| Plan dimension: 35 m × 26 m                                    |                         |                                          |
| Plan layout: open space                                       |                         |                                          |
| Number of floors: 15 floors + 3 floors underground             |                         |                                          |
| Height of floors: 4 m, floor to floor; 3 m, floor to dropped ceiling; 60 cm, dropped ceiling height |                         |                                          |
| Floors area: 745 m², pure area of each floor (82% of each ceiling); core and service departments area, 745 m² |                         |                                          |
| Direction of rotation: 30’ South-East in Tabriz and 15’ South-East in Yazd |                         |                                          |
| Type of skeletons and core: concrete skeleton and central core with a total surface area of 165 m² (18% of each floor) |                         |                                          |
| External wall structure: cement plaster (5.2 cm), concrete wall (15 cm), plaster coating plus color (5.2 cm) | Wall and elements characteristics |                                           |
| Ceiling structure: mosaic flooring (5.2 cm), cement sand melt (5.2 cm), moisture insulating, light concrete (5 cm), structural ceiling (25 cm) |                         |                                          |
| The ceiling of each floor structure: stone floors (5.2 cm), cement sand melt (5.2 cm), concrete (5 cm), the structural ceiling (30 cm) |                         |                                          |
| Underground wall structure: concrete wall (30 cm), moisture insulation |                         |                                          |
| External wall color: medium with an absorption coefficient of 0.6 |                         |                                          |
| Type of opening: aluminum window, 6 cm thick                   |                         |                                          |
| Glass material: transparent double glass, 6 mm thick (double clr/tint) with specification of U, 0.54; SHGC, 0.7; VT, 0.79 |                         |                                          |

Calculating engine of this software is DOE-2.2, which has been used extensively during the past two decades. Actually, eQUEST is the result of adding a graphic user interface layer along with design guides that help the user step by step in building design.

This software provides two various guides to the users. In order to perform the design step by step, various options to choose information associated with the design are prepared for users. Other features of this software include the design of structures, mechanical equipment, the use and size of buildings, layout of the floor layers, building materials, the use of surfaces and places as well as system lighting. The ability to compare between various cases in terms of monthly and annual energy consumption is the future that is used in the present study. Generally, the software utilizes two methods [31]:

1. Efficiency-energy measures: for simpler models that are limited to specific variations
2. Parametric run: the ability to make more and more complex changes.

### 3.3. Introduction to basic research model

In order to study and test the variables of the research, it was necessary to identify a model or case as the main basis of the research. The behavior and the effect of variables were evaluated using this model. The purpose of the present study was to identify the optimal characteristics of the external shell ingredients of official...
high-rise buildings in terms of energy consumption. Therefore, the basic model of research was an official high-rise building where all of its intrinsic characteristics were specified. In order to simplify the extensive characteristics of these buildings, these characteristics were presented in two main parts of structural-architectural characteristics and facility characteristics. According to the architectural strategy of the present study, structural-architectural characteristics were studied.

At the first step, information related to structural-architectural characteristics of the base model including the skeleton, type of core, number of floors, floor heights and wall elements were introduced. These characteristics are shown in Table 3.

Facility characteristics and equipment used in the test basis model were selected based on defaults related to official high-rise buildings in the eQUEST software. Climate condition, the number of days and hours of building use and the tools used by users were introduced as conditions that considering them validates the research.

4. RESULTS AND DISCUSSIONS

The variable that was considered as an element of the shell of the official high-rise building is the W.W.R. In the present study, the W.W.R is the ratio of transparent surface (window) to the surface of the cloudy surface (external wall). The cloudy surface is multiplied by the length of the wall at the useful floor height (from the floor to the dropped ceiling). The investigation of the
The effect of W.W.R on energy consumption of the building was the goal of considering the W.W.R.

The method of considering the W.W.R and its effect on energy consumed was conducted in two cases. In the first case, the W.W.R of the basic model in the North, South, West and East walls decreased from 100% to 80%, 60%, 40%, and 20%, respectively. The W.W.Rs for each wall is shown in Figures 5, 6, 7 and 8. In the second case, the change in the W.W.R was considered separately for each direction. In order to get a better comparison in each test, the W.W.R was changed only in one direction. It had the constant value of 100% for other directions. Finally, the results of the test were presented in Yazd and Tabriz as the hot and dry climate and the cold climate, respectively. Due to software limitations and ease of computing, openings were supposed to be strips. In addition, due to the space applicable in terms of architectural quality, the opening distance from the ceiling and the floor were decreased equally.

The results of W.W.R variable test in Yazd and Tabriz climate conditions are shown in Figures 9–20. The criterion in analyzing and classifying the results was the value of effect on energy consumption. Moreover, in order to classify the results correctly, the thermal behavior was studied.

According to Figure 9, with the increase in W.W.R, heating consumption decreased for Tabriz. But with the increase in W.W.R, cooling and total thermal energy consumptions increased for Tabriz. The lowest heating consumption occurred when W.W.R
According to Figure 10, with increasing W.W.R, electricity and total energy consumption increased for Tabriz. But with increase in W.W.R, gas consumption decreased for Tabriz. The lowest total energy consumption related to W.W.R is up to 40%.

According to Figure 11, with increase in W.W.R, heating consumption and total thermal energy increased significantly for Yazd. But with increase in W.W.R, gas consumption decreased for Yazd. The lowest heating consumption related to W.W.R equals to 10%. The highest cooling and total thermal energy consumptions are when W.W.R equals to 100%.

According to Figure 12, with increases of W.W.R, electricity and total energy consumption increased for Yazd. But with increases in W.W.R, gas consumption decreased for Yazd. The lowest total energy consumption relate to W.W.R is up to 40%.

According to Figures 13–16, with increasing W.W.R, in Southern, Northern, Western and Eastern walls for Tabriz, electricity and total energy consumption increased. But gas consumption changed lightly, and the significant changes were in Southern walls for gas consumption.

According to Figures 17–20, with increasing W.W.R, in Southern, Northern, Western and Eastern walls for Yazd, electricity and total energy consumption increased. But gas consumption changed slightly.

In the first case where the W.W.R changed equally in all directions, decrease in W.W.R led to a decrease in the energy consumed in Yazd and Tabriz. This trend is shown in Figure 21.

As illustrated in Figure 21, the value of this downward trend in Yazd was higher compared to that of Tabriz. Due to the change in the W.W.R, the maximum decrease in energy consumption was 13% and 19% in Tabriz and Yazd, respectively. In other words, the effect of W.W.R on the hot and dry climate was more than that on the cold climate. In addition, Figure 21 shows that maximum decrease in energy consumption in the two cities was in the range of 20%–40% of W.W.R. Since in the W.W.R of 10% it was observed that energy consumed in Yazd was increased, the relation between energy consumed and W.W.R may not always be a direct relation. The correlation coefficient \( R^2 \) related to the relation between W.W.R and energy consumed is approximately equal to 1. Therefore, these two parameters are dependent on correlation factor. A similar trend for the thermal performance of the base model was observed as shown in Figure 22.

The change in the W.W.R led to the decrease in thermal loads in Tabriz and Yazd by 20% and 39%, respectively. The remarkable point was the various behavior performances of heating and cooling loads in terms of the W.W.R. Decreasing the W.W.R led to an
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Figure 21. Total energy consumed in Tabriz and Yazd.

Figure 22. Total Thermal energy consumed in Tabriz and Yazd.

increase in the heating load while it led to a decrease in cooling load. Figure 23 shows the cooling and heating loads in different W.W.Rs in the cities of Tabriz and Yazd.

By considering the effect of the W.W.R in each direction and for various walls, the effect of decreasing W.W.R on decreasing energy consumption was obviously interpreted. The point to be considered was that whether the value of this effect for Tabriz and Yazd is the same. Therefore, the results of considering the W.W.R were analyzed in all directions. In the North side of the external wall of the building in Tabriz, decreasing W.W.R until 40% led to a downward trend of energy consumption. This trend got slower until the W.W.R of 20%. These changes in the W.W.R of the North wall led to a maximum of 4% decrease in energy consumption. In Yazd, the effect of decreasing the W.W.R is sensible until the W.W.R of 40%. It is not sensible by passing this value until 20%. The maximum decrease in energy consumption in the range of 20%–40% of the W.W.R was only 2%. Generally, in the both cities, the effect of W.W.R is sensible until the W.W.R of 40% and by passing this value it is not sensible as illustrated in Figure 24.

Figure 25 shows the energy consumption versus the W.W.Rs in the South wall of Yazd and Tabriz. In the South side, the trend of decreasing energy consumption versus decreasing the W.W.R is sensible. This trend had various effects on the energy consumption. The figure slop related to the relation between the W.W.R and the energy consumption was more in Yazd compared with Tabriz. In the W.W.R of 20%, the energy consumption decreased by 7% in Yazd and 5% in Tabriz. Therefore, the maximum energy consumption was in the range of 20%–40% of W.W.R.

East and West walls had such this rate. The energy consumption decreased due to decreasing the W.W.R. In the W.W.R of 20%, the energy consumption was at minimum. The effect of changing the W.W.R on the energy consumption in the West wall was 5% for both cities. While, in the East wall, it was 4% and 5% in Tabriz and Yazd, respectively. The energy consumptions in various W.W.Rs in the East and West walls are shown in Figures 26 and 27.

By considering the effect of the W.W.R in each direction, it was interpreted that the effect of the W.W.R in each wall was different. Moreover, this effect was more sensitive in less W.W.Rs. In the climate conditions of Tabriz and Yazd, the W.W.Rs in South,
Figure 23. Cooling and heating energy in Tabriz and Yazd.

Figure 24. Total energy consumed in the North wall in Tabriz and Yazd.

Figure 25. Total energy consumed in the South wall in Tabriz and Yazd.
Figure 26. Total energy consumed in the East wall in Tabriz and Yazd.

Figure 27. Total energy consumed in the West wall in Tabriz and Yazd.

Figure 28. Energy consumption in various directions in Tabriz.
Figure 29. *Energy consumption in various directions in Yazd.*

![Energy Consumption in Various Directions in Yazd](image)

Figure 30. *Thermal energy consumption in each direction in Tabriz.*

![Thermal Energy Consumption in Each Direction in Tabriz](image)

Figure 31. *Thermal energy consumption in each direction in Yazd.*

![Thermal Energy Consumption in Each Direction in Yazd](image)
The main outcomes of this study are presented as follows:

- The W.W.R and the energy consumption are directly related to each other. It means decreasing the W.W.R also decreases the energy consumption. In the two studied cities, this relation is a high correlation degree. Moreover, decreasing the W.W.R leads to an increase in heat consumption and decrease in cool consumption.
- The effect of the W.W.R in small values is high. In the study of the W.W.R, which was conducted in the ratios of 100%, 80%, 60%, 40%, and 20%, the maximum effect belonged to the range of 20%–40%.
- Generally, the change in the W.W.R in the two cities decreases 17% in each direction. It shows that the W.W.R has a significant effect on the energy consumption of the building.
- By considering the W.W.R in each direction, the effect of various directions is not the same in terms of decreasing the consumption. The best performances belonged to South, East, West and the North, respectively.
- Based on the results, the appropriate W.W.R for the North and South walls is 40% and for the East and West walls is between 20%–40%.

## 5. CONCLUSION

The main outcomes of this study are presented as follows:

- The W.W.R and the energy consumption are directly related to each other. It means decreasing the W.W.R also decreases the energy consumption. In the two studied cities, this relation is a high correlation degree. Moreover, decreasing the W.W.R leads to an increase in heat consumption and decrease in cool consumption.
- The effect of the W.W.R in small values is high. In the study of the W.W.R, which was conducted in the ratios of 100%, 80%, 60%, 40%, and 20%, the maximum effect belonged to the range of 20%–40%.

## REFERENCES

[1] Dong Y, Cui X, Yin X et al. Assessment of energy saving potential by replacing conventional materials by cross laminated timber (CLT)—a case study of office buildings in China. Appl Sci 2019;9:858.
[2] Ahmadi MH, Ghazvini M, Sadeghzadeh M et al. Solar power technology for electricity generation: a critical review. Energy Sci Eng 2018;6:340–61.
[3] Bojic M, Yik F, Wan K, Burnett J. 1976. Building and Environment: The International Journal of Building Science and Its Applications. Pergamon.
[4] Bojic M, Yik F, Sat P. Energy performance of windows in high-rise residential buildings in Hong Kong. Energy Build 2002;34:71–82.
[5] Yang L, Lam JC, Tsang CL. Energy performance of building envelopes in different climate zones in China. Appl Energy 2008;85:800–17.
[6] Cheung CK, Fuller RJ, Luther MB. Energy-efficient envelope design for high-rise apartments. Energy Build 2005;37:57–48.
[7] Yu J, Yang C, Tian L. Low-energy envelope design of residential building in hot summer and cold winter zone in China. Energy Build 2008;40:1536–46.
[8] Eskin N, Türkmen H. Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. Energy Build 2008;40:763–73.
[9] Lam JC. Energy-efficient measures and life cycle costing of a residential building in Hong Kong. Archit Sci Rev 1993;36:157–62.
[10] Higgs F. Assessing the impact of solar penetration on the thermal performance of Hong Kong Public Housing. ANZASCA Conference, Hong Kong, China, 1994, pp. 91–5.
[11] Leung TM, Chau CK, Lee WL, Yik FWH. Willingness to pay for improved environmental performance of the building envelope of office buildings in Hong Kong. Indoor Built Environ 2005;14:147–56.
[12] Bojic M, Yik F, Sat P. Influence of thermal insulation position in building envelope on the space cooling of high-rise residential buildings in Hong Kong. Energy Build 2001;33:569–81.
[13] Ma H, Li C, Lai J et al. Investigation on energy consumption of public buildings in Tianjin. Energy Procedia 2019;158:3427–32.
[14] Ma H, Lai J, Li C et al. Analysis of school building energy consumption in Tianjin, China. Energy Procedia 2019;158:3476–81.
[15] Mavrokapnidis D, Mitropoulou CC, Lagaros ND. Environmental assessment of cost optimized structural systems in tall buildings. J Build Eng 2019;24:100730.
[16] Giordano R, Giovanardi M, Guglielmo G, Micono C. Embodied energy and operational energy evaluation in tall buildings according to LCA methodology. Energy Build 2011;43:100–8.
to different typologies of façade. Energy Procedia 2017;134:224–33.

[17] Tibermacine I, Zemmouri N. Effects of building typology on energy consumption in hot and arid regions. Energy Procedia 2017;139:664–9.

[18] Chen Z, Shi M, Guoc H, Xu L. Analysis on energy consumption of some comprehensive office building in Jinan. Procedia Eng 2017;205:3769–74.

[19] Wei Y, Xia L, Pan S et al. Prediction of occupancy level and energy consumption in office building using blind system identification and neural networks. Appl Energy 2019;240:276–94.

[20] Deb C, Lee SE. Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data. Energy Build 2018;159:228–45.

[21] Raziei, T. Koppen-Geiger Climate Classification of Iran and Investigation of Its Changes During 20th Century. 2017:419–439.

[22] Climate Date for Cities Worldwide. https://en.climate-data.org/

[23] Mehdi Ghiai M, Mahdavinia M, Parvane F, Jafarikhah S. Relation between energy consumption and window to wall ratio in high-rise office buildings in Tehran. Eur Online J Nat Soc Sci 2014;3:366.

[24] Ramírez-Villegas R, Eriksson O, Olofsson T et al. Life cycle assessment of building renovation measures–trade-off between building materials and energy. Energies 2019;12:344.

[25] Ahmadi MH, Ghazvini M, Alhuyi Nazari M et al. Renewable energy harvesting with the application of nanotechnology: a review. Int J Energy Res 2019;43:1387–410.

[26] Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy Build 2008;40:394–8.

[27] Ahmadi MH, Ahmadi MA, Sadaghiani MS et al. Ground source heat pump carbon emissions and ground-source heat pump systems for heating and cooling of buildings: a review. Environ Prog Sustain Energy 2018;37:1241–65.

[28] Oldfield P, Trabucco D, Wood A. Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings. J Archit 2009;14:591–613.

[29] Jan Hensen. Simulation for performance based building and systems design: some issues and solution directions. In 6th International Conference on Design and Decision Support Systems in Architure. Urban Planning, , Amsterdam, Netherlands: 2002, pp. 30–44.

[30] Hensen JLM. 2004. Towards more effective use of building performance simulation in design.

[31] Amin R. n.d. EQuest Energy Modeling Guide (1).