OPTIMAL WINDOW GEOMETRY FACTORS FOR ELEMENTARY SCHOOL BUILDINGS IN PORTUGAL

Jorge S. Carlos[1]

INTRODUCTION

With respect to thermal performance, windows are the weakest component of the building envelope, essentially because the U-value is usually higher than the opaque envelope. This would allow the highest heat conductance of the building envelope. However, it also helps buildings to gain useful solar heat during winter. Therefore, it has been generally accepted that passive buildings would have small windows towards the poles and large windows facing the equator (Persson, Roos, and Wall 2006). In spite of this guideline, large or fully glazed facades have been used in modern architecture. The intensive use of air conditioning is the result of overheating and high thermal loss problems, which otherwise would lead to thermal discomfort. This extensive use of large windows associated with high energy consumption has motivated researchers to study this building component.

Window areas were investigated by Persson et al. (Persson, Roos, and Wall 2006) on 20 terraced houses with larger windows facing the equator and built in Gothenburg. The building envelope was well insulated and fitted with energy efficient windows. It was found that energy efficient windows do not have a major influence on the heating demand in the winter, but it is relevant for the cooling need in summer. Therefore, reduced indoor illuminance due to small windows can be solved by enlarging them in order to obtain relevant daylighting conditions. When efficient windows are designed for a warm climate, as in Mexico, reducing heat flux and solar transmittance indoors was the best option for energy savings (Aguilar et al. 2017). However, reducing solar transmittance influences the indoor illuminance, which was not analyzed.

KEYWORDS

school building; classroom; windows; solar heat gain; daylight

Solar radiation crossing the windows contribute to space heating in cold climates. In hot climates solar gains are not wanted, but daylighting is still needed. According to Lee at al. (Lee et al. 2013) as window sizes narrow, the building energy load decreases as the thermal transmission is also reduced. The relationship between the windows and the façade are commonly referred

1. 1. Centre of Materials and Building Technologies (CMADE-UBI), Universidade da Beira Interior, Rua Marquês D'Ávila e Bolama, 6200-001, Covilhã, Portugal, jcarlos@ubi.pt

to the window to wall ratio (WWR) in percentage. This metric could oscillate from region to region. In the Japanese climate an appropriate WWR value from 30 to 50% was proposed (Wen, Hiyama, and Koganei 2017), while in Manila and Taipei a lower WWR value of 25% was found to be adequate (Lee et al. 2013) where the relative window size should be minimized. Therefore, window area, amongst physical properties is of great importance for harvesting solar radiation and providing proper daylight indoors. Generally speaking, larger window sizes facing the equator increase cooling demand, while heating demand increases with large windows facing north (Ochoa et al. 2011). Reducing the window size to reduce energy consumption is the worst measure regarding the minimal conditions of daylighting.

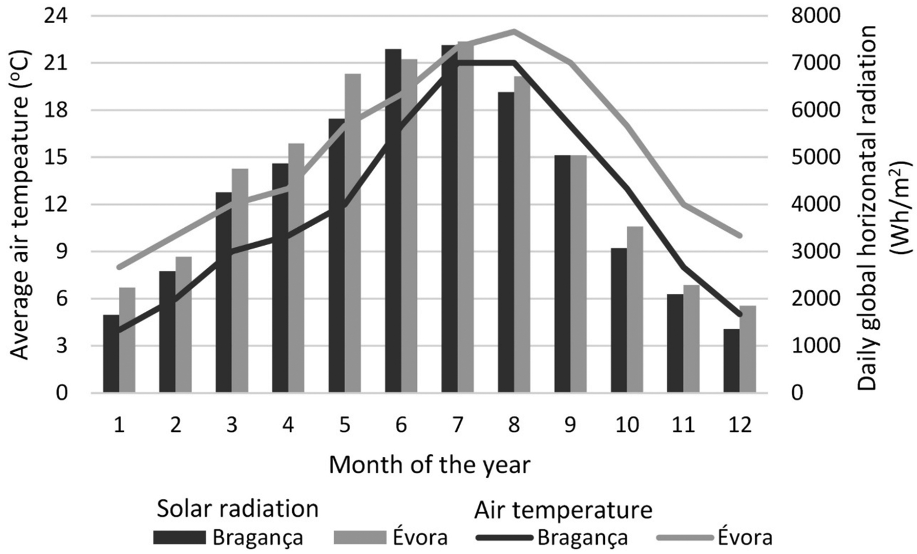
Reducing energy loss through the building envelope requires the optimization of thermal performance of the windows in order to obtain minimal heat losses and optimal solar gains. This means that it is possible to consider the best window size according to orientation, location and building physical properties. The most effective thermal insulation glazing is characterized by low U-values, but associated with low solar transmittance which reduces solar gains (Gasparella et al. 2011), (Amaral et al. 2015) as well as daylighting, when the number of glazing is increased. A reduction of the window U-value can reduce the energy demand for heating and cooling depending on the solar heat gain coefficient (SHGC) (Grynning et al. 2013). For instance, in Tehran's climatic condition, lowering the U-value and SHGC is necessary in north and south faced classrooms to decrease overheating (Zomorodian and Tahsildoost 2017). Thus, from hot climates to cold climates, higher SHGC and optical transmission window properties are beneficial for saving energy (Lee et al. 2013). The thermal balance of the building envelope is affected not only in summer, but also in winter. One should consider not only heat loss or gains, but also the beneficial effects of solar radiation and hence reduced demand for heating and artificial lighting due to daylight.

Other geometry factors, besides the window to wall ratio, play an important role on the thermal performance and daylighting distribution. The window orientation and also the room width to depth ratio have been analyzed by Susorova et al. (Susorova et al. 2013) to find the combination of parameters yielding the lowest energy consumption for office buildings located in various climatic zones of the United States. The highest energy savings with fenestration geometry were found in hot climates while in temperate and cold climates it was low. Different room ratio and dimensions were assessed by Ghisi and Tinker (Ghisi and Tinker 2005) to find the ideal window area based on the Daylight Factor (DF) and to predict the energy savings on lighting. The daylight factor describes the ratio representing the illuminance available at a point indoors in relation to the outdoor illuminance on a horizontal plane under an overcast sky. The authors concluded that the proposed methodology could be applied to any space and energy savings on artificial lighting in any city worldwide. However, this study did not incorporate solar heat gain.

Window to floor ratio is another geometry factor that was studied by Gasparella et al. (Gasparella et al. 2011). Four ratios (16 to 41%) were used alongside orientation and four climate zones (Paris, Milan, Nice and Rome). The results showed a common trend in all climates. The winter energy need always decreased with increasing window area on windows not facing north. It was found that on the south orientation, an increase of the window surface was the most effective expedient to reduce the winter energy need.

The main objective of this study is to define the optimal geometry factor for elementary school buildings in Portugal based on pre-set rules, such as room area, window ratio and orientation.

FIGURE 1. Monthly climate in Bragança and Évora



METHODOLOGY

To investigate an optimal window design for elementary school buildings in Portugal, a model of a single thermal zone of a classroom was created in Sketchup. This model was imported to the Energy Plus (Crawley et al. 2001) simulation engine and also to the VELUX Daylight Visualizer (Labayrade, Jensen, and Jensen 2009). This classroom was located first in Bragança (41.8 N; 6.73 W) and then in Évora (38.57 N; 7.9 W), Portugal, with cold winters and hot summers (Figure 1).

The classroom's ceiling, floor, and three interior walls were considered adiabatic. Heat transfer between the classroom and the exterior occurs only through one exterior wall with the window under study. During summer an interior window shading is provided. The relevant properties of the Portuguese climate zone in the simulations are shown in Table 1.

Reflectance for interior surfaces is within the range of the Standard EN12464-1:2011 (EN 12464-1 2002), which is shown in Table 2.

TABLE 1. Thermal and optical properties of the windows used in the simulations.

	Heat transfer coefficient (reference values) W/m²°K		SHGC (winter)	SHGC (maximum values in summer)		Visual transmittance
	Bragança	Évora		Bragança	Évora	
Wall	0.35	0.50				
Smaller window	2.40	2.90	0.76	0.56	0.50	0.81
Bigger window	2.40	2.90	0.76	0.42	0.38	0.81

TABLE 2. Reflectance of the interior surfaces.

Surface	
Floor	0.4
Walls	0.7
Window	0.14
Ceiling	0.8

The internal loads were accounted to a metabolic rate that was set for 25 people at 100 W/person. There was no equipment and lighting was considered negligible. The schedules were considered from 8:00 am to 5:00 pm, on working days, from September to June (Carlos 2016), (Carlos and Corvacho 2010). The classroom had one opening placed on the center of the external wall. The lower edge of the glazing was located 0.75 m above the floor, at a task level. A free horizon and no external shading were assumed. Portuguese recommendations for classrooms are:

- The thermal comfort levels within the building are 18° C and 24° C in winter and summer, respectively.
- The ceiling should preferably be white, with reflection higher than 75%.
- The glazed equivalent area should be from 15 to 25% of the floor area, according to the climate zone. The geographical orientation of the classroom fenestrations should focus on the Southeast-South-Southwest quadrant.
- Floor to ceiling should be at least 3.2 m.
- The minimum floor area is 48 m^2.
- 3 air changes per hour (ACH) should be ensured in classrooms.

A rule of thumb concerning daylighting (Tregenza 2002).

- A room can have a daylit appearance if the glazing area is at least 1/25th (4%) of the total room area.
- Surfaces that are closer to a window than twice the height of the window head above the desktop level, receive adequate daylight for tasks during most of the working year.

A classroom area should meet good practice daylighting criteria expressed in at least 80% of the floor area with a DF ≥ 2% ("BREEAM New Construction: Non-Domestic Buildings" 2012). With a window head at 3.2 m height and the working plane at 0.75 m height, the length of the classroom could be 4.9 m. Therefore, a classroom of 4.9 m length, 9.8 m width and 3.2 height (±48 m^2) would be expected with a width-to-depth ratio of 2:1. However, to study different classroom geometries two more classroom ratios, such as 1:1 and 1:2, were studied with the characteristics shown in Table 3.

The first evaluated parameter was window orientation, being southeast, south and southwest. Another tested parameter was a window to floor ratio (WFR). For different room geometry the WFR would result in a different WWR. The latter represents the percentage of an exterior

TABLE 3. Resulted characteristics of the classroom model.

Set nº	Classroom ratio	Classroom dimension (m)	Window area (m^2)	Window to floor ratio (%)	Window to wall ratio (%)	Overall heat transfer coefficient $W/m^2{}^oK$	
						Bragança	Évora
1	2:1	9.8 x 4.9	7.2	15	23	0.54	0.69
			12	25	38.3	0.74	0.93
2	1:1	6.93 x 6.93	7.2	15	34.6	0.47	0.59
			12	25	57.7	0.67	0.83
3	1:2	4.9 x 9.8	7.2	15	45.9	0.42	0.52
			12	25	76.5	0.63	0.76

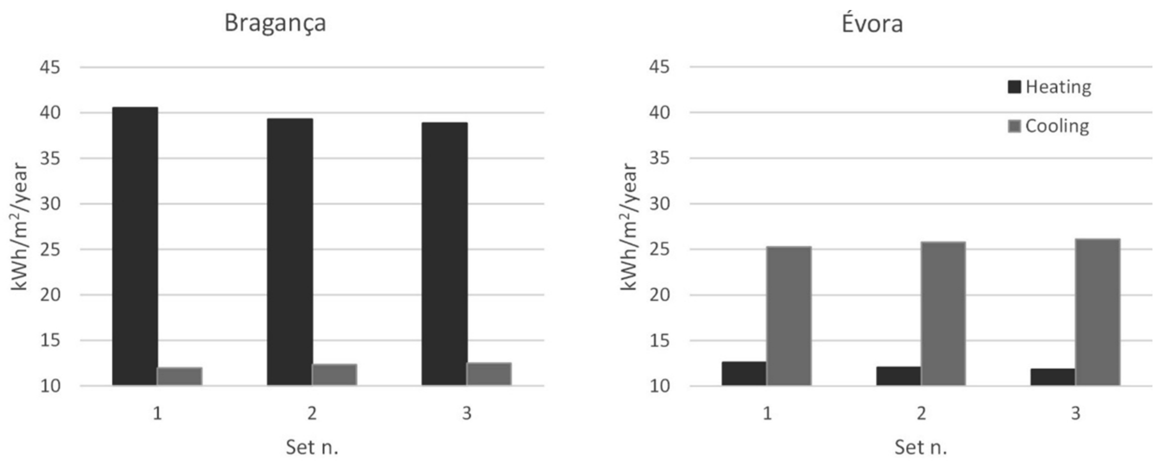
wall area that is transparent. Different WWR would affect not only the overall wall heat transfer coefficient, but also the amount of available daylight and solar heat gains. Two WFR (15% and 25%) were tested for different classroom ratios. The last parameter evaluated by this study was the classroom ratio representing the relationship width to depth (W/D ratio). This is an important room geometry parameter which affects the interrelation between the interior and the outer environment. The width of the classroom exterior wall determines the area exposed to heat transfer through the facade and the amount of received solar radiation. The classroom depth determines the distance of daylight penetration. The classroom ratio was, 2:1, 1:1 and 1:2 (deepest classroom). Therefore, the windows under study comprise the Portuguese recommendation as well as rules of thumb.

RESULTS AND DISCUSSION

Comparisons of the obtained results under two different local climates (Bragança and Évora) are presented. The first analysis refers to the smaller window ratio that corresponds to 15% of the floor area, due south. Figure 2 shows the yearly total heating and cooling load per unit of floor area. As expected, the heating load has reduced from set nº 1 to set nº 3. As the room coefficient thermal reduces, so does the thermal loss and heating demand. Nevertheless, the reduction was not significant. In Bragança it corresponds to a reduction of about 4%, from 40.6 to 38.9 kW/m^2/year, while in Évora it is about 6%, from 12.6 to 11.8 kW/m^2/year. On the other hand, the cooling load has a small increment from set nº 1 to set nº 3. As the external air temperature drops below internal air temperature, the smaller external wall is presented with the lowest thermal losses.

Figure 3 shows the heating and cooling loads for two windows to floor ratio (15% and 25%). It can be read that the heating load has always decreased when the window to floor ratio has increased, both in Bragança and Évora. As these results were obtained during diurnal activity from September to June, it was not affected by the lowest temperature that occurs during the night period of winter. Also, during the day the solar radiation influences the thermal performance of the classroom due to solar heat gain. As the room's overall thermal coefficient

FIGURE 2. Yearly heating and cooling load per unit of floor area for different set number.



increases with the augment of the window ratio, solar heat gain also increases, which overpasses thermal losses. Therefore, the classroom benefits from the higher solar heat gain as the window is enlarged. Also, the heating load has a reduction of about 23% in Bragança and 33% in Évora. On the other hand, the cooling load has increased by about 41% in Bragança and 35% in Évora with the augment of the window area. Nevertheless, the total thermal load has always increased with bigger windows.

The thermal load in Bragança and Évora is shown in Tables 4 and 5, respectively, for all the classroom ratios and orientations. The best orientation for heating load was found to be south and for the cooling load southwest. However, the lowest total thermal load is for southeast orientation where the highest energy saving is achieved. The highest total thermal load is found in south orientations due to high solar heat gain in summer.

The distribution of daylight through the classroom is observed in Figure 4, where DF is plotted at work task level with the smallest window (WFR = 15%). The DF below 2% is

FIGURE 3. Heating and cooling load per unit of floor area for different window to floor ratio.

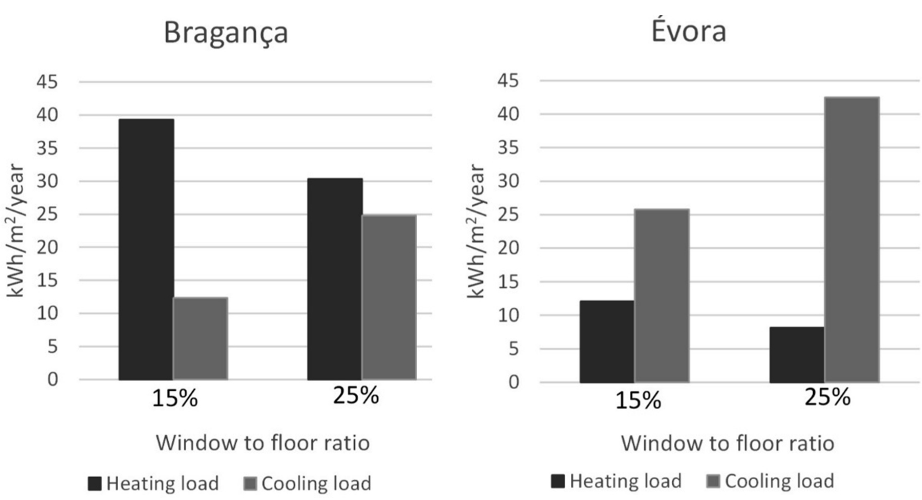


TABLE 4. Thermal load in Bragança for different classroom ratio and orientation.

Classroom rate	Orientation	WWR (%)	Heating load kWh/m^2/year	Cooling load kWh/m^2/year	Total thermal load kWh/m^2/year
2:1	SE	23	44.5	13.1	57.6
		38.3	35.2	24.9	60.1
	S	23	40.5	12.0	52.5
		38.3	31.2	24.1	55.3
	SW	23	47.2	11.9	59.1
		38.3	39.3	22.3	61.7
1:1	SE	34.6	43.1	13.4	56.5
		57.7	34.0	25.5	59.5
	S	34.6	39.3	12.3	51.7
		57.7	30.3	24.8	55.2
	SW	34.6	45.8	12.2	58.0
		57.7	38.2	23.0	61.2
1:2	SE	45.9	42.7	13.6	56.2
		76.5	33.6	25.9	59.5
	S	45.9	38.9	12.5	51.4
		76.5	30.0	25.1	55.1
	SW	45.9	45.3	12.4	57.7
		76.5	37.8	23.3	61.0

obtained near the sidewalls in classroom ratios 2:1 and 1:1, away from the direction of the window. In classroom ratio 1:2 the lowest DF is found at the back of the classroom. The percentage of the room with DF above 2% is lower than 66% of the classroom area with 47% in the classroom ratio 1:2 (deepest classroom). The illuminance uniformity is 0.24 in the classroom ratio 1:1 and below 0.2 in the remaining rooms.

Figure 5 shows the DF with the big window (WFR = 25%). Comparing Figures 4 and 5 it is evident that the illuminance at the back of the classroom does not depend only on the height of the window head. It depends also on the area and the proximity of the window to the side walls. Due to more incident daylight on side walls, more daylight is reflected into the space. The back of the room is not further than twice the height of the window head (left image in Figures 4 and 5). The percentage of the room with DF above 2% is higher than 80% in the classrooms ratio of 2:1 and 1:1. The deepest room has a percentage of about 58% of DF above 2%. The illuminance uniformity in the latter is about 0.13 and in the remaining rooms it is 0.22 and 0.26, respectively (Table 6).

TABLE 5. Thermal load in Évora for different classroom ratio and orientation.

Classroom rate	Orientation	WWR (%)	Heating load kWh/m^2/year	Cooling load kWh/m^2/year	Total thermal load kWh/m^2/year
2:1	SE	23	14.5	26.6	41.1
		38.3	10.3	42.0	52.3
	S	23	12.6	25.3	37.9
		38.3	8.5	41.4	50.0
	SW	23	16.5	25.5	42.1
		38.3	12.8	39.9	52.7
1:1	SE	34.6	13.7	27.0	40.7
		57.7	9.8	42.8	52.6
	S	34.6	12.1	25.8	37.8
		57.7	8.1	42.5	50.6
	SW	34.6	15.8	26.0	41.8
		57.7	12.2	40.8	53.0
1:2	SE	45.9	13.5	27.3	40.8
		76.5	9.6	43.5	53.1
	S	45.9	11.8	26.1	37.9
		76.5	7.9	43.1	51.1
	SW	45.9	15.5	26.4	41.8
		76.5	11.9	41.4	53.2

FIGURE 4. The distribution of DF in the classroom with window to floor ratio of 15%.

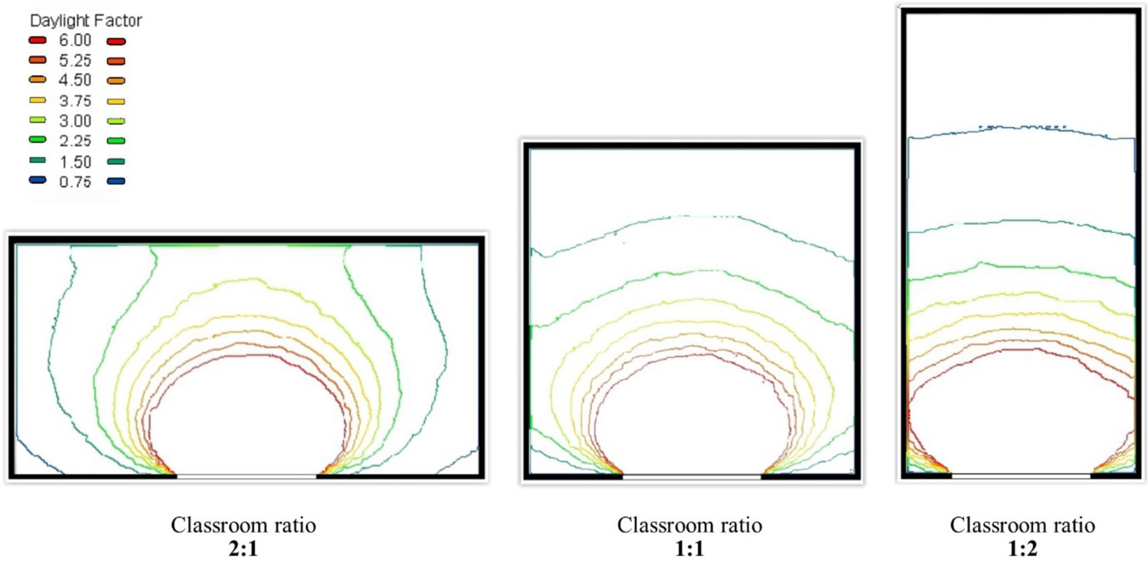


FIGURE 5. The distribution of DF in the classroom with window to floor ratio of 25%.

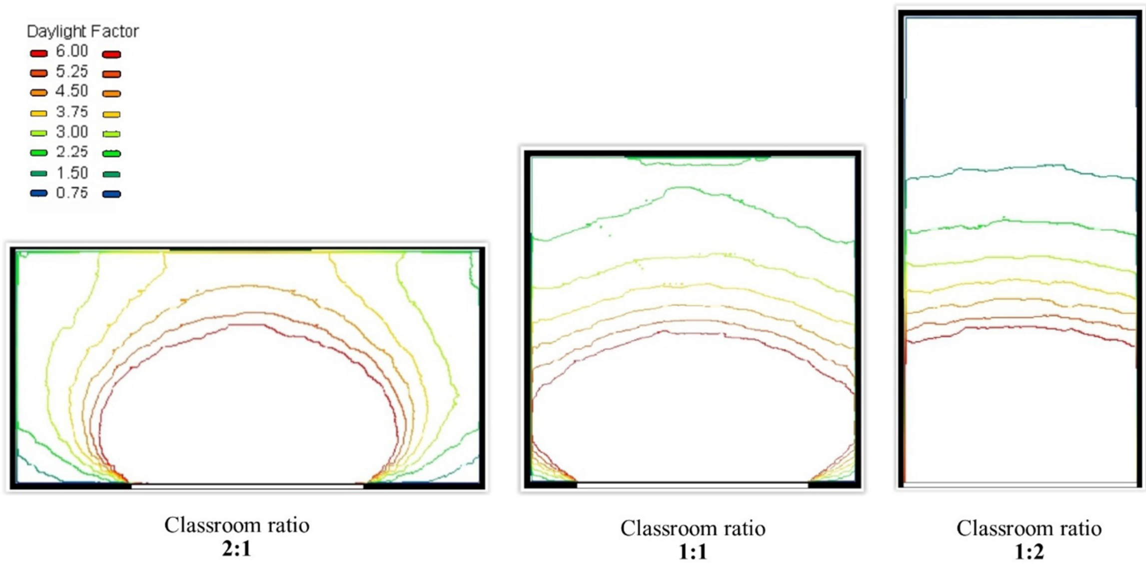


TABLE 6. Illuminance results for the different room ratios.

Room ratio	Window to floor ratio	Average DF	Illuminance uniformity	Above DF of 2%
2:1	15%	4.6	0.17	65.5%
	25%	7.6	0.22	98.8%
1:1	15%	4.5	0.24	61.5%
	25%	7.4	0.26	98.2%
1:2	15%	4.2	0.12	46.8%
	25%	6.4	0.13	57.9%

With respect to daylight, the investigation on the window to floor ratio of 15% was done on the classroom ratio of 2:1. This was the only studied geometry that had the back of the classroom properly lit. The window sill was set in a fixed position of 1.00 m above the floor. The window header was lowered by 0.1 m each time (Figure 6). In order to maintain the minimum required area, the window was enlarged at each step. At a certain point of the simulations, the head of the window could not be lowered more without darkening the back of the room. A minimum DF of 2% was never achieved closer to the side walls. The option was to split the window into two similar windows. With a window height of 1.80 m, 81% of the floor area had a DF above 2%, as it is shown in Figure 7. The average daylight factor is 4.69 and the illuminance uniformity is about 0.31.

FIGURE 6. Façade with alternative windows of same area.

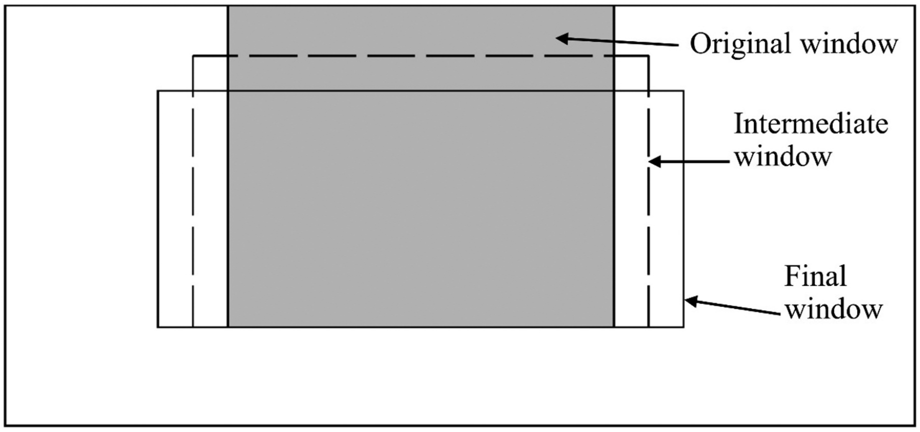
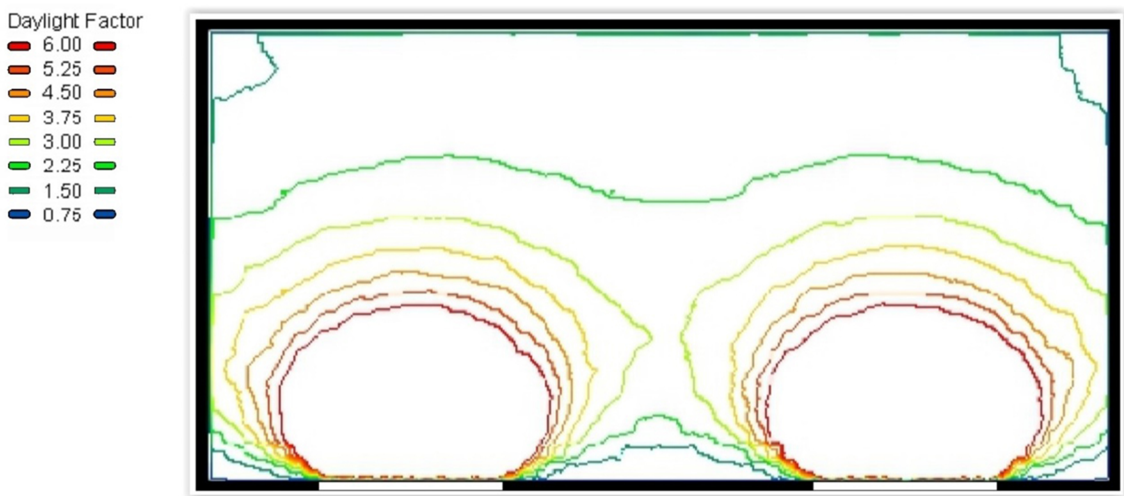


FIGURE 7. The distribution of DF in the classroom with two windows and a window to floor ratio of 15%.



When the classrooms were fitted with a bigger window (25% of the floor area), it was seen that the classroom ratio 1:2 (deepest classroom) was the only one that had lower levels of illuminance than 2%. The back of the enclosure was not properly lit, which means that a big window solely on one façade is not enough to provide daylight to the entire space. The classroom ratio 2:1 had a good illuminance level with a smaller window. The squared classroom with a 25% window to floor ratio may have its illuminance level above the minimum required. This illuminance level may be decreased in order to reduce the window area and therefore the thermal load. The investigation sought to determine to what extent the window could be reduced in in terms of the daylight requirements.

The window sill was set in a fixed position of 1.00 m above the floor and the head of the window lowered 0.1 m each time. Every desk/table should be 1.0 m from the walls. Therefore,

TABLE 7. Results obtained with a square classroom and a window to floor ratio of 22%.

	Orientation	Heating load kWh/m^2/year	Cooling load kWh/m^2/year	Total thermal load kWh/m^2/year
Bragança	E	36.2	21.9	58.1
	S	32.4	20.9	53.3
	SW	40.1	19.8	59.8
Évora	SE	10.5	38.4	48.9
	S	8.8	37.7	46.5
	SW	12.8	36.9	49.7

this closer zone to the walls may see its illuminance level values to be lower than 2% of DF, which defined the height of the head of the window. The area of the window based on the minimum DF was analyzed. As seen previously, the window had to be split into two similar windows and each placed near one of the side walls into order to provide enough illuminance level to that zone. The final window to floor rate was found to be about 22%, with a WWR of 48%, being 81% of the task level with DF above 2%. The average daylight factor is 6.65 and the illuminance uniformity is about 0.23.

New simulations were carried out to analyze the thermal load for this new window geometry factor. The reduction of the window area has also resulted in the reduction of the total thermal load of about 2–3% in Bragança and 6–8% in Évora. During winter, the heating load increased about 5–7% in Bragança and 5–8% in Évora. As the window area reduced so did the solar heat gains affecting winter and summer performance. The cooling load has decreased about 14–16% in Bragança and 10–11% in Évora. The overall results in each local climate and orientation respectively is shown in Table 7.

CONCLUSIONS

The geometry of the window and the classroom affects the thermal performance. Any change in the classroom dimension or percentage of the exterior wall that is transparent represents a new overall heat transfer coefficient of the classroom. The higher the overall heat transfer coefficient, the higher the heat transfer between the inside and outside environments. While the width of the exterior wall determines the area exposed to heat transfer through the façade, the depth determines the distance of daylight penetration. The dimension of the window determines the solar heat gain and the amount of daylighting that penetrates the classroom. This is also dependent on the orientation of the window, due to the incident solar radiation. The location of the window on the wall does not influence the thermal load of the enclosure. This depends only on the thermal properties of the building components. In turn, the daylighting of the interior environment is largely influenced by the geometry of the window and its location on the wall. Other assumptions may be withdrawn:

- Narrower rooms have a lower heating load, of about 4.1% less in Bragança and 6.1% less in Évora and a higher cooling load, of about 4.3%in Bragança and 3.3% in Évora on South orientation;
- The use of large windows enhances winter performance by about 22.8% in Bragança and 32.5% in Évora, but worsens summer performance by about 50.3% in Bragança and 39.3% in Évora on South orientation;
- There is an improved effect for the south orientation, which is the best performing in winter, however worsens in summer, due to higher solar gains of about 9.7% in Bragança and 13.6% in Évora;
- Shallow rooms have the best daylight distribution at the back of the room with a higher percentage of DF above 2%;
- More than one window on the façade brings higher levels of daylight to the zones near the side walls with an increase of DF;
- A higher illuminance uniformity was always obtained in a squared room.

Generally, in Portugal air conditioning is seldom used to cool down the air temperature. Therefore, to obtain indoor thermal comfort direct solar radiation must be blocked, however without compromising the quality of the daylight. Selective shading systems should be installed to improve summer performance without adversely affecting winter performance. These can be manipulated by the class room occupants to establish their level of comfort.

ACKNOWLEDGEMENTS

This work is supported by Portuguese national funds, namely FCT—Foundation for Science and Technology within the UID/ECI/04082/2013 project.

REFERENCES

Aguilar, J.O., J. Xamán, Y. Olazo-Gómez, I. Hernández-López, G. Becerra, and O.A. Jaramillo. 2017. "Thermal Performance of a Room with a Double Glazing Window Using Glazing Available in Mexican Market." *Applied Thermal Engineering* 119 (June):505–15. https://doi.org/10.1016/j.applthermaleng.2017.03.083.

Amaral, Ana Rita, Eugénio Rodrigues, Adélio Rodrigues Gaspar, and Álvaro Gomes. 2015. "A Parametric Study on Window-to-Floor Ratio of Three Window Types Using Dynamic Simulation." In *Energy for Sustainability 2015*, 7. Coimbra, Portugal.

"BREEAM New Construction: Non-Domestic Buildings." 2012. Code for a Sustainable Built Environment. BRE Global.

Carlos, Jorge S. 2016. "Sustainability Assessment of Government School Buildings in Portugal." *Architectural Science Review* 5 (59):413–22. https://doi.org/10.1080/00038628.2016.1167666.

Carlos, Jorge S., and Helena Corvacho. 2010. "Retrofit Measures in Old Elementary School Buildings towards Energy Efficiency." *Journal of Civil Engineering and Management* 16 (4):567–76. https://doi.org/10.3846/jcem.2010.63.

Crawley, Drury B., Linda K. Lawrie, Frederick C. Winkelmann, W.F. Buhl, Y.Joe Huang, Curtis O. Pedersen, Richard K. Strand, et al. 2001. "EnergyPlus: Creating a New-Generation Building Energy Simulation Program." *Energy and Buildings* 33 (4):319–31. https://doi.org/10.1016/S0378-7788(00)00114-6.

EN 12464-1. 2002. *Light and Lighting—Lighting of Work Places—Part 1: Indoor Work Places*.

Gasparella, Andrea, Giovanni Pernigotto, Francesca Cappelletti, Piercarlo Romagnoni, and Paolo Baggio. 2011. "Analysis and Modelling of Window and Glazing Systems Energy Performance for a Well Insulated Residential Building." *Energy and Buildings* 43 (4):1030–37. https://doi.org/10.1016/j.enbuild.2010.12.032.

Ghisi, Enedir, and John A. Tinker. 2005. "An Ideal Window Area Concept for Energy Efficient Integration of Daylight and Artificial Light in Buildings." *Building and Environment* 40 (1):51–61. https://doi.org/10.1016/j.buildenv.2004.04.004.

Grynning, Steinar, Arild Gustavsen, Berit Time, and Bjørn Petter Jelle. 2013. "Windows in the Buildings of Tomorrow: Energy Losers or Energy Gainers?" *Energy and Buildings* 61 (June):185–92. https://doi.org/10.1016/j.enbuild.2013.02.029.

Labayrade, Raphaël, Henrik W. Jensen, and Claus Jensen. 2009. "Validation of Velux Daylight Visualizer 2 against CIE 171:2006 Test Cases." In *Building Simulation*.

Lee, J.W., H.J. Jung, J.Y. Park, J.B. Lee, and Y. Yoon. 2013. "Optimization of Building Window System in Asian Regions by Analyzing Solar Heat Gain and Daylighting Elements." *Renewable Energy* 50 (February):522–31. https://doi.org/10.1016/j.renene.2012.07.029.

Ochoa, C. E., M. B. C. Aries, M. P. J. Aarts, E. J. van Loenen, and J. L. M Hensen. 2011. "Integrating Visual and Energy Criteria for Optimal Window Design in Temperate Climates." In *CISBAT 2011*, 589–94. Lausanne: J. L. Scartezzini.

Persson, Mari-Louise, Arne Roos, and Maria Wall. 2006. "Influence of Window Size on the Energy Balance of Low Energy Houses." *Energy and Buildings* 38 (3):181–88. https://doi.org/10.1016/j.enbuild.2005.05.006.

Susorova, Irina, Meysam Tabibzadeh, Anisur Rahman, Herek L. Clack, and Mahjoub Elnimeiri. 2013. "The Effect of Geometry Factors on Fenestration Energy Performance and Energy Savings in Office Buildings." *Energy and Buildings* 57 (February):6–13. https://doi.org/10.1016/j.enbuild.2012.10.035.

Tregenza, Peter. 2002. "Desktop Guide to Daylighting—for Architects." GOOD PRACTICE GUIDE 245. Sheffield: Environment Transport Regions.

Wen, Liwei, Kyosuke Hiyama, and Makoto Koganei. 2017. "A Method for Creating Maps of Recommended Window-to-Wall Ratios to Assign Appropriate Default Values in Design Performance Modeling: A Case Study of a Typical Office Building in Japan." *Energy and Buildings* 145 (June):304–17. https://doi.org/10.1016/j.enbuild.2017.04.028.

Zomorodian, Zahra S., and Mohammad Tahsildoost. 2017. "Assessment of Window Performance in Classrooms by Long Term Spatial Comfort Metrics." *Energy and Buildings* 134 (January):80–93. https://doi.org/10.1016/j.enbuild.2016.10.018.