Shading and daylighting strategies in classrooms: a comparative study in the four climate zones in Greece using Daylight Factor values

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Abstract. The present work focuses to the efficient use of daylight in school buildings, which has been proved that is able to create a pleasant atmosphere, increase student productivity and comfort and also contribute to energy savings if combined with a daylight-responsive control system. The architectural-bioclimatic design contributes to the creation of technical solutions that provide daylight in existing classrooms, taking into account the climatic conditions and the needs of users. The purpose is to investigate the most prevalent shading and light redirection systems in a typical Greek classroom, in every climatic zone of Greece and come up with the most efficient ones. Research takes into consideration the distribution of daylight on working level and the total heating energy consumption throughout the school year, ensuring conditions of visual comfort. After evaluating and comparing the data, the outcome of this research demonstrates the most efficient shading system for each climatic zone, in order to achieve visual comfort and energy savings.

1. Introduction

It has been proved that the successful use of daylight in school buildings, is an important element in order to provide visual comfort to users, reducing the use of the artificial lighting [1].

The assessment criteria concerning daylight exploitation in buildings are quantitative and qualitative. A widely used quantitative criteria is the Daylight Factor [2], which is related to the quantity of daylight inside a room [3]. According to surveys, DF values range from 0 to 5%, in more than 80% of the buildings’ surface area. On surfaces near the openings, the DF values range are from 10 to 15%. The qualitative factors of daylight are evaluated based on its distribution on the working area, color rendering and glare.

In the interior, in order to ensure the absence of glare and achieve comfortable proportions of brightness, the following should be taken into account: the position, the intensity of the light sources and the reflectivity of the surfaces (ceiling, floor, masonry and equipment). In terms of surface reflectivity, the proposed rates are 70-85% on the roof, 40-70% on the masonry and 15-40% on the floor [4].

When it comes to the evaluation of daylight, the values of daylight (lx) inside a building are measured. This means that they must not be less than 100lux as they are insufficient and not more than 2000 lux, as they are considered high values and possibly cause glare [5].
In the school environment specifically, school construction and design should follow specific guidelines in order to utilize daylight in the optimum way, both quantitatively and qualitatively. Thus, phenomena such as glare, luminance and high contrasts can be avoided. In order to provide uniform distribution of daylight, these are the specific design guidelines: the openings on both sides of the classroom, the external shading systems with a reflective surface, the use of light-colored paints in the classroom, the surfaces with rough texture and matt paint [6] and the use of curtains and interior blinds [7].

Research shows that both students and teachers significantly benefit from the successful use of daylight, as it contributes to health promotion, well-being and student productivity to the maximum [8]. The significant benefits of daylight lead to light direction systems and new techniques that contribute additionally to its utilization. In school buildings, efforts are being made to implement shading and light direction systems to utilize the daylight in classrooms, improving visual comfort and energy savings.

2. Methodology - Data Sources

The typical classroom was selected for the current study, according to OSK (Organization of School Buildings) [6], with south orientation, dimensions of 6.90m x 6.90m and openings larger than 1/5 of its area. Initially, the conditions of a standard classroom were simulated in four cities of Greece, in the four climatic zones: Athens (B climate zone), Thessaloniki (C climate zone), Chania (A climate zone) and Florina (D climate zone).

The four most prevalent shading and light redirection systems in a typical Greek classroom ‘figure 1’, in every climatic zone of Greece, were proposed in the form of the following cases:

- 1st case: The horizontal concrete projection.
- 2nd case: The external blinds that are horizontal, solid, non-transparent and metal ‘figure 1b’.
- 3rd case: The external aluminum light shelf (width: 80cm, inclination: 15°, at a height of 2.00m. from the finished floor level, 90% specular surface) ‘figure 1c’.

| Cities     | Optimum Projection width (cm) |
|------------|-------------------------------|
| Athens     | 46                            |
| Chania     | 38                            |
| Florina    | 56                            |
| Thessaloniki | 54                          |

Figure 1. The four different shading system in a typical classroom designed in ECOTECT V5.5.

- 1st case: The horizontal concrete projection.
  
To find the optimum length of the projection, a calculation of the angle of the solar height is carried out according to the latitude of each city. It seems that, in each city with different latitude a different projection ‘figure 1a’ width is needed (table 1). More specifically, the table below shows the optimum width of the projection corresponding to each city.
4th case: The light shelf with external shutters with the characteristics for the light shelf, as mentioned in the 3rd case, and 30% transparency for the external shutters ‘figure 1d’. According to recent research, the characteristics in the 3rd and 4th case are the optimum [4].

3. Results and Discussion
For the daylighting and shading study, some parameters are taken into account:

• The position of the room
  The classroom is placed with the openings facing south, according to the specifications of the standard room of the OSK.

• The dates
  The two equinoxes are studied, (21st of September and 21st of March) as well as the 21st of December, which is the longest night with the lowest orbit of the sun, at the time of operation of the school which is at 12:00 pm. The daylighting and shading study is carried out with ECOTECT v5.5 [9].

  For the daylight distribution study (under cloudy sky conditions) the simulation results, which are presented, is presented are that of the 21st of December. The daylight factor (DF) values are calculated with RADIANCE [10] software for a city in each of the four climatic zones. Some parameters are taken into account:
  • Sky types
    The types of skies selected for the simulation are: the clear sky with sun (CIE Sunny with Sun) for the sunlight study and the cloud sky (CIE Overcast Sky) for the daylight study for each climate zone.
  • The reflectivity of materials
    In order to simulate the classroom, it is necessary to determine the reflectivity of the surfaces. In this case, surface reflectivity is set as follows: the reflectivity of the roof: 80%, the reflectivity of the walls: 60%, the floor reflectivity: 30%, the reflectivity of the double glass: 11% and the transparency of the double glass was set at 82%. The proposed average Daylight Factor for classrooms, which use natural and artificial lighting, is 2% according to Basic Data for the Design of Buildings, Daylight. Draft for Development, DD73Q 1982, British Standards Inst.. These factors, which constitute the level of general lighting, examine whether there is a uniform distribution of daylight within the classroom.

  For the thermal analysis study the parameters taken into account are:
  • The thermal zone
    The typical study room is placed on the ground floor and so there is no heat flow in all the masonry, on the roof and on the floor. The materials selected for every building element are the following:
      Openings : double glass with aluminum
      Exterior wall : double wall with insulation
      Interior wall : wall 10cm.
      Floor : ground floor on concrete slab
      Ceiling : coated roof on concrete slab
    In addition to the choice of building materials, their thickness is defined at the same time. In the exterior wall, the thickness of the materials depends on the max U-value factor in each climate zone, as discussed below.
  • the U-value (thermal transmittance)
    After determining the materials, it is necessary for the needs of the thermal simulation to calculate the thermal transmittance factor U (W/m²K) of the outer wall. In more detail, the parts of the wall, which are examined are: the part of the exterior wall with double road wall and thermal insulation in between and coating inside and outside and the opening with double glass and aluminum case.

    From table 2 of TOTEE (20701-1/2010 2nd edition, p. 44) one can find the maximum permissible coefficient of thermal transmittance for each climate zone in Greece, as shown above (for both the outer wall and the opening).
Table 2. Table of the thermopermeability factor depending on the building material, Source: Table 2 of TOTEE 20701-1/2010 2nd edition, p. 44.

| Building Material | Sign | Thermopermeability factor [W/(m².K)] |
|-------------------|------|-------------------------------------|
|                   |      | Climate zone in Greece.              |
|                   |      | A  | B  | C  | D  |
| Outer wall        | Uv-w | 0.60 | 0.50 | 0.45 | 0.40 |
| Openings          | Uv-F  | 3.2 | 3.00 | 2.80 | 2.60 |

- thermal properties

For each thermal zone only a heating system is taken into consideration, since in the summer the schools are closed. The general settings define thermal comfort from 20°C to 26°C, relative humidity 40% and lighting levels 300lux according to T.O.T.E.E. 20701-1/2010 2nd edition. In addition, the number of users, their activity and their clothing are determined. The school opening hours were determined as from 8:00am to 14:00 on weekdays and zero opening hours on weekends.

3.1. The daylighting and shading study

The diagrams of the daylighting and shading study for the period 21st March-21st September at 12:00pm indicate the following:

![Diagram](a) 1st case. in Florina. (b) 2nd case to all four cities. (c) 3nd case in Chania. (d) 4th case in Thessaloniki.

Figure 2. The diagrams for the period 21st March-21st September at 12:00pm.
The daylight study (DF%) under cloudy sky conditions

Daylight Factor (DF) values are calculated for this study. Results indicate that the shading systems under study improve the distribution of daylight inside the classroom, without ensuring the recommended levels of the average DF, though (table 1). The forementioned levels should be 2% for classrooms, as proposed by the Basic Data for the Design of Buildings, Daylight. Draft for Development, DD73Q 1982, British Standards Inst.

The resulting DF levels for each case are the following (table 3):

| Cases                | The DF level (%) |
|----------------------|------------------|
| 1st and 3rd case     | From 0.5 to 9.2  |
| 2nd case             | From 0.5 to 3.4  |
| 4th case             | From 0.5 to 4.8  |

The results are graphically captured on a selected scale ranging from 0.5 to 15% ‘figure 4e’. The external blinds (2nd case) ‘figure 4b’ and the light shelf with external shutters (4th case) ‘figure 4d’ provide a uniform distribution of daylight in the classroom. The horizontal projection (1st case) ‘figure 4a’ comes next and the light shelf (3rd case) ‘figure 4c’ comes last, as DF levels reach up to 9.2% at a distance of 1m-2m from the openings. Comparing the last two systems, the light shelf diffuses daylight over a larger area into the classroom than the horizontal projection.

3.3. The calculation of daylight levels on 21st March under sunny sky conditions

Research continues with the calculation of daylight levels (lux) in sunny conditions on 21st March at 12:00pm. The values of daylight were evaluated throughout the study so that they won’t be less than
100lux as they are insufficient and not more than 2000lux, as they are considered high values and possibly cause glare [5].

The conclusions resulting from (table 4) are the following:

- The daylight levels calculated in the typical classroom under sunny conditions are high, with the exception of the surfaces at the back of the classroom. These high daylight levels which are close to the windows can cause glare.
- The most efficient shading system that improves the high daylight levels in all climatic zones is the one with the external shutters.
- The external blinds ‘figure 17’ provide high daylight levels in the classroom surfaces around openings, with these surfaces being smaller than the equivalent ones in the other shading systems.
- The horizontal projection is the second most efficient shading system that improves the daylight levels of the classrooms of all climatic zones, though to a lesser extent compared to the external shutters ‘figure 5a-5c’.

| Cases       | Proportion lux min/max |
|-------------|------------------------|
| 1st case    |                        |
| Athens      | 670/2000=0.335         |
| Chania      | 670/2000=0.335         |
| Florina     | 670/2000=0.335         |
| Thessaloniki| 824/2000=0.412         |
| 2nd case    |                        |
| Athens      | 577.34/2000=0.288      |
| Chania      | 480/2000=0.24          |
| Florina     | 617.43/2000=0.31       |
| Thessaloniki| 432/2000=0.216         |
| 3nd case    |                        |
| Athens      | 1050/2000=0.525        |
| Chania      | 1221.79/2000=0.61      |
| Florina     | 1050/2000=0.525        |
| Thessaloniki| 1392.73/2000=0.69      |
| 4th case    |                        |
| Athens      | 989/2000=0.50          |
| Chania      | 860/2000=0.43          |
| Florina     | 991.99/2000=0.50       |
| Thessaloniki| 963.60/2000=0.48       |

Table 4. The calculation of light levels on 21st March in sunny conditions in every climatic zone of Greece.
Figure 5. The results of daylight levels on 21st March under sunny sky conditions.

- The light shelf with the external shutters slightly improves the daylight levels of the classroom in all climatic zones ‘figure 5d’.
- The light shelf increases the lighting levels until the end of the classroom in all climatic zones, in a way that makes it more difficult due to the uneven distribution of daylight in the space ‘figure 5c’.

3.4. The study of thermal analysis

The study of thermal analysis with the use of ECOTECT V5.5 [9] software indicates the following (table 5):

| Shading cases | Athens | Chania | Florina | Thessaloniki |
|---------------|--------|--------|---------|--------------|
| 1st case      | 380.874| 395.541| 1849.91 | 777.315      |
| 2nd case      | 435.173| 456.244| 2053.48 | 916.290,10  |
| 3rd case      | 365.602| 382.387| 1749.64 | 721.204      |
| 4th case      | 471.336| 437.102| 1970.33 | 858.609      |

Table 5. The calculation of daylight levels on 21st March in sunny conditions in every climatic zone of Greece.
Classrooms in Florina have the highest heating energy consumption. Thessaloniki comes next and finally Chania and Athens.

After comparing and evaluating all shading systems implemented in every climatic zone, it is concluded that the use of the light shelf (3rd case) leads to the least energy consumption. The horizontal projection (1st case) comes next and the light shelf with the external shutters (4th case) comes last. Finally, it was found that the use of the external shutters (2nd case) leads to the highest energy consumption.

Conclusions
The results can be summarized as follows:

- The external shutters provide the best daylight exploitation and even distribution in the typical classroom under study. However, they seem to lead to higher energy consumption in order to achieve thermal comfort inside the classroom.
- The next shading system with positive results to the distribution of daylight is the light shelf with the external shutters, although the amounts of energy required for the thermal comfort of the classroom are significant.
- Therefore, the first option suggested in all climatic zones of Greece is the one with the external shutters. Moreover, the light shelf with the external shutters should be used as a second option so that visual comfort can be ensured.
- The horizontal projection and the light shelf, the best energy-efficient systems for the heating of the classroom, should probably be combined with curtains or internal blinds if implemented in Greek cities. In that way, they can prevent the direct penetration of sunlight inside the classroom.

This research has a prospect of development, since it can trigger the creation of new additional studies in the future, concerning the study of glare in the typical classroom in Greece as well as the further creation of other software, which have the possibility to include other elements such as artificial lighting, automation and the heating-cooling system. Future studies should also consider new metrics, such as Daylight Autonomy (DA), Spatial Daylight Autonomy (SDA) and Useful Daylight Illuminances (UDI).

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