Simulation-Based Optimization of Building Orientation for Optimum Electricity Consumption of Indian Residential Buildings

Ann M Biju¹*, Vignesh Ayyathurai²
¹ RICS School of Built Environment, Mumbai, India
² RICS School of Built Environment, Mumbai, India
¹ Annb.me17m@ricssbe.edu.in
² vayyathurai@ricssbe.edu.in

Abstract. The demand for electrical energy had grown tremendously over the last few decades. The 2019 annual report by electricity sector of India shows that India is the third largest consumer of electricity in the world. Studies revealed that buildings are major consumers of electricity, in which residential buildings consumes the most. Tremendous increase in electricity demand are anticipated in Indian residential sector in the coming years due to development plans such as Power for all policy. Studies depicted that residential buildings have an energy saving potential of about 30-50% and most of the previous researchers had focused only to replace the electrical appliances in the constructed facility and had ignored the design features of the building to minimize electricity consumption. The present study therefore focused on reducing the energy use in residential sector of India by simulation-based optimization of buildings at its design stage. Design Builder software version 6.1.0.006 with Energy Plus simulation engine 8.9 was used for the study. A two storied residential building in Kochi, Kerala was considered for the study. The building model was validated using previous electricity bills and was then retrofitted using Energy Conservation Building Code (ECBC). The model was simulated for eight different orientations for different cases in five different climatic zones in India. East orientation was found to be the best orientation for all cases except cold climatic zone. The percentage saving in annual electricity consumption and cost of electricity bills that could be saved by opting the best orientation were also found.

Keywords: Residential Buildings, Design Builder, Energy Plus, Simulation, Climatic Zones

1. Introduction
The demand for electrical energy has grown tremendously over the last few decades as more people get access to electricity and remaining population is trying to enhance their standard of living [3]. The 2019 annual report by Electricity Sector of India depicts that India is the third largest producer and consumer of electricity with an installed generation capacity of 350.162 GW [5]. The growth of power capacity and consumption in the country projected to year 2030 is illustrated in figure 1. Unlike other developed countries, India utilizes very few renewable sources of energy accounting about 15.3% of total energy sources and is responsible for around 2194.74 Mt CO₂ of greenhouse gas emission. More than 115 million people got access to electricity in the country after 2013, which made the percentage of population with access to electricity from 80% to 86% in 2017 with an average consumption of 1149 kWh per capita [8].
Buildings are one of the important consumers of electricity, consuming about 40% of the total energy consumption worldwide [1]. In India, residential sector consumes about 24% of the total building energy consumption and is forecasted to increase by eight times by 2050. The sector wise distribution of energy consumption in the country for the year 2016-17 is shown in figure 2. The growth in population, urbanization, increasing income of people and technological advancement are the major factors which pulls the demand of electrical energy in domestic sector [7]. It is also expected that there would be a hike in the growth rate of residential electricity consumption in the coming years due to the power for all policy by Government of India, which assures access to electricity for cent percent population in the country by 2022. The increased energy consumption would result in greenhouse gas emission, temperature rise and would also affect occupant health [2].

Energy audits which were conducted by experts using the energy policies showed that residential buildings in the country have energy saving potential of about 30-50% [6]. The high energy consumption of residential buildings cannot be only attributed to high power consuming appliances, but is also attributable to the design features, materials used and climatic conditions in the location of the building [4]. The ways in which energy can be saved should be explored from the early design stage itself [9]. But most of the researchers had neglected the effect of these factors for energy optimization. Designing and constructing residential buildings in a way that saves maximum energy and using energy efficient appliances together can save a lot of energy and would also cut considerable amount of energy demanded.

The study analysed the effect of orientation of the building in different climatic zones and to optimize orientation for different cases in each climatic zone in the country. The study used energy simulation for optimizing the parameter considered for the study and it would motivate people to use energy simulation software for better energy performance of buildings. The percentage of annual electricity bills and annual electricity cost that could be saved were aimed to be found. The amount
of carbon-di-oxide emitted was also aimed to be explored. It had aimed to set a standard for the orientation preferred in different climatic zones of the country for better energy performance.

2. Methodology
The study focused in finding the energy consumption and other environmental related factors in residential buildings. The study also aimed to optimize the given building to give the least possible electricity consumption and to minimize other negative effects on environment. A double storied residential building in Kochi, Kerala was selected for the study. Figure 3 shows the location details of the building. The house was built three years ago. The built-up area is around 159.22 m² and plot area is around 502.34 m². The building was oriented towards the west direction. The East side of the building had a plot with rubber plantation. The west side of the building had a narrow private road of 3.048 width. The plots with proposed building were there in North and South side. Figure 4 shows the picture of case study building.

Design Builder software version 6.1.0.006 with Energy Plus simulation engine 8.9 was used to model and analyse the building. The two-dimensional AutoCAD model prepared was imported in DXF format to the 3D modeller of Design Builder software. The building area was divided into different zones based on the purpose of the area. Each area was assigned with matching zone category defined in Design Builder database. The model was then developed and simulated and similar result as of the data collected from the building was generated in the building.

Energy Conservation Building Code (ECBC) guidelines were followed to retrofit the validated model building envelope, HVAC, lighting system factors were considered slightly more than the minimum criteria mentioned in the code. The thermal resistance and thermal transmittance of walls were calculated using the following equations.

Thermal resistance of building layer,

\[ R_i = \frac{t_i}{k_i} \]  

(1)

where \( t_i \) and \( k_i \) are the thickness and thermal conductivity of the layer.

Thermal conduction of the materials is taken from Table 6 of ECBC, 2017.

Total thermal resistance,

\[ R_{\text{total}} = \frac{1}{k_0} + \frac{1}{k_0} + R_1 + R_2 + \ldots + R_n. \]  

(2)

Thermal transmittance,
\[ U = \frac{1}{R_{\text{total}}} \]  \hspace{1cm} (3)

where \( h_i \) and \( h_o \) are inside and outside air heat transfer coefficients respectively. The default values of the coefficients are 9.36 W/(m\(^2\)k) and 19.86 W/(m\(^2\)k) respectively.

For openings such as window and ventilation, values such as solar heat gain, direct, solar transmission, light transmittance, thermal transmittance were specified. The wall to window ratio was calculated as 40%. Suspended lights were considered for the building. The equipment was considered to be the same as of the case study building. The power density of each area was defined for lighting and equipment. Standard templates in Energy Plus were considered for the scheduling of operation of each factor. A total of 4 members was considered to be the occupants of the building. The number of working days was considered as 5 days/week. The schedule for activity of occupants were taken from the database. The working hours were considered from 7.00 am to 12am. The metabolic factor was given as 0.9. Other details required for the building model were assumed as required.

The building was rotated through 0\(^\circ\) to 360\(^\circ\) to find the best optimum orientation for the building. Four normal orientations such as North, South, East and West and four skewed orientations such as North-East, South-East, South-West and North-West were considered in each climatic zone. Figure 5 shows the three-dimensional model of three storied building with location and sun path details. Table 1 shows the unit electricity charges of each location.

![Figure 5. 3D model of G+2 building in Bangalore facing towards West.](image)

| Location  | Electricity consumption charge per unit for the area as per Tariff issued in 2018 (INR) |
|-----------|---------------------------------------------------------------------------------------|
| Hyderabad | 9.50                                                                                  |
| Bangalore | 7.65                                                                                  |
| Ahmedabad | 4.90                                                                                  |
| Vizag     | 7.75                                                                                  |
| Shillong  | 5.70                                                                                  |

3. Results and Discussions
The electricity consumption in kWh and carbon di-oxide emission in kg of G+2, G+3 and G+4 buildings with and without phase change material BIOPCM M182/Q21 were obtained for composite, temperate, warm-humid, hot-dry and cold climatic zones of the country. The orientation which showed the least electricity consumption (kWh) and \( \text{CO}_2 \) production (kg) was selected as the best orientation. For three storied building without and with phase change material in composite climate, East direction shows the best orientation with electricity consumption 14726.54 kWh and 13775.53 kWh and carbon di-oxide production 8924.27 kg and 8347.96 kg respectively. The worst orientation was obtained as North-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction. For four storied building without and with phase change material
in composite climate, East direction shows the best orientation with electricity consumption 14388.3 kWh and 14435.69 kWh and carbon di-oxide production 8719.3 kg and 8748.02 kg respectively. The worst orientation was obtained as South-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction. East direction showed the best orientation for five storied buildings without and with PCM with electricity consumption of 14405.51 kWh and 15224.76 kWh and carbon di-oxide production of 8729.72 kg and 9226.20 kg respectively. The worst orientation was obtained as North-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction.

For three storied building without and with phase change material in temperate climate, East direction shows the best orientation with electricity consumption 11053.47 kWh and 10484.35 kWh and carbon di-oxide production 6698.42 kg and 6353.49 kg respectively. The worst orientation was obtained as West and the second-best orientation was obtained as North-East direction. For four storied building without and with phase change material in temperate climate, East direction shows the best orientation with electricity consumption 11038 kWh and 11073.36 kWh and carbon di-oxide production 6689.02 kg and 6710.45 kg respectively. The worst orientation was obtained as North-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction. East direction showed the best orientation for five storied buildings without and with phase change material in temperate climate with electricity consumption of 11034.47 kWh and 11689.04 kWh and carbon di-oxide production of 6686.89 and 7083.56 kg respectively. The worst orientation was obtained as North-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction.

For three storied building without and with phase change material in hot-dry climate, East direction shows the best orientation with electricity consumption 17066.98 and 15623.93 kWh and carbon di-oxide production 10342.58 and 9468.09 kg respectively. The worst orientation was obtained as West and the second-best orientation was obtained as North-East direction. For four storied building without and with phase change material in hot-dry climate, East direction shows the best orientation with electricity consumption 16300.73 and 16536.34 kWh and carbon di-oxide production 9878.24 and 10021.04 kg respectively. The worst orientation was obtained as West and the second-best orientation was obtained as North-East direction. East direction showed the best orientation for five storied buildings without and with phase change material in hot-dry climate with electricity consumption of 16316.59 and 17467.13 kWh and carbon di-oxide production of 9887.85 and 10585.08 kg respectively. The worst orientation was obtained as West and the second-best orientation was obtained as North-East direction. For three storied building without and with phase change material in cold climate, West direction showed the best orientation with electricity consumption 19722.1 and 14904.89 kWh and carbon di-oxide production 11981.89 and 9032.36 kg respectively. The worst orientation was obtained as North-East and the second-best orientation was obtained as South-West direction. For four storied building without and with phase change material in cold climate, North-East and East direction showed the best orientation with electricity consumption 15628.42 kWh and 12534.33 kWh and carbon di-oxide production 8640.57 and 5630.08 kg respectively. The worst orientation was obtained as West and the second-best orientation was obtained as East for building without PCM and North-East for building with PCM. West and East direction showed the best orientation for five storied building without and with phase change material in cold climate with electricity consumption of 18155.97 and 17742.05 kWh and carbon di-oxide production of 11002.51 and 8025.13 kg respectively. The worst orientation was obtained as North-East for building without PCM and West for building with PCM. The second-best orientation was obtained as North for building without PCM and North-East for building with PCM. For three storied building without and with phase change material in warm-humid climate, East direction shows the best orientation with electricity consumption 17039.17 and 16015.51 kWh and carbon di-oxide production 10325.74 and 9705.38 kg respectively. The worst orientation was obtained as North-West for building without PCM and West for building with PCM. The second-best orientation was obtained as North-East direction. For four-storied building without and with phase change material in warm-humid climate, East direction shows the best orientation with electricity consumption 16577.98
and 16858.67 kWh and carbon di-oxide production 10046.12 and 10216.34 kg respectively.

Table 2. Percentage reduction in electricity consumption and carbon emission of buildings for its best orientation with respect to the worst and second-best orientations.

| Building                  | COMPOSITE CLIMATIC ZONE                                                                 |
|---------------------------|----------------------------------------------------------------------------------------|
|                          | Reduction in electricity consumption (%) by the best orientation with respect to         |
|                          | Reduciton in CO2 production (%) by the best orientation with respect to                  |
|                          | Worst orientation | Second best orientation | Worst orientation | Second best orientation |
| G+2 without PCM           | 35.11 | 9.18 | 35.11 | 9.18 |
| G+3 without PCM           | 35.58 | 9.56 | 35.58 | 9.56 |
| G+4 without PCM           | 37.74 | 9.49 | 37.74 | 9.49 |
| G+2 with BIOPCM           | 35.80 | 8.51 | 35.80 | 8.50 |
| G+3 with BIOPCM           | 35.69 | 8.50 | 35.69 | 8.50 |
| G+4 with BIOPCM           | 35.54 | 8.59 | 35.54 | 8.59 |

| Building                  | TEMPERATE CLIMATIC ZONE                                                                 |
|---------------------------|----------------------------------------------------------------------------------------|
|                          | Reduction in electricity consumption (%) by the best orientation with respect to         |
|                          | Reduciton in CO2 production (%) by the best orientation with respect to                  |
|                          | Worst orientation | Second best orientation | Worst orientation | Second best orientation |
| G+2 without PCM           | 37.75 | 12.27 | 37.18 | 12.27 |
| G+3 without PCM           | 39.66 | 12.67 | 39.66 | 12.67 |
| G+4 without PCM           | 40.70 | 11.51 | 40.70 | 11.50 |
| G+2 with BIOPCM           | 40.71 | 11.42 | 40.71 | 11.43 |
| G+3 with BIOPCM           | 40.71 | 11.38 | 40.71 | 11.38 |

| Building                  | HOT-DRY CLIMATIC ZONE                                                                  |
|---------------------------|----------------------------------------------------------------------------------------|
|                          | Reduction in electricity consumption (%) by the best orientation with respect to         |
|                          | Reduciton in CO2 production (%) by the best orientation with respect to                  |
|                          | Worst orientation | Second best orientation | Worst orientation | Second best orientation |
| G+2 without PCM           | 34.77 | 5.46 | 34.77 | 5.46 |
| G+3 without PCM           | 37.28 | 5.54 | 37.28 | 5.54 |
| G+4 without PCM           | 40.49 | 5.50 | 40.49 | 5.50 |
| G+2 with BIOPCM           | 36.50 | 4.11 | 36.50 | 4.11 |
| G+3 with BIOPCM           | 36.03 | 4.13 | 36.03 | 4.13 |
| G+4 with BIOPCM           | 35.84 | 4.22 | 35.84 | 4.22 |

| Building                  | COLD CLIMATIC ZONE                                                                      |
|---------------------------|----------------------------------------------------------------------------------------|
|                          | Reduction in electricity consumption (%) by the best orientation with respect to         |
|                          | Reduciton in CO2 production (%) by the best orientation with respect to                  |
|                          | Worst orientation | Second best orientation | Worst orientation | Second best orientation |
| G+2 without PCM           | 18.92 | 2.8  | 18.92 | 2.8  |
| G+3 without PCM           | 42.66 | 1.76 | 55.28 | 7.16 |
| G+4 without PCM           | 20.66 | 0.09 | 20.66 | 3.62 |
| G+2 with BIOPCM           | 27.38 | 6.74 | 27.38 | 6.74 |
| G+3 with BIOPCM           | 43.75 | 4.48 | 52.85 | 2.18 |
| G+4 with BIOPCM           | 43.49 | 4.61 | 43.49 | 4.61 |

| Building                  | WARM-HUMID CLIMATIC ZONE                                                                |
|---------------------------|----------------------------------------------------------------------------------------|
|                          | Reduction in electricity consumption (%) by the best orientation with respect to         |
|                          | Reduciton in CO2 production (%) by the best orientation with respect to                  |
|                          | Worst orientation | Second best orientation | Worst orientation | Second best orientation |
| G+2 without PCM           | 31.07 | 7.57 | 31.07 | 7.57 |
| G+3 without PCM           | 34.31 | 7.84 | 34.37 | 7.84 |
| G+4 without PCM           | 34.34 | 7.82 | 34.34 | 7.82 |
| G+2 with BIOPCM           | 31.27 | 5.71 | 31.27 | 5.71 |
| G+3 with BIOPCM           | 30.91 | 5.74 | 30.91 | 5.74 |
| G+4 with BIOPCM           | 30.58 | 5.79 | 30.58 | 5.79 |
All climatic zones, except cold climatic zone had given least electricity consumption and carbon dioxide production when the minor axis of the building was oriented towards East direction. As per Vastu Shastra also, East is the best direction towards which the building should be oriented. But the cold climatic zone had given West direction as the optimum orientation in some cases. For cold climatic zone, as it gives different results in different cases, it is advised to do building simulation for buildings before fixing the orientation. Also, it was found that around 18% to 56% electricity consumption could be saved by opting the best orientation suggested in the study instead of the worst orientation mentioned. A maximum value of about 13% electricity was found to be conserved if the best orientation is chosen instead of the second-best orientation. In short, choosing the best orientation would reduce the electricity consumption by at most 56%. The reduction in electricity consumption would also reduce the carbon emission and related negative impacts on the environment. Figure 5 to 9 shows the annual electricity cost of buildings with and without PCM in INR for different orientations. This shows that considerable amount of money could be saved by choosing the best orientation.

4. Conclusion
The availability and consumption of electricity is regarded as one of the inevitable factors for comfortable and better standard of living. Residential sector is one of the major consumers of electricity in the country. The increased consumption of electricity would deplete the resources to a great extent and it also has an adverse impact on environment and sustainable future of people living in the country. The consumption of electricity could be controlled to a large extent by designing buildings in such a way that the building consumes the minimum electricity required. It could be done by modelling and simulating the building using an energy analysis software and then numerically optimizing the building design for minimum energy consumption. The present study focused on analyzing residential buildings to find out the effects of various design parameters on the electricity consumption and related impacts on the environment. Design Builder software version 6.1.0.006 with Energy Plus simulation engine 8.9 was used for the study. The study was conducted for three, four and five storied building models with and without phase change material BIOPCM M182/Q21 in five different climatic zones of the country such as composite, temperate, hot and dry, warm and humid and cold climatic zone. Eight different building orientation such as North, North-East, East, South-East, South, South-West, West and North-West were considered for the study. The East orientation was found to be the best orientation for the buildings with and without phase change materials in all climatic zones, except cold climatic zone. For cold climatic zone, as it gives different results in different cases, it is advised to do building simulation for buildings before fixing the orientation. It was also found that considerable economy could be achieved by choosing the best orientation while designing buildings.

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Figure 6. Annual electricity cost of buildings in composite climatic zone.

Figure 7. Annual electricity cost of buildings in temperate climatic zone.

Figure 8. Annual electricity cost of buildings in hot-dry climatic zone.

Figure 9. Annual electricity cost of buildings in warm-humid climatic zone.
Figure 10. Annual electricity cost of buildings in cold climatic zone.

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