Window to floor ratio in the design stage in considering to visual-thermal comfort and safety in building

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Abstract. The building envelope with the openings play an important role in the process energy performance and ensure the well-being in a working space because of the impact of the openings to the visual and thermal comfort of the occupants. When designing buildings and structures, the standards for permissible safety should be taken into account, which are expressed by the value of critical duration of fire and the explosive load. The aim of the study is to propose the integrated approach in determining the rational Window to Floor Ratio to provide the target Daylight Factor, energy efficiency for the tropical climate, in consider to fire and the explosive load using the graphic of the relationship of the Window to Floor Ratio to the target minimum Daylight Factor. The result was shown for tropical of Vietnam, the Window to Floor Ratio was recommended of 15.2% to 18.5% corresponds to recommended target Daylight Factor of 1.35%.

1. Introduction

The Window/opening as element of the enclosing structure to ensure the target DF in the consideration with thermal comfort and safety in building. The indoor and outdoor environment are connected by the opening, design rational WFR provide the visual comfort and well-being for occupants. The research of energy consumption in Vietnam shows, the energy used for air conditioning (cooling) and lighting is the highest proportion, respectively 34% and 18% for Hanoi [1]. These two criteria are influenced by the area of the glazing. Window to Floor Ratio – the rule of thumb: Design parameters of the opening by WFR often cited as the rule of thumb [2-4]. A propose of WFR for North window façade in Malaysia was estimated between 15 to 20% [5]. In European countries with a cooler climate, a window to floor ratio of 20 ÷ 25% is recommended depending on the type of building. Hopkinson argued that this ratio could provide daylight factor value of 2% at a depth of 6 m from the wall with windows [6, 5]. Perez and Capeluto (2009) [7] declare that the ratio of the window to the floor is 10 ÷ 12% for the western and eastern orientation. It is minimal for adequate natural light. In standard SS 91 42 01 [8] (Building-Daylight-Simplified method for checking the required window glass area) in Sweden simple 10% of window area to floor area is applied.

In fact, the WFR to provide good visual for a daylit space depend on the characteristic parameters of this aspect and the parameters, position of the opening. The research using the typical parameter of the aspect and the opening to define the recommendation of WFR, which afford for the target Daylight Factor (DFT). Consider the single side daylight aspect for the 3 m ÷ 3.2 m of high, dH of 6 m ÷ 9 m of depth, the standard window sill height of 0.8 m, a window head height 2.3 m ÷ 2.6 m, window high h₀ of 1.5 m ÷ 1.8 m, these parameters correspond to the common ratio d₀/h₀ of 4 ÷ 5. High WFR allows more daylight in spaces and against the effects of an internal emergency explosion by decrease pressure in volume, but it causes an increased risk of structural damage during in relate of critical
duration of fire $\tau_{cr}$ by hours to the WFR, increases the heating of the room from solar radiation and visual discomfort. Accordingly, Task of the research involves the minimum of WFR to ensure the target DF and requirement of the safe level of explosive loads.

2. Methodology
2.1. The recommended target Daylight Factor for the tropical of Vietnam
The target Daylight Factor is determined when considering the following issues:
- The connectivity with the daylight climate based on cumulative diffuse horizontal illumination.
- The target illuminance value.
- The relative area of daylit space requirement.
- The relative time of usage daylight requirement in space, depends on the fixed a period of time.

Accordingly, the distribution of a daylit space is indicated by the median target Daylight Factor (DFT), which ensures that at least 50% of relative area has reached the target illuminance of 300 lux and all of the relevant floor area has reached the target minimum illuminance of 100 lux at workplane height across for half of the daylight hours per year [9-11]. This mean the ratio of $DFT_{TM}/DFT$ at least should be 1/3. The relevant floor area is the entire regularly occupied floor space inside the perimeter zone of 0.5 ÷ 1 m. Based on the climate hourly typical data ASHRAE IWEC2 file of Hanoi (21.03°N) [12, 13] the cumulative diffuse illuminance curve was obtained in figure 1 if consider difference fixed time period for all daylight hours from 6h to 19h (a) and for the working hour from 8h to 17h (b).

![Figure 1](image)

**Figure 1.** Cumulative diffuse illuminance curve of daylight hours from 6h to 19h (a) and working hours from 8h to 17h (b).

The relative time of usage daylight requirement in space at least 50%, the DFT values were considered at the various of percentages of daylight usage time and computed as shown in the Table 1.

**Table 1.** Recommendation of $DFT$ and $DFT_{TM}$ for period of working hours and daylight hours.

| Working hours | All daylight hour |
|---------------|------------------|
| 50% $E_{cr} = 33300$ lux | 50% $E_{cr} = 7100$ lux |
| $DFT$ | $DFT_{TM}$ |
| 0.9 | 0.3 |

2.2. Window to Floor Ratio in relation to the minimum target Daylight Factor
The more simple but approximate method for determining the size of the openings is the geometric method, in which the area of the openings is set in fractions (or %) of the floor area. This method as properly applied at the stage of study/sketch of the project to select the area of glazing. For side
daylight system, according to SP 23-102-2003 and SP 52-13330-2016, the window area (by WFR
criteria) can be determined by the formula (1) in terms of the minimum Daylight Factor [14]:

\[
100 \frac{S_{\text{win}}}{S_{\text{floor}}} = \frac{\text{DF}_\text{min} \eta_0}{\tau_0 \tau_0} K_{zd} K_z
\]

where: \( S_{\text{win}}, S_{\text{floor}} \) - window and floor areas (m\(^2\)); \( \text{DF}_\text{min} \) - minimum Daylight Factor of the side lighting system, %, which it assigns at a point lying on the working plane at a distance of 1 m from the farthest wall; \( \tau_0 \) - total light transmission coefficient of openings; \( \eta_0 \) - coefficient taking into account the influence of reflected light at the calculated point; \( K_{zd} \) - coefficient taking into account the shading of windows by obstructed; \( K_z \) - reserve coefficient, taking into account the pollution of the glass; \( \eta_0 \) - daylight characteristic windows, showing the WFR to provide the minimum Daylight Factor of 1% at an unfavorable point on the working plane, which in 1 m form the most distant wall [15].

**Figure 2.** Graph of WFR definition with different ratios \( d_n/h_0 \).

For the most common geometrical and parameters of the side daylight system and rooms in the “Code of Practice 367.1325800.2017” [16], a graph was drawn to determine the relative area of the openings, somewhat simplifying the calculation by the formula (1). The graphics in Figure 2 can be used for preliminary determination the area of windows in buildings. The graph based on the ratio of WFR and \( d_n/h_0 \) for office buildings was developed in relation to the most common in the design practice dimensional schemes of the rooms and typical solution of translucent structures – “wooden paired opening covers”. If the design adopted other types of filling openings, the values of WFR found in Figure 2 should be divided and the DFM should be multiplied by the factor \( k_1 \) given in Table 2 (SP 367.1325800.2017) [6].

**Table 2.** The values of coefficient \( k_1 \) (SP 367.1325800.2017)

| Types of filling openings                                      | Coefficient \( k_1 \) |
|---------------------------------------------------------------|-----------------------|
| Single layer of window glass in steel single blind covers     | 1.26                  |
| Single layer of window glass, in the opening bindings         | 1.05                  |
| Single layer of window glass in wooden single opening binders| 1.05                  |

3. Results

3.1. Window to Floor Ratio with the target Daylight Factor

Using the graph in Figure 2, the WRF was determined from the minimum target Daylight Factor \( \text{DF}_\text{TM} \) shown in Table 1.

**Table 3.** The recommended WFR depend on \( \text{DF}_T \) and \( \text{DF}_\text{TM} \)

| Working hours | All daylight hours |
|---------------|--------------------|
| 50\%, \( E_c=33300 \) lux | 50\%, \( E_c=22200 \) lux | 100\%, \( E_c=14200 \) lux | 50\%, \( E_c=25500 \) lux | 50\%, \( E_c=7100 \) lux |
| \( \text{DF}_T \) | \( \text{DF}_\text{TM} \) | WFR | \( \text{DF}_T \) | \( \text{DF}_\text{TM} \) | WFR | \( \text{DF}_T \) | \( \text{DF}_\text{TM} \) | WFR | \( \text{DF}_T \) | \( \text{DF}_\text{TM} \) | WFR |
| \( d_n/h_0 = 4 \) |                      |     |             |                |             | |}| | | | | | |
In the general, the “single layer of window glass in steel single blind covers» is often used, then $k = 1.26$ should be selected for the calculations. In the consideration of typical parameters $d_n/h_0 = 4 \div 5$, the results of recommendation for Window to Floor Ratio depend on the target Daylight Factor and the target minimum Daylight Factor were shown in Table 3.

### 3.2. Window to Floor Ratio for low energy consumption (small opening sizes)

| WFR (%) | Heat gain through window, W |
|---------|----------------------------|
| 10      | 1000                       |
| 20      | 2000                       |
| 30      | 3000                       |
| 40      | 4000                       |
| 50      | 5000                       |
| 60      | 6000                       |
| 70      | 7000                       |
| 80      | 8000                       |
| 90      | 9000                       |

Figure 3. The influence of WFR on the heat gain.

To assess the heat transfer to the room by the heat gain through window on the influence of window sizing, a simulation with the program Heat load DACCS HkGS was conducted. The computational model is a laboratory on the 7th floor at the University of Civil Engineering in Hanoi, parameters of the room 8 x 4.2 x 4 m, the eastern window, the window to wall ratio (WWR) varies from 10.5 ÷ 90%, corresponding to the window to floor ratio (WFR) in Figure 3. The results indicate that the heat gain through window and the values of WFR are directly proportional, i.e. the greater value WFR, the greater will be heat gain through window and the more energy consumption will be.

### 3.3. Window to Floor Ratio, the criteria for safety in construction

Particularly acute is the issue of fire and explosion safety in high-rise office buildings due to serious consequences for people and property. In design enclosure construction with the openings, the size of the openings has an impact on the thermal hazard criteria through the determination of the critical duration of fires $t_{cr}$ and on the explosive loads during internal emergency explosions [17-19].

Figure 4. Gas explosion in Volgograd (Russia).

In Russia, the system of standards and regulations in construction and fire, explosion Safety include SNIP 21-01-97 «Fire safety of buildings and structures» for metal construction [20], GOST R
12.3.047–2012 “Occupational safety standards system. Fire department safety of technological processes. General requirements. Control methods” [21]. Documents work together is SNIP 2.03.01-84 “Concrete and reinforced concrete structures” [22]. The problems of the possible consequences of a fire-explosion indoors in Russia are dealt in documents [23-27]. The stability of buildings in the event of the occurrence and development of fires is ensured while maintaining the structures of the external walls, internal partitions and the flooring of load-bearing properties determined by fire resistance with the values of Critical duration of fire \( \tau_{cr}^1 \). Reducing the risk of structural failure during fires may increase the fire resistance of reinforced concrete structures (on the basis of loss of carrying capacity), that means the smaller the opening area, the higher the fire resistance of structures [18, 28].

Experiments of the study [29] show that with a fixed height of the openings, the values of Critical duration of fire \( \tau_{cr}^1 \) depend on the ratio \( \frac{S_{win}}{S_{floor}} \), which is described in the expression:

\[
\tau_{cr}^1 = \ln\left(\frac{S_{win}}{S_{floor}}.100\right)
\]  

(2)

With different height of the openings \( H \) varies from 0.1 ÷ 5 m, the critical duration of fires \( \tau_{cr}^1 \) described by formulas (3), (4) and (5):

\[
\tau_{cr}^1 = f(H, \frac{S_{win}}{S_{floor}}, \frac{A}{B})
\]  

(3)

\[
A = \pi \frac{V_1^2}{3} \psi_{ad}, \quad B = \frac{c_r \rho_0 T_0 V}{\eta (1-j) Q_0}
\]  

(4)

where: \( A \) – the value depends on the properties of the combustible material; \( B \) – the filling time of the combustion products (smoke, radiation, heat etc.) depends on the shape of the room (s); \( H \) – the openings high (m); \( S_{win} \) – the opening area (m²); \( S_{floor} \) – the floor area (m²); \( V \) – the room volume (m³); \( \rho_0 \) – average gas density at the beginning of a fire (kg.m⁻³); \( V_1 \) – flame velocity linear (m.s⁻¹); \( \psi_{ad} \) – mass burnout rate (kg.s⁻¹.m⁻³); \( C_r \) – gas heat capacity at constant pressure, respectively (J.kg⁻¹.K⁻¹); \( T_0 \) – Room temperature at the initial time (K); \( \eta \) – burning ratio.

The research demonstrated that the \( \tau_{cr}^1 \) proportional dependence to the ratio \( \frac{S_{win}}{S_{floor}} \), which varies from 0.4% to 65%, in other words WFR must not exceed 65% and not depend on which level the openings are located. Internal deflagration explosions are explosions of gas-air mixtures occurring in closed and semi-closed volumes. Excessive pressure in an internal deflagration explosion in a closed volume reaches 700÷ 900 kPa. During explosions inside buildings and structures, the excess pressure should not exceed 10 ÷ 15 kPa, which is limited by the strength of building structures [18, 28]. Therefore, in buildings and premises as a result of the destruction of the enclosure construction or the operation of safety structures, the closed volume becomes open. To limit the growth of overpressure in rooms during internal deflagration explosions, glazed window openings or easily reset structures are used. The design of buildings with explosive technologies is carried out in accordance with the recommendations SNIP 31-03-2001 «Industrial buildings» [30], where it is required for each 1000 m³ of free volume of the room to have at least 50 m² of released openings. Another words, the minimum values of the WFR lies within 15 ÷ 25% with a building height of 3 ÷ 5 m. It is assumed that the explosive load will not exceed 5 kPa, i.e. guaranteed the safe level [18].

4. Discussion

4.1. The proposed Window to Floor Ratio in design building for tropical of Vietnam

From the results of Table 4, it is seen that:

- In aspect, with a certain value of the target Daylight Factor, the Window to Floor Ratio is proportional with the ratio \( d_0/h_0 \) and target illuminance values.
Reducing the openings for energy savings and increasing the fire resistance of structures along with consideration to ensure the target daylight factor and a safe level with limited explosive load will give acceptable WFR.

The research results show that the rational WFR match all criteria at 80% of the working time. I.e. the minimal WFR for explosion safety should not lower than 15%. Specifically, with the target illuminance 300 lux, it corresponds to $DF_T$ equals 1.35% and $E_{cr}$ equals 22200 lux.

4.2. Modelling daylight in a testing space

To demonstrate compliance with the proposal, a model testing was provided with a minimum WFR value of 15% for an aspect with $d_n/h_0 = 4$, the input parameters of which are described in Table 4.

| Model (height x width x depth) (m) | 3 x 9 x 6 |
|------------------------------------|-----------|
| Reflection coefficients (Floor–Walls–Ceiling) | 0.2:0.5:0.7 |
| Level of the work surface from floor (m) | 0.8 |
| parameters of window (height x width) | 1.5 x 5.4 |
| Working hours (hours) | 8h00 ÷ 17h00 |

In that regard, the simulation results must meet the criteria for a daylit space: a target illuminance of 300 lux is achieved across at least 50% of the relevant floor area for at least 80% of the working hours (or more than 50% of all daylight hours).

![Simulation Results](image)

The values $sDA_{300,80\%}$ for different orientations were determined by program Design Builder V5.2. Radiance illuminance simulation. The simulation using the values indicate changes of daylight in time and space are described in the Approved Method [31];

- IES Spatial Daylight Autonomy ($sDA$): describes how much light is available during standard operating hours. In particular, it describes the percentage of floor area that receives at least 300 lux.

**Table 4. The influence of window sizing on the heat gain.**

| Model (height x width x depth) (m) | 3 x 9 x 6 |
|------------------------------------|-----------|
| Reflection coefficients (Floor–Walls–Ceiling) | 0.2:0.5:0.7 |
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![Simulation Results](image)

**Figure 5. The simulation results**

The values $sDA_{300,80\%}$ for different orientations were determined by program Design Builder V5.2. Radiance illuminance simulation. The simulation using the values indicate changes of daylight in time and space are described in the Approved Method [31];
(for offices) within 80% of working hours per year in this case study. The sDA value between 55% and 74% indicates the space in which natural lighting is “nominally taken”.

- **Annual Sunlight Exposure (ASE):** One metric of the probability of visual discomfort is the number of hours that direct sunlight can potentially enter a space, which is called ASE. In particular, ASE measures the percentage of floor space that receives at least 1000 lux for at least 250 busy hours per year. In the supporting research, ASE of daylit spaces were predicted to have no more than 10%, in other words, the accepted ASE should be at least 90%.

- **Useful Daylight Illuminance (UDI):** For UDI we specify the metric pass threshold value of 50% means that a given cell must achieve an illuminance of between 100 and 3000 lux for at least 50% of the occupied hours in the year.

The simulated results were shown in Figure 5. The highest value of the sDA is 71.43% for the southern orientation and decreases to 65.48% for the northern orientation. These sDA values are within the “nominally accepted” of 55÷74% and correspond to the recommendation sDA performance criteria in document [30]. The UDI achieves an illuminance of between 100 and 3000 lux for 93% to 97%. But the accepted values ASE$_{1000,250}$% for the western orientation was 8.04% and increased to 56.85% for the northern orientation, which did not meet the criteria. Thus, with these spaces, in order to enhance the natural lighting condition, it is necessary to consider technical solutions for enhancing the sDA and the ASE in range by using Sunscreens and/or light shelves [32-34].

### 5. Conclusions and future work

This paper concludes by proposing method define the relation of WFR to the target DF. An integrated approach to determining WFR was taking into account in consideration of safety requirements. For Vietnam, the recommended WFR from 15.2% to 18.4% for the DF$_T$ 1.35. The research gives opportunity to design building envelope in accordance with the adaptation to the climate of the region, makes the recommendations for the regulation of Daylight Factors and WFR in the early stage of design enclosure construction with openings. On this basis, rational daylight usage was ensured by the working time and the function of a space.

However, the focus of this study limits to the quantity and quality of daylighting performance in impact of the WFR of unprotected daylight systems. A dynamic daylighting assessment shows that using direct sunlight from the sky through the openings causes of visual discomfort, which demonstrated by barely meet accepted criteria ASE$_{1000,250}$. Therefore, the technical solutions to increase the visual comfort by having good daylight distribution as by using the sunscreen, light shelf and/or shading devices should be more specific in further researches.

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