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Potential Of Energy Savings Through Distribution of Window and Daylight Integration in Indian Building

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Abstract: Application of glazing is increasing in modern building architecture around the world. Glazed surface on building envelope provide good aesthetic view and nature light inside the working space. Window glazing system in building envelope is not only responsible for healthy daylight penetration into the working space but also greatly influences energy consumption of the building. Daylighting inside the building reduces lighting energy consumption of the building but at the same time heat gain of the building increases. Increasing heat gain causes higher cooling energy requirement of the building. Building sector is one of the largest global energy consumer hence conservation of energy in building is essential. In the present study window area has been distributed to different wall for better integration of daylight through the window combinations. Artificial lighting system is controlled according to daylighting in building for better energy efficiency of the building. A parametric study has been conducted with five different WWR and distribution of window around the building envelope for the climatic condition of Kolkata located in India. The applicability of the results has been tested with two more locations in Indian climatic conditions. Results shows substantial energy savings opportunity is there with control daylight integration through distribution of window into the building in India.

Keywords: Building energy, window glazing, energy savings, window-to-wall-ratio, window combination.

1. INTRODUCTION

Energy demand is continuously rising all over the world. Building sector is one of the major consumers of energy and accounts for 30% of global final energy consumption [1]. It is reported that 50% of total carbon dioxide emissions of industrialized countries are due to building energy consumption [2]. Lighting, cooling, heating and equipments are the main area of energy consumption in a building. Cooling, heating and lighting energy consumption in building is directly influenced by building parameters such as envelope, geometry, orientation, building materials, location and climatic conditions. Special attention is required to select those building parameters for energy efficient building design [3].

Growth in population and rapid urbanization has increased the building energy consumption in the developing country like India. The building sector in India is experiencing an exceptional growth from the last few years and the sector is responsible for 38% of total annual primary energy consumption and 31% of the total annual electricity consumption [4]. Energy Conservation Building Code (ECBC) in India has been introduced to design energy efficient building in different climatic zones in India. ECBC provides minimum energy standards for new commercial buildings having a connected load of 100 kW or contract demand of 120 kVA [5]. R. Chedwal et al. quantified substantial energy saving potential in different hotels in Jaipur, India through the implementation of Energy Conservation Building Code [6].

Cooling energy of a building greatly influenced by the structural load of the building. Envelope materials and their thermal property are highly responsible for the heat gain of a building. Window is one of the most thermally weak parts in the building envelope as the thermal conductance of the window glass material is substantially higher than the other building envelope materials. According to T. Berger et al heat gain through windows in building significantly increase cooling load and increase the energy consumption of the building [7].Energy rating of window glazing is important to identify suitable window glazing for the higher energy efficiency of the building.

M.C. Singh, S.N. Garg conducted simulation study to identify the energy saving of different window glazing for different Indian climate conditions [8].

Window glazing system plays an important role to access daylight in to the building working space. Daylight has substantial impact on occupant health and productivity. H. Hens mentioned in his study that Office buildings are responsible for higher lighting energy consumption per unit area due to operational requirements [9]. Daylight integration into the building can reduce building energy consumption which in turn reduces emission and environmental impact. Higher amount of daylight can be access into the the building by increasing the window area in the building envelope. Daylight through the window of building reduces lighting energy consumption [10]. Many researchers in their study have mentioned the energy savings potential of Daylight received through windows [11-13].

But excessive and uncontrolled daylight increase heat gain of the building especially in tropical region in country like India. This heat gain increases the cooling energy consumption of the building. Lim et al. [14] conducted a simulation study to evaluating the impact of daylight on a typical government office building in Malaysia. It is found that selecting suitable glazing of the windows and adding interior blinds, to improvement in daylighting quantity and quality for visual comfort. Shading device controls the daylight penetration into the building space and reduces excessive heat gain. Shading devices not only reduce building heat gain but also reduce energy consumption and associated greenhouse gases emission [15].

According to K. Lai et al. application of proper shading device reduces total building energy consumption up to 37.8% in USA and 24.8% in China [16]. Window-to-wall-ratio (WWR) represents the area of window glazing on the building envelope and useful parameter to access daylight into the building space. Higher WWR in modern building not only used to access daylight in to the building but also used to improve the aesthetic view of the buildings. Increasing WWR of a building allows more heat and daylight inside the working space. S. Fung Fung et al. conducted simulation study in EnergyPlus to evacuate thermal performance of window glazing for different orientation of window and WWR in Hong Kong [17]. Energy savings opportunity with Optimal WWR and daylight link has been evaluated in in india. Result of the study reflects energy savings potential of the daylight integration into the building [18] F. Goia studied to find optimal WWR for office building in different European climates to identify the minimum total energy use for heating, cooling and lighting [19].

The present study aims to understand the impact of controlling artificial lighting system of the building according to available daylight into the building through window glazing. The building is designed according to ECBC and National Building Code in India [20] and window area is distributed into different cardinal direction for better daylighting into the building. Result of the parametric study with WWR and window combinations identifies the energy savings of the building through daylight integration in tropical climatic condition in India.

2.METHODOLOGY

Literature survey shows that significant amount of energy consumption can be avoided with proper integration of daylighting. A number of parametric studies have been found for building energy savings in recent past. In the present study, a parametric approach with WWR and distribution of window area on the building envelope along with daylight based lighting control is incorporated. The study is conducted in Kolkata and the applicability of the result is verified with the result of Delhi and Chennai. All the three locations are in tropical climatic condition. Main energy consumption of the building is considered due to cooling and lighting of the building. Daylighting in the building significantly influences the building energy consumption. The depth of daylight penetration into the building space depends on lot of factors such as orientation of window, location, window size etc. The building models under study consist of eleven number of different window combinations. The building model with windows in east and west wall is termed as EW combination. In similar way NE, NS, NW, SE, SW, NSW, NSE, EWS, EWN, NSEW combination are formed. All the building models were simulated for energy performance with five different WWR (10%, 15%, 20%, 25% and 30%). Results of two different cases are compared to understand the effect of this parametric study.

Case 1: Daylight is allowed into the building space and artificial lighting system is not controlled based on available daylight inside the building space. In this condition, energy consumption of all the building models is evaluated.

Case 2: In this case, daylight is controlled with external window shading and artificial lighting system of the building is controlled according to controlled daylight inside the building. Energy consumption of all the building models is evaluated again to quantify the impact of daylight integration.

A. Location of study

The location of the present study is Kolkata, India and the results are validated with two different locations Delhi and Chennai. The buildings are modeled according to NBC and ECBC code in India. Energy savings due to distribution of window in different cardinal direction and daylight integration with artificial lighting system were computed in Kolkata (22°33' N, 88°21'E) which is located in worm and humid climatic zone in India [5]. The results were validated with two more locations Chennai (13° 4' N, 80° 14' E) situated at lower latitude and Delhi (28° 38' N, 77° 13' E) situated at higher latitude compared to Kolkata. Building energy consumption depends on the weather condition of the study location. Monthly average temperature and global solar radiation of the three study location is shown in Fig. 1and Fig. 2.

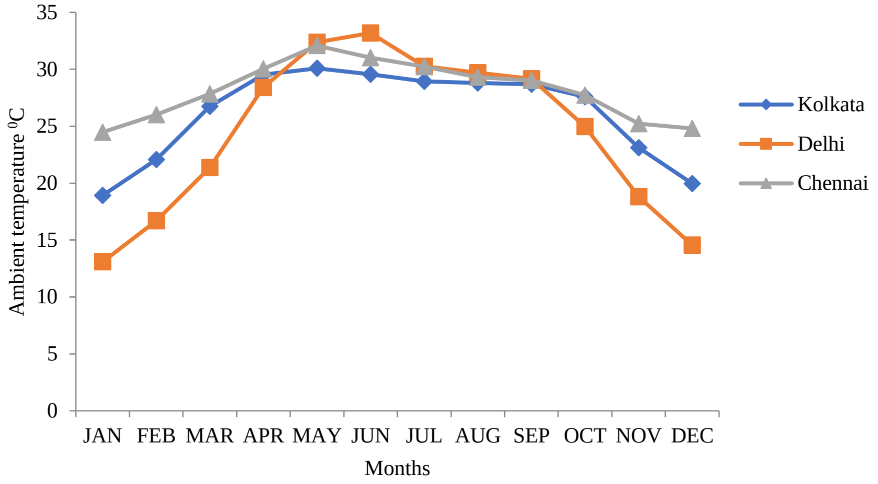


Fig.1: Monthly average global solar radiation in Kolkata, Delhi and Chennai.

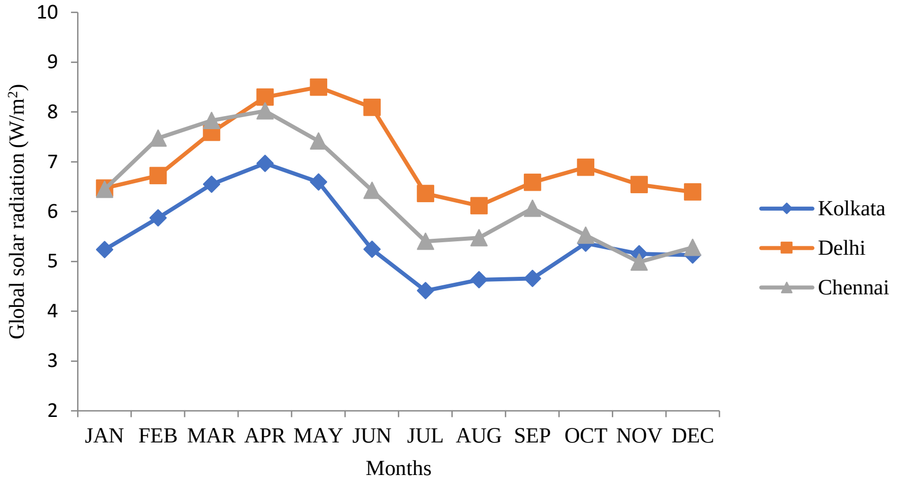


Fig.2: Monthly average temperature in Kolkata, Delhi and Chennai

A. Solar radiation

Solar radiation of the study location has substantial impact on energy consumption of the building. Solar radiation on building surface increases heat gain of the building. Glass window allow solar radiation inside the building working space. Direct solar radiation or beam component of solar radiation (I_b) on a surface is given by:

$$I_b = I_{bn} \cos\theta \qquad (1)$$

Where I_{bn} is the entire beam radiation coming from the direction of the sun, θ is angle of incidence and Cos θ is given by the following equation:

$$\cos\theta = \sin\varphi(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\cos\beta) + \cos\varphi\,(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta \qquad (2)$$

Where β is tilt angle of the receiving surface, γ is azimuth angle of the surface receiving solar radiation, ω is hour angle, δ is declination angle and Φ is latitude of the location. Window is considered as vertical surface hence β is 90^0 and the equation (2) reduces to

$$\cos\theta = \sin\varphi\cos\delta\cos\gamma\cos\omega - \cos\varphi\sin\delta\cos\gamma + \cos\delta\sin\gamma\sin\omega \qquad (3)$$

The amount of global radiation on a surface of a building considering isotropic sky is given by [21]

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \qquad (4)$$

Solar radiation received on a surface considering anisotropic sky is given by [21]

$$I_T = (I_b + I_d A_i) R_b + I_d (1 - A_i) \frac{(1+cos\beta)}{2} \left[1 + f \, sin^3 \frac{\beta}{2}\right] + I \rho_g \left(\frac{1-cos\beta}{2}\right) \qquad (5)$$

Where R_b is tilt factor of beam radiation, R_d is tilt factor of diffusion radiation, R_r is tilt factor of reflected radiation and A_i is anisotropy index which is nearly equal to 1.

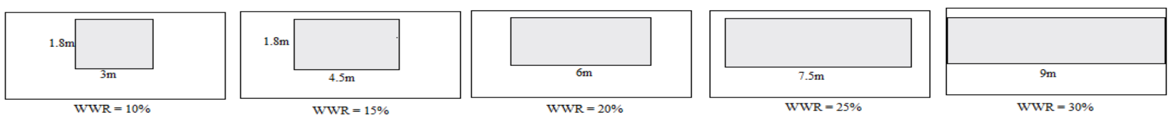
A. Simulation tool

A number of building energy simulator such as DOE2, EnergyPus, Transys, eQUEST, Design Builder are recommended in ECBC Code in India. EnergyPlus is one of the most used building energy simulation tool and hence used in the present study. EnergyPlus has been developed by department of energy of USA. Building models for the present study has been created to study the energy performance of the building in Kolkata, India situated at 22.57^0 N, 88.36^0 E. Applicability of the result have been validated with two other location Delhi situated at 28.7°N, 77.1°E and Chennai 13° N, 80.2° E. EnergyPlus building energy software is used to evaluate cooling, lighting and total energy consumption of different building models developed for three locations to quantify the effect daylight integration through the window combinations.

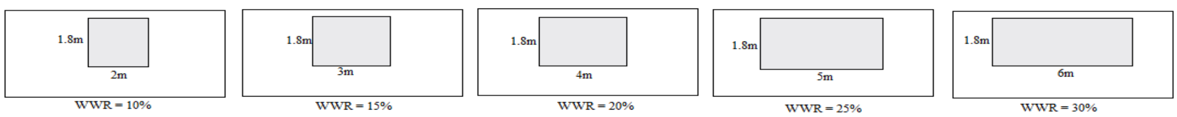
B. Building model

In the present study, all building models are of 9 m X 9 m X 3 m which has been developed according to ECBC and NBC code in India [8]. Roof and floor of the building models are constructed with several layers suitable for Indian climatic conditions. The roof is constructed with RCC and the floor is constructed with the layers of brick and concrete. Thickness of roof RCC is 135mm and conductivity is 1.58 W/mK. Density and specific heat is 2280 kg/m^3 and 880 J/kg K respectively. Thickness of the concrete used in floor is 101 mm, conductivity is 1.78 W/mK, density is 2410 kg/m^3 and specific heat is 880 J/kg K. The walls are constructed with brick with inside and outside cement plaster layer. Thickness of brick layer is 254mm for all the walls of the studied building models. Conductivity, density and specific heat of the brick layer are 0.811 W/mK, 1820 kg/m^3 and 840 J/kg K respectively. In all building models, the window sill height is fixed to 1m above the floor height complying with the NBC code in India [20]. Fig. 3 shows the dimensions of window in different combinations under study. Clear glass with 4mm thickness has been used as window glazing material. U-value, solar heat gain coefficient (SHGC) and visible transmittance of glass is 5.6 W/m2K, 0.83 and 77.8% respectively. External horizontal blind is used to control the excess daylight penetration into the building working space. Slat width, slat thickness and slat separation of the blind is 2.5 cm, 1mm and 1.875 cm respectively. Front and back side reflectance of the slat is 0.8. Slat angle to control daylight penetration inside the working space is 45^0.

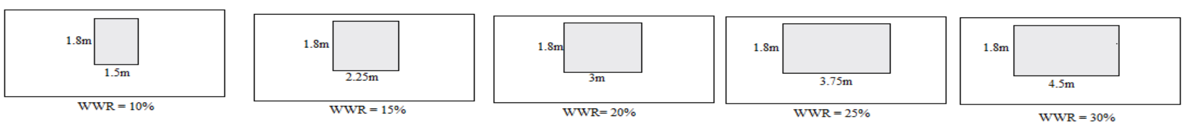
Light power density of the building is considered as 9.5 W/m^2 [5] and constant ventilation with outside air of 0.5 air change per hour [8] has been considered. The building operates for 10 hours of operation from 08:00 am to 06:00 pm [5] during the weekdays and cooling temperature set point of the HVAC is 25^0 C [8]. A continuous dimming control of artificial lightings is used based on daylight at two reference points located at 3m and 6m away from the window and at 0.8m above the floor area. Reference point illumination has been taken as 500 LUX to control the artificial lighting system of the building [22]. At minimum dimming level, the light output of the artificial lighting is fixed to 30% of its full illumination and further increase in the daylight illuminance will not dim the artificial lighting. To control excessive daylight and heat gain, external horizontal blind with fixed slat angle of 45^0 is used to controlled daylight into the building space [22].



Specification of window in each wall for EW, NE, NS, NW, SE and SW combination



Specification of window in each wall for NSW, NSE, EWS and EWN combination



Specification of window in each wall for NSEW combination

Fig. 3. Position and dimensions of window in different combinations.

1. RESULT

The result of the study is obtained with two different approaches. In case 1, all the building models were simulated for the weather condition of Kolkata and the applicability of the result is verified with two othe locations in India. Annual cooling and lighting energy consumptions are obtained from the simulation result. Total energy consumption of the building is the sum of annual cooling and lighting energy consumption. In case 2, daylight through the window glazing is controlled with external blind and this controlled daylight is used to control the artificial light of the building models.

A. *Energy consumption in case 1*

Annual energy consumption per square metre of floor area for different building models under study in Kolkata is shown in table I. Result of the study shows that annual energy consumption in each building model in Kolkata increases with increasing WWR. Increasing WWR for a particular building model increases heat gain of the building through the window. This heat gain increases cooling energy consumption of the building. The simulation result shows that distribution of window in the building envelope significantly influences energy consumption of the building. Building models in Kolkata with SW, SE, EW and EWS window combinations are responsible for higher energy consumption whereas building models with NE, NS, NW, NSW, NSE, EWN and NSEW combinations of window consumes comparatively lower energy. This deference in energy consumption is more prominent with higher WWR of the building. Higher window area in south, west and east wall is responsible for higher energy consumption of the building. Similar results have been found for Delhi and Chennai as shown in table II and table III. Energy consumption of the building models in Kolkata varies from 120.1 kWh/m^2 to 156.0 kWh/m^2 depending on WWR and distribution of the window around the building envelope. Energy consumption of the building models in Delhi and Chennai varies from 120 kWh/m^2 to 155.1 kWh/m^2 and 143.3 kWh/m^2 to 187.1 kWh/m^2 respectively.

Table I. Energy consumption per unit floor area in Kolkata.

Window Combination	Energy consumption (kWh/m^2) in Kolkata				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
NE	120.1	125.9	131.5	137.0	142.2
NW	120.3	126.1	131.8	137.4	142.8
EWN	121.2	127.4	133.6	139.6	145.4
NS	120.5	126.7	133.0	139.3	145.5
NSE	121.4	127.9	134.4	140.8	147.1
NSW	121.5	128.0	134.6	141.0	147.4
NSEW	121.9	128.6	135.2	141.7	148.1
EW	123.4	130.8	138.2	145.4	152.6
EWS	123.6	131.3	138.9	146.6	154.1
SE	123.8	131.7	139.7	147.7	155.6
SW	123.9	131.9	140.0	148.1	156.0

Table II. Energy consumption per unit floor area in Delhi.

Window Combination	Energy consumption (kWh/m^2) in Delhi				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
NW	120.0	125.1	130.2	135.2	139.9
NE	120.2	125.4	130.6	135.5	140.2
NS	119.6	124.8	130.1	135.6	141.2
EWN	121.5	127.4	133.1	138.8	144.3
NSW	121.1	127.0	132.9	138.9	144.9
NSE	121.2	127.2	133.1	139.0	144.9
NSEW	122.0	128.2	134.4	140.6	146.8
EW	124.5	132.0	139.4	146.8	154.1
EWS	124.2	131.7	139.3	147.0	154.6
SE	124.2	131.9	139.9	148.0	156.0
SW	124.1	131.8	139.7	147.9	156.1

Table III. Energy consumption per unit floor area in Chennai.

Window Combination	Annual Total Energy (kWh/m^2) in Chennai				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
NS	143.3	150.4	157.3	164.1	170.6
NW	144.3	151.8	159.1	166.1	172.8
NE	144.7	152.4	159.9	167.1	174.0
NSW	145.0	152.9	160.5	167.9	175.1
NSE	145.3	153.3	161.1	168.6	176.0
EWN	145.9	154.2	162.2	170.0	177.5
NSEW	146.0	154.4	162.5	170.3	177.9
SW	147.7	156.9	166.0	174.8	183.2
EWS	148.2	157.6	166.8	175.8	184.5
SE	148.1	157.6	166.9	175.9	184.6
EW	149.0	158.8	168.5	177.9	187.1

A. *Energy consumption in case 2*

In this case, daylight through the window is controlled with external shading applied to the window combinations. Artificial lighting system of the building is controlled according to available controlled daylight into the building spaces. Controlled daylight reduces energy consumption of the all the building models under study. Energy consumption under is condition in Kolkata is shown in table IV. Energy savings due to daylight integration is calculated from the results of two cases in Kolkata which varies from 15.3% to 37.1% depending on WWR and window combination. Similarly energy savings in Delhi and Chennai varies from 14.9% to 37.7% and 16% to 36.8% respectively. Result of the study shows that energy consumption per unit floor area in case 1 is increasing with increasing WWR but in case 2, energy consumption for all the building models initially decreasing with increase in WWR and reaches a minimum value and further increase in WWR increases the total energy consumption of the building. This result indicates that glass area on the building envelope can be increased with higher energy efficiency if suitable daylighting strategy is incorporated. Applicability of the result is verified with two other locations and the result are shown in table V and table VI. Results of the study reveal that proper integration of daylight reduces energy consumption of building. Unlike case1 it is observed from the study that higher WWR and distribution of window area into different walls reduces energy consumption of the building when daylight is integrated with proper way.

Table IV. Energy consumption per unit floor area in Kolkata in case 2.

Window Combination	Energy consumption with daylight integration (kWh/m^2) in Kolkata				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
EW	98.9	96.6	96.1	96.6	97.5
NE	101.7	99.8	98.6	98.1	98.2
NS	99.3	96.9	96.2	96.5	97.1
NW	101.8	99.3	98.1	97.8	98.0
SE	100.3	97.9	97.5	97.6	98.2
SW	99.8	97.7	97.2	97.4	98.1
NSW	99.7	96.9	96.0	96.3	97.0
NSE	99.8	97.1	96.2	96.4	97.0
EWS	99.0	96.4	96.0	96.4	97.3
EWN	100.1	97.2	96.0	96.2	96.9
NSEW	100.2	97.1	96.0	96.2	96.9

Table V. Energy consumption per unit floor area in Delhi in case 2.

Window Combination	Energy consumption with daylight integration (kWh/m^2) in Delhi				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
EW	98.2	96.0	95.5	96.0	96.7
NE	101.7	99.7	98.3	97.7	97.6
NS	99.1	96.5	95.6	95.7	96.1
NW	102.0	99.3	97.9	97.5	97.5
SE	99.5	97.0	96.5	96.7	97.2
SW	99.2	97.0	96.4	96.6	97.2
NSW	99.3	96.2	95.4	95.6	96.2
NSE	99.4	96.4	95.6	95.7	96.1
EWS	98.0	95.2	95.2	95.7	96.4
EWN	99.6	96.7	95.5	95.5	96.1
NSEW	99.7	96.1	95.1	95.5	96.0

Table VI. Energy consumption per unit floor area in Chennai in case 2.

Window Combination	Energy consumption with daylight integration (kWh/m^2) in Chennai				
	WWR=10%	WWR=15%	WWR=20%	WWR=25%	WWR=30%
EW	118.0	115.8	116.0	117.0	118.3
NE	121.2	119.2	118.2	118.1	118.6
NS	119.3	116.6	116.0	116.5	117.4
NW	121.2	118.6	117.7	117.7	118.4
SE	120.4	118.1	117.7	118.1	118.9
SW	120.0	117.9	117.3	117.7	118.7
NSW	119.6	116.4	115.8	116.4	117.4
NSE	119.8	116.7	116.1	116.6	117.5
EWS	118.5	115.9	115.8	116.7	117.9
EWN	119.2	116.2	115.7	116.4	117.5
NSEW	120.1	116.4	115.7	116.4	117.4

3. CONCLUSION

Glass area in building envelope is increasing in modern building design. Higher glass area in building envelope is responsible for higher energy consumption in the building. In the present study, energy consumption per unit floor area has been considered as a measuring parameter of energy performance of window glazing system in building. When daylight is not linked with the lighting system of the building, energy consumption of the building per unit floor area considerably increases with increasing WWR in all the building models. Result of the study reveals that energy consumption of the building models with NE, NS, NW, NSW, NSE, EWN and NSEW window combinations consumes lower energy whereas building models with SW, SE, EW and EWS consumes comparatively higher energy.

When daylight is controlled with external shading applied to the window combinations total energy consumption per unit floor area reduced remarkably in all the study locations. Moreover increasing WWR decreases energy consumption and reaches to minimum and increase again which definitely indicates the application of optimal WWR in the building. This strategy of integrating daylight reduces energy consumption of building with high glass area. Moreover distribution of glass area to different walls reduces energy consumption of the building. Similar result is observed in Delhi and Chennai which suggest the applicability of the strategy in tropical climate in India.

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REFERENCES

1. International Energy Agency. (n.d.). *Energy efficiency: Buildings*. Retrieved from https://www.iea.org/topics/energyefficiency/buildings
2. Loveday, D. L., Parsons, K. C., Taki, A. H., & Hodder, S. G. (2002). Displacement ventilation environments with chilled ceilings: Thermal comfort design within the context of the BS EN ISO7730 versus adaptive debate. *Energy and Buildings, 34*(6), 573–579.
3. Renuka, S. M., Maharani, C. M., Nagasudha, S., & Raveena, P. R. (2022). Optimization of energy consumption based on orientation and location of the building. *Materials Today: Proceedings, 65*, 527–536.
4. Alliance for an Energy Efficient Economy (AEEE). (2017). *Roadmap to fast track adoption and implementation of Energy Conservation Building Code (ECBC) at the urban and local level*. Retrieved from http://www.aeee.in/wpcontent/uploads/2017/10/AEEE-ECBC-Report-Final-for-NITI-Aayog-BEE-UNDP-GEF.pdf
5. Bureau of Energy Efficiency. (2017). *Energy Conservation Building Code (ECBC) 2017*. India.
6. Chedwal, R., Mathur, J., Das Agarwal, G., & Dhaka, S. (2015). Energy saving potential through Energy Conservation Building Code and advance energy efficiency measures in hotel buildings of Jaipur City, India. *Energy and Buildings, 92*, 282–295.
7. Berger, T., Amann, C., Formayer, H., Korjenic, A., Pospichal, B., Neururer, C., & Smutny, R. (2014). Impacts of urban location and climate change upon energy demand of office buildings in Vienna, Austria. *Building and Environment, 81*, 258–269.
8. Singh, M. C., & Garg, S. N. (2009). Energy rating of different glazings for Indian climates. *Energy, 34*(11), 1986–1992.
9. Hens, H. (2009). Thermal comfort in office buildings: Two case studies commented. *Building and Environment, 44*(7), 1399–1408.
10. Hosseini, S. M., Heiranipour, M., Wang, J., Hinkle, L. E., Triantafyllidis, G., & Attia, S. (2024). Enhancing visual comfort and energy efficiency in office lighting using parametric-generative design approach for interactive kinetic louvers. *Journal of Daylighting, 11*, 69–96.
11. Ke, M. T., Yeh, C.-H., & Jian, J.-T. (2013). Analysis of building energy consumption parameter and energy savings measurement and verification by applying eQuest software. *Energy and Buildings, 61*, 100–107.
12. Wong, Y. W. (1988). Energy performance of office building in Singapore. *ASHRAE Transactions, 94*(2), 546–559.
13. Shen, H., & Tzempelikos, A. (2013). Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading. *Building and Environment, 59*, 303–314.
14. Lim, Y. W., Kandar, M. Z., Ahmad, M. H., Ossen, D. R., & Abdullah, M. A. (2012). Building facade design for daylighting quality in typical government office building. *Building and Environment, 57*, 194–204.
15. Nikoofard, S., Ugursal, V. I., & Beausoleil-Morrison, I. (2014). Techno-economic assessment of the impact of window shading retrofits on the heating and cooling energy consumption and GHG emissions of the Canadian housing stock. *Energy and Buildings, 69*, 354–366.
16. Lai, K., Wang, W., & Giles, H. (2017). Solar shading performance of window with constant and dynamic shading function in different climate zones. *Solar Energy, 147*, 113–125.
17. Fung Fung, S., & Lu, L. (2017). Thermal performance analysis on different types of glazing of public rental housing in Hong Kong. *Procedia Engineering, 205*, 794–801.
18. Biswas, B., Neogi, S., & Roy, B. (2024). Application of delighting to optimize window-to-wall ratio (WWR) in buildings in Indian climatic conditions. *Archives for Technical Sciences, 31*(2), 248–258.
19. Goia, F. (2016). Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. *Solar Energy, 132*, 467–492.
20. Bureau of Indian Standards. (2016). *National Building Code of India 2016*.
21. Duffie, J. A., & Beckman, W. A. (2006). *Solar engineering of thermal processes*. John Wiley & Sons.
22. Raphaela, W. D. F., Evelise, L. D., & Fernando, O. R. P. (2013). Using artificial neural networks to predict the impact of daylighting on building final electric energy requirements. *Energy and Buildings, 61*, 31–38.