‘Impact of window wall ratio in office building envelopes on operational energy consumption in the temperate climatic zone of India’

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Abstract

The construction of predominantly glazed facades in commercial buildings has become a standard practice in India irrespective of the climate and in particularly in cities such as Bangalore, an Indian IT hub with temperate climate. In recent decades, urbanisation has been rapid and fully glazed buildings have increased, resulting in high energy consumption and demand. The development and implementation of energy efficiency codes and initiatives can help ensure a sustainable future. Window wall ratio is one of the key parameters and if designed properly, could have a substantial impact on the overall energy consumption of a building. In order to understand the impact of solar radiation and daylight entering through the building envelope, a reference high rise office building with an operation period of 24 hours was simulated and after optimization of WWR with daylight utilization, the average EPI of 350 kWh/m2/yr. (BEEP India 2013) improved to 306 kWh/m2/yr. The building envelope is evaluated with reference to different WWR and orientation (North, South, East and West). The optimum WWR was selected on the basis of the lowest energy consumption while at the same time achieving the lighting threshold as specified in the ECBC. The building has been modelled and analysed using Energy Plus and COMFEN.

Keywords*: *Optimum WWR, orientation, EPI, daylight utilization, Annual energy consumption, office building

I. INTRODUCTION

The Fast-increasing world energy consumption levels have already raised concerns over the excessive usage of resources and subsequent environmental impacts. According to WEO (2009), energy is accounting for 65% of the World’s Greenhouse gas (GHG) emissions. Being a developing country, power consumption has been increasing at greater pace in India. (Nagaraju Kaja,2015). Unfortunately, the current building stock is oriented towards high energy consumption (Hirst, 2013) and the commercial sector has become the fastest growing energy demand sector globally (EIA, 2016). The commercial sector accounts for 8.6% of total electricity consumption of India and increasing with 5% rate annually due to rapid urbanization. The building's major energy consuming end-uses are air-conditioning including heating, cooling, lighting, and equipment during the operational phase (Bhatnagar et al, 2019). The average annual electricity consumption for space conditioning and lighting in India is around 160 KWh/m2 for commercial (Nagaraju Kaja,2015). In a typical commercial office building, the major share of energy is from Cooling-25%, Equipment 28%, Lighting 30%.(Central Electric Authority). Energy savings in the building sector are critical for the achievement of sustainable development. Current trends of energy use indicate that buildings’ energy demands and related emissions will continue to increase.

However, buildings offer great opportunities to reduce growth in energy demand in terms of design and architects have a great role to play in it. The energy conscious design approach helps designers and building owners to economically reduce building operating costs, while improving comfort for the building’s occupants. The energy consumed by a building depends on its use (whether residential, commercial or industrial), the type of building (air-conditioned or naturally ventilated and the climate classification. Architects have to ensure that the design of the built form suits the intended use of the building and the specific needs of the user within the framework of the prevailing climatic conditions.

The construction of predominantly glazed facades in commercial building has become a standard practice in India irrespective of the climate which has led to high energy consumption in such buildings. The glazed components of the building allow heat and solar gain which primarily determines the operational energy requirement of buildings.

Especially in cities like Bangalore, an IT hub of India which has a temperate climate. It has seen rapid urbanization in the past few decades and rise in fully glazed buildings without any consideration for energy efficiency which has resulted in high energy demand and consumption. Heat loss or gain through the

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building envelope and solar gain should be considered together with internal energy demands in assessing the energy performance of glazed building components (Grynning, 2013).

Optimizing the glazing system considering area, thermal performance, and localization of glazed building components in a building envelope are ways to reduce energy consumption in buildings (Grynning, 2013). Window wall ratio restricted up to 40% in Energy Conservation Building Code (ECBC) is one of the key parameters, if designed properly, could have a substantial impact on the overall energy consumption of a building. Hence, the analysis and optimization of WWR is an important way to achieve efficiency in the energy performance of a building. But there is an apparent lack of understanding amongst practitioners of what might be considered appropriate in the temperate climatic context of Bangalore.

II. BACKGROUND STUDY

A. WWR- Window to Wall ratio

The window-to-wall ratio is the measure of the percentage area determined by dividing the building's total glazed area by its exterior envelope area. Window-to-wall ratio (WWR) is an important variable affecting energy performance in a building and determining thermal and visual comfort indoors. Window area will have impacts on the building's heating, cooling, and lighting, as well as the indoor environment in terms of access to daylight, ventilation, comfort and views. The Window Wall Ratio is restricted up to 40% in ECBC.

B. Daylighting

Daylight has qualities that cannot be replicated by artificial lighting. The design of a window and choice of glazing can dramatically affect the quantity and quality of daylight in a space and how it is experienced. Daylight design is far more sophisticated than simply providing a window with a high enough visible transmittance. More daylight does not necessarily equate to better lighting conditions. It is a matter of balancing daylight admission with glare control, as well as providing uniform light distribution.

The usability of daylight is dependent on the task. For some tasks, bright illumination improves visual acuity and glare is of little concern. For computer tasks, glare may be problematic and it is better to control illuminance levels. The average annual daylight illuminance is linearly related to the product of the window-to-wall ratio and visible transmittance (VT*WWR).

The Useful Daylight Illuminance (UDI) is a holistic analysis method measuring the useful daylight as well as glare on the work plane.

The ECBC defines UDI between 300 to 500 Lux as useful daylight. We are considering 500 lux as the threshold daylight level on the work plane in an office space for this study.

C. EPI-Energy Performance Index

Energy performance index (EPI) is total energy consumed in a building over a year divided by total built up area in kWh/sq.m./year or MJ/sq.m./year **(where 1kWh= 3.6MJ)** and is considered as the simplest and most relevant indicator for qualifying a building as energy efficient or not. Most commercial buildings in India have EPI between 200-400kWh/m2/year. Energy conscious buildings in India have achieved EPIs of 100-150kWh/m2/year. The national benchmark is 180kWh/ m2/year. Buildings with EPI of 180kWh/m2/year are ECBC compliant.

In order to understand the impact of solar heat and daylight entering through the façade of a reference high rise office building with an operation period of 24 hours and an average EPI index of 350 kWh/m2/yr (approx.) as mentioned in Table 1.

Table 1. Averages Annual Energy Consumption for different office building typologies (Source: Building Energy Benchmarking study undertaken by the USAID ECO-II Project)

No. of Buildings	Building Type	Floor Area (sq.m.)	Annual Energy Consumption (kWh)	Benchmarking Indices	
				kWh/sq.m./year	kWh/sq,m,/hour
145	One shift Building	16,716	20,92,364	149	0.068
55	**Three shifts Building**	**31,226**	**88,82,824**	**349**	**0.042**
88	Public Sector Buildings	15,799	18,38,331	115	0.045
224	Private Sector Buildings	28,335	44,98,942	258	0.064
10	Green Buildings	8,382	15,89,508	141	-

D. Research gap

Previous research has clearly established the role and benefits of building envelope optimization on the overall energy performance of the building. But there is lack of understanding of daylight integration to reduce artificial lighting energy consumption in an office building. This research paper fills that gap as it aims to determine an optimum WWR for different orientation of a building whilst achieving a threshold lighting level and studying the impact on the building's energy performance.

III. AIM

The main aim of the paper is to determine an optimum WWR for each orientation of a building situated in Bangalore, which lies in temperate climatic zone to reduce the overall energy consumption whilst achieving a threshold lighting level as mentioned in ECBC.

IV. OBJECTIVE

In order to meet the aim, the study focuses on the following objectives:

1. To understand the importance of energy efficiency in the current commercial building sector in India.
2. Optimization of WWR of the glazing systems taking daylight utilization into consideration in different orientation using simulation tools- Modelling, input data, shoebox analysis
3. To study and analyze the results of the simulation and formulate solutions for future reference.

V. SCOPE & LIMITATION

The study of daylight use was one of the main objectives of this work and shading devices were not considered. Additional optimization of features for each orientation will require more study, with shading included. This methodology could be followed during the initial stages of designing to determine fenestration levels which would lead to a building with better energy performance.

VI. METHODOLOGY & RESEARCH DESIGN

In order to understand the impact of solar heat and daylight entering through the façade of a reference high rise office building with an operation period of 24 hours and an average EPI of 350 kWh/m2/yr. (acc. to BEEP India 2013), the building fenestration is assessed with reference to different WWR and orientation. The optimum WWR was selected on the basis of least energy consumption whilst achieving a threshold lighting level as mentioned in ECBC. The building has been modelled and analysed using Design Builder, Energy Plus and COMFEN.

A. To understand the importance of energy efficiency in the current commercial building sector.

A detailed literature study of the current trends in commercial building design and its impact on the energy performance of the building was conducted. A major issue identified was increased levels of energy consumption due to lack of attention paid to climatic responsive design instead following international trends of extensively glazed facades. Through the literature study, the relation between specific components of building envelope and their impact on the overall energy consumption.

Optimization of WWR of the glazing systems in different orientation using simulation tools- Modelling, input data, shoebox analysis.

A baseline building as mentioned above was modelled using Design Builder. COMFEN (COMmercial FENestration), an energy modeling tool developed by LBNL (Lawrence Barkley National Laboratory), for comprehensive analysis of building glazing systems with respect to energy efficiency and comfort was used to achieve the objectives of this study. COMFEN also uses the powerful calculation engine of Energy Plus. A reference building envelope was referred for the baseline building specifications and inputs.

The impact of altering WWR on the energy consumption of a building with daylight utilization was studied for each orientation (north, south, east, west). The energy use intensity (EUI), in MJ/m2-yr for each variant was determined to find the optimum WWR.

Investigation of the optimum WWR with daylight utilization required the use of a dynamic daylight performance metric. For this, DA (Daylight Autonomy) was used to implement daylighting in a building. DA is regarded as a comprehensive parameter since it considers the effects of orientation, climate and fenestration optical properties to describe the daylighting performance of the space. With daylight utilization, identification of optimum WWR for each orientation was based on the lowest energy consumption for the parameters at which the work plane illuminance threshold criteria of 500 lux were met by daylight alone for 50% of the occupancy time during the year. Annual energy consumption and daylight availability at the work plane were calculated.

COMFEN -Input data

The input data was derived from the reference building modelled in previous research where they studied around 200 office buildings. According to ASHRAE 2010 the perimeter and interior zones need to be separated for energy modelling. So, a reference room which is 4m wide, 3.05m high (floor to ceiling height) with a perimeter zonal depth of 4.57m (thermal and daylight lighting zone depth as per ASHRAE standard 90.1 and International Energy Conservation Code (IECC).It was assumed that the reference office room forms part of a perimeter zone of an office building (as per the reference building zoning). The base case glazing was double glazed, clear glass (DGI). It was assumed that there was no shading from additional shading devices or any surrounding buildings.

Input data required in this study for an office building/reference room including thermostat set points, schedules (occupancy, lighting, equipment), and outdoor air flow rate were set according to the default values of COMFEN. The loads for each schedule were set according to reference building specifications. Work place density, miscellaneous equipment power and artificial Lighting Power Density (LPD) for an office building were specified as 14 m2 / person, 16.14 W/m2 and 8.32 W/m2 respectively. The illumination level of 500 lux was specified at the work plane height during office hours as recommended by ASHRAE standards and IESNA (Illuminating Engineering Society of North America). Daylight control logic is embedded in the software COMFEN. Continuous lighting controls were modeled in this study as providing continuous dimming control based on daylight levels to maintain constant, undisturbed, fluorescent light levels during office hours.

Since a building can have maximum glazing of about 40%, the WWRs considered for simulation are 10%, 15%, 20%, 25%, 30%, 35%, 40% (Fig.1) respectively for each orientation (North, South, East, West) considering the building is perfectly aligned in the N-S direction. Window position has significant effect on lighting energy demand when there is a daylight control system. Windows positioned in the center of the façade were considered in this study as being most advantageous when daylight controls are to be used (Bokel, 2007). The outdoor climatic data used in this study included monthly average temperatures, horizontal solar radiations, horizontal illuminance were set according to an in-built file in COMFEN with climatic details of the city.

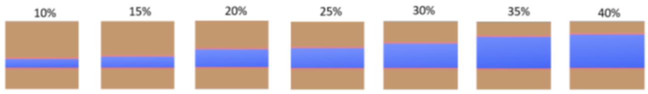

Figure 1. Different WWRs considered for simulation

B. To study and analyze the results of the simulation and formulate solutions for future reference.

Shoebox modelling is a good practice in the energy modelling process, as it helps the architects/engineers to take informed decision on what passive measures to integrate in the building design. In shoebox modelling we plot a graph between the annual energy consumption derived from the simulation and the different WWRs selected for the study and a linear relation between the two variables is established which is then compared and analyzed further to draw conclusions and derive an optimum WWR which is case specific.

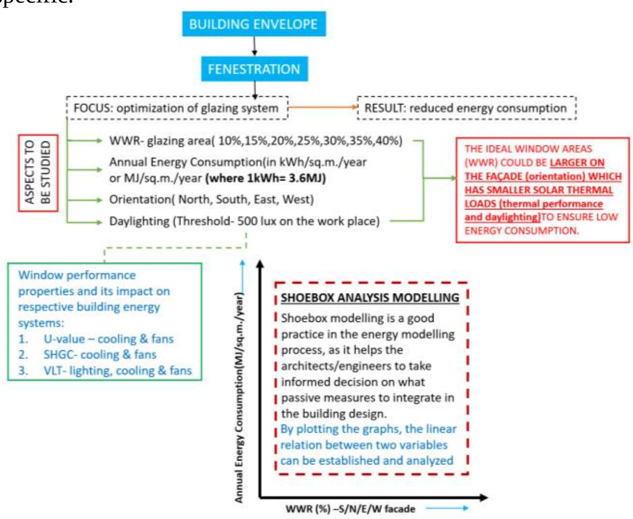

Figure 2. Methodology- Research Design Outline

VII. RESULT & DISCUSSION

It was found from the simulation results that daylight utilization reduced building energy demand significantly by reducing the artificial lighting requirement and also the cooling load associated with artificial lighting. Optimum WWR selection with daylight utilization was based on the lowest energy consumption for the parameters which satisfied the preset threshold criteria of 500 lux provided at the work plane by daylight alone. For this purpose, intermediate WWRs between the two with lowest energy consumption were simulated to investigate the optimum condition for energy demand reduction and find the minimum WWR that provided the required daylighting.

A. North Orientation

It was derived from Figure 3 for North orientation, WWRs between 20% and 25% have to be simulated to find the optimum condition for energy demand reduction in order to find the minimum WWR that provided the required daylighting.

Table 2. Total energy consumption and heat gain for North orientation with daylight utilization

Scenario /Sr. No.	**WWR**	**Average Daylight Illuminance lux**	**Cooling MJ/m2-yr**	**Fans MJ/m2-yr**	**Lighting MJ/m2-yr**	**Total energy consumption MJ/m2-yr**	**Window total heat gain MJ/m2-yr**
1.	10%	79.49	347.32	96.45	150.69	594.47	55.43
2.	15%	131.13	349.89	97.55	132.30	579.75	89.81
3.	**20%**	**205.15**	**354.44**	**98.70**	**115.02**	**568.17**	**129.12**
4.	**25%**	**264.98**	**361.84**	**100.56**	**108.67**	**571.07**	**164.45**
5.	30%	338.36	377.83	110.01	105.33	593.18	201.62
6.	35%	425.72	388.49	113.21	103.32	605.01	238.96
7.	40%	492.89	399.13	116.45	102.39	617.97	275.51

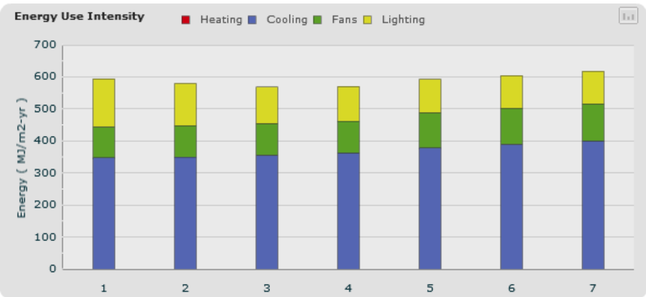

Figure 3. Comparison of energy consumption of different WWRs for North orientation with daylight utilization.

After comparing all the WWRs for daylight availability for north orientation, a WWR of 20% (Table 3) was identified as optimum for north orientation, providing the required threshold daylight illumination levels of 500 lux throughout the working time. As direct sunlight does not strike the north façade at this latitude in the northern hemisphere, higher WWRs on the north orientation were found to provide sufficient daylight levels throughout the occupancy hours with reasonable energy demand. If required, a higher WWR up to 25% could most readily be planned on the north façade due to low solar gains from this direction.

Table 3. Annual average hourly daylight (lux) at different (intermediate) WWRs for North orientation

WWR	**Annual average hourly daylight (lux) for five counted hours**				
	10:00 am	**11.00 am**	**12:00 pm**	**1:00 pm**	**2:00 pm**
20%	**469.43**	**542.87**	**562.96**	**591.83**	**537.268**
23%	537.03	593.86	620.71	643.53	676.32
25%	605.51	668.25	697.52	732.51	763.38

B. South Orientation

It was derived from Figure 4 for south orientation, WWRs between 15% and 20% have to be simulated to find the optimum condition for energy demand reduction in order to find the minimum WWR that provided the required daylighting.

Table 4. Total energy consumption and heat gain for South orientation with daylight utilization.

Scenario /Sr. No.	**WWR**	**Average Daylight Illuminance lux**	**Cooling MJ/m2-yr**	**Fans MJ/m2-yr**	**Lighting MJ/m2-yr**	**Total energy consumption MJ/m2-yr**	**Window total heat gain MJ/m2-yr**
1.	10%	111.80	356.03	95.08	139.62	590.73	83.44
2.	**15%**	**184.35**	**364.25**	**95.86**	**122.51**	**582.62**	**137.62**
3.	**20%**	**288.14**	**376.51**	**96.65**	**109.76**	**582.92**	**201.96**
4.	25%	372.48	389.92	97.99	106.46	594.37	258.21
5.	30%	475.94	411.92	106.41	104.36	622.69	317.85
6.	35%	599.91	427.93	109.02	102.81	639.77	377.68
7.	40%	695.07	443.09	111.52	102.03	656.65	435.61

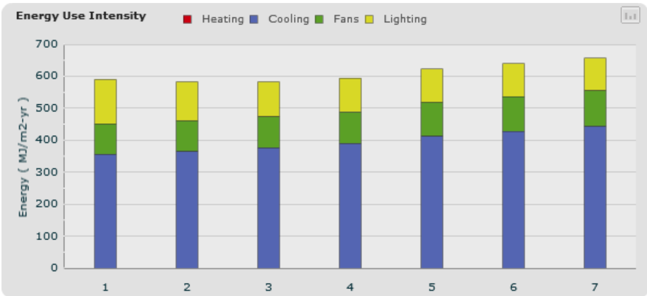

Figure 4. Comparison of energy consumption of different WWRs for South orientation with daylight utilization.

A WWR of 18% (Table 5) was identified as optimum glazing size for south orientation satisfying the pre-set criteria for the working duration with lowest energy consumption of 579.81 MJ/m-yr.

The south orientation was found to be better than north, east and west orientations for useful daylighting as it receives direct sunlight throughout the working time. However, minimum energy demand was found with a WWR of 18%, allowing natural light to bathe the space for most of the working time without causing glare or overheating.

Table 5. Annual average hourly daylight (lux) at different (intermediate) WWRs for South orientation.

WWR	Annual average hourly daylight (lux) for five counted hours				
	10:00 am	11.00 am	12:00 pm	1:00 pm	2:00 pm
15%	440.16	524.95	568.94	586.09	575.45
18%	**611.15**	**728.13**	**791.20**	**820.33**	**815.48**
20%	678.72	808.01	877.23	909.03	903.64

C. East Orientation

It was derived from Figure 5 that for East orientation, WWRs between 10% and 15% have to be simulated to find the optimum condition for energy demand reduction in order to find the minimum WWR that provided the required daylighting.

Table 6. Total energy consumption and heat gain for East orientation with daylight utilization

Scenario /Sr. No.	WWR	Average Daylight Illuminance lux	Cooling MJ/m2-yr	Fans MJ/m2-yr	Lighting MJ/m2-yr	Total energy consumption MJ/m2-yr	Window total heat gain MJ/m2-yr
1.	**10%**	**119.51**	**387.91**	**126.85**	**143.53**	**658.29**	**87.49**
2.	**15%**	**203.90**	**413.80**	**146.68**	**127.67**	**688.15**	**144.45**
3.	20%	338.57	446.60	171.01	114.52	732.13	212.85
4.	25%	443.02	477.41	193.68	109.02	780.11	272.54
5.	30%	561.40	511.20	218.72	105.55	835.47	336.18
6.	35%	789.80	546.65	245.33	103.25	895.23	400.43
7.	40%	928.25	580.16	269.95	102.21	952.33	462.42

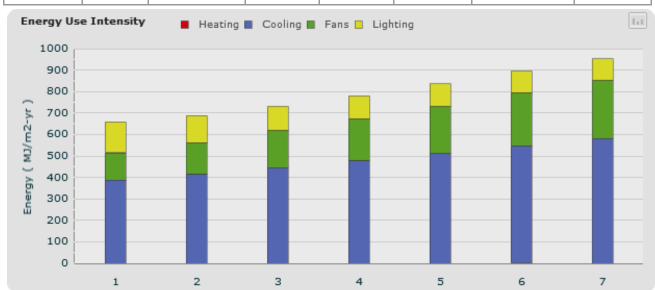

Figure 5. Comparison of energy consumption of different WWRs for East orientation with daylight utilization.

A WWR of 15% (Table 7) was found to be optimum for east orientation, providing the required illumination at the work plane with daylight alone for 55% of the working time. High illumination levels (causing glare or visual discomfort) were observed during morning hours for east orientation due to low solar altitudes.

Table 7. Annual average hourly daylight (lux) at different (intermediate) WWRs for East orientation.

WWR	Annual average hourly daylight (lux) for five counted hours				
	9:00 am	10:00 am	11.00 am	12:00 pm	1:00 pm
10%	469.62	512.33	415.17	288.72	226.36
12%	**568.63**	**622.79**	**505.58**	**351.43**	**275.39**
15%	773.73	842.58	681.93	474.19	371.69

D. West Orientation

It was derived from Figure 6 that for West orientation, WWRs between 10% and 15% have to be simulated to find the optimum condition for energy demand reduction in order to find the minimum WWR that provided the required daylighting.

Table 8. Total energy consumption and heat gain for West orientation with daylight utilization.

Scenario /Sr. No.	WWR	Average Daylight Illuminance lux	Cooling MJ/m2-yr	Fans MJ/m2-yr	Lighting MJ/m2-yr	Total energy consumption MJ/m2-yr	Window total heat gain MJ/m2-yr
1.	**10%**	**132.26**	**365.72**	**105.40**	**133.82**	**604.93**	**91.59**
2.	**15%**	**217.09**	**379.17**	**109.51**	**119.38**	**608.06**	**149.05**
3.	20%	336.79	413.18	132.62	109.32	655.12	214.97
4.	25%	440.11	442.97	151.93	105.57	700.48	273.95
5.	30%	623.35	474.81	172.64	103.59	751.04	335.85
6.	35%	801.90	506.25	193.02	102.37	801.64	397.89
7.	40%	923.84	537.05	213.47	101.71	852.23	485.90

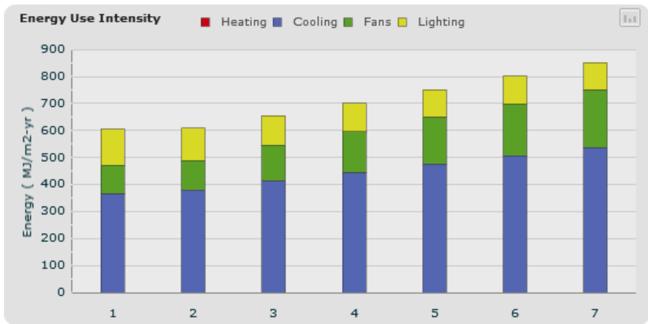

Figure 6. Comparison of energy consumption of different WWRs for West orientation with daylight utilization.

A WWR of 12% (Table 9) was found to be optimum for west orientation, providing the required illumination at the work plane with daylight alone for 55% of the working time. High illumination levels (causing glare or visual discomfort) were observed during evening hours for west orientation due to low solar altitudes.

Table 9. Annual average hourly daylight (lux) at different (intermediate) WWRs for West orientation.

WWR	Annual average hourly daylight (lux) for five counted hours				
	1:00 pm	2:00 pm	3:00 pm	4:00 pm	5:00 pm
10%	260.36	376.72	484.27	491.52	390.49
12%	**316.68**	**457.79**	**587.49**	**594.64**	**470.88**
15%	427.96	621.04	800.09	813.40	729.68

By optimizing WWR for all orientations from the presently traditional (reference building model) 30% WWR, a total of 4% to 19% of the energy could be saved as shown in Table 10. Owing to different solar conditions, the optimal glazing size varies for different orientations in daylight use. With daylight utilization, energy demand is reduced by 19% by use of optimum WWR for east and west, while 6.88% and 4.21% reductions are available from optimum WWRs for south and north orientations, respectively, compared to 30% WWR. For more than 50% of the working time, these optimum WWRs have daylighting levels above 500 lux at desk level.

Table 10: Total reduction in annual energy consumption optimum WWR for East, West, North and South orientation with daylight utilization.

Orientation	Baseline scenario		Optimized scenario		Reductions in overall energy requirement %
	WWR	Total energy consumption MJ/m2-yr	WWR	Total energy consumption MJ/m2-yr	
North	30%	593.18	20%	568.17	4.21%
South	30%	622.69	18%	579.81	6.88%
East	30%	835.47	12%	668.68	19.96%
West	30%	751.04	12%	604.95	19.45%

VIII. CONCLUSION

This study illustrated that by using optimized WWRs, substantial energy savings in glazed commercial buildings are possible in cooling dominant climates. By optimizing WWR for all orientations from the presently traditional (reference building model) 30% WWR, a total of 4% to 19% of the energy could be saved as shown in Table 10. Owing to different solar conditions, the optimal glazing size varies for different orientations in daylight use. With daylight utilization, energy demand is reduced by 19% by use of optimum WWR for east and west, while 6.88% and 4.21% reductions are available from optimum WWRs for south and north orientations, respectively, compared to 30% WWR. For more than 50% of the working time, these optimum WWRs have daylighting levels above 500 lux at desk level. The results showed that the heat gained through windows is responsible for the excessive energy demand in Bangalore (a cooling dominant region).

Therefore, the control of penetration of solar radiations through windows is essential for saving energy. Daylight use lowered the energy demand for buildings by reducing the energy requirements for artificial lighting and the cooling load associated with artificial lighting. Therefore, a choice needs to be made between taking advantage of natural daylighting by optimal WWR in order to minimize energy demands; hence, decreasing the use of artificial lighting and decreasing WWR to suitable sizes to minimize heat gains via windows.

Buildings with EPI of 180 kWh/m2/year or 648 MJ/sq.m./year are ECBC compliant. The average EPI index of a standard 24 hours operation high rise office building is 350 kWh/m2/yr. which reduced to 306 kWh/m2/yr. after optimization of WWR with daylight utilization..

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