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APPLICATION OF DELIGHTING TO OPTIMIZE WINDOW-TO-WALL RATIO (WWR) IN BUILDINGS IN INDIAN CLIMATIC CONDITIONS

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SUMMARY

This research focuses on the energy performance of buildings with glass windows to allow daylight in three different locations in India. The utilization of glass in modern commercial buildings is rapidly increasing for aesthetic views and daylighting through the glazing. Much research has been conducted on WWR and daylight integration into the building through window glazing. In this study, the window area is distributed to different cardinal directions and the result is compared with the reference building in the study location. Focus has been given to optimizing WWR for different window combinations. Energy consumption in eleven different window combinations and five different WWRs were studied. The result shows the reduction of total energy consumption of buildings with different window combinations as a result of the integration of daylight. Window combinations for higher WWR and the optimum value of WWR in all window combinations are determined.

Key words: *daylight, glazing, daylighting, window to wall ratio.*

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INTRODUCTION

Window glazing and glass facades are an integral part of building design. Window glazing allows daylight into the building and also provides an aesthetic view of modern commercial buildings [1]. Natural daylight has an important role in the visual comfort of human beings. Daylighting in buildings has a substantial impact on the health [2, 15], productivity, and performance of the occupant [4]. Integration of daylighting systems can save a lot of lighting energy as reported in many research papers but the glass surface as a window in the building allows a lot of heat inside the indoor working space. The lighting energy requirement of a building is greatly influenced by daylight availability in the building. Heat gain due to daylight increases the cooling energy requirement of the building. Selecting a window glazing given energy conservation in the building is one of the prime issues for achieving energy-efficient building design.

In India, the building sector is responsible for 38% of the total annual primary energy consumption and 31% of the total annual electricity consumption [5]. Perez-Lombard et al stated that the energy consumption by both residential and commercial buildings in developed countries accounts for 20–40%

of total energy used. Those energies are mainly used for space heating and cooling for residential buildings and lighting for commercial buildings [16]. The major electric loads in a building are lighting, air conditioning, and equipment. Residential and commercial in India consume 33% of total electrical energy consumption. Consumption of energy in residential and commercial buildings sectors is predicted to rise by 5 folds and 3 folds respectively by 2032 [7]. Several studies have already been conducted on the application of daylight in buildings. The impact of glass facades and shading controls on energy consumption for lighting and cooling was investigated. Different ways of saving energy and maintaining indoor thermal comfort conditions have been studied [8]. Conducted a study on the effects of window parameters and their impact on the cooling energy and peak energy load of the building [17]. The impact of different types of window glazing, window size, and orientation on the winter and summer energy [12] consumption and peak loads of the residential building was investigated [10]. This paper intended to optimize the window glazing area in view of energy-efficient building design in Indian climatic conditions [6]. In this paper, the building is modeled according to the Energy Conservation Building Code and National Building Code in India [11, 18].

From the literature survey, it is found that several studies related to daylighting were carried out on window glazing systems as a single unit and most of the work concentrated on points such as daylight-linked lighting systems, window orientation, locations, and climate conditions, window glazing materials, window to wall ratio (WWR), window aspect ratio, heat gain and cooling and heating load etc [3]. Little attention was paid to the combination of windows for daylighting and its effect on the energy consumption of the building and optimum WWR for the window combinations [9].

The purpose of the research is to study the integration of daylight and hence optimize the window glazing area compared to the reference building model in the Indian climatic condition [20]. The paper examines the effect of the distribution of window glazing in different cardinal directions compared to single windows in Kolkata (22°33' N, 88°21' E), Delhi (28°40' N, 77°12' E), and Chennai (13°04' N, 80°14' E), in India. Attention is given to increasing window glazing areas within targeted energy consumption in the building [14]. The study identifies the optimum WWR for different combinations of windows allowing daylight into the building.

METHODOLOGY

In the present study, attention has been given to integrating daylight into the building through the glazing of different window combinations. The benefit of integration of daylight through different window combinations was investigated as compared to the reference building model developed following ECBE 2017 and National Building Code in India. As the study locations are in the northern hemisphere, the window position of the reference buildings is placed on the south wall. The window-to-wall ratio of the reference building model is chosen as 10% for this study. Clear glass has a universal heat transfer coefficient (U value) of 5.8 W/m^2K, solar heat gain coefficient (SHGF) of 0.79, and visible transmittance of 87.8% has been chosen as the window glazing material. Cooling, Lighting, and total energy consumption for the reference building models for Kolkata, Delhi, and Chennai are simulated using EnergyPlus building energy simulator. The total energy consumption in the reference building has been considered as a benchmark for increasing daylight through window glazing and finding optimum WWR for the window combinations.

The window glazing area is distributed to different cardinal directions of the building to improve daylight into the building's interior space. The window area of the building under study is taken as 10%, 15%, 20%, 25% and 30%. Increasing window area in different walls influences the energy consumption of the building. The daylight integration with the building lighting system reduces the energy consumption of the building. The impact of the distribution of windows to different walls has been compared with the reference building for optimum WWR. Building models for eleven different window combinations and five different windows to wall ratio (WWR) are developed for energy simulation and the results are compared with the reference building model to find optimum WWR. In all the building models, the material and all specifications are the same except the WWR and orientation of window glazing. Window combinations used in this study are shown in Table 1.

Table 1. Different window combinations under study

Window Combination	Direction of Window
EW	East West
NE	North East
NS	North South
NW	North West
SE	South East
SW	South West
NSW	North South West
NSE	North South East
EWS	East West South
EWN	East West North
NSEW	North South East West

SOLAR RADIATION ON THE WINDOW SURFACE

The solar radiation on the window surface is one of the deciding factors for saving lighting and cooling and the total energy required of the building. Solar radiation on a vertical wall or window depends on several angles related to solar geometry such as the tilt angle (β) of the receiving surface, surface azimuth angle (γ), solar azimuth angle (γ_s), hour angle (ω), altitude angle (α_a), zenith angle (θ_z), declination angle (δ) and latitude(Φ) of the location. When solar radiation falls on a surface, the angle between beam radiation and normal to the surface is called the angle of incidence. It is important to mention that the entire beam radiation coming from the direction of the beam radiation (I_{bn}) will not be received by the surface until the angle of incidence is zero. This angle signifies how much solar radiation (I_b) will be received by the surface. The relationship among I_b, $I_{bn,}$ and θ is given below.

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

Daylight and solar heat gain of any building window depends on the geometrical, optical, and thermal properties of the window. The amount of global radiation on a window of the building i.e. vertical surface is given by [13].

$$I_T = I_bR_b + I_dR_d + (I_b + I_d)R_r \qquad (2)$$

Where R_b is the tilt factor of beam radiation, R_d is the tilt factor of diffusion radiation and R_r is the tilt factor of reflected radiation.

$$R_b = \text{Cos } \theta / \text{Cos } \theta_z \qquad (3)$$

$$R_d = (1 + \text{Cos } \beta)/2 \qquad (4)$$

$$R_r = \rho_g (1 - \text{Cos } \beta)/2 \qquad (5)$$

SIMULATION TOOL

Several simulation tools for building energy such as EnergyPlus, DesignBuilder, DOE2, ECOTECT, TRNSYS, Energy Quest, and BSim used to analyze building energy performance. In the present study, EnergyPlus has been used as the building energy simulation tool. EnergyPlus has been developed by the Department of Energy of USA. It is one of the widely used whole building energy simulation software. A building model for the present study has been created for the energy performance evaluation in three different locations in India namely Kolkata situated at 22.57^0 N, 88.36^0 E. EnergyPlus building energy software is used to calculate cooling, lighting energy, and total energy consumption of the building in the study locations in India.

BUILDING MODEL

In the present study, the dimensions of the reference building are 9 m X 9 m X 3 m [19]. The reference building is modeled according to the specifications mentioned in the National Building Code of India and Energy Conservation Building Code 2017 [11] for all three study locations in India [12]. The walls roof and floor of the building model are constructed with several layers of different materials suitable for Indian climatic conditions and following ECBC 2017 and NBC 2016 codes existing in India. From outside to inside, the layers of the developed building walls are cement plaster layer, bricklayer, and cement plaster layer. The roof is constructed with RCC with concrete layers on both sides. On the floor, the layers are brick, concrete, and cement plaster layer. The window is placed only on the south wall and WWR in the reference building is 10%.

Building models other than reference models are simulated with five different WWRs namely 10%, 15%, 20%, 25%, and 30%. The WWR of the building model is calculated following the NBC code of India. The window is made of clear glass with a U-value of 5.6 W/m^{2}K, solar heat gain coefficient of 0.83, and visible transmittance of 77.8%. The window glass area of the different models is 10.8 m^2, 16.2 m^2, 21.6 m^2, 27 m^2, and 32.4 m^2 respectively for 10%, 15%, 20%, 25%, and 30% WWR. The mentioned glass areas were equally distributed to different walls to investigate the impact of the combination of window glazing on building energy performance. Eleven number of window combinations for each WWR were formed by distributing the glass area into different walls. Figure 1 shows the combination of windows in different walls of the building models.

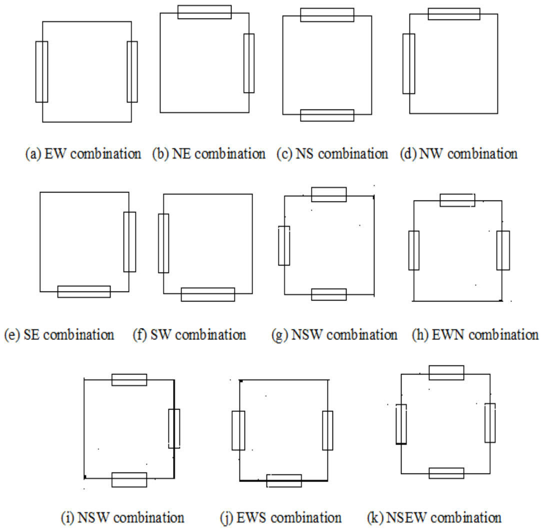

Figure 1. Window combinations under study

The sill height in the study is fixed to 1m above the floor height complying with the NBC code in India. Internal gain of the building from lighting is fixed to 9.5 W/m^2. Constant ventilation with outside air of 0.5 air change per hour has been considered to maintain healthy indoor quality [19]. The building model is meant for 10 hours of operation and the indoor temperature is controlled to 25^{0}C with the help of an HVAC system. The artificial lighting of the building is linked to delighting to reduce the energy consumption of the building. A continuous control of artificial lighting is designed based on daylight through window combinations to maintain the illuminance level at 500 LUX at reference points at a height of 0.8 m from the floor of the building [1]. Dimming of the artificial lights is continuous and linearly from maximum light output to minimum light output as the daylight illuminance increases. 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.

RESULTS

The building models of all three locations are simulated in EnergyPlus to determine annual cooling, lighting, and total energy consumption. The building was simulated for two different cases.

Case 1: In this case reference building for all three locations is simulated and annual cooling, lighting, and total energy consumption are determined. Annual cooling energy consumption of reference buildings in Kolkata, Delhi, and Chennai are 8092.5 kWh, 8051.7 kWh, and 9895.6 kWh respectively. Annual lighting energy consumption is 2008.4 kWh in all three locations as there was no lighting control incorporated in the reference buildings during the hours of operation. Annual total energy consumption is 10101 kWh, 10060.1 kWh, and 11904 kWh in Kolkata, Delhi, and Chennai respectively. Energy consumption of reference buildings is considered as a benchmark for optimizing glass area in the building in different window combinations as a result of daylight integration into the building.

Case 2: Buildings with different window combinations are simulated with and without integrating daylight with the artificial lighting system of the building. Annual cooling, lighting, and total energy consumption of different building models with increasing WWR are evaluated for all three locations.

Building Performance in Kolkata

Energy consumption with different window combinations with and without daylight integration is simulated for increasing WWR. From the result it is evident that increasing WWR compared to the reference building increases the total energy consumption of the building as shown in Figure 2. Integration of daylight into the building significantly reduces the total energy consumption of the building with all window combinations as shown in Figure 3. In reference building in Kolkata, total energy consumption is 10101kWh. Comparing Figure 2 and Figure 3, it is clear that daylight integration into the building greatly reduces the total energy consumption.

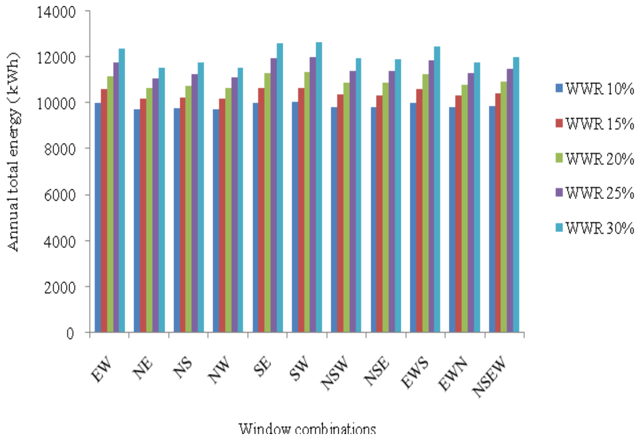

Figure 2. Annual total energy consumption without daylight in Kolkata.

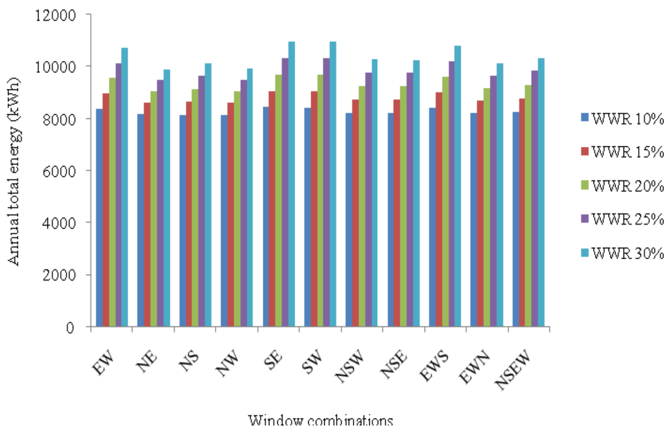

Figure 3. Annual total energy consumption with daylight in Kolkata.

Figure 3 suggests that WWR can be increased in all combinations within the reference energy consumption of 10101kWh. WWR of the building can be increased to allow more daylight through the window combinations. Increasing WWR may increase the heat gain of the building which in turn increases the cooling energy. But at the same time, lighting energy is greatly reduced from 2008.4 kWh; lighting energy consumption without daylight integrating. This reduction in lighting energy reduces the internal heat gain of the building which reduces the cooling energy of the building. Hence a balance between heat gain due to daylight through window glazing and energy saving is required. The annual energy consumption of the building with different window combinations in Kolkata is given in Table 2.

Table 2. Annual Energy Consumption for Different Window Combinations in Kolkata

WWR (%)	**Window Combination**	**With daylight**			**Without daylight**
		Annual Cooling Energy(kWh)	***Annual Lighting Energy (kWh)***	***Annual Total Energy(kWh)***	***Annual Total Energy(kWh)***
10	EW	7658.4	729.4	8387.8	9992.8
	NE	7406.7	777.5	8184.2	9727.9
	NS	7428.4	736.3	8164.7	9763.3
	NW	7412.0	740.2	8152.2	9740.4
	SE	7692.6	768.3	8460.9	10025.4
	SW	7696.9	735.2	8432.1	10036.4
	NSW	7504.2	732.9	8237.1	9839.1
	NSE	7498.7	745.7	8244.4	9831.1
	EWS	7673.4	734.0	8407.4	10011.0
	EWN	7484.5	734.7	8219.2	9815.2
	NSEW	7537.2	740.5	8277.7	9870.4
15	EW	8255.3	716.4	8971.7	10595.5
	NE	7865.5	747.9	8613.4	10194.0
	NS	7923.9	721.2	8645.1	10266.6
	NW	7880.8	723.1	8603.9	10213.7
	SE	8324.3	743.5	9067.8	10668.9
	SW	8336.5	720.8	9057.3	10685.0
	NSW	8029.3	717.1	8746.4	10371.5
	NSE	8018.7	726.3	8745.0	10359.2
	EWS	8287.6	718.5	9006.1	10633.7
	EWN	7987.2	719.1	8706.3	10322.8
	NSEW	8073.1	722.3	8795.4	10413.7
20	EW	8846.9	709.8	9556.7	11191.1
	NE	8318.4	733.5	9051.9	10650.8
	NS	8424.8	713.4	9138.2	10772.9
	NW	8342.7	714.4	9057.1	10678.2
	SE	8966.1	730.8	9696.9	11318.6
	SW	8984.2	713.1	9697.3	11339.7
	NSW	8553.1	708.3	9261.4	10900.2
	NSE	8537.7	715.7	9253.4	10883.8
	EWS	8902.5	709.6	9612.1	11254.7
	EWN	8480.8	709.9	9190.6	10819.6
	NSEW	8604.7	711.6	9316.3	10950.5
25	EW	9431.5	705.5	10137.0	11778.3
	NE	8761.5	725.0	9486.5	11096.1
	NS	8928.0	708.7	9636.7	11280.2
	NW	8794.9	709.0	9503.9	11131.8
	SE	9609.6	723.0	10332.6	11967.7
	SW	9633.5	708.1	10341.6	11993.5
	NSW	9073.1	702.6	9775.7	11424.3
	NSE	9053.2	709.2	9762.3	11403.4
	EWS	9514.8	704.0	10218.8	11871.7
	EWN	8964.0	704.3	9668.3	11305.1
	NSEW	9129.9	704.8	9834.7	11479.5
30	EW	10008.2	702.8	10711.0	12357.1
	NE	9185.3	719.4	9904.7	11520.7
	NS	9431.2	705.6	10136.8	11786.2
	NW	9228.4	705.2	9933.6	11565.6
	SE	10241.5	717.9	10959.4	12603.2
	SW	10270.1	704.8	10974.9	12632.6
	NSW	9587.4	698.8	10286.2	11941.0
	NSE	9562.5	704.7	10267.3	11915.5
	EWS	10121.1	700.2	10821.3	12480.9
	EWN	9435.7	700.5	10136.2	11777.7
	NSEW	9647.3	700.1	10347.4	11999.6

Building Performance in Delhi

Delhi is located in a composite climate zone in India [11]. Energy consumption of the building without daylight integration and with daylight integration for different window combinations in Delhi is shown in Figure 4 and Figure 5. Similar to Kolkata, total energy consumption in each window combination is reduced as a result of daylight integration into the building as shown in Figure 5. WWR of different window combinations may be increased to allow more daylight into the building space within the reference energy consumption as a result of daylight integration. It shows that the application of daylight through optimum use of window glazing is also valid in Delhi. Table 3 shows the energy consumption of the building with different window combinations and WWR.

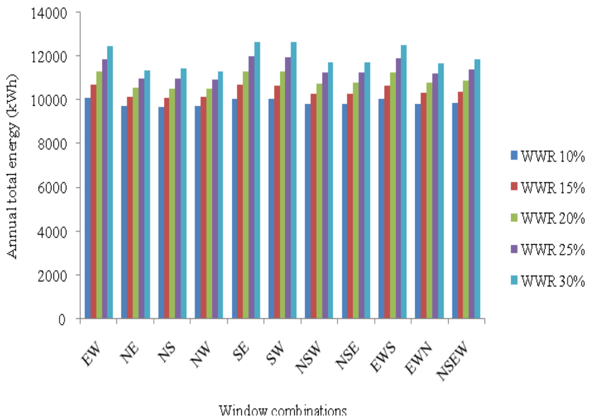

Figure 4. Annual total energy consumption without daylight in Delhi

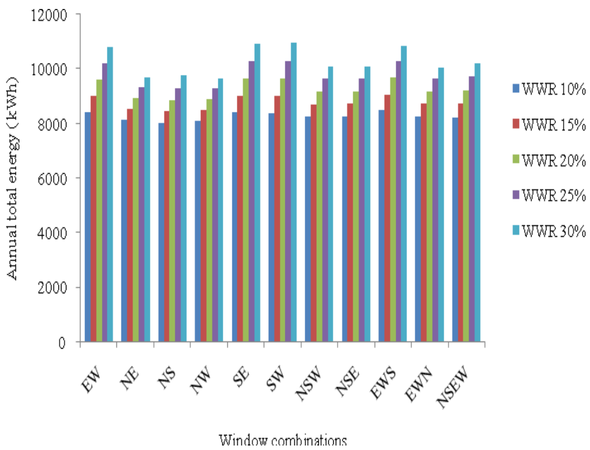

Figure 5. Annual total energy consumption with daylight in delhi

Building Performance in Chennai

Chennai is located in a warm and humid climatic zone in India. Energy consumption of the building without daylight integration and with daylight integration for different window combinations in Chennai is shown in Figure 6 and Figure 7 respectively. From the result, it is found that daylight integration reduces energy consumption in all window combinations. Similar to Kolkata and Delhi, the WWR of buildings for different window combinations can be increased compared to reference buildings as a result of daylight integration. Energy consumption in each window combination in Chennai is shown in Table 4.

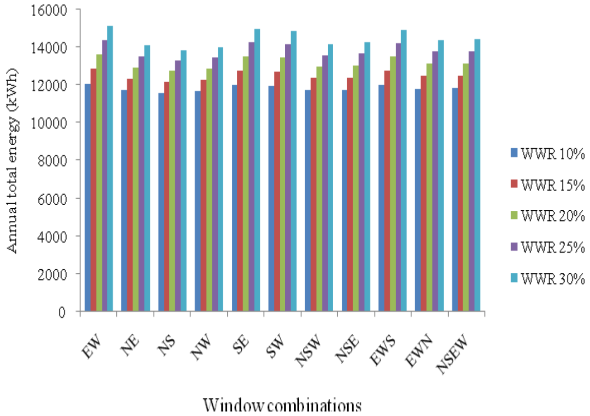

Figure 6. Annual total energy consumption without daylight in chennai

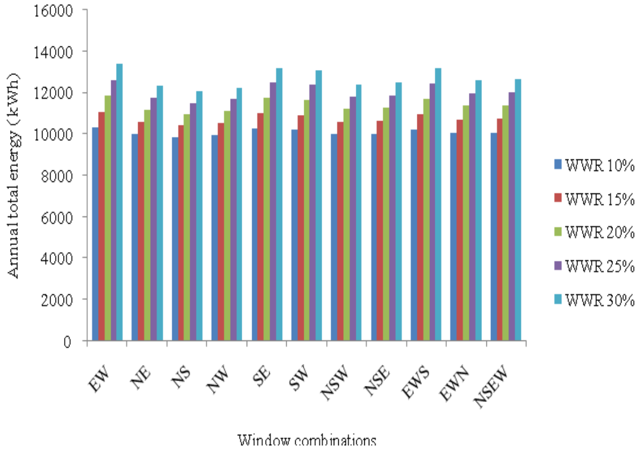

Figure 7. Annual total energy consumption with daylight in chennai

Table 3. Annual energy consumption for different window combinations in delhi

WWR (%)	**Window Combination**	**With daylight**			**Without daylight**
		Annual Cooling Energy(kWh)	***Annual Lighting Energy(kWh)***	***Annual Total Energy(kWh)***	***Annual Total Energy(kWh)***
10	EW	7788.5	645.4	8433.9	10084.4
	NE	7450.7	691.4	8142.1	9736.0
	NS	7391.7	652.1	8043.8	9686.8
	NW	7427.8	662.5	8090.3	9716.2
	SE	7766.1	673.5	8439.6	10064.1
	SW	7747.4	650.6	8398.0	10048.5
	NSW	7513.8	732.9	8246.7	9809.8
	NSE	7526.4	745.7	8272.1	9821.0
	EWS	7759.0	734.0	8493.0	10058.9
	EWN	7548.7	734.7	8283.4	9840.3
	NSEW	7583.9	651.3	8235.2	9879.0
15	EW	8389.7	639.0	9028.7	10690.2
	NE	7871.0	662.8	8533.8	10160.1
	NS	7807.8	643.3	8451.1	10108.4
	NW	7842.8	645.4	8488.2	10134.2
	SE	8378.0	654.7	9032.7	10686.8
	SW	8361.7	641.1	9002.8	10672.8
	NSW	7985.1	717.1	8702.2	10286.6
	NSE	7999.8	726.3	8726.1	10300.0
	EWS	8358.5	718.5	9077.0	10666.1
	EWN	8022.0	719.1	8741.1	10316.8

	NSEW	8083.9	641.7	8725.6	10384.2
20	EW	8987.2	636.0	9623.2	11291.3
	NE	8284.1	652.6	8936.7	10575.1
	NS	8233.1	639.3	8872.4	10539.8
	NW	8252.8	639.4	8892.2	10545.6
	SE	9009.6	646.7	9656.3	11328.5
	SW	9000.3	637.1	9637.4	11318.8
	NSW	8459.8	708.3	9168.1	10767.4
	NSE	8473.6	715.7	9189.3	10778.7
	EWS	8966.4	709.6	9676.0	11281.8
	EWN	8487.1	709.9	9197.0	10784.1
	NSEW	8582.6	637.3	9219.9	10887.4
25	EW	9580.3	634.1	10214.4	11887.4
	NE	8687.0	647.4	9334.4	10978.5
	NS	8671.6	637.1	9308.7	10983.4
	NW	8654.7	636.5	9291.2	10947.7
	SE	9657.9	642.5	10300.4	11984.5
	SW	9655.1	634.8	10289.9	11980.0
	NSW	8939.3	702.6	9641.9	11251.6
	NSE	8948.2	709.2	9657.4	11258.7
	EWS	9581.8	704.0	10285.8	11903.2
	EWN	8943.2	704.3	9647.5	11241.7
	NSEW	9080.7	634.6	9715.3	11389.9
30	EW	10168.9	633.2	10802.1	12478.6
	NE	9067.8	644.2	9712.0	11359.4
	NS	9121.3	635.6	9756.9	11437.0
	NW	9037.3	634.7	9672.0	11329.8
	SE	10303.7	639.9	10943.6	12636.5
	SW	10314.3	633.5	10947.8	12643.8
	NSW	9382.9	698.8	10081.7	11736.0
	NSE	9386.7	704.7	10091.4	11739.2
	EWS	10161.1	700.2	10861.3	12526.1
	EWN	9353.4	700.5	10053.9	11688.9
	NSEW	9577.3	632.9	10210.2	11889.6

Table 4. Annual energy consumption for different window combinations in chennai

WWR (%)	Window Combination	With daylight			Without daylight
		Annual Cooling Energy(kWh)	*Annual Lighting Energy(kWh)*	*Annual Total Energy(kWh)*	*Annual Total Energy(kWh)*
10	EW	9659.2	645.9	10305.1	12068.2
	NE	9321.9	687.0	10008.9	11719.3
	NS	9203.3	652.3	9855.6	11608.1
	NW	9286.7	652.9	9939.5	11688.4
	SE	9590.9	681.6	10272.4	11994.4
	SW	9551.4	650.4	10201.8	11959.9
	NSW	9339.5	647.6	9987.1	11745.6
	NSE	9362.6	660.4	10023.0	11767.4
	EWS	9591.9	649.6	10241.5	12001.0
	EWN	9413.6	650.1	10063.7	11818.8
	NSEW	9423.4	652.7	10076.1	11829.7
15	EW	10454.7	638.3	11093.0	12865.5
	NE	9940.8	662.6	10603.4	12342.6
	NS	9775.0	641.3	10416.3	12181.2
	NW	9891.6	642.4	10534.0	12294.6
	SE	10354.5	660.0	11014.5	12762.8
	SW	10298.5	641.0	10939.5	12709.1
	NSW	9973.8	638.3	10612.1	12381.3
	NSE	10007.7	644.8	10652.5	12415.2
	EWS	10353.9	639.2	10993.1	12765.2
	EWN	10080.3	639.7	10720.0	12487.2
	NSEW	10096.6	641.0	10737.6	12504.9
20	EW	11235.2	634.8	11870.0	13646.0
	NE	10547.6	651.6	11199.1	12949.9
	NS	10336.3	636.9	10973.3	12741.6
	NW	10482.7	637.8	11120.4	12884.8
	SE	11107.2	650.0	11757.2	13516.5
	SW	11033.0	636.5	11669.5	13443.5
	NSW	10593.3	634.1	11227.4	13000.1
	NSE	10638.8	638.2	11277.0	13045.9
	EWS	11100.0	634.8	11734.8	13511.2
	EWN	10730.3	635.3	11365.6	13136.7

	NSEW	10753.3	635.8	11389.1	13161.3
25	EW	11999.7	633.0	12632.7	14409.1
	NE	11136.8	645.5	11782.3	13538.0
	NS	10885.4	634.7	11520.1	13288.7
	NW	11056.5	634.8	11691.2	13456.8
	SE	11843.0	644.3	12487.3	14251.6
	SW	11750.0	634.2	12384.2	14159.1
	NSW	11196.0	631.8	11827.8	13601.1
	NSE	11253.0	630.0	11883.0	13658.6
	EWS	11827.4	632.3	12459.7	14237.3
	EWN	11361.7	632.8	11994.5	13766.5
	NSEW	11391.3	632.9	12024.2	13797.7
30	EW	12748.1	632.0	13380.0	15155.4
	NE	11695.6	641.8	12337.4	14094.4
	NS	11421.7	633.3	12055.0	13822.3
	NW	11601.3	633.2	12234.5	13998.8
	SE	12547.9	640.6	13188.5	14954.6
	SW	12436.4	632.7	13069.1	14843.1
	NSW	11780.9	630.4	12411.3	14183.4
	NSE	11849.0	633.1	12482.1	14252.2
	EWS	12534.9	630.7	13165.6	14942.6
	EWN	11973.8	631.1	12604.9	14376.3
	NSEW	12009.4	631.0	12640.4	14413.5

CONCLUSION

In the present study, the optimum use of window glazing area or WWR is investigated for each combination of windows in the study locations. In each window combination, the optimum value of WWR is calculated so that the total energy consumption of the building does not exceed the total energy consumption of the reference building in the study location. The linear regression method is used to evaluate the optimum WWR of the window glazing for all window combinations. Table 5 shows the optimum value of WWR for different window combinations as a result of daylight integration into the buildings in Kolkata, Delhi, and Chennai. In Kolkata, the optimum value of WWR is maximum with NE and NW combinations. In Delhi, the optimum value of WWR is maximum with NW combination whereas in Chennai optimum value of WWR is maximum with NS combination. In all three locations, a higher value of optimum WWR is possible with NE, NW, NS, EWN, NSW, NSE, and NSEW combinations but EW, SE, SW, and EWS combination shows comparatively lower value of optimum WWR. From the result, it is observed that the incorporation of window glazing in the north wall is beneficial for achieving higher WWR when daylight is integrated into the building.

Table 5. Optimum WWR in kolkata, delhi and chennai

Window Combination	**Optimum WWR**		
	Kolkata	***Delhi***	***Chennai***
EW	25	24	20
NE	32	34	26
NS	30	34	29
NW	32	35	27
SE	23	23	21
SW	23	23	22
NSW	28	30	26
NSE	28	30	25
EWS	24	23	21
EWN	30	30	24
NSEW	28	28	24

Modern commercial buildings use a considerable amount of glazing to allow daylight and to improve aesthetic views. Increasing the glass area causes additional heat load into the building space although it reduces the lighting energy of the building. It is desirable to determine optimum window glazing depending on the window combinations in the building. From the present study, it is evident that energy savings can be possible with the integration of daylight into the building. The study shows the optimum window size or WWR for all combinations of window combinations as a result of daylight integration. The result of the study identifies the window combinations with the higher and lower optimum WWR. The study specifically provides the optimum WWR for different window combinations in Kolkata, Delhi, and Chennai.

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