PASSIVE DESIGN AND PERFORMANCE EVALUATION OF BUILDING USING E-QUEST: A CASE STUDY

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Abstract

There are many factors that drive the energy consumption and demand in high-rise commercial office buildings. Through a case study, this paper presents an approach to evaluate how different types of sunshields, building orientations, position of windows and wall window ratio (WWR) affect the energy consumption of a facility. e-Quest, an energy simulation software is used to simulate the energy performance of the facility. The simulation model is calibrated against the measured monthly electrical consumption. The subject facility is located in Kolkata, India. Calibrated simulation model of a building has been created using the real data gathered during energy audit to estimate the energy saving potential through the implementation of the passive building architectural designs by a simulation software e-Quest. Finally an optimum passive building design recommendation to reduce the building energy consumption is in this paper to assist the facility managers. The detailed energy simulation gives recommendation on window orientation, WWR and optimum shading design.

Keywords: e-Quest, building orientation, window shading, wall-window ratio, zero energy building, passive architecture.

Introduction

Since the industrial revolution, the world has witnessed incalculable technological achievements, population growth, and corresponding increases in resource use and the “side effects” of these activities: pollution, landfills at capacity, toxic waste, global warming, resource and ozone depletion and deforestation are straining the limits of the Earth’s “carrying capacity”. In India, buildings are responsible for 40 per cent of national energy consumption (Ashish Jain). Of the building energy consumption, some 39 per cent on an average is utilized for lighting, 46 per cent for HVAC (heating ventilation air- conditioning) and 15 per cent is utilized for other purposes in an office building which varies according to conditions such as seasons, latitude etc. So the reduction of energy consumption in buildings is of high socio-economic relevance. The distributions of energy consumption in various fields of India and the percentage energy consumption by various utilities of an office building are shown in Figure1.

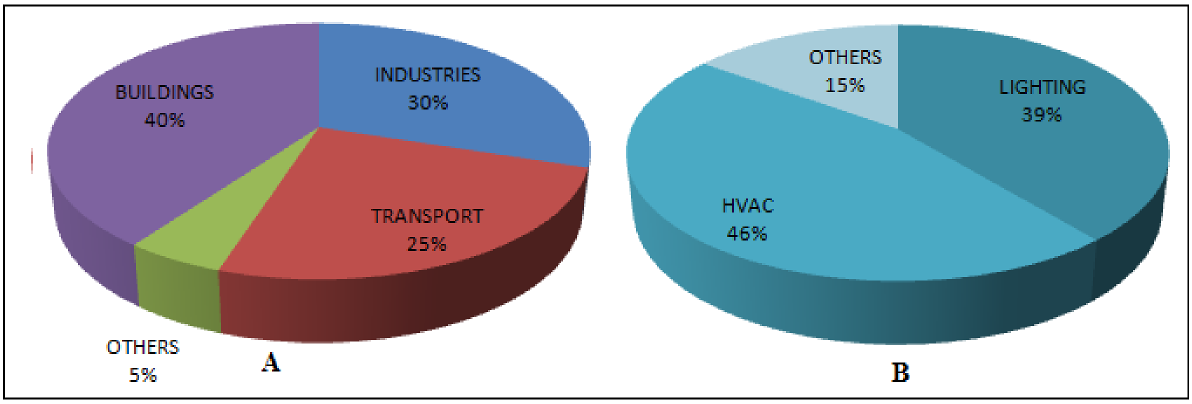


Figure1: Energy consumptions pattern: (A) Distribution of energy consumption in various fields of India; (B) The percentage energy consumption by various utilities of an office building in India

As the buildings are responsible for maximum amount of national energy consumption, researchers are trying to find advanced technologies, renewable energies and useful strategies to build a green environment through green buildings. The object of a zero energy building is not only to minimize the energy consumption of the building but it also reduces the carbon emission and provides a green environment to the people (Wang, Gwilliam, Jones, 2009). In addition, due to the rising cost of energy, looking for efficient ways of building operation such as load management or renewable energy becomes more and more important (Bush, Maestas, 2009, Vine, Mills, Chen, 2000). Still now the general awareness of green building in India is scattered. Though architects have been sporadically adopting concepts like passive architecture and natural air-conditioning but integrated and holistic approach towards construction of modern green structures is yet to emerge. There is a tremendous potential for construction of green buildings in India as two-thirds of the commercial and high-rise residential structures that will exist in 2030 are yet to be built. In the following, the paper will discuss a case using an off-shelf software tool, e-Quest, as a complementary tool to validate recommendations from a thoroughly data collection process. This paper also explores an approach to evaluate how different types of sunshields, building orientations, position of windows and wall-window ratio affect the energy consumption in that building under common scenarios. To reduce the energy consumption, an optimum building design recommendation mainly in passive architecture, is also presented in this paper. Details of the modeling process, as well as the results of using the simulation technology, are also discussed.

Literature review

Computer-based simulation is accepted by many studies as a tool for evaluating building energy. M.S. Al-Homoud evaluates the energy performance of a building with the help of computer-aided building energy analysis tool (Al-Homoud, 2001). Abraham Yezioro, Bing Dong, Fernanda Leite present an approach towards assessing building performance using computer based energy simulation tool: artificial neural networks (ANN) for predicting building energy performance. It also shows that the predicted results had a good fitness with the mathematical model with a mean absolute error of 0.9%(Yezioro, Dong, Leite, 2008). Yin et al. presented the procedure used to develop and calibrate simulation models of 11 commercial buildings in California (Yin et.al,2010). Pan et al. developed simulation models of two office buildings with a data center, in Shanghai, China, to evaluate the energy cost savings of various ECMs compared with the baseline building(Pan et al.2008). Nedhal Ahmed M and Al-Tamimi M. stated that Building orientation is a significant design consideration, mainly with regard to solar radiation and wind. He described the effect of building orientation in view of solar radiation absorption of exterior wall, varied area ratio of glazed window to wall and also the effect of natural ventilation on the thermal performance for residential building in tropical region with the help of a case study conducted in very hot and humid region (Al-Tamimi,2011). R. Pacheco, J. Ordonez, G. Martinez (Pacheco et.al 2012) in their paper 'Energy efficient design of building: A review' present an overview of building design criteria that can reduce the energy demand for the heating and cooling of residential buildings. The authors talk about the different design criteria that lead to reduction of energy consumption in buildings such as Influence of shape on the energy optimization of buildings, Orientation, Influence of the building envelope in the energy demand, Shading on buildings and Passive systems. . De Kay made a comparative analysis of various envelopes allowing for daylight access (Kay,1992). Shaviv proposed a computerized model for the design of fixed external sunshades (Shaviv,1975). Chia Sok Ling, et al. examines the effect of geometric shapes on the total solar insolation received by high-rise buildings. Two different types of generic building shapes (square and circular) have been studied with variations in width to length ratio and building orientation using the computer simulation program ECOTECT to determine the optimum parameters of that building (Chia Sok Ling, et al, 2007). A general model is proposed by Victor et al. to optimize the shading interaction between an awning and an external wall that project shadows on the facade of a construction (Victor Angel, 2003).

An introduction to the case

The facility used in the case study is an office building (of 3 stories) located in Kolkata, India. The total area for these structures is more than 1,50,000 square feet . The U-values of the exterior wall and the roof are 0.48 W/m^2 K and 0.24 W/m^2 K, respectively. The internal loads having the occupancy density is 150 FT^2 per person; the lighting density is 1 W/FT^2 and the plug load density is 2 W/FT^2. The HVAC system is a packaged variable air volume type. The cooling set point is 24℃ during the office operating hours. The weekly average working hours is 84 hours. Before conducting the energy simulation study, various building energy performance parameters and monthly electricity consumption data from January 2011 to December 20011 are collected to validate the energy simulation study using e-quest.

Methodology

In the following, the paper discusses the methodology applied in this study, including data collection, modeling by using e-Quest, validation of the model with actual monthly electricity consumption and thereby the optimum passive building design has been recommended. The paper mainly gives a view of passive design to reduce the energy consumption of a facility in a hot and humid climate such as Kolkata, India.

Data collection

Data acquisition is primarily concerned with collecting data relevant to the energy performance of the building to ultimately simulate the actual energy behavior of the building. The majority of collected data comes from the building blueprints (e.g., architectural, electrical, HVAC (heating ventilation air-conditioning), lighting, etc. Bulk amount of the data are also collected through interviewing with building management personnel and through measurement during the Energy Audit.

Modeling of the building using e-Quest

In order to determine the energy consumption pattern of the building a baseline model building is developed from the building characteristics acquired from our building survey and as the built documentations, specifications and drawing. The types of internal loads considered in the model include human occupants, overhead lighting, task lighting and plug-loads. The thermal zone wise HVAC system data is also specified in the model. The geometric layout of the facility is shown in the Figure 2

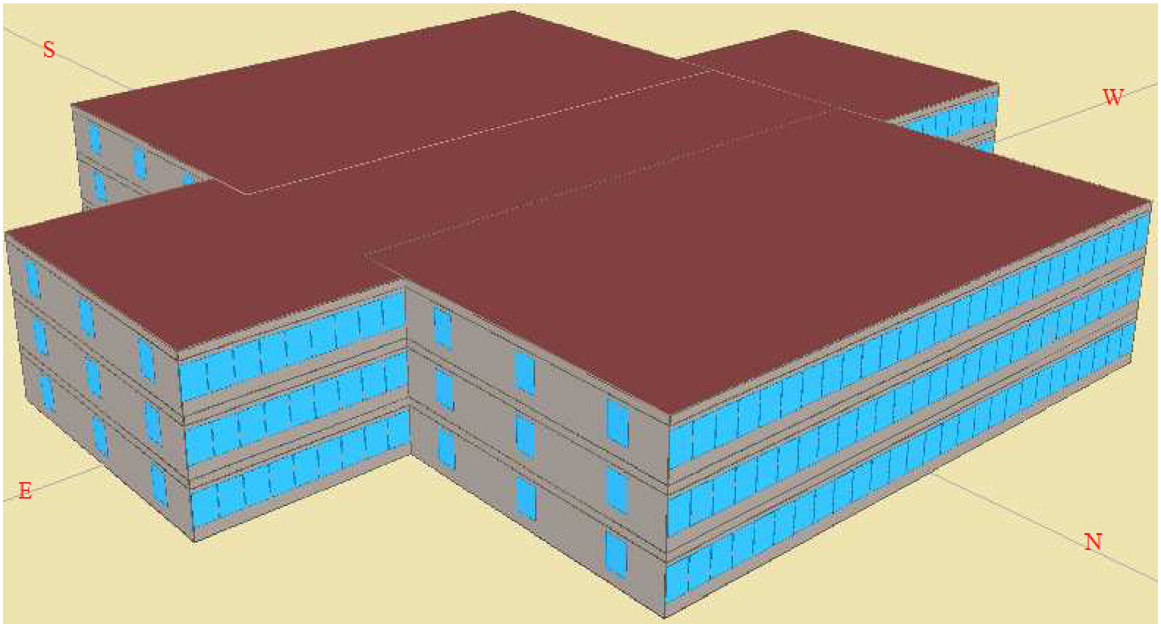


Figure 2: Geometric layout of the facility (north facing)

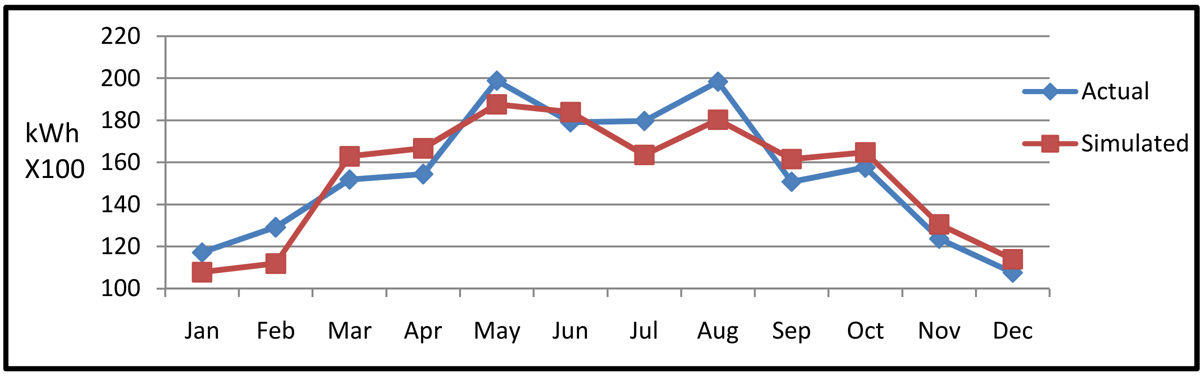
Validation of the simulation model

Paul et al. described a systematic, evidence-based methodology for the calibration of simulation models, which is intended for detailed calibration with high resolution measured data (Raftery et.al, 2011). Maile, Vladimir Bazjanac, Martin Fischer applied the Energy Performance Comparison Methodology (EPCM), which enables the identification of performance problems based on a comparison of measured data and simulated data. To calibrate the whole-building simulation models with measured data is described in the ASHRAE Guideline 14- 2002 (Maile et.al, ASHRAE Guideline 14). In the present paper, a statistical approach is developed and applied to the model for validation. Collected monthly electricity consumption data from January 2011 to December 2011 are applied for paired-samples t-tests for validation and to determine if there is a significant difference. A statistics software tool, SPSS version 20(Daniel et.al, 2011) is used to facilitate the analysis. The month wise actual and simulated electricity consumptions data for one year are shown in the Table 1. Figure 3 descriptively demonstrates the patterns of the two data series.

Table1: Monthly electricity consumption data for model assessment (units: kWh X 100)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Actual (Metered)	117.2	129.1	151.9	154.4	198.9	179.1	179.7	198.5	150.8	157.6	123.7	107.6	1848.5
Simulated (Baseline)	107.8	111.9	162.9	166.7	187.6	184	163.6	180.3	161.6	164.8	130.6	114	1835.8

Figure 3: Actual vs. simulated electricity usage



The results of the paired-samples t-tests from the SPSS software are shown in the Table 2. The probability value, 0.76, labeled as ‘‘Probability’’ indicates that there is no significant difference between the two data sets. Meanwhile, the correlation analysis shows that these two data sets are significantly correlated. The correlation value between the actual and simulated data is 0.91. The statistics also show that the means for the two data sets are very similar. Additionally, mean absolute errors (MAE) and root mean square error (RMSE) are also evaluated to judge the predictive accuracy of the developed simulation model (Willmot,2005). The results are also shown in the Table 2.

Table 2: Results of the statistical data analysis from the SPSS software

	Mean	Standard deviation	Standard error mean	t value	Probability (Two tailed)	Correlation	MAE	RSME
Actual	154.04	30.69	8.85	0.46	0.76	0.91	10.98	11.75
Simulated	153.03	29.03	8.38					

Thus from the statistical analysis, it can be concluded that the model has generated viable data and from MAE and RSME data it is understood that the model is quite acceptable.

Energy analysis

Before going to the optimum passive architectural building design recommendation various kind of energy simulation studies are carried out with building orientations, position of windows, wall-window ratio and with the use of different types shading strategy.

a. Optimum building orientation

In case of passive building design, orientation is a major consideration, mainly with regards to solar radiation, daylight, wind and overall building energy consumption (Wang et.al,2009). In order to determine the optimum orientation for the building seven different orientations N, S, W, E, NE, NW and SW have been investigated and simulated with e-Quest in this study. The total energy consumption of the building with the change of it’s orientation is demonstrated in the Table3. It is seen that for Kolkata region the north facing building consumes less energy compared to other orientation.

Table 3: The energy consumption pattern of the building with the change of its orientation

Orientation	West	South	East	North-East	North West	South West	North(base line)
Total energy consumption (KWh X 100)	1,849.50	1,837.30	1,852.00	1842.900	1845.50	1842.4	1835.8
% decrease	-0.76	-0.09	-0.89	-0.40	-0.54	-0.37	0.00

The north facing building consumes less energy because the amount of solar insolation falling on the building surface depends on building orientation and the climate zone. The stereographic sun path diagram of Kolkata depicts that the maximum solar insolation is received on west and east horizons and southern horizon also receives a fair share of solar insolation, thus the heat transfer is maximum though this walls. Any building orientation on these faces provides maximum heat transfer path for the heat to ingress into the building envelope which leads to increase in cooling load. So it is clear from the above discussion that north facing building is best as far as building energy consumption is concerned but it is impossible to change the orientation of any existing building, still the study would help the facility manager during the planning stage of a new building.

b. Optimum wall window ratio

An important consideration in energy efficient building design is the management of solar gain, as it is the largest and most variable gain in a building**.** Building with high window-to-wall ratio allows more daylight into the building which provides an artistic effect, visual perception, and energy savings from natural ventilation and the integration of daylight and artificial light but the benefits from daylight may be penalized by the increased solar heat gain through the windows**.** Thus the load on HVAC increases, resulting in overall increase in energy consumption. So proper wall window ratio is most essential consideration (Wang, 2005). An interesting study would therefore conducted to determine the optimum wall window ratio(WWR) taking into consideration the visible light transmittance (VLT), Solar Heat Gain Coefficient(SHGC) requirement and U value as per ECBC guidelines(ECBC User Guide,2012). The simulation study is conducted with the help of e-quest. Table 4 presents detailed simulation test results.

Table 4: Energy consumptions of the facility for different values of wall-window ratio

Wall window ratio (%)	20%	40%	60%	Baseline Model
	U= 0.58 SHGC= 0.25 VLT = 0.27	U= 0.58 SHGC= 0.25 VLT = 0.2	U= 0.58 SHGC= 0.20 VLT = 0.13	
Total energy consumption (KWhX100)	1699.10	1741.00	1742.70	1835.80
% decrease	7.44%	5.15%	5.06%	0.00%

It can be concluded from the e-Quest simulation results that the building with lower WWR(20%) has very low cooling load requirement which helps to reduce the total energy consumption. The building having 20% wall window ratio (WWR), increases the use of day light at the same time it reduces the building energy consumption required for lighting, heating and cooling and ventilation load. It also allows people to control their own environments and be healthier and more productive as a result.

c. Energy efficient shading design

The implementation of passive solar elements such as high wall window ratio and large numbers of south facing window substantially decreases a building's cooling and lighting load. However, given a highly insulated envelope, such a passive solar design would also pose a risk of overheating the indoor space during high solar intensity periods. So an appropriate solar gain control strategy is a very essential consideration. Without appropriate solar gain control strategies, building peak cooling loads and increased cooling energy can offset any benefit from thermally benign envelopes. Thus control of solar gain is not only necessary in current highly glazed, poorly insulated buildings, but is critical in the design of new energy efficient residential and commercial green buildings. Proper shading technique is most appropriate to solar gain control. Shading is the use of building elements to avoid direct sunlight, in order to avoid excessive light or solar heat gain. It can be located either outdoors or indoors, and in some cases, internal to the glazing system. Shading materials used include metal, wood, plastic, and fabric. The external shadings are mainly of three types: projecting horizontal overhangs, vertical fins, movable shading. Different types shading strategies are shown in the Figure 4.

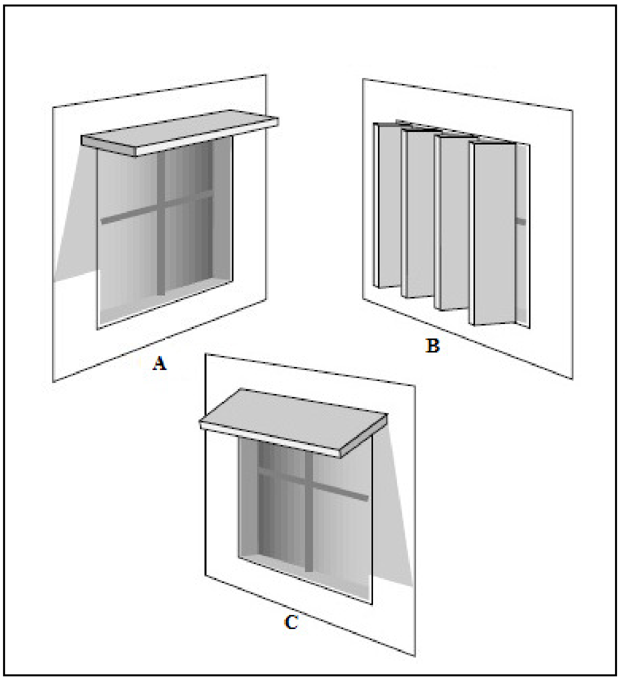


Figure 4: Shading strategies: (A) Projecting horizontal overhangs; (B) Vertical fins; (C) Movable shading

Now to study the impact of different types of shading strategy on the building energy consumption, a detailed analysis has been conducted with the help of e-quest simulation tools. It also provides the recommendation for optimum position of window and optimum external shading type for the facility. Table 5 presents the detailed comparison results of the building cooling load and total energy consumption for different positions of the window. It can be seen that building having only north facing window consumes minimum energy.

Table 5: Building cooling load and total energy consumption for different positions of the window

Windows position	North (only)	East(only)	West(only)	South(only)
Cooling Load	722.9	766.6	762.2	757.3
Total Energy Consumption(kWhX100)	1716.9	1760.6	1757.3	1751.4
% decrease	6.4	4.1	4.2	4.5

Table 6 presents detailed comparison results of the total energy consumption depending upon the various types of external shadings used. The total energy consumption of the building with appropriate shading technique and without incorporating any shading technique is also compared here. The result is also shown in the table6. It can be concluded from table6 that with the use of both overhang and fins the cooling load of the building is reduced that's why the total energy consumption is also reduced. Depending upon the various types of shading technique, table6 is also depicts the percentage decrease in energy consumption of the facility compared to the base line building.

Table 6: Building energy consumption pattern for various fenestration

Types of external shading	Overhangs & Fins	Fins	Overhangs	Baseline Model (without Shading)
Total energy consumption(KWhX100)	1,787.9	1,813.5	1,808.0	1835.8
% decrease	2.60%	1.20%	1.50%	0.00%

d. Energy evaluation of the proposed building

Based on the identified optimum building design parameters for Kolkata region a proposed model building has been developed and evaluated using e-quest. Figure 5 and Table VII show the results of the evaluation. Table7 includes five data series by month for one year. The first is the twelve months baseline simulation electricity consumption pattern. The second, third, fourth and fifth series include data generated from the baseline simulation model after considering the optimum passive building design parameters such as, building orientation, wall-window ratio, position of window and various shading methods respectively.

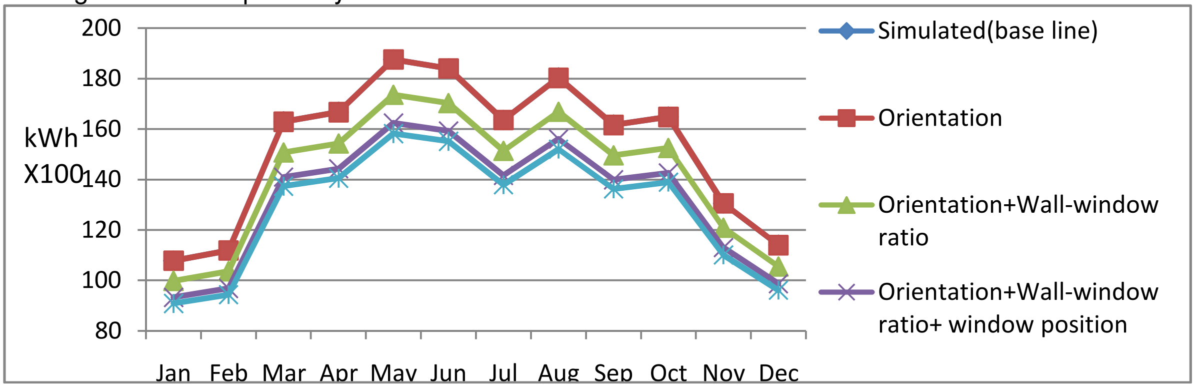


Figure 5: Building total energy consumption by different scenarios

Changing in building orientation is first introduced to the simulation model, which resulted in a zero percent energy reduction compared to the total energy consumption of the ‘‘Baseline’’ data series. This is because the base line building is already north oriented. Then optimum wall-window ratio is added to the model, which resulted in 7.44% of energy reduction cumulatively compared to the baseline total energy consumption. On top of these two strategies, the best position of the window is introduced to the model which resulted in 13.4 % of energy reduction cumulatively compared to the base case. Finally along with the previous three strategies, the most efficient shading strategy is also added to the model. There is a total energy saving of 15.6% observed from the simulation.

Table 7: Simulated energy usage of the facility under different scenarios (kWhX100)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Baseline	107.8	111.9	162.9	166.7	187.6	184	163.6	180.3	161.6	164.8	130.6	114	1835.8
Orientation	107.8	111.9	162.9	166.7	187.6	184	163.6	180.3	161.6	164.8	130.6	114	1835.8
Orientation+ Wall-window ratio	99.7	103.5	150.7	154.3	173.6	170.3	151.4	166.9	149.6	152.5	120.8	105.5	1699.3
Orientation+ Wall-window ratio+ window position	93.3	96.8	141.0	144.3	162.4	159.3	141.6	156.1	139.9	142.6	113.0	98.6	1589.2
Orientation+ Wall-window ratio+ window position+ shading	90.8	94.3	137.3	140.5	158.2	155.1	137.9	152.0	136.3	138.9	110.1	96.1	1547.8

Conclusion

In the framework of the current energy markets especially in a developing country like India, where energy prices are growing and the influence of the demand side is more and more important, it is essential to avoid wasting energy. In this context this study has concluded that very basic and easy-to-implement actions can really reduce the energy consumption of a building which ultimately leads to reduce the environmental pollution. The study clearly depicts that in a hot and humid region (such as Kolkata, India) the building should be truly north facing and both overhangs and fins should be used for external shadings. The study also indicates that the north facing window with WWR 20% is the optimum passive architectural design for this climate as the energy decrease is 6.4% but for better ventilation purposes south positioned window are also recommended (energy decrease 4.5%). Finally a building is developed combining the four recommendations such as building orientation, window orientation, WWR and optimum external shading. The decrease of energy consumption after implementation of one by one recommendation is also shown. Finally after inclusion of all four recommendations the best passive architectural design of the building is presented which gives a saving of 15.6% from the base case. In a developing country like India where building are responsible for maximum amount (about 39%) of national energy consumption there a saving of 15.6% by changing the passive architecture only will play an important role.

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