Impact of Aspect Ratio of Floor Plan on the Energy Performance of Office Rooms in New Delhi, India

Rashmi Kumari
Assistant Professor, Architecture Department, National Institute of Technology Hamirpur, India
Email: rashmi@nith.ac.in

Abstract. The use of efficient building design strategies at the inception of the building project helps to improve the overall building energy performance. This paper focuses on the effect of aspect ratio of the floor plan on the energy performance of a building to reduce the energy demand of the office buildings. The other factors deciding energy performance of a building, like orientation, floor area, floor height, floor number and window to wall ratio, have been kept constant. The simulation is performed in Design Builder software, and the energy consumptions at different assumed cases have been analysed using correlation and regression analysis technique, thoroughly to find the optimum solution. The findings of this research will be useful in providing solutions for the reduction of energy demand of the office buildings in the study area.

Key words: Building simulation; energy-efficiency; aspect ratio; and building design

1. Introduction

The energy consumption in buildings accounts for more than one-third of the total global energy consumption [1]. Thus, the buildings have very high potential for energy savings. Many researchers suggest that energy conservation in buildings especially in office and commercial buildings is very important for all regions including those situated in warm climates. Several researches have worked for finding better solutions for building envelop to save energy. The optimization of building envelope energy-saving technology (BEEST) for improvement of the energy performance of office buildings is among topic of interest for the researchers in the recent past [1,2,3]. The researchers found that the energy efficient building can be attained not only by evaluating the thermal properties of the materials applied, but also by analyzing its form, orientation, the size and placement of elements of fenestration, color and texture of outdoor surfaces, and the type of shading devices [4,5]. It has been established that the building geometry factors, such as form, arrangement, dimensions, and window to wall area ratio, have a great impact on the energy consumption pattern of a building [4,6]. The building design guidelines suggest that form of building affects the building energy performance at significant scale [3,7,8]. A few papers discuss about the comprehensive energy simulation environment to get optimum features for building envelope [8,9,10]. The findings of researches give the range of optimal window-to-wall ratio (WWR) which is $0.30 < \text{WWR} < 0.45$, in different climates [10,11,12]. Many studies found that the impact of building form on the energy consumption can be analyzed with speed, accuracy, and diligence, by using building information modelling (BIM) [13,14,15]. The geometric factors should be carefully considered while designing a building to reduce the energy wastage without a large increase in the initial capital costs.
2. Methodology
The present paper proposes a basic investigation technique to estimate the effect of the aspect ratio of plan on the energy performance of office rooms in New Delhi, India. The technique is based on a systematic whole building energy simulation analysis for the analysis of building energy performance. The weather data, “New Delhi IND ISHRAE WMO#=421820,” has been used for extracting the climatic data in the present investigation. The different aspect ratio of the office room plan have been considered while keeping other factors, like orientation; height; window to wall ratio; surrounding spaces; and material of construction, constant. Then the result of whole building performance analysis has been analyzed thoroughly using statistical techniques to find the conclusion. The climate is considered as composite and study area for the present investigation is New Delhi, India.

3. Study area
In India, the building sector is continuously growing with the increase in energy and environmental concern. The vast increase in energy consumption of office buildings has become a major concern during the past few years, where significantly larger portion of the built space are air-conditioned. It is mainly because of increase in number of office buildings and the higher demand for energy, especially in the big cities, like New Delhi. New Delhi has been considered as the study area for the present investigation (Table 1). The New Delhi region comes under composite climatic zone of India, having large deviation of weather conditions among various seasons. The temperature varies from average 38°C during summer to a low of 6-7°C during winters, thus the buildings necessitate the energy demand for both heating and cooling during the whole year cycle.

Table 1. About New Delhi

|                         |        |
|-------------------------|--------|
| Latitude [deg]          | 28.58  |
| Longitude [deg]         | 77.2   |
| Elevation [m]           | 216    |
| Time Zone               | 5.5    |

The growing demand for office buildings and increasing cost of energy have drawn the attention of Government of India toward the significance of the energy efficient strategies for building designs. The Energy Conservation Act (EC Act) was enacted in 2001 to achieve the goal of reducing energy consumption for strengthening the Indian economy. The Bureau of Energy Efficiency (BEE) has been set up as the statutory body on 1st March 2002, at the central level, to facilitate the implementation of the EC Act. The Bureau of Energy Efficiency showed great forethought and instigated the formation of commercial building energy code in 2004 which intended to reduce the rising energy demand in this sector. The Energy Conservation Building Code (Code) has been established, in accordance with section 14(p) of the Energy Conservation Act 2001, to provide minimum requirements to achieve energy efficiency in building through design and construction techniques [11]. The strategies to achieve energy efficiency in buildings are also being encouraged by the state government agencies, like local governance bodies, and banks, through various rewards and low interest loans for those using renewable energy sources.

4. Building Configuration and Boundary Conditions
A prototype small office building model is created in Design Builder software. The defining attributes have been decided on the basis of results obtained from a survey of 60 actual projects in the study zone. The Building orientation has been dependent on the urban road layout, with most of the buildings having main façade on the south direction. The floor area of an office room has been found in the range of 12–20 m², with square or rectangular shape of floor plan. The floor-to-floor height has been found in the range of 2.5–3.5 m. The windows are generally equally distributed on the exposed
wall, and the window to wall ratio have been found varying from 0.3 to 0.5. The result of the survey has been utilized to set the boundary condition for the present research.

The floor area of the prototype office room model has been presumed to be 16 m$^2$ (Table 2). The model has a rectangular or square shape floor plan. The office room is considered to be situated at the S-W corner of the building with two facades exposed and other two sides of the room share internal partition wall with 3.0 m wide adjacent indoor space. The model has been assumed to be detached with no surrounding buildings or component. The floor to floor height has been set as 3.0 m. The fenestration of all facades has been assumed same with a window to wall ratio of 30 per cent. The roof of the office room is not exposed as there is another floor above the office area under investigation. The office area is an air-conditioned zone. The Occupancy density is set as 0.1 People/m$^2$. The metabolic activities in the office room are limited to light office work, walking, and standing. The metabolic factor is set as 0.9. The external walls are 225 mm thick brick walls having U-Value of 1.700 W/m$^2$-K, whereas, the internal partitions are 105 mm thick brick wall plastered at both sides, having U-Value of 1.993 W/m$^2$-K. The flat roof has U-Value of 0.42 W/m$^2$-K, and the floor have U-Value of 1.463 W/m$^2$-K. The airtightness has been set as model infiltration value of 0.7 air change/hour. The U-Value of Glazing provided at the windows is 6.121 W/m$^2$-K. The radiant fraction of lighting is considered as 0.42 and visible fraction is considered as 0.18 in the present investigation.

Table 2. Geometric design parameters of the office room under investigation

| Sl. No. | Room Aspect Ratio | Length [m] | Breadth [m] | Area of Office Room [m$^2$] | Total building area [m$^2$] |
|---------|-------------------|------------|-------------|-----------------------------|----------------------------|
| 1       | 1:1.0             | 4.0        | 4.0         | 16                          | 92                         |
| 2       | 1:1.2             | 4.4        | 3.6         | 16                          | 92                         |
| 3       | 1:1.5             | 4.9        | 3.3         | 16                          | 92                         |
| 4       | 1:1.6             | 5.1        | 3.1         | 16                          | 92                         |
Result and Discussion

According to the investigation of the single parameter of the prototype office room model, the correlations between energy consumption and the ratio of the length to the width of the floor plan (rectangle/square plan) found to be strong with $R^2$ value more than 0.9. As the aspect ratio (between length and width) of the office floor plan is increased, the energy consumed per area for sensible cooling also increases, and can be represented with equation 1 (Table 3, Figure 1).

$$y = 35.708x^2 - 33.159x + 220$$

\[(1)\]

Similarly, the energy consumed per area for sensible heating decreases as the aspect ratio (between length and width) of the office floor plan is increases, and can be represented with equation 2 (Table 3, Figure 2).

$$y = 39.985x^2 - 72.627x + 170.23$$

\[(2)\]

The total annual energy consumed per area decreases as the aspect ratio (between length and width) of the office floor plan is increases, and can be represented with equation 3 (Table 3, Figure 3).

$$y = 201.59x^2 - 362.79x + 941.49$$

\[(3)\]

Slight change in energy consumption for lighting has been observed with the change in aspect ratio of the floor plan because daylight distribution of the office room gets impacted. There is a behavioral opposing between energy consumed for heating and energy consumed for cooling.

**Table 3. Result summary of energy consumption**

| Sl. No. | Parameters                     | Aspect Ratio |
|--------|-------------------------------|--------------|
|        |                               | 1:1.0        | 1:1.2        | 1:1.5        | 1:1.6        | 1:2.0        |
| 1      | Lighting Consumption [kWh]    | 921.02       | 911.00       | 929.60       | 907.05       | 896.83       |
| 2      | Zone Sensible Cooling User Design Load [W] | 3268.46   | 3169.57       | 3158.90       | 3088.57       | 3043.35       |
| 3      | Zone Sensible Heating User Design Load per Area [W/m²] | 222.29   | 217.94       | 212.86       | 213.29       | 212.57       |
| 4      | User Design Air Flow [m³/s]  | 0.27         | 0.26         | 0.26         | 0.26         | 0.25         |
| 5      | Zone Sensible Heating User Design Load [W] | 2019.14   | 2011.17       | 2056.39       | 2039.49       | 2063.48       |
| 6      | User Design Load per Area [W/m²] | 137.32   | 138.29       | 138.57       | 140.85       | 144.13       |
| 7      | User Design Air Flow [m³/s]  | 0.06         | 0.06         | 0.06         | 0.06         | 0.06         |
| 8 | Energy Per Conditioned Building Area [kWh/m²] | 778.72 | 784.00 | 783.12 | 795.81 | 811.76 |

Figure 1. User Design Load for Cooling vs. Aspect ratio

$$y = 35.708x^2 - 33.159x + 220$$  
$$R^2 = 0.9784$$

Figure 2. User Design Load for Heating vs. Aspect ratio

$$y = 39.985x^2 - 72.627x + 170.23$$  
$$R^2 = 0.9374$$
6. Conclusion
The present research shows that while considering building design solutions for saving energy resources, the optimum ratio of the plan area can play a vital role. The optimum floor plan aspect ratio can obtain and utilized to achieve reduction in heating and cooling energy consumption in different climatic zones. This could have important application in preparing guidelines which can be followed at early design stage, in order to achieve energy conservation. It is envisaged that some principles can be evolved for application in all regions having similar climates. It is believed that the present research method can be extended to other building types at various locations.

Acknowledgements
The author would like to recognize the financial support from the Ministry of Education, Government of India. The author also acknowledges the anonymous reviewers for their valuable comments.

References
[1] Lu M and Lai J H 2019 Building energy: a review on consumptions, policies, rating schemes and standards Energy Procedia 158 pp 3633-3638
[2] Li H, Geng G, and Xue Y 2020 Atrium energy efficiency design based on dimensionless index parameters for office building in severe cold region of China BUILD SIMUL. 13 pp 515–525
[3] Liu Li, Wu1 D, Li X, Hou S, Liu C, and Jones P 2017 Effect of geometric factors on the energy performance of high-rise office towers in Tianjin, China BUILD SIMUL. 10 pp 625–641
[4] Lu1 S, Lin B, and Wang C 2020 Investigation on the potential of improving daylight efficiency of office buildings by curved facade optimization BUILD SIMUL. 13 pp 287–303
[5] Parasonis J, Keizikas A, and Kalibatiene D 2011 The relationship between the shape of a building and its energy performance Architectural Engineering and Design Management Jan 2011 p 11
[6] Pathirana S, Rodrigo A, and Halwatura R 2019 Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate International Journal of Energy and Environmental Engineering 10 pp 107–120
[7] Raof B 2017 THE CORRELATION BETWEEN BUILDING SHAPE AND BUILDING ENERGY PERFORMANCE International Journal of Advanced Research 5(5) pp 552-561
[8] Bencheikh D and Bederina M 2020 Assessing the duality of thermal performance and energy efficiency of residential buildings in hot arid climate of Laghouat Algeria International Journal of Energy and Environmental Engineering 11 pp 143–162
[9] Catalina T, Virgone J, and Iordache V 2011 STUDY ON THE IMPACT OF THE BUILDING FORM ON THE ENERGY CONSUMPTION Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November

[10] Kumari R and Devadas V 2017 Modelling the dynamics of economic development driven by agricultural growth in Patna Region, India. Economic Structures 6, 15 https://doi.org/10.1186/s40008-017-0075-x

[11] Energy Conservation Building Code 2017 Bureau of Energy Efficiency, India p 181

[12] McKeen P and Fung A S 2014 The Effect of Building Aspect Ratio on Energy Efficiency: A Case Study for Multi-Unit Residential Buildings in Canada Buildings 4 pp 336-354

[13] Mutani G and Todeschi V 2020 Building energy modeling at neighborhood scale Energy Efficiency 13 pp 1353–1386

[14] Oree V and Anatah H K 2017 Investigating the feasibility of positive energy residential buildings in tropical climates Energy Efficiency 10 pp 383–404

[15] Tokbolat S, Al-Zubaidy S, and Badr A 2016 Low-energy design for future housing developments in Kazakhstan: a case study Energy Efficiency 9 pp 211–222