WINDOW SIZES REQUIRED FOR THE ENERGY EFFICIENCY OF A BUILDING AGAINST WINDOW SIZES REQUIRED FOR VIEW

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ABSTRACT

If not carefully considered, windows may often contribute to a high energy consumption in a building. Large window areas may provide good daylight provision and a good view, but they also allow for correspondingly large heat gains or losses that will affect the energy consumption of the building. This paper presents an analysis of the maximum window area on the façade of a building that will lead to an energy efficient design compared with window areas recommended for view. The energy analysis was undertaken using dynamic thermal modelling and the maximum window sizes obtained from this analysis were compared with the minimum window areas recommended for view in the British Standard BS 8206-2 (1992). Window areas were determined for rooms of different room ratios and dimensions in buildings located in eight different cities. The analysis indicated that window areas recommended for view tended to be larger than those recommended for energy efficiency. This implies that by specifying a minimum window area for view rather than a window area to optimise the energy efficiency of the building, might incur a higher energy consumption.

1. INTRODUCTION

An assessment of the window area on the façade of a building is essential at design stage in order to optimise the energy efficiency, particularly when there is to be integration of the daylight with artificial light. Bell and Burt (1995) present a review of daylight in building design and give guidance on the design of windows and roof-lights. They report that there is a threshold size below which windows do not provide a sufficient view, depending on how far one is from the window. These critical minimum window sizes are given in Table 1 and are for when windows are restricted to one wall. The same minimum window areas are also recommended in the *Code of practice for daylighting* (BS 8206-2 1992).

TABLE 1. Minimum glazed areas for view

Maximum depth of room (distance from window wall)	Minimum area of window in the wall (as seen from inside - %)
< 8m	20
8-11m	25
11-14m	30
>14m	35

In comparison with the above values, CIBSE (1998) states that to minimise the energy consumption in a building, the window area should be limited and suggests this limit to be 30% of the main façade area.

In a survey over 280 residential buildings in Hong Kong, Lam (2000) observed that the window-to-wall ratio (WWR) of living rooms and bedrooms ranged from 15% to 50%; and about 90% of buildings had WWR between 25% and 35%. As for the glass type, single clear glazing was found in 210 buildings (75% of the sample).

Gratia and De Herde (2003) state that choices of the overall form of the building, the depth and height of rooms, and the size of windows can together double the energy consumption of the finished building.

By simulation using the DOE-2 computer programme, Lam (2000) found that the cooling load due to solar heat gain through windows for a high rise residential building is the single largest heat source, accounting for 45% of the total cooling load.

In order to investigate the compatibility between the two design criteria (window sizes required for energy efficiency against window sizes required for view), the influence of the window area on the energy consumption of a building in which daylight and artificial lighting are to be integrated was studied.

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2. OBJECTIVES

The main objective of this paper is to compare the maximum size of window that will maintain energy efficiency in a building to the minimum window area required for view as recommended in the *Code of practice of daylighting* (BS 8206-2 1992) and to evaluate their compatibility.

3. METHODOLOGY

In order to reach the objective of this paper, the window areas recommended for view as presented in Table 1 should be compared to window areas for energy efficiency, i.e. Ideal Window Areas. The paper describes briefly the methodology to determine the Ideal Window Areas, as it has already been publish (Ghisi 2002; Ghisi and Tinker 2001), and the methodology to compare the Ideal Window Area with window areas required for view.

3.1. Ideal Window Area

The window area in which the energy consumption of the room is the lowest is referred to as the Ideal Window Area (IWA) (Ghisi and Tinker 2001). To investigate the energy changes associated with different glazed areas, a dynamic thermal model was used to identify the Ideal Window Area in which there is a balance between an acceptable thermal load and daylight supply. The dynamic model selected for the analysis was VisualDOE. This was appropriately validated to ensure its capability to predict monthly energy consumptions and energy savings due to the designed integration of artificial light with daylight using dimming systems.

Once validation had been completed, rooms of different sizes, window areas, room ratios and window façade orientation were then simulated to determine their Ideal Window Area.

The simulation model was based on a building 10 storeys high. Five rooms were generated with the floor ratios 2:1, 1.5:1, 1:1, 1:1.5, and 1:2, as shown in isometric view in Figure 1. For reference purposes, the first dimension is related to the wall where the window is located, and the window wall is the only one that is external.

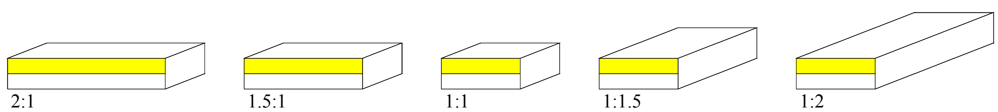

FIGURE 1. Isometric view of the five room ratios.

Each room ratio was simulated in 10 different sizes calculated as a function of the room index – as used in lighting design. Equation 1 presents the room index formula.

$$K = (WD)/[(W+D)h] \tag{1}$$

Where:
K is the room index (non-dimensional);
W is the overall width of the room (m);
D is the overall depth of the room (m);
h is the height between the work surface and the ceiling (m).

The overall height of the rooms is taken as 2.80 m and the working surface as 0.75 m above floor level so that h = 2.05 m. Room dimensions used in the computer simulations are presented in Table 2.

The climate is a critical element in the building design. Therefore, to verify the influence of different climatic conditions and geographical location on daylight provision and thus changes to the ideal window area, one city in the UK and seven cities in Brazil were considered in the simulations. Due to Brazil's large territory it was considered appropriate to select some cities to cover a certain latitude range. Climatic data ready to be used in VisualDOE were available for the selected Brazilian cities. As for the climatic data of Leeds, this had to be requested from the British Atmospheric Data Centre and converted to the VisualDOE format. The cities studied and their geographical locations are listed in Table 3.

TABLE 2. Room dimensions for each room index (K) and room ratio

K	Room ratio									
	2:1		1.5:1		1:1		1:1.5		1:2	
	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)
0.60	3.69	1.85	3.08	2.05	2.46	2.46	2.05	3.08	1.85	3.69
0.80	4.92	2.46	4.10	2.73	3.28	3.28	2.73	4.10	2.46	4.92
1.00	6.15	3.08	5.13	3.42	4.10	4.10	3.42	5.13	3.08	6.15
1.25	7.69	3.84	6.41	4.27	5.13	5.13	4.27	6.41	3.84	7.69
1.50	9.23	4.61	7.69	5.13	6.15	6.15	5.13	7.69	4.61	9.23
2.00	12.30	6.15	10.25	6.83	8.20	8.20	6.83	10.25	6.15	12.30
2.50	15.38	7.69	12.81	8.54	10.25	10.25	8.54	12.81	7.69	15.38
3.00	18.45	9.23	15.38	10.25	12.30	12.30	10.25	15.38	9.23	18.45
4.00	24.60	12.30	20.50	13.67	16.40	16.40	13.67	20.50	12.30	24.60
5.00	30.75	15.38	25.63	17.08	20.50	20.50	17.08	25.63	15.38	30.75

W stands for room width and D for room depth

TABLE 3. Latitude and longitude of the eight cities

City	Latitude	Longitude
Leeds	53°48’	-1°34’
Belém	-01°27’	-48°30’
Natal	-05°48’	-35°13’
Salvador	-12°58’	-38°31’
Brasília	-15°47’	-47°56’
Rio de Janeiro	-22°54’	-43°12’
Curitiba	-25°26’	-49°16’
Florianópolis	-27°36’	-48°33’

The thermal properties (U-value and Heat Capacity) as used for the walls and roof in the VisualDOE simulations are given in Table 4.

TABLE 4. Thermal properties of building components

Brazil	U (W/m^2K)	HC (kJ/m^2K)
Light walls	1.92	202
Light roof	2.22	77
England	**U (W/m^2K)**	**HC (kJ/m^2K)**
Mass walls	0.55	324
Mass roof	0.25	228

In terms of equipment, the input data into the programme is expressed in watts per floor area (W/m^2) and the adopted equipment power density was 15.0 W/m^2. The occupation density is expressed in m^2/person and was assumed to be 15.0 m^2/person. Regarding the lighting system, the input data into the VisualDOE programme is expressed by the lighting power density (LPD). It is reported that the smaller the room, the higher the LPD necessary to provide the same illuminance level as in larger rooms (Ghisi and Lamberts 1998). Because of this, it was decided to consider this particular statement in the simulations. Table 5 shows the lighting power density as a function of the room index (K) necessary to provide 500 lux on the working surface as used in the simulations.

TABLE 5. LPD used in the simulations

K	LPD (W/m^2)	K	LPD (W/m^2)
0.60	22.0	2.00	13.1
0.80	18.9	2.50	12.2
1.00	17.1	3.00	11.5
1.25	15.5	4.00	10.6
1.50	14.5	5.00	10.0

As for the glazed area in each room ratio, in order to facilitate the identification of the IWA of each room, simulations were performed considering an incremental glazed area ranging from 0 to 100% at increments of 10% of the façade area. Single clear glazing with a U-value of 5.7 W/m^2K, light transmission of 88% and thickness of 6 mm was considered in all computer simulations.

All the simulations took into account the differences in building use between England and Brazil. For the simulations using the climatic data for the cities in Brazil, the occupancy schedule considered an occupation of 100% between 8am-12noon and 2pm-6pm, with artificial lighting and equipment operating over the period. The cooling set point for the HVAC equipment was assumed to be 24°C during summer for Brazil, with no heating in the winter. For the simulations run under the UK climatic conditions, the occupancy schedule was assumed as 100% between 9am-5pm; a cooling set point of 23^{o}C was assumed for summer operation condition and 20^{o}C for winter heating.

Thus, 2200 simulations were run for each city, making a total of 17600 simulations over the eight cities.

Prior to the simulations, an analysis was performed to identify the influence of the parameters used to establish the Ideal Window Area. This analysis was performed under the climatic conditions of Florianópolis over a whole year, north window orientation, room ratio of 1:1, and room indices (K) of 0.60 and 5.00. These two room indices were selected as they represent, respectively, the smallest and the biggest room size for the room ratio 1:1. The lighting power density was kept at the value to provide 500 lux on the working surface, namely, 22.0 W/m^2 and 10.0 W/m^2, respectively for room index 0.60 and 5.00. The other parameters that were assessed to evaluate their impact on the Ideal Window Area were equipment power density, occupant density, infiltration rate, thermal transmittance (U-value) of roof and walls, heat capacity (HC) of roof and walls, colour (α-value) of roof and walls, U-value of the glazing and light transmission of the glazing.

The possible influence of these variables on the final energy results and on the IWA was performed through ten simulations. It was observed for both room indices of 0.60 (Figure 2) and 5.00 (Figure 3) that there was a significant difference on the energy consumption for each case, but the Ideal Window Area was approximately the same for each of the ten cases. Plotting polynomial trendlines for the ten cases, Ideal Window Areas ranging from 14% to 17% with R-squared ranging from 0.9988 to 0.9996 were obtained. This shows that there is not a significant difference on the IWA when the input data differs from those used in the simulations. The same procedure was then applied to large rooms with room index of 5.00. The Ideal Window Areas ranged from 31% to 40% between the ten cases, with R-squared ranging from 0.9827 to 0.9987. For this situation, it can be stated that there is a significant difference on the IWA for input data different than those used in the simulations. However, the curve of energy consumption as a function of window area for larger rooms is flat, indicating that applying window areas slightly different than the IWA will not affect the energy consumption of the room significantly.

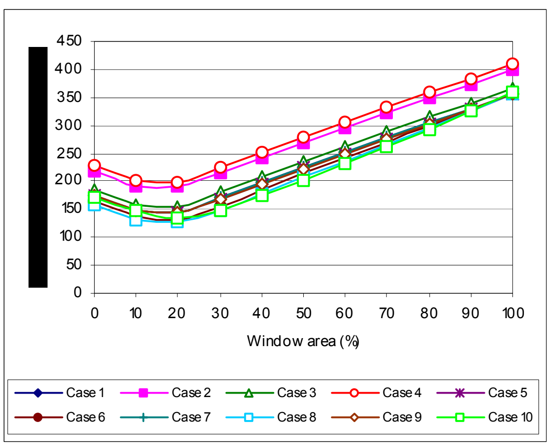

FIGURE 2. Analysis of input data for room index of 0.60 and climatic conditions of Florianópolis

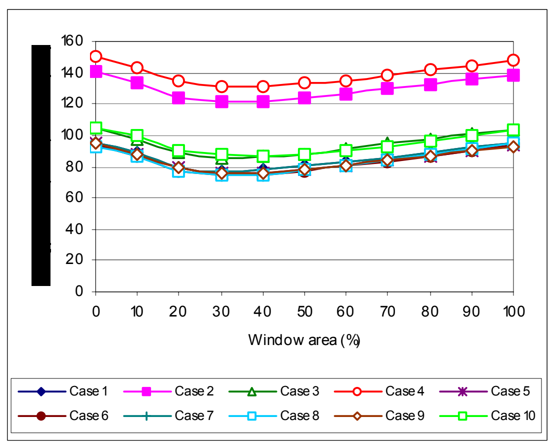

FIGURE 3. Analysis of input data for room index of 5.00 and climatic conditions of Florianópolis

3.2. Comparison of IWAs to window areas for view

As the minimum window areas required for view are defined as a function of room depth only, the room dimensions used in this analysis (Table 2) were classified in a similar way, as shown in Table 6.

Using the Ideal Window Areas (IWA) obtained from the simulations, each figure was compared to the corresponding value presented in Table 1. Using this methodology and the corresponding room depths given in Table 6, it was then possible to identify if the IWA was larger than the window area recommended for view. If so, a Y (standing for Yes, the Ideal Window Area is larger than the minimum window area for view) was marked in the respective space of a new table (like Table 8). For IWAs smaller than the window area recommended for view, the space was left blank.

TABLE 6. Classification of room depths used in the analysis (according to BS 8206-2)

K	Room ratio				
	2:1	1.5:1	1:1	1:1.5	1:2
0.60	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m
0.80	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m
1.00	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m
1.25	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m
1.50	D ≤ 8m	D ≤ 8m	D ≤ 8m	D ≤ 8m	8 < D ≤ 11m
2.00	D ≤ 8m	D ≤ 8m	8 < D ≤ 11m	8 < D ≤ 11m	11< D ≤ 14m
2.50	D ≤ 8m	8 < D ≤ 11m	8 < D ≤ 11m	11< D ≤ 14m	D > 14m
3.00	8 < D ≤ 11m	8 < D ≤ 11m	11< D ≤ 14m	D > 14m	D > 14m
4.00	11< D ≤ 14m	11< D ≤ 14m	D > 14m	D > 14m	D > 14m
5.00	D > 14m	D > 14m	D > 14m	D > 14m	D > 14m

D stands for room depth

4. RESULTS

From the computer simulations, energy consumptions were obtained for each room index, room ratio, window area, orientation and location. The Ideal Window Areas were then obtained by identifying the lowest energy consumption. Figure 4 shows an example for Florianópolis, room index ranging from 0.60 to 5.00, room ratio of 2:1, North orientation. For room index of 0.60 the Ideal Window Area was identified to be 11% (window area which matches with the lowest energy consumption). Following this procedure, the Ideal Window Areas were determined for all the other room sizes, room ratios, orientations and locations.

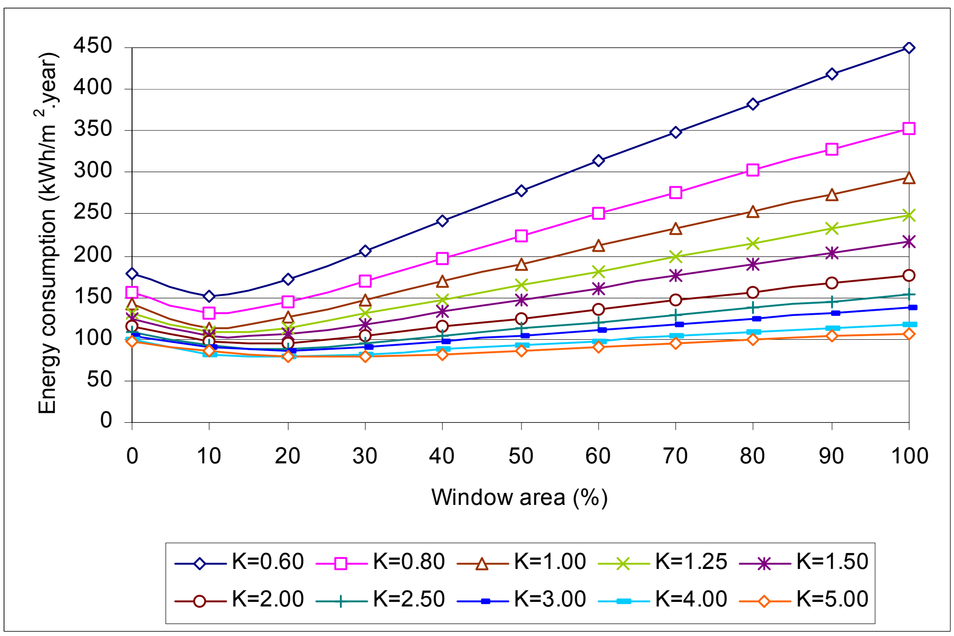

FIGURE 4. Energy consumption against window area for a room located in Florianópolis

Table 7 shows the Ideal Window Areas for buildings in the city of Florianópolis, Brazil, as a function of ten room indices (K), five room ratios (2:1, 1.5:1, 1:1, 1:1.5 and 1:2) on four orientations (North, East, South and West). To avoid repetition, the Ideal Window Areas for the other cities are presented in Appendix A.

TABLE 7. Ideal Window Areas for buildings in the city of Florianópolis (% of the room façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	15	18	10	11	15	20	10	16	19	21	12	20	25	25	15	25	26	31	19
0.80	11	15	19	11	12	16	21	11	17	19	22	12	21	26	26	16	27	27	33	19
1.00	12	16	20	11	13	17	22	11	18	20	24	13	22	27	28	17	28	29	36	20
1.25	13	17	20	12	14	18	23	12	19	21	25	14	24	28	30	17	29	31	38	21
1.50	13	18	21	12	15	19	24	13	20	22	27	15	25	29	32	18	31	32	41	21
2.00	15	20	23	14	17	20	26	15	21	24	30	16	27	31	36	20	34	36	47	23
2.50	16	21	25	15	19	22	28	16	23	26	33	18	30	34	40	22	37	40	53	25
3.00	18	23	26	16	22	24	30	18	25	28	36	19	32	36	44	23	40	43	58	26
4.00	21	27	30	19	26	28	35	21	29	32	43	22	37	41	52	27	45	50	69	29
5.00	24	30	33	22	30	31	39	24	33	36	49	25	42	46	59	30	51	58	81	33

By comparing the IWAs for buildings in the city of Florianópolis, as presented in Table 7, to the minimum glazed areas required for view as given in Table 1, it can be observed that many of the Ideal Window Areas are smaller than the minimum glazed areas recommended for view as given in BS 8206-2 (1992). The same trend was observed for the other seven cities studied in the research. Following this observation it was decided to investigate how widespread the problem might be in the various rooms in a building.

For example, referring to Table 7 for a room index of 0.60, room ratio of 2:1 and South orientation, the IWA is 18%. From Table 2, for the same room index and room ratio, the room depth is 1.85 m. As the room depth is smaller than 8 m (Table 6), the minimum recommended window area for view is 20% (Table 1). Therefore, as the IWA is smaller than the minimum window area recommended for view, the corresponding space in Table 8 was left blank. As a further example, again referring to Table 7, for a room index of 1.50, room ratio of 2:1 and a South orientation, the Ideal Window Area is 21%. From Table 2, the room depth is 4.61 m – still smaller than 8 m; thus from data given in Table 1, the minimum recommended window area for view is 20%. Since the IWA is now larger than the minimum window area for view the corresponding space in Table 8 is marked Y. This procedure was repeated for all the other room indices, room ratios and orientations until Table 8 was completed. Data for the other cities in the study were similarly analysed and are presented in Appendix B. The differences in results observed are due to the different climatic conditions and geographical locations of the cities.

TABLE 8. Situations in which the IWA for buildings in Florianópolis, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60							Y				Y		Y	Y	Y		Y	Y	Y	
0.80							Y				Y		Y	Y	Y		Y	Y	Y	
1.00			Y				Y			Y	Y		Y	Y	Y		Y	Y	Y	Y
1.25			Y				Y			Y	Y		Y	Y	Y		Y	Y	Y	Y
1.50			Y				Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
2.00		Y	Y			Y	Y				Y		Y	Y	Y		Y	Y	Y	
2.50		Y	Y				Y			Y	Y		Y	Y	Y		Y	Y	Y	
3.00			Y				Y				Y			Y	Y		Y	Y	Y	
4.00			Y				Y				Y		Y	Y	Y		Y	Y	Y	
5.00							Y			Y	Y		Y	Y	Y		Y	Y	Y	

Y stands for Yes, the Ideal Window Area is larger than the minimum window area for view

From Table 8, it can be observed that narrow rooms (room ratios of 1:1.5 and 1:2) tend to have IWAs larger than the minimum areas recommended for view. A similar trend was observed for all the other cities as it can be observed in Appendix B (Tables B1-B7).

Table 9 shows the percentage of cases in which the IWA is larger than the minimum recommended glazed area for view. It can be observed, for buildings in the city of Leeds for example, that only 17.5% of the rooms with room ratio of 2:1 have Ideal Window Areas that are larger than the minimum glazed area recommended for view. This percentage increases to 50.0% for rooms having a room ratio of 1:2, but is still a relatively small percentage. For the city of Brasília in Brazil, the figures look more encouraging, but even for a building in this location there would be a great number of window areas smaller than the minimum window area recommended for view. This analysis indicates that there is a design conflict between the IWA, i.e., the maximum window area for energy efficiency and the minimum window area recommended for view. Table 9 also shows the results for each city and room ratio over the four orientations in which the IWA is larger than the minimum window area recommended for view. It can be seen that on some of the orientations, none of the Ideal Window Areas are larger than the minimum window area recommended for view. This indicates that minimum window areas recommended for view should also be designed as a function of the window orientation if the two design requirements are to agree.

TABLE 9. Percentage of room ratios in which the IWA is larger than the minimum glazed area recommended for view for each window wall orientation (%)

K	2:1					1.5:1					1:1				
	N	E	S	W	T	N	E	S	W	T	N	E	S	W	T
Leeds	17.5	0.0	0.0	0.0	17.5	22.5	0.0	0.0	0.0	22.5	20.0	5.0	0.0	0.0	25.0
Belém	0.0	12.5	2.5	0.0	15.0	0.0	12.5	10.0	0.0	22.5	0.0	12.5	20.0	0.0	32.5
Brasília	0.0	15.0	25.0	0.0	40.0	0.0	17.5	25.0	0.0	42.5	10.0	22.5	25.0	0.0	57.5
Curitiba	0.0	5.0	20.0	0.0	25.0	2.5	12.5	25.0	0.0	40.0	20.0	25.0	25.0	0.0	70.0
Florianópolis	0.0	5.0	17.5	0.0	22.5	0.0	2.5	25.0	0.0	27.5	2.5	12.5	25.0	0.0	40.0
Natal	0.0	2.5	0.0	0.0	2.5	0.0	10.0	0.0	0.0	10.0	5.0	12.5	10.0	0.0	27.5
Rio	0.0	0.0	7.5	0.0	7.5	0.0	0.0	12.5	0.0	12.5	0.0	2.5	25.0	0.0	27.5
Salvador	0.0	0.0	10.0	0.0	10.0	0.0	0.0	17.5	0.0	17.5	0.0	0.0	25.0	0.0	25.0

T stands for total, meaning the total percentage over the four orientations

TABLE 9. continued

K	1:1.5					1:2				
	N	E	S	W	T	N	E	S	W	T
Leeds	22.5	22.5	0.0	0.0	45.0	25.0	25.0	0.0	0.0	50.0
Belém	10.0	20.0	25.0	2.5	57.5	17.5	22.5	25.0	12.5	77.5
Brasília	25.0	25.0	25.0	2.5	77.5	25.0	25.0	25.0	10.0	85.0
Curitiba	25.0	25.0	25.0	0.0	75.0	25.0	25.0	25.0	5.0	80.0
Florianópolis	22.5	25.0	25.0	0.0	72.5	25.0	25.0	25.0	5.0	80.0
Natal	20.0	20.0	22.5	0.0	62.5	25.0	20.0	22.5	0.0	67.5
Rio	0.0	22.5	25.0	0.0	47.5	15.0	25.0	25.0	0.0	65.0
Salvador	0.0	5.0	25.0	0.0	30.0	10.0	20.0	25.0	2.5	57.5

T stands for total, meaning the total percentage over the four orientations

It was noticed through all the results from the simulations that the adoption of a window area different than the Ideal Window Area may cause the energy consumption to be much higher for rooms of small room index. However, for rooms of large room index the energy consumption does not increase significantly when the selected window area is different than the Ideal Window Area. Therefore, it was deemed necessary to assess the influence of applying window areas other than the Ideal Window Area on the energy consumption of rooms. Table 10 presents, as an example, percentages of the energy consumption increase for window areas different than the Ideal Window Area for the city of Florianópolis. The data are related to room ratios of 2:1 and room indices of 0.60 and 5.00. It can be observed that choosing, for example, a window area of 30% for a north-oriented window of a room index of 0.60 the energy consumption will be 35.6% higher than the energy consumption for the same room with an IWA; if the window area is to be increased to 100% then the energy consumption will be 195.6% higher than when adopting an IWA. Considering now a room index of 5.00 with a window area of 30% for a north-oriented window in Florianópolis, the energy consumption will be only 1.5% higher than the energy consumption for the same room with an IWA. Similar results were observed for the other cities.

TABLE 10. Percentage of the energy consumption increase for window areas different than the IWA for room ratio 2:1 in Florianópolis

Energy consumption increase (%) due to the window area (%), room ratio 2:1, K=0.60											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	17.0	0.0	12.9	35.6	59.4	82.6	106.3	129.0	151.9	174.5	195.6
East	13.5	0.7	3.1	25.0	47.6	69.6	90.3	111.6	132.1	151.7	170.4
South	19.6	5.7	0.5	7.4	16.6	25.7	34.6	43.3	51.7	59.8	67.9
West	10.5	0.0	11.1	27.0	45.5	63.8	84.8	104.8	124.0	142.9	160.9
Energy consumption increase (%) due to the window area (%), room ratio 2:1, K=5.00											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	23.6	10.4	0.4	1.5	5.5	10.7	15.8	21.2	26.7	32.1	37.2
East	20.7	11.1	2.9	0.0	3.0	7.6	12.6	17.7	22.8	27.8	32.6
South	24.4	15.8	3.9	0.1	0.5	1.4	2.7	4.3	6.1	7.8	9.5
West	19.0	6.5	0.3	3.1	4.0	7.8	11.7	15.8	20.9	25.7	30.4

5. CONCLUSIONS

It was shown that using parameters other than those fixed in the simulations might strongly influence the energy consumption of the rooms, but slightly the Ideal Window Area (IWA). However, improvements on the energy efficiency of the lighting system, or on the type of glazing or yet on the envelope may cause the Ideal Window Area to change.

The investigation has shown that there is disagreement between the maximum window size permitted to ensure energy efficiency and the minimum window areas recommended for view as presented in the British Standard BS 8206-2 (1992). From the results, it was observed that adopting window areas different than the IWA might incur a percentage increase in the annual energy consumption, which becomes more significant as the window area differs from the IWA. This indicates that the minimum window areas recommended for view should be revised in order to ensure lower energy consumptions in buildings.

It is recommended that further work be done to investigate the minimum window areas that are recommended for view not only as a function of the depth of the room (as present), but also as a function of room width, room ratio, orientation of the window façade and geographical location (particularly latitude).

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APPENDIX A Ideal Window Areas

TABLE A1. Ideal Window Areas for Leeds, UK (% of the room façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	16	11	10	7	19	12	11	7	16	16	11	7	18	20	11	8	23	20	14	9
0.80	18	12	11	7	20	13	11	7	18	17	12	7	21	21	12	9	26	21	14	10
1.00	19	13	11	8	21	14	12	8	20	17	12	8	24	22	13	10	29	23	15	11
1.25	21	13	11	8	23	15	12	8	23	18	13	9	27	24	14	11	32	25	17	12
1.50	23	14	12	9	25	16	12	9	26	20	14	10	31	25	16	12	36	27	18	13
2.00	27	16	13	10	28	19	13	10	31	22	15	11	37	28	18	14	43	31	20	15
2.50	30	17	14	11	31	21	14	11	37	24	17	13	44	31	20	15	50	35	22	18
3.00	34	19	14	12	34	23	14	12	42	26	18	14	51	34	22	17	58	39	25	20
4.00	41	22	16	14	40	28	16	14	53	31	21	18	65	40	27	21	72	47	29	24
5.00	49	25	18	16	47	32	17	17	64	35	24	21	79	46	32	25	87	55	34	29

TABLE A2. Ideal Window Areas for Belém, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	12	14	10	12	11	14	11	14	13	17	11	18	19	22	14	19	20	26	18
0.80	12	13	15	11	13	12	15	12	15	14	19	12	19	20	24	15	21	21	28	19
1.00	12	14	16	12	14	13	16	13	15	15	20	12	20	20	25	16	22	22	30	21
1.25	13	15	17	13	14	14	18	14	16	16	22	13	21	21	27	18	24	23	33	23
1.50	14	16	17	13	15	15	19	15	17	17	23	14	22	22	29	19	25	24	35	24
2.00	15	18	19	15	17	17	21	17	19	18	26	16	24	24	33	22	29	26	40	28
2.50	16	20	21	17	18	19	24	19	21	20	30	17	26	26	37	25	32	28	45	31
3.00	17	21	23	19	20	21	26	21	23	22	33	19	28	27	41	28	36	30	50	35
4.00	20	25	26	22	23	25	31	26	27	26	39	22	32	31	49	34	42	34	60	42
5.00	22	29	30	26	26	29	36	30	31	30	46	25	36	34	57	40	49	38	70	49

TABLE A3. Ideal Window Areas for Brasília, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	12	16	20	10	15	16	21	11	17	19	27	13	20	26	31	17	24	30	41	19
0.80	13	17	21	11	16	17	23	11	18	21	29	14	21	28	34	18	26	33	44	20
1.00	13	18	22	11	16	18	24	12	19	23	30	15	22	30	36	18	27	35	46	21
1.25	14	19	23	12	17	20	26	13	20	25	32	16	24	32	39	19	30	38	49	22
1.50	15	20	24	13	18	21	27	14	21	27	34	17	26	34	42	20	32	41	52	23
2.00	16	23	27	14	19	24	30	16	23	31	38	19	29	39	48	22	36	48	57	26
2.50	18	25	29	15	21	27	34	17	25	35	42	22	33	44	54	24	40	54	63	28
3.00	19	27	32	17	22	29	37	19	27	39	46	24	36	49	60	25	45	60	69	30
4.00	23	32	37	19	26	35	44	23	31	47	53	28	43	58	71	29	53	72	80	34
5.00	26	36	42	22	29	41	50	26	36	55	61	32	50	68	83	32	62	84	91	39

TABLE A4. Ideal Window Areas for Curitiba, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	12	14	18	10	15	17	20	11	17	20	24	12	23	26	32	16	29	32	43	19
0.80	13	14	19	11	16	18	21	11	19	21	26	13	24	28	34	17	31	33	45	19
1.00	14	15	20	12	17	19	23	12	20	22	27	13	26	29	36	17	33	35	48	20
1.25	15	16	22	12	18	20	24	12	21	23	29	15	27	30	39	18	35	37	50	21
1.50	16	17	24	13	18	21	26	13	22	24	31	16	29	32	42	19	36	39	53	22
2.00	17	20	27	14	20	23	30	14	25	27	35	18	32	35	47	21	40	44	58	23
2.50	19	22	30	16	22	24	33	15	27	29	39	20	35	39	52	23	44	48	64	25
3.00	21	24	33	17	24	26	37	17	30	32	43	22	38	42	58	25	48	52	69	26
4.00	25	28	39	20	27	30	44	19	35	36	51	27	45	49	68	29	56	61	80	30
5.00	28	32	46	23	31	34	51	22	40	41	59	31	51	55	79	33	64	69	91	33

TABLE A5. Ideal Window Areas for Natal, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	12	11	9	12	12	14	9	13	12	15	9	18	16	19	11	20	16	18	18
0.80	12	13	12	9	13	13	14	9	15	14	16	10	19	18	20	12	22	19	20	19
1.00	12	14	13	10	13	15	15	10	16	16	18	11	20	20	22	13	24	21	22	19
1.25	13	15	14	11	14	16	16	11	17	18	19	12	22	23	23	15	26	24	24	19
1.50	14	16	15	11	15	18	17	11	19	20	20	13	24	25	25	16	28	27	26	20
2.00	16	19	17	13	17	21	19	13	22	24	23	14	28	31	28	19	33	33	31	21
2.50	18	21	19	14	19	24	21	14	25	28	26	16	32	36	32	21	37	38	35	22
3.00	20	24	21	15	21	27	23	16	28	32	29	18	35	42	35	24	42	44	40	23
4.00	24	29	25	18	25	34	27	18	34	41	35	22	43	52	42	29	51	56	49	25
5.00	28	34	30	21	29	40	31	21	40	49	40	25	50	63	48	34	60	68	58	26

TABLE A6. Ideal Window Areas for Rio de Janeiro, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	9	9	18	8	10	11	16	9	14	14	20	9	16	18	22	10	20	26	29	13
0.80	10	9	18	8	10	11	17	9	14	15	21	9	17	20	24	11	21	28	31	13
1.00	10	10	19	8	11	12	18	9	15	16	22	10	17	21	26	12	22	29	33	14
1.25	11	11	19	9	13	14	19	9	15	17	23	10	18	23	28	13	23	31	35	15
1.50	12	12	20	9	14	15	20	10	16	19	25	11	19	24	30	14	24	33	37	15
2.00	13	14	21	10	16	17	22	10	17	21	28	12	21	28	34	16	26	37	42	17
2.50	15	16	22	10	18	19	24	11	19	24	31	13	22	31	39	18	28	41	47	18
3.00	16	18	24	11	21	22	26	12	20	26	34	14	24	35	43	20	31	45	51	20
4.00	19	22	26	12	26	26	31	13	23	32	39	16	27	42	52	23	35	52	60	23
5.00	22	26	29	13	30	31	35	14	26	37	45	19	31	49	60	27	40	60	69	26

TABLE A7. Ideal Window Areas for Salvador, Brazil (% of the façade area)

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	10	9	16	7	10	11	18	8	11	16	20	9	16	17	23	10	20	21	29	11
0.80	10	10	17	8	10	11	19	8	12	16	21	10	16	18	25	11	20	22	31	12
1.00	11	10	18	8	11	12	19	9	13	17	22	10	17	19	26	12	21	23	33	13
1.25	11	11	19	9	12	12	20	10	14	17	23	11	17	20	28	13	21	25	35	15
1.50	12	12	20	10	12	13	21	10	15	18	24	12	18	21	30	15	22	26	38	16
2.00	13	13	21	11	14	15	23	12	17	19	27	14	19	23	35	17	24	29	42	19
2.50	14	14	23	13	15	16	25	13	18	20	29	16	21	24	39	19	25	32	47	22
3.00	15	16	25	14	16	17	27	14	20	22	32	18	22	26	43	22	26	35	52	25
4.00	18	18	29	17	19	20	31	17	24	24	37	22	25	30	51	26	29	42	61	30
5.00	20	21	33	20	22	23	35	20	28	27	42	26	28	34	59	31	32	48	70	36

APPENDIX B Ideal Window Areas larger than the window area for view

TABLE B1. Situations in which the IWA for buildings in Leeds, UK, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60														Y			Y	Y		
0.80					Y								Y	Y			Y	Y		
1.00					Y				Y				Y	Y			Y	Y		
1.25	Y				Y				Y				Y	Y			Y	Y		
1.50	Y				Y				Y	Y			Y	Y			Y	Y		
2.00	Y				Y				Y				Y	Y			Y	Y		
2.50	Y				Y				Y				Y	Y			Y	Y		
3.00	Y				Y				Y				Y				Y	Y		
4.00	Y				Y				Y				Y	Y			Y	Y		
5.00	Y				Y				Y	Y			Y	Y			Y	Y		

Y stands for Yes, the Ideal Window Area is larger than the minimum window area for view

TABLE B2. Situations in which the IWA for buildings in Belém, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60															Y				Y	
0.80															Y		Y	Y	Y	
1.00											Y		Y	Y	Y		Y	Y	Y	Y
1.25											Y		Y	Y	Y		Y	Y	Y	Y
1.50										Y	Y		Y	Y	Y		Y	Y	Y	
2.00		Y				Y	Y				Y			Y	Y			Y	Y	
2.50		Y	Y			Y				Y	Y			Y	Y			Y	Y	
3.00		Y				Y	Y			Y	Y			Y	Y		Y	Y	Y	Y
4.00		Y				Y	Y			Y	Y			Y	Y		Y	Y	Y	Y
5.00		Y				Y	Y			Y	Y		Y	Y	Y	Y	Y	Y	Y	Y

TABLE B3. Situations in which the IWA for buildings in Brasília, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60			Y				Y				Y		Y	Y	Y		Y	Y	Y	
0.80			Y				Y			Y	Y		Y	Y	Y		Y	Y	Y	Y
1.00			Y				Y			Y	Y		Y	Y	Y		Y	Y	Y	Y
1.25			Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y
1.50		Y	Y			Y	Y		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	
2.00		Y	Y			Y	Y			Y	Y		Y	Y	Y		Y	Y	Y	
2.50		Y	Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
3.00		Y	Y			Y	Y			Y	Y		Y	Y	Y		Y	Y	Y	
4.00		Y	Y			Y	Y			Y	Y		Y	Y	Y		Y	Y	Y	
5.00		Y	Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y

TABLE B4. Situations in which the IWA for buildings in Curitiba, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60							Y			Y	Y		Y	Y	Y		Y	Y	Y	
0.80							Y			Y	Y		Y	Y	Y		Y	Y	Y	
1.00			Y				Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y
1.25			Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y
1.50			Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
2.00		Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
2.50		Y	Y				Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
3.00			Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
4.00			Y			Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	
5.00			Y				Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	

TABLE B5. Situations in which the IWA for buildings in Natal, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60																	Y			
0.80															Y		Y		Y	
1.00													Y	Y	Y		Y	Y	Y	
1.25													Y	Y	Y		Y	Y	Y	
1.50										Y	Y		Y	Y	Y		Y	Y	Y	
2.00						Y							Y	Y	Y		Y	Y	Y	
2.50		Y							Y	Y	Y		Y	Y	Y		Y	Y	Y	
3.00						Y				Y			Y	Y	Y		Y	Y	Y	
4.00						Y				Y	Y		Y	Y	Y		Y	Y	Y	
5.00						Y			Y	Y	Y		Y	Y	Y		Y	Y	Y	

TABLE B6. Situations in which the IWA for buildings in Rio de Janeiro, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60											Y				Y		Y	Y	Y	
0.80											Y			Y	Y		Y	Y	Y	
1.00											Y			Y	Y		Y	Y	Y	
1.25											Y			Y	Y		Y	Y	Y	
1.50			Y				Y				Y			Y	Y			Y	Y	
2.00			Y				Y				Y			Y	Y			Y	Y	
2.50			Y								Y			Y	Y			Y	Y	
3.00							Y				Y			Y	Y			Y	Y	
4.00							Y				Y			Y	Y		Y	Y	Y	
5.00							Y			Y	Y			Y	Y		Y	Y	Y	

TABLE B7. Situations in which the IWA for buildings in Salvador, Brazil, is larger than the window area recommended for view

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60											Y				Y		Y	Y	Y	
0.80											Y				Y		Y	Y	Y	
1.00											Y				Y		Y	Y	Y	
1.25							Y				Y			Y	Y		Y	Y	Y	
1.50			Y				Y				Y			Y	Y			Y	Y	
2.00			Y				Y				Y				Y				Y	
2.50			Y				Y				Y				Y				Y	
3.00			Y				Y				Y				Y			Y	Y	
4.00							Y				Y				Y			Y	Y	
5.00							Y				Y				Y			Y	Y	Y