Housing Policies and Urban Economics Vol.7 (Dicembre 2017), pp. 73 - 84

Daylighting and solar control in school environments

Monica Cannaviello[1]

[1]Università della Campania,
Dipartimento di Architettura e Disegno Industriale,
Via San Lorenzo 31, Aversa (CE),Italy
monica.cannaviello@virgilio.it

Abstract

The use of natural light, especially in school buildings, takes on a central strategic role for the well-being of the direct users of these spaces and the control of energy lighting performance of buildings. On the other hand, solar radiation on transparent surfaces, if not controlled, can cause an increase in energy consumption during the summer season. The Research investigates the conditions of natural lighting and solar control of the "Andreozzi" State Technical Institute, located in Aversa, Campania [IT].

Parole chiave: Daylight, solar control, School buildings, UNI 10840.

1. Introduction

The control of solar radiation through a transparent envelope represents one of the most complex design elements above all in the Mediterranean countries. In fact, the glass surface plays the difficult role of mediation among contrasting needs: reducing infrared radiation in summertime, exploiting solar gains in wintertime and optimizing the lighting transmission all year round. In summer conditions the solar gains can represent even 70-80% of the overall energy requirement. The lack of control of such gains results not only in high consumptions of primary energy for summer cooling, but it specially influences thermo-hygrometric and visual comfort conditions negatively (Cannaviello, 2017).

In this context, it is necessary to individualize opportune parameters of design control for sizing, positioning and choice of transparent components, aiming at optimizing the relationship among building, thermal radiation and daylight.

The paper illustrates the results of a research carried out on a school building located in Aversa, Campania [IT], to assess the comfort conditions in the classroom, in terms of natural lighting and solar control, through some indicators derived from the current regulatory and legislative framework.

2. Designing with natural light

Daylighting is the controlled flow of natural light, direct sunlight, and diffused-skylight into a building, not only in order to reduce the electric lighting consume, but also to improve visual comfort, which can be defined as subjective perception of the suitability of lighting taking into account various factors including uniform illumination, optimal light levels, glare, contrast, correct colors.

For existing buildings, however, the size and orientation of the transparent components is already given and generally cannot be changed, but it is still necessary to analyze the performance of the existing window system, in relation to the characteristics of the room in which it is located, to verify whether they are met not only the requirements of energy efficiency, but also those of thermal and visual comfort.

"The design control of lights is, therefore, necessary for the implications it has got on other aspects related to the quality of the architectural space: natural light is energy and direct solar radiation carries a heat component, combined with the light component; existing rules establish that it must be monitored and controlled quantitatively for a proper energy balance; but it is also a condition of psycho – physical wellness and visual comfort, linked with the quality of the natural light ray entering in a confined space. […].(James Thurber)" (Violano, 2006).

This concept open a new way of reconsidering the light as one of factors decisive for the quality of life.

The negative reaction of people spending their lives in an environment, partially or wholly illuminated by the artificial light, without an appropriate control of natural light, lead to psychophysical illness, because light affects a large number of psychological and physiological processes to determine actual dysfunctions in case of insufficient quality and quantity, whose manifestations are: demotivation, internal lag caused by the lack of perception of the passing of time, depression, frequent headaches, eye fatigue and blood pressure issues.
Therefore, the control of natural lighting conditions is especially important in a school environment.
Latitude, place topography, orientation of building facades, weather conditions, natural and artificial obstacles and reflection rate of surrounding surfaces are the most important characteristics for the management of indoor natural light (Björkstén et al., 2009).
The amount of natural light depends in turn on geometrical characteristics of the space considered and openings outwards, presence of any external obstacle and characteristics of transparent components (mainly the percentage of light transmission value).
In addition to formal-perceptive and technical-physical evaluation of light aimed at defining the quantity and quality of natural and artificial light, interpretation of contemporary architecture offers us an alternative approach, morphological-space type, in which the light is one of the elements of project (Bosco and Muzzillo, 2005).
A research[1] carried out on school buildings in Campania, has highlighted the lack of an adequate lighting design, particularly with regard to natural lighting.
The main parameter used to assess the ability of the transparent building envelope to provide adequate natural lighting conditions is the “average daylight factor” (FLDm) . The DM. 5/7/75 (according to the Ministerial Decree of 5 July 1975, concerning the minimum height and the main hygienic-sanitary requirements of the living quarters) imposed a minimum value to be satisfied for residential buildings, equal to 2%. For school buildings have been established, by the standard UNI 10840: 2007 – “School premises - General criteria for artificial and natural lighting”, higher minimum values.
The UNI/PdR 13:2015 standard on environmental sustainability in buildings, In area D, relating to indoor environmental quality, in relation to the visual comfort category, introduces the criterion: natural lighting. The performance indicator used to assess whether the requirement for natural lighting is met is the average daylight factor.
The calculation must be carried out for each room, in the absence of mobile shielding and considering only fixed shading, for each type of glass and room, according to the procedure described in Appendix A in standard UNI 10840.

[1]Research project: “Guidelines for the energy and functional requalification of school buildings in the Mediterranean area”. Financed by the Campania Region pursuant to Regional Law no. 5 of 2002.

3.Technical Regulation UNI 10840

From a quantitative point of view, the lighting design for a school building must refer to the Standards UNI 10840: 2007.
The lighting requirements set out in the standard must meet three main requirements:

- visual comfort;
- visual performance, i.e. the possibility for users (students/workers) to carry out their activities, even in difficult conditions and over a long period of time;
- health safety, i.e. the guarantee that the lighting does not adversely affect the health conditions of the students.

The standard sets out the general criteria for the artificial and natural lighting of classrooms and other school buildings, which guarantee the general conditions for wellness and safety of students and other school users and establishes the minimum values of the average daylight factor [FLDm] for the different school environments. This value will be higher if the task to be carried out in a certain room is long lasting and requires greater visual effort. The regulation also states that the natural lighting should be used to the greatest extent possible in order to favor the psycho-physical well-being of the occupants and reduce energy consumption.
The windowed surfaces must fulfill the dual function of allowing visual contact with the outside environment and achieving a satisfying distribution of the luminance in the indoor environment.
Considering educational activities carried out using audiovisual media, windows must, in addition, be equipped with total dimming systems. As previously mentioned, the illumination is calculated using the FLD indicator.
It is a ratio, expressed as a percentage, between the internal [natural sources] and the external light, measured on a horizontal plane that sees the whole sky but is shielded from solar radiation:

$$FLD = \frac{E_{in}}{E_{out}} [\%] \qquad (1)$$

Performing this calculation requires knowledge of the geometry of the internal environment [*including transparent openings*] and of the urban surrounding [*buildings, obstacles of other nature*]. Daylight Factors recommended for different environments and visual tasks:

Type of building	Environment	FLD
School, University	Classroom	2%
	Laboratory	4%
	Offices	1%

Table 1- Daylight Factors for different type of buildings and environment –Source: Technical Regulation UNI 10840 "School buildings- General criteria for artificial and natural lighting"

We need the **FLDm**, *Medium Daylight Factor*, defined by the regulation on the type of activity, in order to calculate this factor within the school environment.

Type of environment, field of vision or activity Scolar building	*FLDm*(%)
Middle School's Classrooms	≥3
Reading Rooms	≥3
Common Rooms and Auditorium	≥2

Table 2 - Minimum values of daylight factor in school premises - Source: Technical Regulation UNI 10840 "School buildings- General criteria for artificial and natural lighting"

we can use the formula referred to the simplified model of the environment in order to calculate the FLDm, reported in the standard:

$$\eta_m = \frac{(A_f \cdot t)}{(A_{tot} \cdot (1 - r_m))} \cdot \frac{E_{0v}}{E_0} \cdot \Psi \qquad (2)$$

Considering:

$$\varepsilon = \frac{E_{0v}}{E_0} \qquad (3)$$

we have:

$$\eta_m = \frac{(A_f \cdot t)}{(A_{tot} \cdot (1 - r_m))} \cdot \varepsilon \cdot \Psi \qquad (4)$$

in which:

E_{0v}= outdoor lighting of the vertical glass surface;
A_f= area of the window surface, excluding the frame;
t = glass light transmission factor;
ε = window factor, representative of the sky position from the window's center of gravity, equal to:

- 1,0 for horizontal window (skylight) without obstructions;
- 0,5 for vertical window without obstructions;
- < 0,5 for vertical windows with obstructions.

A_{tot}= total surface area of the environment delimitations;
r_m= average factor of reflection of surfaces of the environment delimitations;
Ψ= window factor reduction factor, obtained from the glass position and the wall thickness. It is obvious that a certain average daylight factor can change the perception of space by the observer.

4. Solar control of the transparent building envelope

In school buildings, the transparent envelope must also be designed with respect to solar control, especially in the Mediterranean area.
In the thermal balance of a building, in fact, in the summer season, the most significant energy contribution is represented by solar radiation.
In Italian school buildings, most of the environments and especially the classrooms have no summer air conditioning system. This means that the lack of control of the solar radiation entering the summer season, leads to overheating and negatively affects the thermal comfort, affecting the performance of the students.
To evaluate the solar energy that affects the glass surfaces of a building, it is necessary to know, hour by hour, the relative position of the sun with respect to the orientation and inclination of the windows. The value of the unit solar radiation depends on latitude, time of day, day of year and orientation.
To evaluate the amount of energy transmitted through a glass as a result of solar radiation, the most suitable indicator is the solar factor, a dimensionless quantity that identifies the ratio between the total flow of solar energy through the transparent surface and the flow incident on it.
D.M. 26/06/2015 Minimum requirements, implemented by Law 90/2013, which establishes the design constraints for nearly zero Energy Building, introduced a new parameter to evaluate the performance of the "window system". It is g_{gl+sh}total solar energy transmittance factor, which evaluates the combined performance of the glass with the possible mobile shielding system, calculated in July, when solar shielding is used. For important second level renovations and for energy rehabilitations, it is necessary to verify that for the transparent technical closures delimiting the air-conditioned volume outwards with orientation from East to West and South, the value of

the total solar transmission factor of the window component, when solar shielding is used $g_{gl+sh} \leqslant 0.35$ [1].

5. The Study Case of ITS Andreozzi

The ITS "Andreozzi", located on the northern outskirts of Aversa (CE) is the selected case of study. The building, which houses a technical high school, is developed on two floors.

Figure 1. The ITS "Andreozzi" of Aversa (CE)

The classrooms are displayed on the four main fronts, North – South – West - East.
The typical classroom measures 6.2 m x 6.35 m in plan, and the height is of 3,2 m.
The two adjacent windows are located on the only vertical outer wall and measure 2.16 m x 1.60 m each.

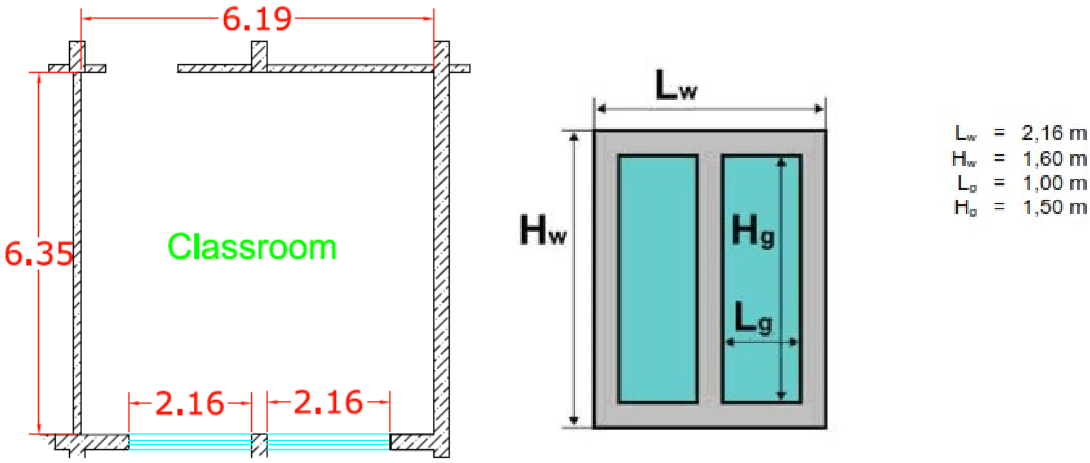

Figure 2. Typical classroom, plan and windows

The data used to calculate the average daylight factor for these classrooms are as follows:

A_f= area of window surface, excluding the frame: 6,0 (2,0 m x1,5 m x2) ;
t = 0,70 (typical clear, double-glazed, 4-12-4);
ε = 0,5 (vertical window without obstructions);
A_{tot}= 151,8 m^2(total surface area of the environment delimitations);

$r_m = \frac{\Sigma\, Si \bullet \rho i}{\Sigma\, Si} = 0{,}5$ (ρ = reflection factor)
Considering:

- light-coloured floor: ρ= 0,4
- upper floor with clear plaster: ρ= 0,6
- perimeter walls with medium-coloured plasterρ= 0,5

Ψ= 1.
Considering:

- p= wall thickness= 0,30 m
- h= window height = 1,6
- L= window length =2,16 m x 2= 4,32 m

L/p= 14,4 h/p = 5,3

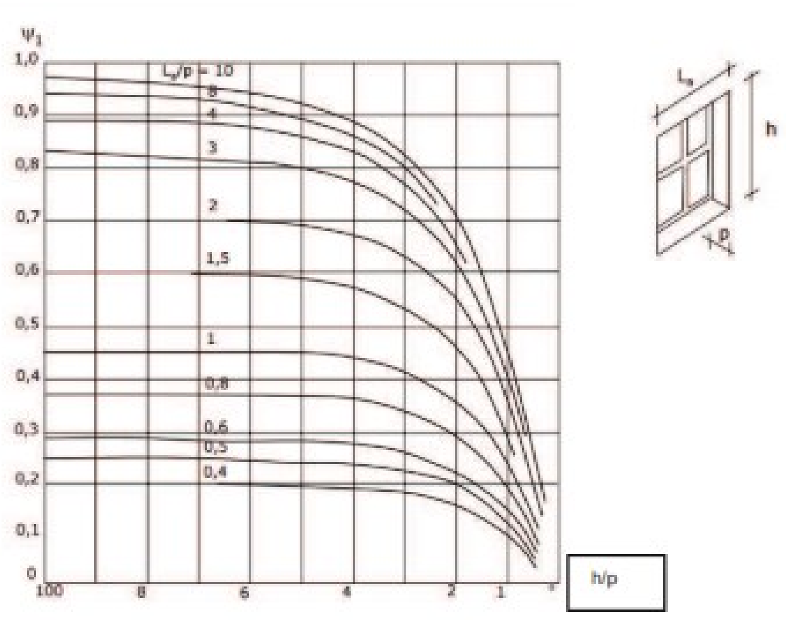

Figure 3. Vertical opening reduction factor - Ψ

So we have:

$$\eta_m = \frac{(6{,}0 \cdot 0{,}7 \cdot 0{,}5)}{(151{,}8 \cdot (1-0{,}5))} \cdot 1 \cdot 100 = 2{,}77\% \qquad (4)$$

The average daylight factor is therefore less than 3% (minimum value for classrooms and reading rooms set by the UNI 10840 standard). But this is not the only criticism found.

The classrooms analyzed have windows placed on one side only. This means that natural lighting decreases progressively as it moves away from the window.

Figure 4.One of the Classes with southern exposure

Other problems encountered, when analyzing (also through interviews with direct users) the conditions of visual and thermal comfort in the classroom, are those related to glare and summer overheating.

Glare is the visual sensation produced by surfaces of high luminance within the field of view and can be perceived as annoying (the direct one) or debilitating (the reflected one) glare. “In direct light areas, the sight clearly perceives the delineation of areas with higher luminance: it depends on margin (clearly distinguishable) and dimension (the larger the surface is directly illuminated, the greater the potential dazzle). The proper use of colours, materials and textures makes this physical condition an architectural quality perceived as static and immutable at time x and, on the other hand, variable and dynamic at different times of the day and in several months of the year.” (Franchino and Violano, 2017).

In the classrooms analyzed, it was found that the glare caused by direct solar radiation entering through the windows, because they are completely free of external shielding and the internal ones are absent or not functioning. “The envelope, in its alternation of opacity and transparency, determines the quality of the internal space and the use of appropriate internal or external shielding systems can orient, filter and modify the flow of natural light.” (Violano and Merola, 2018).

The energy performance of the window system in terms of solar control was verified using the Apollo 1 software[2]. This verification allowed to compare the performance of the window analyzed with the current regulatory standards set by the Ministerial Decree 26/06/2015.

[2] APOLLO is the software of the ANIT suite for the analysis of the transparent building envelope and for the control of the shading. The software is based on calculation models that comply with current standards and is aligned with the verification methods defined at national level by DM 26/6/2015.

The calculation carried out showed that the current window-system, consisting of a clear double glazing (4-6-4) without any type of shielding, does not meet the requirements of the law ($g_{gl+sh} \leqslant 0.35$), because $g_{gl+sh} = 0{,}743$.

Energy performance of the window				
	Geometrical data	**Thermal Trasmittance**	**Total solar transmittance**	**Total solar transmittance with shading**
Frame	A_f= 0,46	U_f= 7,00 W/m²K		
glazed surface	A_g= 3	U_g= 3,28 W/m²K		
glass-frame joint	L_g= 10	ψ_f= 0,02 W/mK		
TOTAL	**A_w= 3,46**	**U_w= 3,83W/m²K**	**g_{gl}= 0,743**	**g_{gl+sh}= 0,743**

Table 3 - Energy performance of the window in terms of thermal trasmittance and solar control

This causes significant problems of overheating, especially in the summer season, causing thermal discomfort.
The newspapers attached to the glass are a clear manifestation of need!

5. Conclusions

The use of natural light in school buildings is very important because it affects the visual comfort and performance of students and other users. It also affects energy consumption for artificial lighting. "Only in the event of a lack of natural light, the artificial light design must provide for the fulfilment of the requirements of uniformity, colour rendering and "colour temperature" close to the natural one, the luminous flux must be able to be regulated in direction and intensity, and must not be harmful to health (no fluorescent lamps) (Violano and Merola, 2018).
However, it is believed that the design of the window system cannot be done solely on the basis of natural lighting, but must also take into account the problems of solar control.
The research has shown that, although the average daylight factor is a useful parameter, it is not sufficient to assess the natural lighting conditions in a school environment.
In the case study analysed, not only is the average daylight factor not guaranteed, but the absence of shielding on the windows causes major problems in terms not only of glare but also of overheating.
Solar control is a very important aspect, which cannot be neglected, especially in a school building, and must be addressed together with natural lighting. The verification

of the solar factor of the window + shielding system can therefore be of support in planning the renovation intervention, and also allows to verify the compliance with legislative requirements.

References

Cannaviello M., (2017). “Daylight vsSunlight:Technological Design Strategies”. In: SMC – SustainableMediterranean Construction, n.5/2017ISSN:2420-8213

Violano A. (2006), Il “Lighting and Thermal Method” per la valutazione metaprogettuale delle prestazioni energetiche degli edifici. in Metodi, Modelli e Tecnologie dell'informazione a Supporto delle Decisioni. Procida (NA), 28-30 settembre 2006, RCE Edizioni, Napoli

Björkstén K. S., Kripke D. P., Bjerregaard P., (2009) “Accentuation of suicides but not homicides with rising latitudes of Greenland in the sunny months”. In: BMC Part of Springer Nature, BMC Psychiatry, 2009.

Bosco A., Muzzillo F., (2005) “La luce naturale. Criteri di valutazione per un materiale immateriale”. In: Franchino R. (a cura di), Materiali e prodotti per il controllo della qualità in edilizia, Vol. 2, Alinea Editrice, Firenze

Franchino, R., Violano, A. (2017) Re-searching Light and Space for Art. In: SMC– Journal of Sustainable Mediterranean Construction, N. 5/2017; pp.40-46, ISSN:2420-8213

Violano A., Merola M. (2018). La scuola inclusiva: criteri di progettazione tecnologica “oltre l’aula”. In: Fumo M., Ausiello G., Buanne M. (a cura di), Verso una scuola resiliente, Atti del Convegno, Napoli, 31 maggio-01 giugno 2018, Luciano Editore, Napoli (ISBN: 978-88-6026-244-8, pp. 237-249).