Optimization of the building form and fenestration for the current and future climate scenarios Conference

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Abstract

The paper aims to analyse the impact of building form and fenestration on energy demand for current and future climate scenarios. For the purpose of this study, a typical 24-hour operational small office building with 1000 m² floor area located in New Delhi (28.6139° N, 77.2090° E), India is considered. The base case building model compliant with ECBC (Energy conservation building code) guidelines is modelled using Grasshopper software tool. Relative compactness is varied from 0.43 to 1, window to wall ratio is varied from 20% to 40% and orientation from 0° to 90°. Cooling and heating loads are analysed for current weather condition using TMY (typical meteorological year) weather file and IPCC (Inter-governmental panel on climate change) future climate scenarios (A1B) for year 2018 and 2070. Optimization of building form and fenestration is carried out for the building configuration alternates using Response surface method. The paper presents the impact of climate change on cooling demand. It highlights the need to consider the climate change impact in building energy demand predictions.

Introduction

Collective studies present climate change scenarios and the impact on heating and cooling load due to the building envelope variables like window-wall ratio (WWR), orientation and relative compactness(RC). IPCC exhibited correlation between energy use in a building and existing weather conditions. (Wan et al. 2011).

Currently buildings account for about 35% of total energy consumption and growing at 8% (Bhawan and Puram n.d.). Building form and fenestration plays a vital role on influencing the energy demand of the building. Although, the efficiency of the HVAC systems has improved impressively, it is not sufficient to counterbalance the tremendous increase of the future cooling demand (Santamouris 2016). Due consideration has been given in the early design stage in order to reduce the cooling and heating load. The study intends to give end users a better understanding of the dynamic interactions and energy use implications. (Eskin and Türkmen 2008). Identification of envelope characteristics that influence energy demand the most can help make more informed investment decisions for future retrofits.(Kalvelage et al. 2014).

Role of building envelope variables

The characteristics of the building envelope are crucial variables that are taken into account because they are relevant to the energy requirements for maintaining the building at a comfortable temperature. To design energy-efficient building, design variables and construction parameters must be optimized (Pacheco, Ordóñez, and Martínez 2012)

The climate change impact is more acute in composite climate zone, which require both heating and cooling. Therefore this study demonstrates the sensitivity of design features to climate change impacts.(Karimpour et al. 2015) demonstrated which design feature are more sensitive to climate change. According to the Fourth Assessment Report of the IPCC, the building sector has the greatest potential for climate change mitigation, which poses a major challenge for building professionals.

To investigate the performance of buildings in a future climate IPCC published a set of emission scenarios for use in climate change studies.

It indicates that for the year 2040 global temperature rises depending on the scenario for the year 2080. Several studies have investigated the impact of the climate change on office buildings and they conclude that cooling loads are likely to increase by 50 to over 90% until the end of the century depending on the climate zone, considering the strong optimization potential for building properties (Roetzel and Tsangrassoulis 2012).(de Wilde and Coley 2012) state that with a growing global concern about climate change, the building industry is facing the question of how predicted changes in climate will influence the performance of buildings around the world. (Pacheco et al. 2012) observed that the (i) compactness index; (ii) shape factor; (iii) climate and (iv) the influence of shape on the lifecycle of the building are related to building form and influence heating and cooling requirements.

Objectives of the study

Based on the above literatures this paper derives the following objectives:

Figure 1 Methodology

- To evaluate the variation between building form and envelope characteristics on the building energy use,
- To establish optimized building form and fenestration for current climatic scenario and further,
- To analyse the impact of climate change scenario on the optimized form and fenestration.

Scope and Limitations

The National Building Code (NBC) of India defines New Delhi under Composite Climate. As per Köppen-Geiger climate classification, New Delhi (28.6139°N, 77.2090°E), is humid subtropical zone having high variation between summer and winter temperatures. The city experiences the diversities of all the major season of summer, winter and monsoon. The city experiences extreme heat during summer, which ranges from early April to June and extreme cold in winter from December to January. Due to the extremities in temperature and emerging demand for commercial buildings being the capital state, the city of New Delhi is considered as the area of study for this paper. Square shape of 1000m² is considered as the base model that represents a typical small office building as per ECBC.

Methodology

This section describes the stepwise work process undertaken for this study

Details of the study

Window-wall ratio, orientation and relative compactness are used as the indicators to predict the cooling and heating load for present and future climatic scenarios. Figure 1 shows the methodology followed in this paper for creating a parametric model to optimize the best alternates of these variables. Eventually, optimum building configuration, which requires minimum cooling

load, is established. There are numerous ways how the actual dimension of length, breadth and depth varies which contributes to different building form and surface area. The compactness of a form can reduce energy consumption (Granit & Möller, 2008). While AlAnzi *et al.*, (2009) use compactness as an indicator in assessing the impact of shape on energy performance. There is a less research on building performance of the form based on cooling load capacity (Rashdi and Embi 2016). He also states that orientation plays an important role as it relates to the climate. Exploration in manipulating the building form with constant area of 1000m² area projected wide range of variation on the building envelope parameters taken into consideration. WWR ranging from 20% to 40% is studied with orientation from 0° to 90° and RC ranging from 0.43-1. Figure-2 lists the geometric dimensions and the upper limit (UL) and lower limit (LL) of RC. Using design expert, best alternatives of these combinations are extracted and the parametric model was run for observing the response of cooling load and heating load.

Building shape

The shapes include square (S1), rectangle (S2), I-shape (S3), T-shape (S4), C-shape (S5), L-shape (S6), cross-shape (S7). The floor area is constant for all the shapes and to ensure that the volume remains constant, height is constant for all the configurations. This also makes all the shapes comparable to each other. Taking the L (length) and B (breadth) of the square as the base, combinations of L and B are found, that gives a rectangle of same area with a condition that the breadth should not be less than 15m. Length and breadth are indirectly proportional to each other, if the breadth is reduced further, the shape thus obtained will be longitudinal, that makes the shape impractical to be considered as a building. In addition, 15 m is considered as a standard depth for a doubly corridor office building. Square shape that has the least perimeter and surface area of walls are considered as the reference

shape for all the other shapes for studying the heating and cooling load.

Relative compactness

(Ourghi, Al-Anzi, and Krarti 2007) has established direct correlation between relative compactness and total building energy use as well as the cooling energy requirement. Relative compactness is defined as the wall surface area of base shape (W_{SA})_{reference} divided by the wall surface area of the specific shape (W_{SA})_{shape}. (AlAnzi, Seo, and Krarti 2009).

$$Rc = \frac{(W_{SA})_{reference}}{(W_{SA})_{shape}}$$

Surface area of wall is used to find the relative compactness so that effect of exterior walls on heating and cooling load can be studied. Figure-1 lists the geometric dimensions and the upper limit (UL) and lower limit (LL)

of relative compactness (RC) of the building forms used in this study.

Modelling

3D modelling of different building configurations complaint with ECBC guidelines is done using grasshopper software tool. The typical small size office building operational schedules, occupancy pattern, internal loads and other operational parameters are entered in the software and this information are constant for all the building configurations considered for simulation. WWR uniformly distributed in all cardinal directions is considered. The window to wall ratio is set to vary from 20% - 40%. Building is considered with conditioned with ideal air load system. Construction details fed in the model are as per SP41. Orientation range is between 0-90 for the analysis. Several combinations of WWR and orientation is used to analyse heating and cooling load for different building shapes and relative compactness. Cooling and heating loads are analysed for current weather condition using TMY weather file and

Figure 2 Building shapes

Figure 3 Algorithm program for building energy analysis

three IPCC future climate scenarios A1B for the year 2070. Energy plus is used to perform for Energy simulations. Response surface method is used for optimization of all alternatives with different combinations of WWR, Orientation and RC.

Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3D modelling tools. Honeybee is an open source environmental plugins. This software is used to create the building model and is used to perform parametric study using graphical components. Also, multiple types of simulations is performed with these plugins along with the weather analysis, by extracting the psychrometric chart from the same. The building geometry is brought into grasshopper as zones and fed with the construction details and energy simulation is carried out (Anon 2018). Grasshopper script is prepared to feed in the calculated range of building dimensions like length (L), breadth (B) and depth (D). Floor area and range of L of the building kept constant, corresponding B and D were calculated using mathematical conditions. Figure-3 shows the algorithm program of building energy analysis. This script was used to calculate the effect of building envelope variables like WWR, RC and orientation on the building.

Dynamic interaction of the RC, WWR, orientation on different building configurations are studied by running these scripts, (ii) extracting the data and (iii) analyzing the response of cooling load for current and future climate scenario. The three output performance indicators are WWR, RC and orientation for the years 2018 and 2070. Cooling load and heating load were extracted from the energy simulation done using Energy plus engine.

Climate change analysis

Predicting future climatic conditions is the starting point to all climate change impact studies (de Wilde and Coley 2012). The last three decades have been the warmest since 1850. If emissions continue such as the current trends, average air temperature over the period 2081–2100 will be 4.8 °C higher than that over 1986–2005. As per IPCC, there are four distinct scenario families A1, A2, B1 and B2 where A1B is a balanced across energy resources

which considers the use of fossil and renewable energy sources The heating energy demand will decrease over the years while the cooling energy demand will increase due to global warming (Andrea Invidiata 2016).

The Weather data for the year 2070 was generated using meteonorm software. This software is a weather data generator and a database developed by the Swiss Federal Office of Energy. Figure-4 describes the variation in running mean temperature for the typical three hot days and cold days of the year. A1B is a sub-climate change

Figure 4- Variation in running mean temperature for the month of June and December in the year 1995, 2040, 2070 – A1B climate change scenario

Figure 5- Psychrometric chart for the city of Delhi for current and future climate scenario

scenario condition under A1 major scenario which explains the balance across energy resources. In this paper, epw. file for A1B climate change scenario is taken into consideration (Roetzel and Tsangrassoulis 2012). This database is a comprehensive source of weather data covering 7700 meteorological stations worldwide.

Meteonorm includes three IPCC scenarios and allow the projections to the year 2100. Climate study is undertaken to study the impact of the building envelope variables for current and future climate scenarios. Figure-5 is the graphical representation using psychrometric for the New Delhi city in 2018 and 2070. This describes that in 2070 number of hot days are more, demanding for more cooling load.

Results and discussion

Ultimate goal of this paper is to study and analyse the impact of different building configurations on cooling load. Compactness of the building, also known as shape factor plays a vital role in determining the cooling and heating load of the building. Orientation and WWR has an impact on cooling and heating load require for buildings of different configurations. When RC increases, the percentage of cooling load decreases illustrating that

more compact the building form is, lesser the cooling load is required.

Impact of Relative Compactness

Result obtained initiates on the optimum building configuration required to decrease the cooling and heating load for the S2, S3, S4, S5, S6, S7 building configurations. The total annual cooling load of 160820 kWh is observed to be the least when compared with the rest of the shapes. This was obtained with rectangle shape building configuration (RC-1, WWR=20% and orientation 0°) which is accounted as the shape which requires minimum cooling load. In contrast, optimized building configuration of S3, S5 shaped building form which has the lower relative compactness of 0.7 with WWR=20% and building placed at 0° which accounted for a cooling load of 189601.14 and 190076.61 kWh respectively. Approximately 18% increase in cooling load is observed with respect to change in relative compactness.

Impact of orientation

Rectangle shape showed 7% variation in cooling load with respect to change in orientation whereas no variation was observed for cross, S4 and S6 shapes as the orientation varied from 0 to 90. Shapes like S3 and S5 showed 10% variation in cooling load with change in orientation.

Impact of WWR

Rectangle shape showed 4% variation in cooling load with respect to change in WWR whereas 6% variation was observed for cross, S6 and S4 shapes as the WWR varied from 20 to 40. Shapes like S3 and S5 showed 6% variation in cooling load with change in orientation.

Combined Impact of WWR, RC and orientation

Significant impact of building envelope variables like WWR, RC and orientation on the annual cooling load were analysed using design expert. Different building forms like S2, S5, S3, S7 and S4 had significant correlation factor stating the impact of these variables on cooling load.

As relative compactness increased, cooling energy decreased gradually with the correlation factor of -0.785 for rectangle and -0.968 for all other building forms that is considered. This establishes the inverse proportionality between the variable and the response. As WWR increased, cooling load increased linearly with the correlation factor of 0.395 for rectangle to 0.166 for rest of the building forms that is considered. When the orientation is varied from 0° to 90°, the correlation factor was 0.342 i.e., the cooling load showed gradual variation on varying the building orientation.

Figure 7- Interaction between RC, WWR and orientation for different building shapes considering the year 2070

Combined impact of these variables were studied to achieve the ultimate goal of minimizing the cooling load goal for which the optimum combination of WWR, RC and orientation for different building forms like gle, C-shape, L-shape, H-shape, Cross-shape and T shape is studied. For e.g., RC and orientation had an interactive effect on the rectangular building form whereas their significant effects were not prominent. To achieve this, for every combination, two variables among the three is constant and the third variable was varied from their lower from 0°-90° with RC as 0.43 to 1 and WWR 20%, then the percentage increase in cooling load is observed to be 6%

Table- 1 Percentage variation in cooling and heating load obtained by the optimum combination of variables for each shape for the year 2018 and 2070

Shapes	RC	WWR	Orientation	% Diff. (CL)	% Diff. (HL)
C	0.70	20.00	0.00	39.68	-83.41
Cross	0.98	20.00	0.00	39.53	-80.60
I	0.70	20.00	0.00	39.73	-83.22
L	0.98	20.00	0.00	39.50	-80.86
Rec	1.00	20.00	0.00	39.52	-80.87
T	0.98	20.00	90.00	39.49	-80.75

and when the RC is decreased to 0.43 for the same conditions the percentage increase in cooling load is 10%. In H shaped configuration, the percentage increase in cooling load is 5.13% and 8.88% for RC 0.7 and 0.43 respectively. Whereas, increase percentage of cooling load for the Cross-shape, L-shape and T-shape building configuration varied from 5.43% to 3.8% for RC from

Figure 6- Variation in cooling load obtained by the optimum combinations of variables for each shape for the year 2018 and 2070

0.47-0.98 respectively, when the building was rotated from 0°-90°.

This defines that combination of orientation, RC and WWR plays significant role in determining the cooling load and heating load needed in a building (Table-1). This describes the percentage increase and decrease in the cooling load obtained when the variable combination for each building shape that requires minimum cooling load are analysed. Further analysis for future climate scenario A1B, as per IPCC for the year 2070 is studied.

Conclusion

The study revealed the optimized building configuration generated based on minimum cooling load and better energy performance. Parametric analysis of building envelope variables is performed with the aim of minimizing the need for cooling load and heating load for the specific building configuration. Optimized configurations were further analysed for future climate scenarios.

A simple analysis is performed to investigate the statistical variation in the obtained cooling load and heating load for current and future climate scenarios.

The investigation is carried out for a small sized office building by varying relative compactness, WWR and orientation of the building configuration. The optimization is performed through an implementation of response surface method. HVAC load adhere to the Building configuration manipulation, so the results will be highlighted on how the manipulation can be done to minimize HVAC load.

- Building forms with higher relative compactness has lower cooling load as compared to the other building forms that are studied.
- Cooling load varies linearly with WWR.
- Building orientation has a significant role in reducing the cooling load required for the building.

As the result shows, in future climate scenario there is a 40% increase in cooling load and 80% decrease in heating load in the building shapes that has optimum variable combination for current scenario.

The results of this study helps in decision making by the end users in the early design stage of energy efficient building envelope. Further research on building shape parameters has potential in saving energy for future climate scenario. This also helps in predicting the indicators that needs focus to achieve building energy efficiency in future climate scenario.

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