ISSN: 0974-5823 Vol. 7 No. 3 March, 2022

International Journal of Mechanical Engineering

# Analysis of Optimal Window to Wall Ratio and Orientation in Composite Climate of India

**Nishima Goyal[1], Sakshi Jindal[2], Manoj Panwar[3]**

Department of Architecture, Deenbandhu Chhotu Ram University of Science & Technology, Murthal (Sonepat), India

**Abstract**

Windows are a crucial component of building envelope, and its configuration and specification thus contribute directly to the overall heat gain of the building. In Composite Climate, universal criteria for window openings are given by codes, regardless of the orientation & optimum daylight requirement inside the building. Although the Government of India has initiated energy conservation codes which provides standards for Window to Wall Ratio (WWR) to improve the energy efficiency in commercial and group housings respectively. But none of the codes mention the variation in WWR with respect to orientation and thus the codes have rigidity of WWR. The rigidity in WWR required addressing in respect to variation in orientation. The investigators analyzed the impact of variation of orientation on WWR by considering Daylight factor, illuminance and EPI as criteria on a 20 sq.m bedroom in isolation with conventional building materials in composite climate using simulation tool Design Builder.It is concluded that the higher the WWR, greater the energy consumption and daylight factor and thus amount of glare inside the building; this stands true for all eight orientations taken for evaluation. The results provided the optimal Range of WWR for eight orientations namely North, South, East, West, North East, North West, South East & South West, and it is recommended that with variation in orientation the optimal range of WWR needs to be considered in Composite Climate in India.

***Keywords:*** WWR (window to wall ratio); day lighting; Energy consumption; building orientation

**Introduction**The day lighting design is not only about enough daylight provision to an occupied space, but how to do so without any undesirable side effects such as careful heat gain & loss, glare control, and variations in daylight availability. (Ander, 2016)For example, careful adoption of window sizes will help in reducing glare in any living space. Day lighting helps in creating a productive and simulative environment for the occupants of the building, and in turn it also reduces one third of energy cost of a building if designed thoughtfully. (Edwards & Torcellini, 2002) The admission of sunlight is controlled by various configuration & specifications of design, size & materials of windows. Additionally, spacing and glass selection, reflectance of floor finishes and presence of any internal partitions is requisite.(NBS, 1977) WWR is one of the important parameter impacting day lighting and heat gain. As defined in (ECBC, 2017) **"**WWR is the ratio of vertical fenestration area to gross exterior wall area" also mentioned in (eq.1). Maximum allowable WWR as 40%. However, the mention is only for commercial buildings and has no consideration of orientation.

Window Wall Ratio = Net Glazing Area / Gross Wall Area …… (eq.1)

Where, "Gross wall area is measured horizontally from the exterior surface; it is measured vertically from top of floor to the bottom of the roof." (ECBC, 2017)

(Hien, 2003) analyzed that the window outlet majorly affects the natural ventilation & daylight, and energy exchanges and the effective Solar Heat Gain Coefficient is substantially reduced with the use of a shading device. (Didwania et al., 2011)while investigating on the glazing materials recommended that WWR should be given due attention for different directions, different floors and different types of glass. (Freewan, 2014) recommended that well-designed building require the integration of many factors, such as orientation, shading devices and building form, to reduce energy consumption throughout a building.

(Bhagwat, 2017) analyzed window orientation, day lighting and energy for a patient room in healthcare and concluded the ingress of maximum day lighting from the windows oriented to the West followed by East, North & least from the windows orientated to the South.

**Indian building codes on Window to Wall Ratio**

Building codes suggests a minimum standard size for windows for single houses for varying orientation. The Government of India has launched Energy conservation codes such as Energy Conservation Building Code (ECBC) and Eco Niwas Samhita, which provides optimum standards for windows to improve the energy efficiency in commercial and group housings respectively. But none of the codes take into account any project <500 sq.m area. Windows facing different orientations need different WWR and shadings but no attention has been given to the orientation specific window sizes. Various codes such as National Building Code (BIS, 2016)recommend day lighting levels between 30-100lux with no mention of EPI and WWR. Haryana Building code is applicable to all types of buildings in composite climate of Haryana but does not recommend day lighting levels inside the building and there is no mention of EPI as well. However, it recommends that area of open able windows should not be less than 1/8$^{th}$ of the total floor area of the room. SP41 suggests a range between 100-150 lux for a bedroom space with no mention of EPI & WWR. (TERI, 2019)GRIHA on the other hand recommends daylight level of 100-2000 lux with an EPI OF 90 kWH/sq.m and a WWR of 60%. ECBC follows GRIHA benchmark for energy and Daylight levels inside the building. Recommended range of WWR as per ECBC is 40%.Eco Niwas Samhita does not specify ranges for WWR and EPI. (SVA GRIHA, 2007) on the other hand follows GRIHA benchmark for WWR and SP-41 benchmark for daylight levels. (Refer table 1).

By analyzing Applicable codes and bye laws it can be seen that there is –

- Rigidity in WWR
- No variation in WWR/window sizes with respect to orientation.

Clearly, there is need to find out the optimum WWR in terms of energy saving and day lighting optimization. Therefore, investigators undertook this research to analyze the impact of various WWRand orientation of building in terms of optimal Day lighting. To analyze this, the performance of building in terms of energy consumption and day lighting was evaluated with the help of a base case using the simulation tool design builder

A comparison of day lighting, EPI & WWR standards provided by various codes is mentioned in Table 1.

Table 1 Comparison of day lighting, Energy performance index and Window to Wall ratio standards as per various codes & bye-laws

| S.no. | Codes | Day lighting recommendations for bedroom | Recommended values for EPI | Recommended Range of WWR (%) | Applicability |
|---|---|---|---|---|---|
| 1 | National Building Code, 2016 | 30-50-100lux | - | - | All building types |
| 2 | SP41 | 100-150lux | - | - | All building types |
| 3 | GRIHA | 100 -2000 | 90 kWh/sq. m | 60% | Buildings having area >2500 sq.m. |
| 4 | Energy Conservation Building Code | 100 - 2000 lux | GRIHA benchmark | 40% | Buildings having connected load of 100kW or more or a contract demand of 120kVA or more used for commercial purpose. |
| 5 | The Haryana | - | - | **Area of open able windows** | |

| | | | | | |
|---|---|---|---|---|---|
| | Building Code,2017 | | | -Total area not less than1/8th of the total floor area of the room.<br>-Applicable on all buildings of Haryana. | |
| **6** | SVA GRIHA | as required by SP-41 | - | 60% | Buildings having area < 2500 sq.m. |
| **7** | Eco-Niwas Samhita | - | - | - | Residential Buildings having area >500 sq.m. |

(Source:(TERI, 2019)(The Haryana Building Code, 2017)(ECBC, 2007) (SVA GRIHA, 2007)(ENS, 2018)Compiled by author)

## 1. Methodology

Design Builder (DB) is a suitable tool having easy approach towards achieving results in terms of energy simulation and daylighting. (Heidari et al., 2021)A whole building simulation method is adopted by using Design Builder (Trial version 7.0). This is a suitable method that provides valid results based on the required outputs i.e., thermal analysis, lighting analysis, ventilation and environmental performance.(Heidari et al., 2021) For analyzing the optimal WWR, EPI, DF and illuminance are used as measuring parameter.

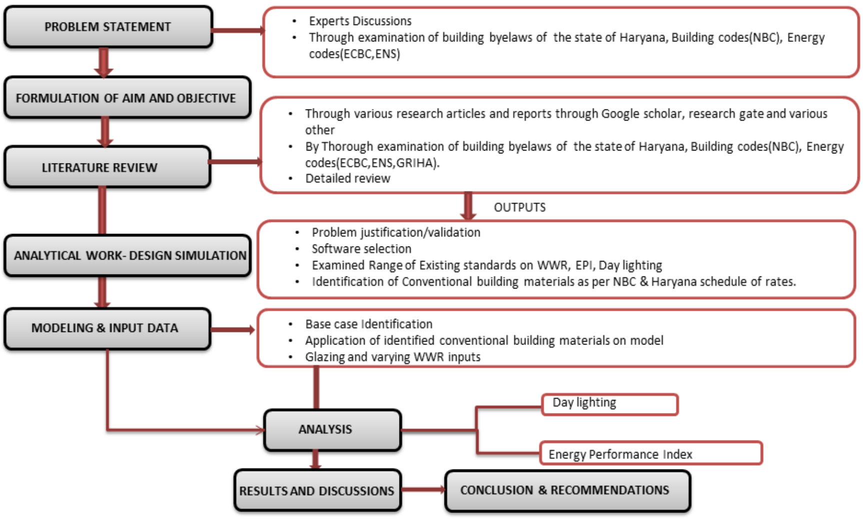


Fig.1Methodology adopted for the present investigation

### 2.1. Model information – input data

To keep the modeling and simulation very basic in nature the investigators have considered a bedroom of area 20 sq. The base case is considered in the climate of Hisar, Haryana. To test the problem the investigator has considered a base case in isolation to simulate. The materials of construction are conventional materials for roof as well as walls. 150mm flat roof casted in concrete and 230 mm thick brick wall is taken to test the WWR with respect to the impact of Orientation only (refer table 2). The base case has been analyzed on eight orientations namely North, South, East, West, North East, North West, South East & South West and 0-100 per cent WWR with a variation of 10 per cent each to find the variation in terms of EPI and illuminance levels. The plan of the base case showing a WWR – 10 per cent & 100 per cent with projection of 0.45 metre and the section showing inside and outside of the built area as well as relation of WWR with the standard projection is shown in Fig. 2. Simulations were conducted using the climatic data of the city of Hisar,Haryana, India

dia

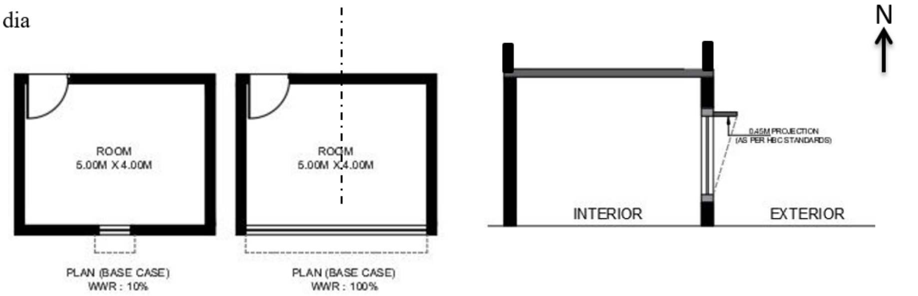


Fig.2 Plan & section of base case showing WWR 10per cent & 100per cent with 0.45 metre projection (source: author)

Assumptions: The base case is considered to be in isolation. Also, the shade over window is considered to be constant in size i.e., as suggested by codes and bye laws. The window is taken at the longer side of the room whereas the entry to the room is from the opposite wall of same length. Simulation results are obtained on this base case to analyse the impact of varying WWR on different orientations keeping a standard overhang depth.

Table 2Conventional building materials chosen for simulation

| Sr. No. | Element | Conventional building | U – value<br>Obtained from DB |
|---|---|---|---|
| 1 | WALL | 230mm Clay brick with internal and external plaster of 18 mm | 1.3W/m2-K |
| 2 | ROOF | 150 mm RCC slab with brick batt coba | 1.3W/m2-K |
| 3 | GLASS | 6mm Clear Float Glass | 5.6 W/m2-K |

(Source:(BIS, 2016) )

- Area of unit : 5m x 4m = 20sq.m.
- Typology : Residential

The screenshot of Graphical User Interface (GUI) of design builder software showing window size inputs and overhang information for a specific case of 40 per cent WWR and local shading type of size 0.45 metre overhang is presented in Fig.3.

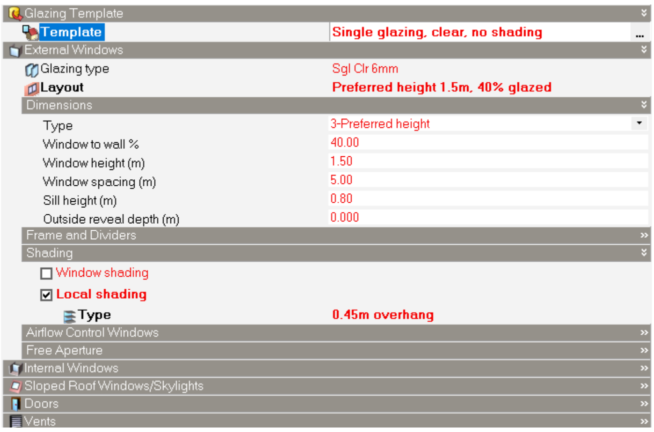


Fig.3 the screenshot of Graphical user interface of design builder window size and overhang information, Design builder (source: author)

## 2. Results and discussions

### 3.1. Impact of variation of WWR on EPI

The impact of variation in WWR with respect to constant overhang size is seen to have a substantial amount of increment in the EPI of the building. Various WWR considered for simulation are shown in Fig. 4 below. The results obtained are for a constant orientation i.e., South. On the simulation at a WWR of 10 per cent an EPI of

222.1 is observed, for a WWR of 20 per cent an EPI of 225.73 is observed, for 30 per cent WWR an EPI of 230.09 is observed, for 40 per cent WWR an EPI of 235.51 per cent is noted, for 50 per cent WWR an EPI of 242.41is observed, for 60 per cent WWR an EPI of 253.72 is observed, for 70 per cent WWR an EPI value of 267.66 is observed, for 80 per cent WWR an EPI value of 281.74 is observed, for 90 per cent WWR an EPI value of 297.21 is observed, and for a WWR of 100 per cent an EPI of 312.03 is observed. It was observed that there occurs a substantial increment in EPI as we increase the window to wall ratio. This was seen to be true for all orientation. The results are shown in Fig. 4.

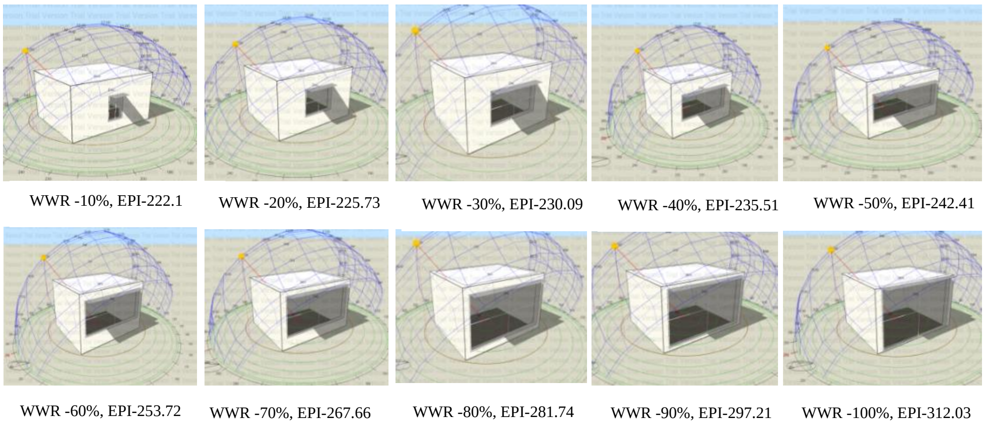


Fig. 4 Window to Wall Ratio variation for energy consumption calculations, Design Builder (source: author)

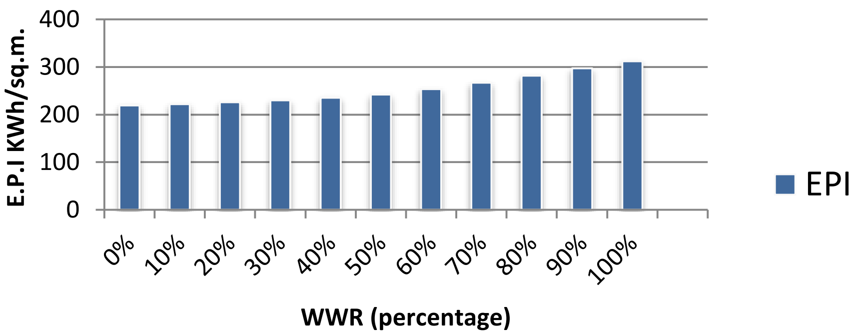


Fig.5 Graphical representation of Impact on Energy consumption by various WWR for south orientation (source: author)

### 3.2. Impact of variation of WWR on day lighting

The impact of variation in WWR with respect to constant overhang size is observed to have a substantial amount of increment in the daylight level inside the building. Various WWR considered for simulation are shown in Fig. 6 below. The results obtained are for a constant orientation i.e., South. On daylighting simulation at 0% WWR 0.00 lux illuminance is observed, at 10 % a minimum illuminance of 7 lux & maximum illuminance of 1202 lux is observed, at 20 % a minimum illuminance of 19 lux & maximum illuminance of 1509 lux is observed, at 30 % a minimum illuminance of 37 lux & maximum illuminance of 1550 lux is observed, at 40 % a minimum illuminance of 106 lux & maximum illuminance of 1560 lux is observed, at 50 % a minimum illuminance of 160 lux & maximum illuminance of 1632 lux is observed, at 60 % a minimum illuminance of 208 lux & maximum illuminance of 1880 lux is observed, at 70 % a minimum illuminance of 243 lux & maximum illuminance of 1965 lux is observed, at 80 % a minimum illuminance of 267 lux & maximum illuminance of 1980 lux is observed, at 90 % a minimum illuminance of 299 lux & maximum illuminance of 2050 lux is observed, and at 100 % a minimum illuminance of 328 lux & maximum illuminance of 2143 lux is observed.

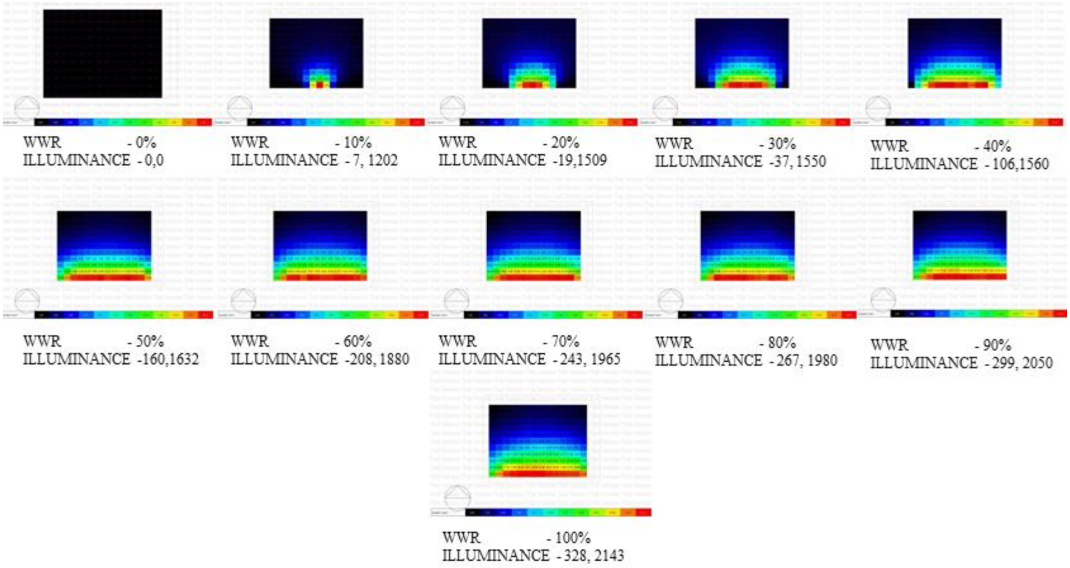


Fig. 6 Impact of variation in WWR on Daylight factor and illuminance (source: author)

From the results, it is clear that as the WWR increases, the glare as well as the energy consumption & cooling demand surges, this phenomenon occurred in all orientations. This suggests that as the window becomes larger in size, the overall heat gain increases, which in turn increases the cooling energy consumption demand. Simulation results confirmed that higher the WWR, the greater is energy consumption and illuminance and thus amount of glare inside the building. This was observed to be true for all orientations. Thus, to maintain benchmark energy consumption and glare free indoors, it is necessary to use optimum window size specific to the orientations.

### 3.3. Analyzing the impact of variation of orientation on Day lighting

To prove that sun's position is different at all times and is determined by lower angles at the time of sunrise and sunsets and this orientation experience daylight ingress more rigorously, causing glare which cannot be cut simply by providing an overhang as sun cutter. An overhang of standard size 0.45 is considered for analysis. Energy consumption for 8 orientations with 11 changing WWR has been calculated with the help of design builder software at 45 degrees each. Fig.7 below shows that Daylight Factor vary or substantially increase with change in orintation even if the window and shading size are kept constant. In terms of daylight factor the results at East orientation are observed to have a DF of 14.30, while at South East a DF of 12.20 is observed, at North a DF of 14.29 is observed, at North East a DF of 12.04 is observed, at North West a DF of 11.93 is observed, at south a DF of 12.02 is observed, at South-West a DF of 12.06 is observed, and at West orientated window a DF of 14.23 is observed.

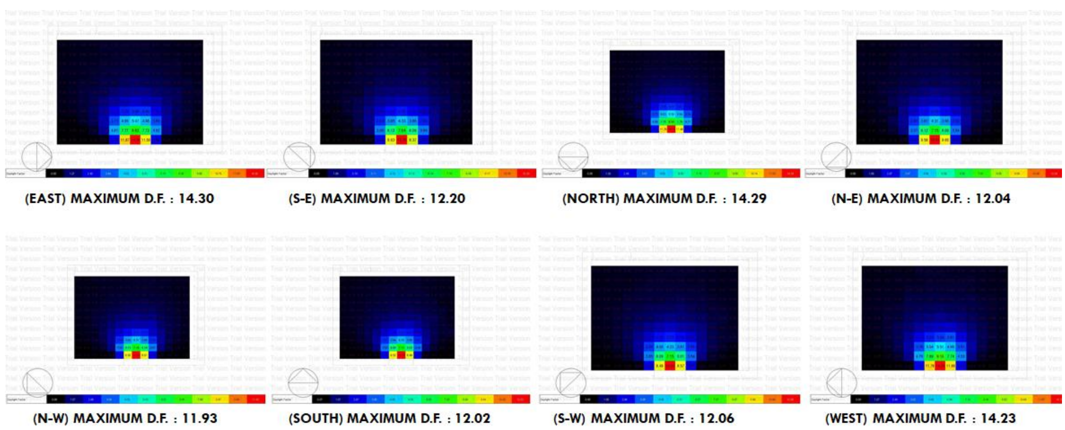


Fig.7 variation in Daylight Factor with orientation (source: author)

### 3.4. Analyzing the impact of variation of orientation on EPI

The variation in energy performance index for each orientation is the gradual increment i.e. 219.36 to 312.03 at Southern orientation, 219.17 to 271.67 on North orientation, 224.71 to 327.72 on East and 222.97 to 342.66 on West orientation. Similarly, on North West façade the values increase as 225.16 to 294.8, whereas on North East a declination in the values can be seen from 226.2 to 286. The same window on South East orientation experiences the increment in EPI value as 226.6 to 315 and on South West it is 225.1 to 327 the last one being the highest after the West orientation. The results are mentioned in table 3.

Table 3 Results of EPI and day lighting values wrt Change in WWR and Orientation (source:author)

| Sr. no. | ORIENTATION | WWR | EPI VALUE | MAX. D.F. | MIN. D.F. | MAX. ILLUMINANCE | MIN. ILLUMINANCE |
|---|---|---|---|---|---|---|---|
| 1 | SOUTH | 0% | 219.36 | 0 | 0 | 0 | 0 |
| | | 10% | 222.11 | 12.02 | 0.07 | 1202 | 7 |
| | | 20% | 225.73 | 15.09 | 0.19 | 1509 | 19 |
| | | 30% | 230.09 | 15.5 | 0.37 | 1550 | 37 |
| | | 40% | 235.51 | 15.59 | 1.06 | 1560 | 106 |
| | | 50% | 242.4 | 16.32 | 1.6 | 1632 | 160 |
| | | 60% | 253.72 | 18.8 | 2.08 | 1880 | 208 |
| | | 70% | 267.06 | 19.63 | 2.43 | 1965 | 243 |
| | | 80% | 281.74 | 19.8 | 2.67 | 1980 | 267 |
| | | 90% | 297.27 | 20.5 | 2.99 | 2050 | 299 |
| | | 100% | 312.03 | 21.42 | 3.28 | 2143 | 328 |
| 2 | NORTH | 0% | 219.17 | 0 | 0 | 0 | 0 |
| | | 10% | 223.95 | 14.29 | 0.08 | 1429 | 7 |
| | | 20% | 229.2 | 18.86 | 0.22 | 1886 | 22 |
| | | 30% | 234 | 21.26 | 0.47 | 2126 | 47 |
| | | 40% | 239.77 | 21.36 | 1.57 | 2136 | 157 |
| | | 50% | 245.24 | 22.34 | 1.88 | 2234 | 185 |
| | | 60% | 250.65 | 22.63 | 2.54 | 2263 | 252 |
| | | 70% | 256 | 22.93 | 2.92 | 2293 | 290 |
| | | 80% | 262.29 | 23.03 | 3.06 | 2305 | 306 |
| | | 90% | 266.78 | 24.45 | 3.33 | 2445 | 333 |
| | | 100% | 271.67 | 24.84 | 3.65 | 2484 | 365 |
| 3 | EAST | 0% | 224.71 | 0 | 0 | 0 | 0 |
| | | 10% | 232.87 | 14.3 | 0.08 | 1431 | 8 |
| | | 20% | 242.5 | 19.05 | 0.21 | 1907 | 20 |
| | | 30% | 252.57 | 21.33 | 0.43 | 2133 | 43 |
| | | 40% | 262.6 | 20.71 | 1.47 | 2071 | 146 |
| | | 50% | 273.3 | 21.49 | 1.92 | 2151 | 197 |
| | | 60% | 284.1 | 22.67 | 2.54 | 2268 | 253 |
| | | 70% | 295.53 | 23.99 | 2.88 | 2400 | 283 |
| | | 80% | 304.02 | 24.63 | 3.43 | 2464 | 342 |
| | | 90% | 317.31 | 24.06 | 3.06 | 2408 | 306 |
| | | 100% | 327.72 | 24.73 | 3.75 | 2476 | 375 |
| 4 | WEST | 0% | 222.97 | 0 | 0 | 0 | 0 |
| | | 10% | 232.07 | 14.23 | 0.09 | 1421 | 8 |
| | | 20% | 242.87 | 18.91 | 0.23 | 1886 | 22 |
| | | 30% | 254.28 | 20.02 | 0.5 | 2098 | 50 |
| | | 40% | 266.09 | 21.26 | 1.53 | 2121 | 153 |
| | | 50% | 278.31 | 22.69 | 1.87 | 2264 | 187 |
| | | 60% | 291.07 | 22.75 | 2.58 | 2269 | 256 |
| | | 70% | 303.39 | 24.17 | 3.23 | 2415 | 320 |
| | | 80% | 316.71 | 22.96 | 2.46 | 2295 | 244 |
| | | 90% | 330 | 24.41 | 3.1 | 2441 | 310 |
| | | 100% | 342.66 | 25.28 | 3.66 | 2521 | 364 |
| 5 | NORTH WEST | 0% | 225.16 | 0 | 0 | 0 | 0 |
| | | 10% | 230.78 | 11.93 | 0.08 | 1195 | 7 |
| | | 20% | 236.77 | 16.05 | 0.22 | 1606 | 21 |
| | | 30% | 242.87 | 16.26 | 0.43 | 1626 | 42 |
| | | 40% | 249 | 16.63 | 1.22 | 1663 | 122 |
| | | 50% | 255.5 | 16.63 | 1.69 | 1625 | 169 |
| | | 60% | 263.63 | 19.03 | 2.28 | 1905 | 228 |
| | | 70% | 271.86 | 20.3 | 2.6 | 2033 | 260 |
| | | 80% | 278.42 | 21.52 | 3.1 | 2153 | 311 |
| | | 90% | 288.46 | 20.14 | 2.83 | 2015 | 283 |
| | | 100% | 294.8 | 21.48 | 3.25 | 2150 | 335 |
| 6 | NORTH EAST | 0% | 226.28 | 0 | 0 | 0 | 0 |
| | | 10% | 230.97 | 12.04 | 0.08 | 1205 | 7 |
| | | 20% | 236.07 | 15.26 | 0.2 | 1527 | 20 |
| | | 30% | 241.6 | 16.27 | 0.4 | 1628 | 40 |
| | | 40% | 248.68 | 16.12 | 1.14 | 1614 | 114 |
| | | 50% | 251.58 | 16.49 | 1.71 | 1651 | 171 |
| | | 60% | 258.96 | 18.69 | 2.23 | 1871 | 223 |
| | | 70% | 266.14 | 20.14 | 2.48 | 2015 | 248 |
| | | 80% | 273.37 | 18.48 | 2.2 | 1849 | 220 |
| | | 90% | 280.66 | 20.22 | 2.89 | 2023 | 259 |
| | | 100% | 286 | 21.51 | 3.28 | 2161 | 328 |
| 7 | SOUTH EAST | 0% | 226.64 | 0 | 0 | 0 | 0 |
| | | 10% | 231.67 | 12.2 | 0.08 | 1220 | 8 |
| | | 20% | 235.85 | 15.47 | 0.2 | 1548 | 20 |
| | | 30% | 241.56 | 16.28 | 0.42 | 1625 | 42 |
| | | 40% | 247.47 | 16.84 | 1.15 | 1586 | 115 |
| | | 50% | 254.82 | 16.38 | 1.68 | 1639 | 168 |
| | | 60% | 266.4 | 19.14 | 2.2 | 1916 | 219 |
| | | 70% | 278.43 | 19.87 | 2.92 | 1970 | 292 |
| | | 80% | 291.97 | 18.32 | 2.24 | 1834 | 224 |
| | | 90% | 304 | 20.47 | 2.83 | 2048 | 282 |
| | | 100% | 315 | 21.52 | 3.35 | 2155 | 335 |
| 8 | SOUTH WEST | 0% | 225.1 | 0 | 0 | 0 | 0 |
| | | 10% | 230.26 | 12.06 | 0.08 | 1206 | 8 |
| | | 20% | 236.48 | 15.16 | 0.22 | 1518 | 21 |
| | | 30% | 243.38 | 15.62 | 0.43 | 1563 | 43 |
| | | 40% | 250.25 | 16.3 | 1.24 | 1631 | 124 |
| | | 50% | 258.45 | 17.03 | 1.68 | 1704 | 163 |
| | | 60% | 270.9 | 19.29 | 2.26 | 1930 | 226 |
| | | 70% | 284 | 19.87 | 2.84 | 1990 | 284 |
| | | 80% | 299.32 | 18.28 | 2.22 | 1830 | 222 |
| | | 90% | 315.6 | 20.36 | 2.78 | 2036 | 278 |
| | | 100% | 327.19 | 21.37 | 3.38 | 2137 | 337 |

From the results of 3.3 and 3.4, it can be seen that maximum illuminance/DF is seen at the Western and eastern façade. This analysis also resulted that orientation alone has a noticeable impact on the day light ingress of a building with a similar set of window and overhang size. It is also noted that the gradual increment in EPI of the building through envelope while keeping overhang size constant and varying WWR, the façade where maximum EPI is achieved is west of south west direction where the sun angle remains low near the ground and thus larger window lets more heat gain inside the building.

The optimal range obtained for WWR on each orientation in respect to illuminance, daylight factor and EPI is mentioned in table 4. The optimal range of WWR for North on the basis of illuminance is 40-80% however on the basis of DF it is 30-40%, for South on the basis of illuminance and DF both it is 30-40%, for East on the basis of illuminance and DF both it is 30-40%, For West on the basis of illuminance and DF it is 30-40%, for North West on the basis of illuminance is 40-60% however on the basis of DF it is 30-40%,for North East on the basis of illuminance is 40-60% however on the basis of DF it is 30-40%,for South East on the basis of illuminance is 40-80% however on the basis of DF it is 30-40%, and the optimal range of WWR for South West on the basis of illuminance is 40-80% however on the basis of DF it is 30-40%. It can be seen that WWR within the range of 30-80% is recommended for composite climate on the basis of illuminance and a range of 30-40% is recommended on the basis of Daylight Factor. All the EPI observed are greater than the prescribed standard of EPI as per GRIHA, this can be attributed to the details of building materials and consideration of isolation which makes the building exposed to sun from all directions and thus the overall heat gain inside the building increases.

Table 4 Optimum range of WWR as Resulted

| Sr. No. | Orientations | Optimal WWR ranges on the basis of Illuminance | Optimal WWR ranges on the basis of Minimum Daylight Factor |
|---|---|---|---|
| 1 | North | 40-80% | 30-40% |
| 2 | South | 30-40% | 30-40% |
| 3 | East | 30-40% | 30-40% |
| 4 | West | 30-40% | 30-40% |
| 5 | North West | 40-60% | 30-40% |
| 6 | North East | 40-60% | 30-40% |
| 7 | South East | 40-80% | 30-40% |
| 8 | South West | 40-80% | 30-40% |

Source: Author

Note: The optimal range of WWR is provided by considering ECBC, GRIHA & SP41 standards of day lighting.

## 4. Conclusion

There was no specific mention of variation in WWR with respect to orientation and the codes have rigidity of WWR. The rigidity in WWR required addressing in respect to variation in orientation. The investigators analyzed the impact of variation of orientation on WWR by considering Daylight factor, illuminance and EPI as criteria on a 20 sq.m bedroom in isolation with conventional building materials in composite climate. The simulation was done in Design Builder trial version 7.0 freely available for this. The results provided the optimal Range of WWR for eight orientations namely North, South, East, West, North East, North West, South East & South West, and it is recommended that with variation in orientation the optimal range of WWR must be considered in Composite Climate in India. The results from this paper can also be incorporated into Indian building codes to provide architects with a much more precise orientation specific WWR guideline to achieve energy efficiency in Residential sector.

**Funding**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Bibliography**


1. Ander, G. D. (2016). *whole building design guide*. https://www.wbdg.org/resources/daylighting
2. Bhagwat, A. S. A., & Environment, M. A. (n.d.). *Effect of window to wall ratio , orientation on daylight & thermal comfort of hospital patient room in warm & humid climate* . 1–10.
3. BIS. (2016). National Building Code of India, 2016 Volume 1. In *National Building Code of India* (Vol. 80).
4. Didwania, S., Garg, V., & Mathur, J. (2011). Optimization of Window-Wall Ratio for Different Building Types. *Research Gate*, *January*. http://www.researchgate.net/publication/259921312_optimization_of_window-wall_ratio_for_different_building_types.
5. Edwards, L., & Torcellini, P. (2002). A Literature Review of the Effects of Natural Light on Building Occupants A Literature Review of the Effects of Natural Light on Building Occupants. *Contract*, *July*, 55.
6. ENS. (2018). Energy Conservation Building Code for Residential Buildings. In *Ministry of Power, Government of India* (Vol. 1). https://www.beeindia.gov.in/sites/default/files/ECBC_BOOK_Web.pdf.
7. Freewan, A. A. Y. (2014). *Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions*. 1–8..
8. Heidari, A., Taghipour, M., & Yarmahmoodi, Z. (2021a). The Effect of Fixed External Shading Devices on Daylighting and Thermal Comfort in Residential Building. *Journal of Daylighting, Vol. 8, Issue 2, Pp.165-180*, *8*(2), 165–180. https://doi.org/10.15627/JD.2021.15.
9. Heidari, A., Taghipour, M., & Yarmahmoodi, Z. (2021b). The Effect of Fixed External Shading Devices on Daylighting and Thermal Comfort in Residential Building. *Journal of Daylighting, Vol. 8, Issue 2, Pp.165-180*, *8*(2), 165–180. https://doi.org/10.15627/JD.2021.15.
10. Kumar. (2007). Design guide. *Fire Prevention and Fire Engineers Journals*, *MAR*. https://doi.org/10.1680/dofrcs.64447.205
11. Kumar, S., Rawal, R., Bajpai, A., & Rao, G. S. (2009). Energy Conservation Building Code User Guide. In *Bureau of Energy Efficiency*.
12. NBS. (1977). *NBS BUILDING SCIENCE SERIES 104 Window Design to Conserve Energy*.
13. SVA GRIHA. (2007). *SVA GRIHA*.
14. TERI. (2019). *GRIHA Version 2019*.
15. The Haryana Building Code. (2017). The Haryana Building Code 2017. *Journal of Chemical Information and Modeling*, *53*(9), 287.
16. Wong Nyuk Hien, A. D. I. (2003). *Effects of external shading devices on daylighting and natural ventilation*.