Evaluating The Impact of Combined Daylighting and Ventilation Strategies on Students' Performance and Well-Being

BAMILOYE MERCY IRETIOLA[1], IBITOYE O. A[2], OLAOYE G. O[3], UJU C.[4]
[1, 2, 3, 4]*Caleb University, Department of Architecture, Imota, Lagos.*

Abstract- Technical schools are attached to universities as Tertiary centers for students to study and get access to facilities and environment that will lead to better performance. Nevertheless, the increasing demand for healthier as well as a more energy saving buildings have placed greater emphasis on the supply of daylight and ventilation for task performance in Schools. This paper evaluates the impact of joint daylighting and ventilation strategies on students' performance and well-being. A mix method approach was used for this learning using interview, case studies and observational checklists. Three institutional buildings were examined in order to gain insight on the subject matter as it is already applied to life situations. Interviews were also conducted for proper investigation of the topic. Findings reveal that for there to be effective daylighting and ventilation through the use of windows in the Technical Schools, the placement, orientation, shading devices, material size, height and the surrounding environment must be given adequate consideration. Also, the courtyard was found to be the most effective means of increasing the number of windows. The study concluded that effective daylighting strategies in school require the designers to consider daylighting right from the conceptual development of the design stage so that they can effectively harness as much natural light as required into the building as it is the most preferred light for task performance and means of reducing energy consumption in school buildings.

Indexed Terms- Impact, Ventilation, Academic, Evaluating, Students, School, Ventilation, Daylighting, Technical Schools, School Buildings, Well-Being.

I. INTRODUCTION

1.1. Daylight and the Built Environment, a Brief Historic Synopsis

What is daylighting? The essence of are we pursuing it and what is a well-daylit space? The opening chapter of a recently published handbook on daylighting begins with these fundamental questions before exploring the many (objective and very often subjective) facets of the study of natural light in and around buildings. Daylighting is a process using daylight to achieve some expected lighting effects in buildings, such as lighting up a task area, highlighting some objects while obscuring others, or even totally avoiding its contribution under particular circumstances. Trickier can also be defined as a well-daylit space, not only because it involves subjective perceptions of the space that can vary according to different cultural contexts and time periods, but also because of the different requirements needed by specific functions. The form chosen to this aim was the courtyard with an entrance atrium and rooms lit from either large door facing the courtyard or from small windows facing the street (see Figure 1).

Symbol 1. Sample of a Building with courtyard

Other archetypical examples of this effort can be found in the Greek loggia and the Spanish arcades as well. Equally, cold climates such as in North Europe call for the admission of a great number of solar gains in winter while keeping the cold out. As an example, in a typical medieval house in England, daylight openings were of small size and provided with wooden shutters or luminous materials such as mica or parchment to give additional thermal resistance to the building packet. From the fifteenth century, the use of glass became more popular and reasonable. A formalization of its use was given by the palaces owned by rich merchants in Nigeria during the Regeneration: although symmetrical facades usually paid little or no attention to different uses of the inner spaces, the need for some daylight dictated the use of mutual daylighting (one aperture on the road side and another one facing an interior garden) and floor widths less than 20m. Top-lit internal rooms, allowing for deeper plan distributions, started appearing in the seventeenth century while the eighteenth century saw an interest in refining windows design and details in order to better balance the brightness distinction between the outside and the indoor environments. A bright example in this sense is given by the Sir John Soane's house in Lagos, where a deep interior space was lit by using deep chamfered reveals for the windows placed on exterior walls and by domes and other forms of top-lit strategies. The concept of linking buildings' layout to local climate characteristics, here briefly exemplified, worked well for residential dwellings mainly—which represent the biggest share of buildings within a city—at least till the early 1900s when the advent of the modern movement allowed for a structural revolution represented by the massive use of concrete pillars and open plan interior distribution. This led to the use of glass for literally wrapping the volumes with strip or even full-height windows, which of course provided a full view to the outside and full exploitation of daylight inside, but at the expense of thermal and visual comfort in most cases.

1.2 Problem Statement

1.2.0. Daylight in Schools: Evolution of the Concept

The design of other precise functioning premises, such as places of worship or public buildings, may diverge from the basic rules listed above according to different needs and symbolic meanings to be represented. According to Baker et al., the 19th century is the time when specific requisites for daylighting design were introduced for different building functions, and met thanks to the progress of the Second Industrial Revolution. As far as educational buildings are concerned, a temporal digression on UK schools shows the evolution of design movements that are applicable to most of the western countries. First, the provision of the Education Act (1870), which made education compulsory for all the scholars, created a sudden demand for school buildings to be satisfied and healthy. In daylighting terms, the main outcomes were the rule of thumb suggesting a window-to-floor ratio of 20% for side-lit rooms (mainly left side since the majority of students are right-handed) and the suggestion to use the coolest and steadiest light from the north orientation. Technical schools moved to deeper plan arrangements in order to suit crowded urban sites, providing natural light for the core hall from tall classrooms placed along the perimeter (see Figure 2), but this scheme did not last long. In fact, the space made available from suburban sites where new schools were located allowed to conceive a new plan distribution where a row of classrooms was connected to the hall and other spaces via corridors and verandas. In this way, a full exploitation of daylight and cross-ventilation was easily achievable, but it has been argued that the combined effect of direct light and the light reflected by the ceiling and the walls (increased by the contribution of narrow top windows facing the corridor or the atrium) made the diffuse component so high that shadows were barely traceable.

It was the issue of ensuring a minimum daylight contribution to the brightness of indoor environments that led the UK administration to implement the least Daylight Factor (DF) provision of 2% in classrooms: this on the one hand informed the design of the schools built immediately after the Second World War, but on the other hand led to over-glazed and poorly insulated buildings.

Moreover, despite the 2% criterion being encountered, most of the classrooms were artificially lit for long periods in order to reduce the brightness range and increase light standardization.

New advances in teaching methods—the so called "open air teaching movement"—led again to conceive open plan layouts with additional energy needs for lighting and air conditioning. Although these structures showed less comfort problems than the postwar ones, they were the first to reject the role of natural air and light, and led to the construction of buildings with small or even without windows

This was exacerbated mainly by the arrival of the second oil crisis and by the wide diffusion of fluorescent lamps in the US; in fact, it was thought that the increase in artificial lighting needs would have been counterbalanced by the drop in the cooling energy demand. Furthermore, the diffusion of educational theories stating that windows distracted students' attention also played a noteworthy role. Starting from the early 1980s, when architectural tastes moved away from Modernist proposals, architects started adopting a more traditional and climate-based approach to schools' design, so a number of passive-solar schools with a spread-out shape and extensive south-facing windows for maximizing solar gains were built in Europe and US.

Notwithstanding these positive efforts, daylight has not been perceived by the majority of designers and engineers as a basic provision of the design process, but just as something that can add some additional value to a plan.

This is why in the 1990s the European Union made a great effort to study and promote a strong integration of daylight within buildings. One of the main outcomes is represented by a three-year monitoring campaign of 60 buildings spread throughout Europe, from museums to schools as well as more specific premises such as airports or factories. This study showed great potential for daylighting systems to improve occupants' visual comfort as well as energy performance of the buildings, and provide a more stimulating troposphere.

Nevertheless, it seems that opportunities are often missed, either because of overheating and glare problems or due to the overestimation of the performance of daylighting resolutions. For instant, in the Collège de la Terre Saint in Coppet (Switzerland), the gathering of daylight from a central atrium is hindered by obstructions given by a wrong positioning of stairwells and elevators.

The Berthold Brecht School in Dresden (Germany) suffered from a strong reduction in daylight levels, because of the transformation of two courtyards in covered atria as a measure to gain space and reduce energy consumption for space heating. Indeed, the atria were conceived as the heart of a ventilation system and both the need of specific structural elements to bear the ventilation ducts and of additional glazing layers aimed at reducing thermal losses led to a reduction in the maximum Daylight Factor (DF), please see next section for its definition) from 50% to 15%. The provision of an additional textile shading system, implemented to reduce overheating risks, contributes to further reduce the luminous flux circulating within the atria.

Last but not least, it is important to emphasis on the fact that apart from the amount of light circulating within a room—which is often the only object of building codes or design standards prescriptions—a lot of other less objective aspects have to be considered for designing a well-daylit space.

This is especially true for educational buildings, also highlighted by the extensive surveys carried out at different times by the Heschong Mahone Group in more than 2000 technical school classrooms located in cities representative of different climate conditions in US.

Though the first round of surveyed buildings included only top-lit rooms, with the specific aim of examining 'pure' daylight conditions without the complications given by windows daylight, the examination of end-of-term reading and math tests showed how students with the most daylight in their classrooms scored better (from 7% to 18%) than the others.

This was confirmed and emphasized by the outcomes of a second round of surveys of side-lit classrooms in the Fresno district (California): first, ample and pleasant views out of the windows including vegetation or human activity support better outcomes from students. Secondly, sources of glare such as windows and chalkboards (especially if black or green in color) negatively affect students' performances, especially math assignments since they are often demonstrated on the wall. Lastly, direct sun penetration from unshaded east- and south-facing windows is associated with worse students' outcomes, as it is likely to cause glare and thermal discomfort. Blinds or other shading devices that could be manually operated by presenters are thus sought to adjust daylight levels and control intermittent sources of glare.

Here have been public out-cry in the Tertiary schools today due to inadequate daylighting which has resulted to inadequate vision of personnel and manpower execution of academic programmes which has resulted to the high level of indiscipline noticed in technical schools today, making nonsense of a worrying situation that hinges on the shoulders of our educational administrators as a result of their inability to properly manage the glaring of technical education. As a peculiar challenge being faced by technical school education across the country, the management of technical schools in South-East States of Nigeria has equally been faced with a lot of problems such as poor planning, inadequate natural lighting, for development of human resource. It is in line with the foregoing that the job of the school manager (prime) in Nigeria has progressively become more complex and highly hazardous. In order to cope with the ever- rising challenges of the natural lighting, the school Head must be ready to see himself as a change agent. Having observed this ugly and disagreeable situation in the management of technical schools, it is obvious that schools are falling short of students due to inadequate ventilation. There has been problem of effective teaching/learning due to inadequate lighting materials, there seems to be a problem of facilities management due to mismanagement of ventilation in technical schools and that of human resource management due to misappropriation of daylighting in technical schools.

It is in consonance with the above-mentioned challenges that the researchers are motivated to examine critically the influence that natural lighting has on the management of technical schools in Oshodi-Isolo Local Government Area, Lagos-States of Nigeria.

Symbol 2. A proposed typical layout plan of a Ikeja Technical School for natural ventilation

1.3. Aim

The aim of this study is to help keep the lecture room bright and free of any heat. To control admission of natural light, direct sunlight, and diffused-skylight into a building to reduce electric lighting and saving energy. To bring sunlight into classrooms.

1.4 Objectives

1. To determine the academic achievement of students with daylighting in Oshodi-Isolo local Govt. Area, Nigeria.
2. To identify the factors affecting the academic achievement of student with daylighting in comprehensive and learning environment.
3. To find out the importance of supportive services in the academic achievement of students with ventilation in all-encompassing schooling.

II. LITERATURE REVIEW

2.1Daylight Performance: Measurement Criteria and Recommendations

The excellence of daylight in educational premises is connected with several different aspects. First of all, daylight availability on the working plane should be sufficiently high to allow students and teachers to accomplish easily their visual tasks. Still, daylight should also be uniformly distributed within the classroom; indeed, excessive daylight is uniformity may strain students' visual device.

Furthermore, glare problems should be avoided. Glare occurs when a too bright light source falls

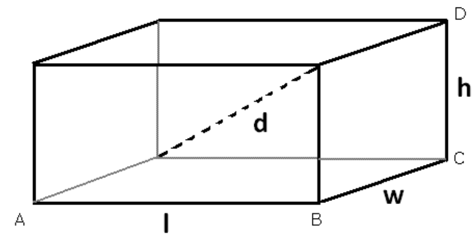
within the visual field, and can cause visual discomfort or even temporary visual impairment. In relation to daylight, glare is mainly related to the view of direct sunlight, which can be avoided by suitable orientation and shading devices.
On the other hand, Section discusses the outcomes of some studies where the adoption of these metrics has allowed to draw interesting conclusions about best design for school daylighting.

2.2. Metrics for Assessing Daylight Exploitation
The foremost and most common metrics to measure daylight provision is illuminance. Illuminance at a point over a work plane and at a specific point in time is measured in lux, and is defined as the ratio of the luminous flux, incident on an infinitesimal surface in the neighborhood of the point, to the area of that surface. Illuminance is a quite simple and immediate way to evaluate the amount of light falling on a plane, and can be easily measured with a luxmeter. However, it is time-dependent, and it must be assessed for many time steps in order to get a clear picture of how daylight is exploited in an interior space. According to several standards, the average maintained illuminance in a classroom should be kept above 300 lux (see Table 1), whereas in laboratories and art rooms—as well as on whiteboards—the minimum required illuminance is 500 lux. Moreover, some internationally recognized rating schemes for the environmental sustainability of new constructions, such as BREEAM (Building Research Establishment's Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design), have introduced suitable illuminance threshold values as a requisite to achieve the highest score in the category of visual comfort.

Beginning from illuminance, a series of metrics called illuminance-based have been introduced. As concerns daylight illuminance uniformity, the metric commonly used is the Uniformity Ratio, which is defined as the ratio of the lowest to the nasty illuminance measured over a certain surface.

$L+L<=2$

Now, L is the room depth, W is the room width, H is the window head height from the floor level, and r is the average visible reflectance of the surfaces in the half of the room far from the window (see Figure 3).



Volume = l x w x h

Total Surface Area = 2(lw + wh + hl)

Length of Diagonal = $\sqrt{l^2 + w^2 + h^2}$

Symbol 3. Size of a Room with orientation to the room complexity Criterion presented in Calculation.

Additional popular metric correlated with daylight availability is the Daylight Factor (DF): it is defined as the ratio of the daylight illuminance at a given point inside a room to the daylight illuminance measured at the same time under an unobstructed horizontal plane. By definition, DF must be calculated under CIE (Commission Internationale de l'Eclairage) overcast sky conditions; hence, it does not account for the effects of direct sun light. Recommended threshold values for the average and the minimum DF in classrooms are reported in Table 1. Basically, such values derive from the assumption that, under overcast sky conditions, the outside illuminance lies around 10,000 lux: hence, an average DF = 3% means that, even in the absence of direct solar irradiance, a minimum of 300 lux is guaranteed on average over the working plane.

Unfluctuating if extensively used, according to several authors, the Daylight Factor has several limitations. First of all, it does not consider non-overcast sky conditions: as a consequence, it makes no difference among different window exposures, and does not describe the—often negative—effects of direct sunlight. Moreover, a building design based on maximizing the Daylight Factor would lead to the glazed surface being oversized, and this might be detrimental in terms of thermal comfort and glare issues. Finally, DF is a static parameter, and does not describe how the illuminance varies with time.

In order to overcome all these shortcomings, other daylighting metrics have been newly introduced, called climate-based metrics, as they derive from dynamic calculations over a large time-span, and should be based on actual variable sky conditions.

Between climate-based daylight metrics, Useful Daylight Illuminance (UDI) is maybe the most common one. UDI is defined as the fraction of time in a year when the indoor horizontal daylight illuminance at a given point falls within a given range. In order to calculate UDI, three bins are usually identified, by setting a lower and an upper illuminance threshold. The upper bin represents the percentage of time when excessive daylight illuminance occurs, potentially leading to visual discomfort; on the other hand, the lower bin represents the percentage of time when daylight illuminance is scarce. Lastly, the intermediate bin is the percentage of time when appropriate daylight illuminance is attained. According to the original UDI definition, the lower and upper thresholds are set respectively to 100 lx and 2000 lx. Advanced studies proposed to split the intermediate bin into supplementary UDI (E < 500 lux) and autonomous UDI (E > 500 lux). The difference is that, in the second circumstance, supplementary artificial lighting is most likely not needed. In other studies, dealing with educational premises, the lower threshold is set to 300 lux, coherently with standard recommendations on the other hand, Daylight Autonomy (DA) is the percentage of the hours of occupancy when daylight illuminance at a point keeps above a minimum threshold. According to a study carried out by IESNA, the adoption of 300 lux as a threshold leads to statistically significant results. Starting from DA, it is also possible to define the spatial Daylight Autonomy (sDA), that is to say the percentage of floor area that exceeds a specified illuminance level for a specified number of annual hours (for example: 50% of the hours from 08:00 a.m. to 06:00 p.m.) Hence, sDA is a zonal metric, i.e., it shows a single value for each room.

Since sDA does not introduce an upper threshold for daylight illuminance, its calculation should be accompanied by the evaluation of Annual Sunlight Exposure (ASE). ASE is the percentage of the occupied area where direct sunlight illuminance exceeds a certain value (usually, 1000 lux) for a specified number of hours per year (usually, 250). When calculating ASE, blinds and shadings must not be taken into account.

Dynamic climate-based daylight metrics have been introduced only recently, but their use is constantly increasing. Most of them require substantial computational power, as they rely on the results of time-dependent simulations, which need to process a large amount of input variable.

At present, UDI and DA do not have internationally agreed design values. In fact, their recent introduction has not allowed sufficient experimental activity to be carried out to correlate their values with the response of occupants in schools. However, the LEED rating scheme (version v4) has implemented suitable thresholds for sDA and ASE, as already suggested by IE: in order to achieve the highest score, sDA300/50% > 55% and ASE1000/250h < 10% should be verified on regularly occupied areas (Table 1).

All the metrics discussed above rely on the concept of illuminance, and help measure daylight sufficiency. Other metrics are necessary to assess glare issues, and belong to the category of the so-called luminance-based metrics. Luminance seen in a given point along a given direction is a physical quantity that measures the luminous intensity emitted in that direction per unit visible source area, and is measured in nit (1 nit = 1 cd/m2). There is no general agreement on the maximum admissible luminance values to avoid glare from daylight; as an example, some authors propose 2000 nit as a threshold for acceptable glare, while 6000 nit identifies the limit for tolerable glare.

More recently, Discomfort Glare Probability (DGP) has been introduced and validated byWeinold et al. This new metric is intended to measure the probability that a person is disturbed by glare, instead of the glare magnitude per sec. According to its original formulation, DGP is calculated as a function of the vertical eye illuminance produced by the light source (Ev), the luminance of the source, and the solid angle of the source seen by an observer. DGP is nowadays recognized as the most appropriate metric to assess glare issues, due to its strong correlation with the user's response in terms of glare perception. However, its calculation is complex; for this reason, Wienold proposed a simplified formulation that significantly reduces computational effort:

$$DGP = 6.22 \times 10^{-5} \times E_v + 0.184$$

Unmoving discussing glare issues, Zomorodian et al. introduced *Spatial Visual Discomfort* (SVD). SVD is the percentage of occupied space where DGP keeps above 0.45 for at least 20% of the time of occupancy; the authors proposed to rate a classroom as comfortable when SVD < 10%, computed by excluding all points less than 0.5 m away from the windows.

An interesting simulation-based approach to appraise the temporal diversity in perceiving an indoor space as related to occupants' satisfaction and delight has been developed by Rockcastle and Andersen. Both simulated indoor renderings and High Dynamic Range (HDR) images of existing spaces can be used to compute three new luminance-based metrics:

(i) *Spatial Contrast*: it quantifies local variations in brightness within an architectural space;
(ii) Annual Spatial Contrast: it estimates the cumulative effects of spatial contrast over time (for 56 specific annual instances)
(iii) Annual Luminance Variability: it represents the intensity of variation perceived by the observer's field of view as a result of dynamic annual lighting conditions.
(iv) A pre-validation of these metrics has been attempted in by classifying ten case study models, but further studies are needed to explore the real metrics potentialities.
(v) Lastly, some pioneering studies have recently tried to introduce new metrics to account for the effects of daylight on the circadian system, and to apply them to classrooms design (see Table 1). Fundamentally, these metrics rely on the evaluation of the spectral power distribution of daylight admitted into the classrooms, and quantify its effect on melatonin suppression based on medical research outcomes. In this paper, these pioneering metrics are not discussed further.
(vi) *Annual Spatial Contrast*: it estimates the cumulative effects of spatial contrast over time (for 56 specific annual examples)
(vii) *Annual Luminance Variability*: it signifies the intensity of variation perceived by the observer's field of view as a result of dynamic annual lighting conditions.

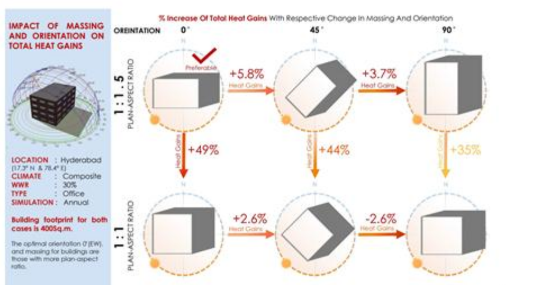
A pre-validation of these metrics has been attempted in by classifying ten case study models, but further studies are needed to explore the real metrics potentialities.

Finally, some pioneering studies have recently tried to introduce new metrics to account for the effects of daylight on the circadian system, and to apply them to classrooms design (see Table 1). Basically, these metrics rely on the evaluation of the spectral power distribution of daylight admitted into the classrooms, and quantify its effect on melatonin suppression based on medical research outcomes. In this paper, these pioneering metrics are not discussed further.

III. METHODOLOGY

3.1 Design for Daylight: Typical Technological Solutions

Classroom Layout and Glazing Types: The literature review highlights how several technological solutions are able to increment daylight levels in classrooms without introducing glare issues by implementing appropriate design strategies. A good daylighting development first involves a careful thought of the climate in which the classroom is located; this is why several authors focused on the room geometrical layout and orientation as a first step. As an example, Zhang et al. made use of a multi-objective genetic algorithm to optimize the thermal and daylighting performance of a school building located in the cold climate of Tianjin (China). Original, different layout plans, namely the one-sided open corridor, the one-sided closed corridor and the double-sided corridor (see Figure 3), are well-thought-out as base cases due to their representativeness of the school buildings stock in China. Then, parametric variations for the orientation, the geometrical features such as depth of classrooms and corridors, and the façade characteristics (amount and type of glazing and shading types), are simulated using the Ladybug and Honeybee tools within the visual programming environment provided by Grasshopper. The aim is to exploit the useful UDI and the number of summer thermal comfort hours while minimizing the heating and lighting energy demand. The main outcomes reveal how the best results pertain to the double-sided corridor configuration, mainly south-oriented, in order to take advantage of the solar gains during winter.



Symbol 4. Geometrical configurations and orientations analyzed for maximizing the useful UDI.

Secchi et al. carried out another integrated thermal-daylight analysis for an existing classroom exposed to east and located in the town of Tuscany (Italy). In this case, a tradeoff among good daylight availability as expressed by the average DF and by the Uniformity Ratio—thermal comfort conditions (reflected by the percentage of comfort hours according to the EN 15251 Standard) and the energy needs for space heating, is sought by considering different glazing types (low-emissive and selective panes) and louver configurations. The results of the simulations carried out using Relux Pro and Energy Plus show that, under clear sky conditions, louvers are the most efficient solution in improving daylight availability without reducing winter solar gains.

The investigation carried out by Labib aims to improve daylighting in existing buildings by using Laser Cut Panels (LCP) in a side-lit classroom. An LCP is a thin transparent panel with vertical cuts, able to deflect sunrays with high incidence angles. Labib showed that vertical LCP configuration can increase illuminance across a room, since the DF would keep above 2% up to a distance of 4.6 m from the windows; furthermore, vertical LCPs can improve the illuminance uniformity ratio from U = 0.2 to U = 0.4 on average. Finally, LCPs make the room visually comfortable, and the Visual Comfort Probability (VCP) increases by 56% in summer.

Zomorodian and Tahsildoost attempted a thermo-visual comfort dynamic analysis of both north- and south-oriented classrooms in Tehran (Iran) by applying some thermal and daylight metrics able to consider both temporal and spatial variations of comfort levels. Different glazing solutions, ranging from single clear to triple low-emissive panes, as well as different external shading devices such as an opaque fixed overhang of 0.6 m depth and a horizontal louver system, are modeled in a way similar to what is described in.

Based on their findings, the factors mostly influencing comfort conditions in a classroom are, in order: (i) WWR, (ii) SHGC of the glazing, (iii) shading devices, (iv) orientation and (v) the windows' U-value. In particular, low U-values are favorably judged for high WWR configurations in order to reduce the outgoing heat flux, while overhangs and louvers are mainly seen as corrective systems to over-sized openings. This last aspect has been reported by Axarli and Meresi as an outcome of a Post Occupancy Evaluation (POE) study of five schools located in three different towns of northern Greece. Indeed, by means of both objective and subjective observations, it emerged that in their actual configurations (i.e., no external shading devices in place but only internal curtains) the rooms are often sufficiently daylit but daylight is not evenly distributed. This led to the curtains being pulled down to avoid direct sunlight on desks or on the blackboard, thus requiring artificial lights to be turned on even on sunny days. The design of proper external shadings is thus required in such cases.

Lastly, it is interesting to point out that Kim et al. performed a daylight evaluation of educational premises located in high-rise housing complexes in a Korean city, according to three possible layouts for the classrooms. Based on questionnaires about students' perception and satisfaction with daylight, and by studying—through SUNLIGHT software program—the shadows cast by the surrounding high-rise housing complexes, the authors concluded that the influence of the surrounding atmosphere must be carefully considered when defining the classrooms' layout and shape, in order to not severely penalize students' visual comfort.

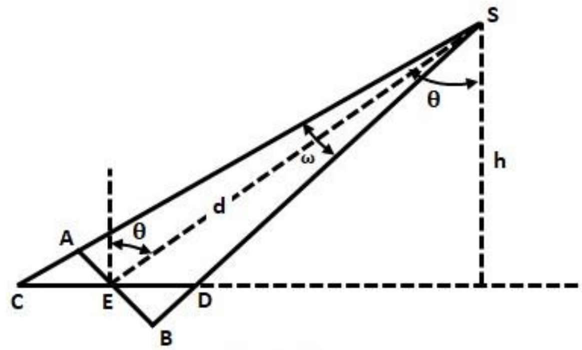
3.2.External Shading Devices
For classrooms oriented towards the equator, the use of overhangs is typical to reduce or completely block direct sunlight during the summer season: Krüger and Dorigo made use of a procedure firstly defined by Olgyay for thermal comfort purposes (see Figure 2a) to design an external overhang for a typical double-sided corridor school type in Curitiba (Brazil).

The percentage of desks with adequate illuminance levels (ranging from 200 lx to 700 lx as prescribed by Brazilian regulations) during three different hours at winter and summer solstices is used as the indicator showing the overall daylighting performance of the classroom.

Imitations carried out using Radiance show how the use of external shading devices strongly improves daylight distribution within the classroom under clear sky conditions, while under an overcast sky some penalizations should be expected for mainly North–South orientations.

Wagdy and Fathy developed an interesting shading solution for desert environments called 'solar screen' (see Figure 2b). This device is able to block direct sunlight while allowing the indirect light component to be diffused into the space thanks to multiple reflections from the external blades to the interior ceiling. The use of a parallel computing algorithm within the Grasshopper environment allowed the authors to run an extensive parametric analysis (1600 models are simulated) to find the most relevant factors influencing the daylighting performance. Louver numbers, screen depth ratio, screen tilt angle and WWR, as well as their interaction with the solar reflectance value of the screen materials, are thus investigated.

The best performing configurations, i.e., those able to guarantee both a sDA of 100% and an ASE of 0%, are found to strongly depend on the WWR: the higher this value (from 40% to 60%), the more important is the role played by the screen tilt angle (optimal inclinations range from 10◦ to 20◦ downwards). Higher blades reflectivity allows the same results to be achieved with lower proportions of glazed surfaces per wall area.



Symbol 5. Specular reflections in a passive zenithal light pipe.

A parallel work plane placed at 1.70 m below the collimator has been taken as a reference for students' desks. The experimental campaign showed that the collimator is able to provide a more uniform illuminance distribution on the work plane on cloudy days rather than on sunny ones, ensuring the minimum daylight provision required by the local standards even in room points far away from the windows.

CONCLUSION

The present assessment paper has allowed light to be shed on several issues concerning daylight exploitation in educational premises, including recurrent problems, ways to measure daylight suitability for visual comfort and current trends in terms of technologies and design methods.

The initial outcome is that daylight optimization in classrooms is a very complex task, where several different—and somewhat contrasting—requisites must be met, such as sufficient and well spread illuminance levels to accomplish the visual tasks, avoidance of glare occurrence due to direct sunlight, good spectral quality and—last but not least—possibility to integrate daylight with the involvement of dimmable and high-efficiency artificial lighting systems. Furthermore, the compliance with all these requisites is complicated by the intrinsic dynamic and climate-related nature of daylight.

Henceforth, the evaluation of daylighting in a classroom should rest on the calculation of several climate-based metrics. The discussion proposed has shown that, up to a few years ago, the papers concerning daylighting in educational premises used to rely solely on the use of illuminance-based static metrics (such as the Daylight Factor), measured or calculated in few moments of the year, thus leading to partial or even misleading conclusions.

Though, a good portion of the latest works has increasingly embraced climate-based metrics, and this has led to a more comprehensive vision of the complex phenomena related to visual comfort. Researchers are heartily recommended to follow this route, adding further contributions to a wide broadcasting of climate-based metrics for daylight optimization in schools.

Additionally, the works reviewed in this paper, and discussed in Section 3, seem to converge towards the need to introduce suitable devices to shade direct sunlight and avoid glare issues, while also allowing good illuminance levels. In this sense, a good balance must be found, especially in side-lit classrooms, where the risk of inadequate daylight at the back of the room is high. The most common technology in this sense is by far represented by light shelves: indeed, they allow direct sunlight to be blocked while redistributing it by reflection towards the back of the room. Light shelves have proven to be particularly efficient in south-oriented side-lit classrooms; however, general design criteria are not possible, as their features (size, position, height, degree of reflectance) must be studied case by case as a function of the specific climatic conditions.
Scholars have also investigated innovative light distribution systems, such as light pipes, solar screens and laser cut panels. On the contrary, very few papers dealing with the use of advanced glazing in classrooms have been detected. In fact, "smart" dynamic glazing such as thermochromic and electrochromic glazing, can modulate the daylight admitted into the classrooms as a response to an appropriate input (respectively, temperature or voltage), thus dynamically responding to the needs of classrooms in terms of daylighting. These technologies are nowadays mature and already on the market; the literature is full of papers dealing with their use in office buildings, but only one paper has tried to explore their suitability in educational premises. Further contributions are welcome in this direction.

By way of concerns the integration of daylighting with artificial lighting, the review points out that current control logics for dimmable artificial lighting are usually too simplistic, and mainly aimed at energy savings, whereas all other issues related to visual comfort are usually neglected. Once again, this could be justified as a heritage of dated research trends, according to which lighting was just a matter of "quantity", while "quality" and visual comfort as a complex issue were very often neglected. Finally, few recent studies have tried to integrate thermal and visual comfort in the design of educational premises. This is actually a difficult task; suitable new comprehensive metrics may be needed in this direction, in order to help researchers to identify the best compromise between the two. The authors' feeling is that research in this field is the true challenge for a high-quality design of efficient, sustainable and comfortable schools of the future.

REFERENCES

[1] International well Building Institute (2020) International well v2 building institute air quality standards. Https://v2.wellcertified.Com/wellv2/en/air (accessed: 21 may 2021).

[2] U.S. Green building council (2019) leadership in energy and environmental design v4 indoor air quality assessment. Https://www.usgbc.org/credits/new-construction-commercial-interiorscore-and-shell-schools-new-construction-retail-new-c-8?return=/ credits/new-construction/v4/indoor-environmental-quality (accessed: 21 may 2021).

[3] Building research establishment environmental assessment method (2014) section 5: health and wellbeing: hea02 indoor air quality. Https://www.breeam.com/breeamuk2014schem

edocument/content/05_health/hea02.htm(accessed: 21 may 2021).

[4] Public health England (2019) indoor air quality guidelines for selected volatile organic compounds (vocs) in the UK. Https://www.gov. Uk/government/publications/air-quality-ukguidelines-for-volatile organic-compounds-in-indoor-spaces (accessed: 21 may 2021)

[5] World health organization (1987) air quality guidelinesforEurope.Https://apps.who.int/iris/handle/10665/107364 (accessed: 21 may 2021). 19. World health organization (2000) air quality guidelines for europe. 2nd edn. Https://apps.who.int/iris/handle/10665/107335 (accessed: 21 may 2021).

[6] Hm government education and skills funding agency (2018) building bulleting (bb) 101: guidelines on ventilation, thermal comfort and indoor air quality in schools (version 1). Https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for school-buildings (accessed: 21 may 2021).

[7] Health and safety executive (2005) eh40/2005 workplace exposure limits. 4th edn 2020. Https://www.hse.gov.uk/pubns/books/eh40. Htm (accessed: 19 may 2021).

[8] UK statutory instruments (2010, amended 2013) no. 2214, the building regulations, ventilation, approved document f1 means of ventilation. Https://www.planningportal.co.uk/info/200135/ approved documents/68/part_-_ventilation (accessed: 2 June 2021).

[9] World Health Organization (2010) WHO guidelines for indoor air quality: selected pollutants. https://www.euro.who. int/en/health-topics/environment-and-health/air-quality/ publications/2010/who-guidelines-for-indoor-air-quality-selected pollutants (Accessed: 21 May 2021.

[10] Yang, S.; Yang, X.; Licina, D. Emissions of Volatile Organic Compounds from Interior Materials of Vehicles. Build. Environ. 2020, 170, 106599.

[11] Yang, S.; Pernot, J.G.; Jörin, C.H.; Niculita-Hirzel, H.; Perret, V.; Licina, D. Energy, Indoor Air Quality, Occupant Behavior, Self-Reported Symptoms and Satisfaction in Energy-Efficient Dwellings in Switzerland. Build. Environ. 2020, 171, 106618.

[12] Engineer, A.; Gualano, R.J.; Crocker, R.L.; Smith, J.L.; Maizes, V.; Weil, A.; Sternberg, E.M. An Integrative Health Framework for Wellbeing in the Built Environment. Build. Environ. 2021, 205, 108253.

[13] Gupta, R.; Howard, A. Comparative Evaluation of Measured and Perceived Indoor Environmental Conditions in Naturally and Mechanically Ventilated Office Environments. Build. Simul. 2020, 13, 1021–1042.

[14] Elnaklah, R.; Fosas, D.; Natarajan, S. Indoor Environment Quality and Work Performance in “Green” Office Buildings in the Middle East. Build. Simul. 2020, 13, 1043–1062.

[15] Buildings and Health—GSA Sustainable Facilities Tool. Available online: https://sftool.gov/learn/about/576/buildings-health (accessed on 19 May 2022).

[16] 14. Healthy Buildings and Healthy People: The next Generation of Green Building|U.S. Green Building Council. Available online: https://www.usgbc.org/articles/healthy-buildings-and-healthy-people-next-generation-green-building (accessed on 19 May 2022).

[17] Licina, D.; Wargocki, P.; Pyke, C.; Altomonte, S. The Future of IEQ in Green Building Certifications. Build. Cities 2021, 2, 907–927.

[18] Engineer, A.; Gualano, R.J.; Crocker, R.L.; Smith, J.L.; Maizes, V.; Weil, A.; Sternberg, E.M. An Integrative Health Framework for Wellbeing in the Built Environment. Build. Environ. 2021, 205, 108253.

[19] Gupta, R.; Howard, A. Comparative Evaluation of Measured and Perceived Indoor Environmental Conditions in Naturally and Mechanically Ventilated Office Environments. Build. Simul. 2020, 13, 1021–1042.

[20] Elnaklah, R.; Fosas, D.; Natarajan, S. Indoor Environment Quality and Work Performance in “Green” Office Buildings in the Middle East. Build. Simul. 2020, 13, 1043–1062.