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Effect of Building Orientation and Window-to-Wall Ratio on HVAC and Energy Loads for Different Climate Zones in India

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ABSTRACT

Window-to-wall ratio (WWR) of a building is crucial parameter in energy efficiency because a substantial amount of solar heat gain happens via windows. The goal of this research is to determine the optimum WWR of an institutional building. A baseline model is simulated in eQUEST software to investigate the HVAC and total annual energy consumption of the building for five climate zones of India. One representative city from each climate zone was considered for this study. The WWR was varied from 0-80% with a 10% step increase, and the HVAC and total energy consumption was simulated for East, West, North and South orientations of the building in each climate zone. For all climate zones and for all ranges of WWR, the HVAC and total annual energy consumption was observed to be minimum in East-West orientation when compared to North-South orientation. While, the optimum WWR varied from 10-40% for different orientations and climate zones.

Keywords - eQUEST, Building Envelope, HVAC, Climate Zones, WWR.

1. Introduction

Buildings consume 40% of total energy usage worldwide. Energy consumption by buildings ranges from 20- 40% in developing nations and approximately 40% in developed countries of overall energy consumption [1]. India's building industry utilises one third of the country's overall electricity consumption. Without energy-efficient structures, the energy demand would increase as energy consumption outpaces power generation capacity. There is numerous potential for energy conservation in buildings as massive infrastructure is being built and upgraded [2]. Improper orientation, large glazing area and lack of shading devices are a few factors which cause overheating of the building resulting in increased energy demand. Type of glazing impacts heat gain or loss, while improper shading devices contribute to solar heat gain, affecting thermal comfort and resulting in increased HVAC loads [3]. Increased energy consumption due to these inefficient selection of building envelope components can be reduced by optimising them early in the design process based on the climate zone.

Institutional buildings are included among the buildings with the highest energy consumption. Various studies have found that the quality and amount of daylight, as well as the indoor thermal conditions, have a significant impact on the learning/teaching performance and health of students and teachers. The utilisation of daylight in school buildings can lower energy consumption by more than 10% [4].

The energy performance of lighting and cooling systems in conventional buildings is over 50% higher than that of buildings with energy efficient systems, as shown in Table 1.

Table 1: Energy performance comparison (TERI 2010)

	Conventional Buildings	Low Energy Buildings
Lighting	37-60 kWh/sq. m/year	21-28 kWh/sq. m/year
Cooling (warm-humid regions)	263 kWh/sq.m/year	195 kWh/sq. m/year

This study investigates the effect of orientation and Window-to-Wall Ratio (WWR) of institutional buildings on the energy demand in various climate zones of India.

1.1. Climatic Zones in India

Indian climate is divided into five different zones as per Energy Conservation Building Code (ECBC) [5], which are hot and dry, warm and humid, composite, cold, and temperate.

India has a rich history of climate-responsive architecture, which incorporates a variety of passive design concepts. The values of solar heat gain that are beneficial in offsetting building energy demands are determined by local climatic conditions as well as orientation of the building. Outdoor temperatures and wind conditions, which impact heat losses are also location dependent [6]. Hence, it is important to determine the climatic factors of the region in which a building has to be designed.

This research was conducted by taking one representative city from each climate zone. The representative cities are Ahmedabad, Jaipur, Chennai, Bangalore and Shillong for Hot and Dry, Composite, Warm and Humid, Moderate, Cold and Cloudy respectively. The average monthly temperature for these cities is displayed in Fig.1.

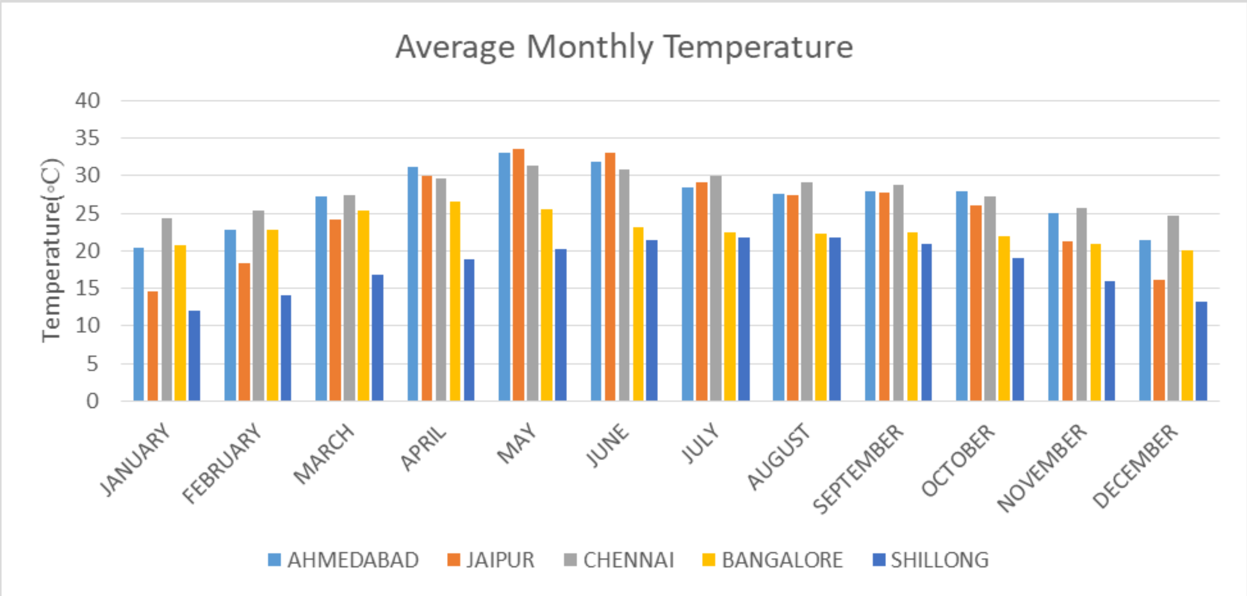

Fig.1 Average monthly temperatures of Ahmedabad, Jaipur, Chennai, Bangalore and Shillong for the period of 1991-2021(Data from the Indian Meteorological Department)

2. Methodology

This study is divided into five different climatic zones such as Hot and dry, Composite, Warm and Humid, Cold and Cloudy and Moderate. The information about solar radiation intensity on vertical plane, solar radiation intensity on horizontal plane, dry-bulb temperature and wet-bulb temperature of different regions were obtained from Indian meteorological department. Utilizing eQUEST, a baseline institutional building is created to evaluate how WWR and orientation affects energy usage in various climatic zones. After model creation, eQUEST ran an energy simulation of it.

The 3D energy model created in eQUEST is shown in Fig.2. For the purpose of energy simulations, Table 2 lists the assumed data for the baseline model. The WWR percentage is varied from 0% to 80% with a 10% step on all orientations of the building. The outcomes of the simulation were analysed in order to investigate how WWR and building orientations affects energy usage.

Table 2: Design Assumptions for Baseline Model

Building Characteristics	Description
Building Type	Institutional
Building Footprint (m^2)	4645
No. of floors	4
Operation (hrs.)	7
Occupancy schedule	5 days/week
Wall type	Double Brick Plaster

Roof Type	Concrete and Plasterboard
Ceiling Type	Gypsum Board
Glass Type	Single clear glazed with aluminum frame

2.1. Energy Simulation Tool

The simulation tool used in this research is eQUEST, which takes into account hourly climatic data, properties of walls, windows, glass, occupants, plug loads, and ventilation for energy demand simulation. 8760 hours of data from various weather parameters, such as dry bulb temperature, wet bulb temperature, and solar radiation intensity on vertical and horizontal planes, are contained in the weather files used by eQUEST [8]. Annual energy use (KWh) or annual Energy Performance Index (EPI) (KWh/m^2/year) are the outputs of the simulation findings.

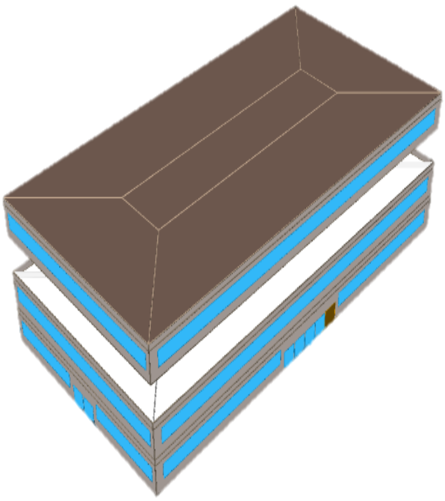

Fig.2 Energy model developed in eQuest

3. Results and Discussions

The building's energy demand is determined for the cities of Ahmedabad, Jaipur, Chennai, Bangalore and Shillong after simulation. From initial simulations, it was observed that the energy consumption in East and West, and North and South directions, respectively, was similar. It is attributable to the symmetrical geometry of the building. So the results are represented for East-West and North-South orientations.

3.1. HVAC Energy Demand

The energy demand of HVAC systems for the building with varying WWR (0-80%) and for North-South and East-West orientation for all representative cities from each climate zone is shown in Fig. 3(a) - Fig.3 (e).

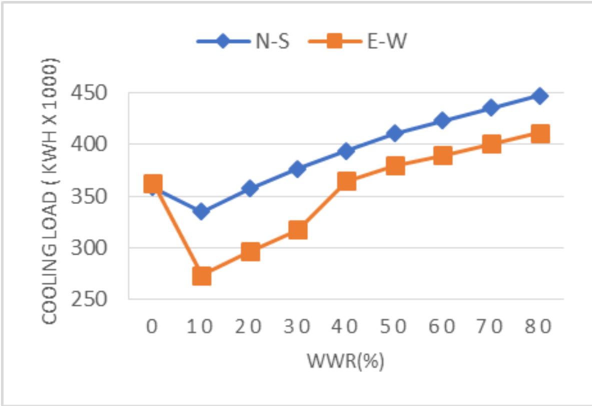

Fig.3 (a). HVAC energy loads for Ahmedabad

In Ahmedabad, the East-West orientation with 10% WWR, has least HVAC energy consumption of 273.5 MWh. For North-South orientation, the least HVAC energy consumption was 273.5 MWh which was also for 10% WWR.

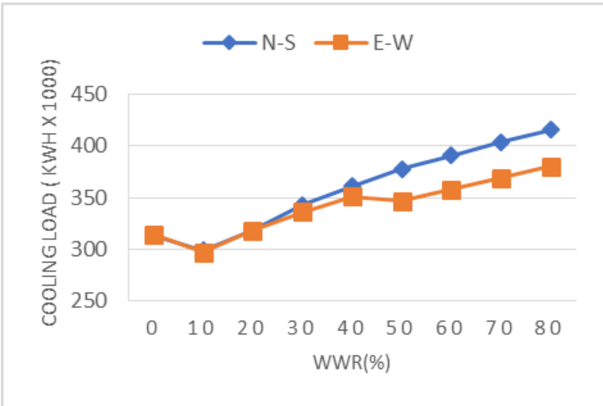

Fig.3 (b). HVAC energy loads for Jaipur

In Jaipur, the East-West orientation with 10% WWR, has least HVAC energy consumption of 296.87 MWh. For North-South orientation, the least HVAC energy consumption was 335.17 MWh which was also for 10% WWR. However, for East-West orientation, there was a second dip in HVAC energy consumption at 50% WWR, but it was not significant.

Fig.3 (c). HVAC energy loads for Chennai

In Chennai, the East-West orientation with 10% WWR, has least HVAC energy consumption of 358.95 MWh. For North-South orientation, the least HVAC energy consumption was 361.88 MWh which was also for 10% WWR.

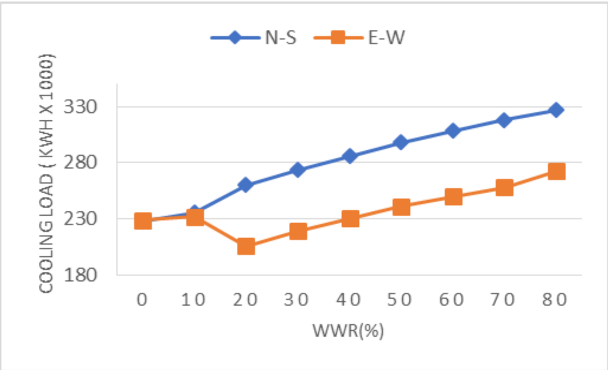

Fig.3 (d). HVAC energy loads for Bangalore

In Bangalore, the East-West orientation with 20% WWR, has least HVAC energy consumption of 206.15 MWh. For North-South orientation, the least HVAC energy consumption was 227.83 MWh for 0% WWR and it was observed to be constantly increasing with increase in WWR.

Fig.3 (e). HVAC energy loads for Shillong

In Shillong, the East-West orientation with 30% WWR, has least HVAC energy consumption of 113.83 MWh. For North-South orientation, the least HVAC energy consumption was 108.8 MWh for 0% WWR and it was observed to be constantly increasing with increase in WWR.

3.2. Total Energy Consumption

The total annual energy loads (electrical loads, task lighting, plug loads, area lighting, HVAC, miscellaneous, etc.) for the building with varying WWR (0-80%) and for North-South and East-West orientation for all representative cities from each climate zone is shown in Fig. 4(a) - Fig.4 (e).

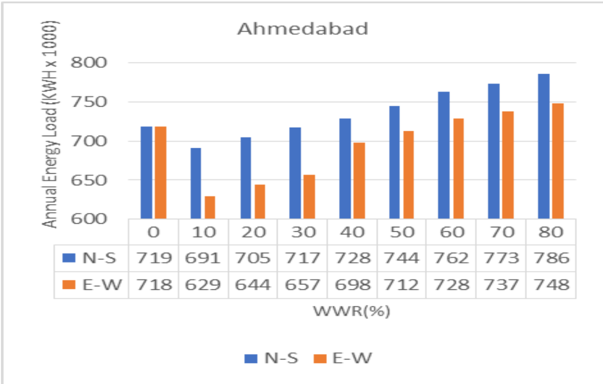

Fig.4 (a). Total energy loads for Ahmedabad

In Ahmedabad, the East-West orientation with 10% WWR has least total annual energy consumption of 629 MWh. For North-South orientation, the least total annual energy consumption was 691 MWh which was also for 10% WWR.

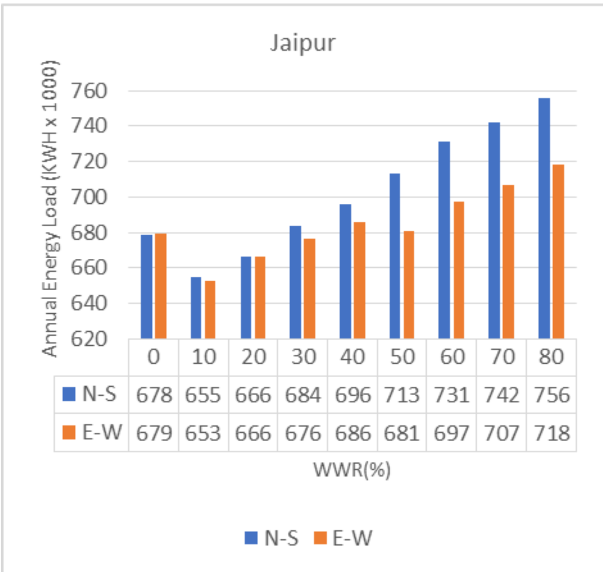

Fig.4 (b). Total energy loads for Jaipur

In Jaipur, the East-West orientation with 10% WWR has least total annual energy consumption which is 653 MWh. For North-South orientation, the least total annual energy consumption was 655 MWh which was also for 10% WWR. It is observed from Fig.4 (b), that with increase in WWR, the total annual energy load increases for the North-South orientation whereas for the East-West orientation there is a second dip at 50% of the WWR which can be utilized depending upon the specific use of the building.

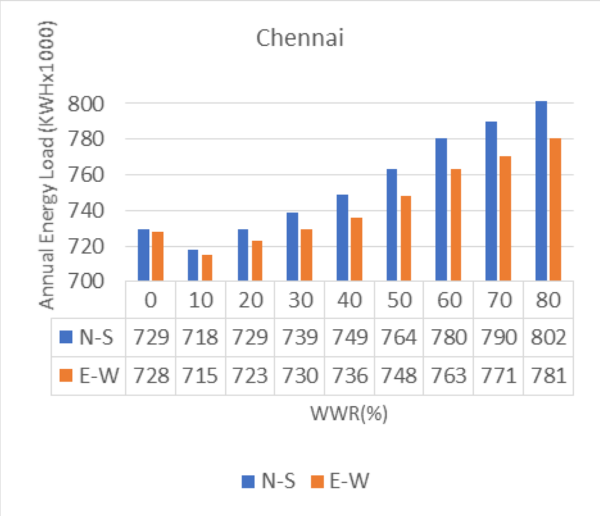

Fig.4 (c). Total energy loads for Chennai

In Chennai, the East-West orientation with 10% WWR has least total annual energy consumption which is 715 MWh. For North-South orientation, the least total annual energy consumption is 718 MWh which also corresponds to 10% WWR.

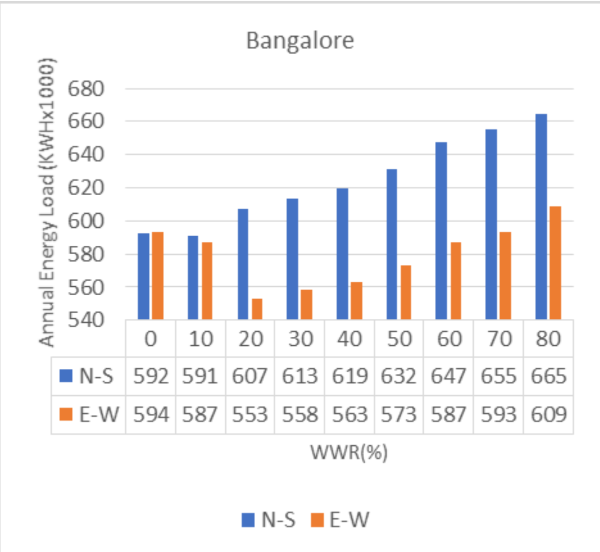

Fig.4 (d). Total energy loads for Bangalore

In Bangalore, the East-West orientation with 20% WWR has least total annual energy consumption which is 553 MWh. For North-South orientation with 10% WWR has the least total annual energy consumption of 591 MWh.

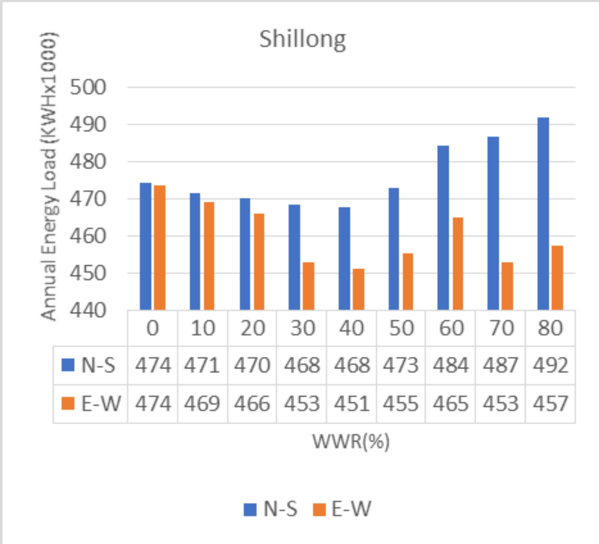

Fig.4 (e). Total energy loads for Shillong

In Shillong, the East-West orientation with 40% WWR has least total annual energy consumption of 451 MWh. The North-South orientation with 30-40% WWR had minimum total annual energy consumption of 468MWh. It can be observed from Fig.4 (e) that there is a second dip at 70% WWR for the East-West orientation with total annual energy consumption of 453 MWh.

4. Conclusion

In this research, the optimum percentage of WWR for the North, South, East, and West orientations of an institutional building was determined for Ahmedabad (Hot and Dry climate), Jaipur (Composite climate), Chennai (Warm and Humid climate), Bangalore (Moderate climate) and Shillong (Cold and Cloudy climate). Moreover, the same type of building, with the same electrical setup, mechanical setup, and materials, was used in all climate zones to standardize the research. A simulation was conducted through eQUEST software, and the HVAC and total energy consumption of the building were calculated. The following conclusions are drawn:

For all climate zones and for all ranges of WWR, the HVAC and total annual energy consumption was least in East-West orientation as compared to North-South orientation.

For Hot & Dry Climate zone i.e.; Ahmedabad, the optimum WWR for East-West orientation was 10% and North-South orientation was also 10%.

For Composite Climate zone i.e.; Jaipur, the optimum WWR for East-West orientation was 10% and North-South orientation was also 10%.

For Warm & Humid Climate zone i.e.; Chennai, the optimum WWR for East-West orientation was 10% and North-South orientation was also 10%.

For Moderate Climate zone i.e.; Bangalore, the optimum WWR for East-West orientation was 20% and North-South orientation was 10%.

For Cold & Cloudy Climate zone i.e.; Shillong, the optimum WWR for East-West orientation was 40% and North-South orientation was 30-40%.

The above concluded parameters can be utilized by engineers and architects in the energy efficient building planning and design.

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