Optimizing the thermal and visual comfort conditions in the glazed Observatory of the Meteorological Bureau of the Aristotle University of Thessaloniki

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ABSTRACT: The paper involves the study of the indoor comfort conditions prevailing in the glazed Observatory located on the roof of the Meteorological Bureau of the Aristotle University of Thessaloniki. The study was based on in situ measurements and simulations of the thermal and visual environment as regards the existing conditions, the types of sun protective devices and ventilation rates. Conclusions are drawn and proposals are made regarding the improvement of the indoor climatic conditions.

Conference topic: 5 Materials and building techniques
Keywords: thermal and visual comfort, energy requirements, sun protection, night ventilation

INTRODUCTION

Glazed structures at the top of the buildings are attractive architectural elements and useful to the function of the building. However, they are fully exposed to solar radiation (critical spaces); for that reason, certain provisions for their construction and use must be made with relation to the efficient confrontation of the ambient environment.

It is very common that a large area of the facades of such structures is glazed (Pavilion type). Thus, they offer significant visual contact between the indoor and the ambient environment. However, adverse conditions regarding glare and overheating may also occur during summer.

The requirements for the achievement of thermal and visual comfort in these spaces are met by thermally protecting the building envelope, as well as by incorporating effective and flexible sun-shading devices which will control the solar gains during the warm period without reducing the indoor daylight levels and the desired solar gains during the winter. Natural ventilation also contributes towards the decrease of high indoor temperatures.

The Observatory is a construction with similar morphology. It is located on the roof of the Meteorological Bureau of the Aristotle University of Thessaloniki (Figure 1). It concerns a structure of regular polygonal plan with 24 sides of 1.44m in length each, with a diameter of 11.00m and covers a surface of 95m². It has been recently built (2001) in the position of the old Observatory, which covered a lesser area, was also a lightweight construction but without thermal insulation, resulting thus in an uncomfortable indoor environment [7].

1. DESCRIPTION OF THE BUILDING

The interior is divided into offices which are placed around a central hall (Figure 2). The offices form 4 zones orientated to North, East, South and West. The vertical envelope of the building (i.e. the 24 sides of the polygon) consists of spandrel units made of lightweight insulating panels and fenestration with double glazing in aluminium frames. The roof above the offices is inclined and is made of the same lightweight material as the spandrel units. The roof of the hall is horizontal and as a part of the bearing structure is composed of reinforced concrete and thermal insulation (Figure 2, Table I).

The partition walls in the interior of the observatory are also made of lightweight panels. The calculation of thermal storage capacity showed that the Observatory belongs to the category of lightweight constructions (C=75 Wh/Km²) [11]. On the contrary, the lower floor which is formed by heavy interior walls, floor and roof made of reinforced concrete, can be considered a heavy construction (C>130Wh/Km²) [11]. At present, the shading of the facades is achieved by means of adjustable internal louver blinds (Figure 2.). At the moment, the space is used as offices for postgraduate students.

2. THE SCOPE OF THE STUDY

The scope of the current paper focuses on the investigation of the thermal and visual comfort conditions prevailing in the offices of the Observatory during the warm summer period. Moreover,
interventions are proposed for the further improvement of the existing indoor climate with minimum energy consumption. Furthermore, the study of the Observatory can be the basis for drawing general conclusions as regards the thermal behavior and the daylight levels of spaces with similar morphology.

3. ANALYSIS OF THE INDOOR CONDITIONS

The indoor conditions were assessed by in situ measurements of the air temperature and illumination levels, with simulations for the estimation of the thermal and daylight conditions, along with the recording of the users’ perception of comfort during the working hours with the help of questionnaires.

Regarding the case of non-air-conditioned offices, the daily distribution and maximum value of air temperature for each space were considered as criteria for the evaluation of the thermal protection as well as the thermal comfort offered by the building. In the case of air-conditioned offices, the assessment was based on the total cooling load, which is required for the achievement of comfort conditions indoors.

The analysis of visual comfort involved the estimation of the daylight levels prevailing on the working plane with the integration of the sun shading devices as well as the possibility of glare occurrence.

### Table I. Description of the materials and the structural elements of the Observatory.

<table>
<thead>
<tr>
<th>Location</th>
<th>Altitude: Sea level 30m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude: 40° 38’ Β.Γ.Π.</td>
</tr>
<tr>
<td></td>
<td>Free perimeter.</td>
</tr>
<tr>
<td></td>
<td>Facades to all orientations.</td>
</tr>
<tr>
<td>Elevation</td>
<td>Construction on the roof of the upper floor.</td>
</tr>
<tr>
<td>Geometrical elements of the space</td>
<td>Plan with the shape of a regular 24-sided polygon. E=95m²</td>
</tr>
<tr>
<td></td>
<td>Length of each side: 1,44m.</td>
</tr>
<tr>
<td></td>
<td>Depth of offices: 3,05m.</td>
</tr>
<tr>
<td>Ratio of glazing to total façade surface:</td>
<td>60%</td>
</tr>
<tr>
<td>Opaque building elements:</td>
<td></td>
</tr>
<tr>
<td>Exterior walls, roof above the offices:</td>
<td>lightweight, insulating panels, $U=0.275 \ W/\text{m}^2\text{K}$</td>
</tr>
<tr>
<td>Layers:</td>
<td>0.002m Aluminium sheet</td>
</tr>
<tr>
<td></td>
<td>0.08m Polyurethane foam</td>
</tr>
<tr>
<td></td>
<td>0.002m Aluminium sheet</td>
</tr>
<tr>
<td>Roof 1 (hall): reinforced concrete slab, $U=0.37\ W/\text{m}^2\text{K}$</td>
<td></td>
</tr>
<tr>
<td>Layers:</td>
<td>0.002m Plaster</td>
</tr>
<tr>
<td></td>
<td>0.18m Reinforced concrete</td>
</tr>
<tr>
<td></td>
<td>0.07m Extruded polystyrene</td>
</tr>
<tr>
<td></td>
<td>0.08m Porous concrete</td>
</tr>
<tr>
<td></td>
<td>0.02m Cement mortar</td>
</tr>
<tr>
<td></td>
<td>0.04m Roof tiles</td>
</tr>
<tr>
<td>Floor: reinforced concrete slab, $U=0.37\ W/\text{m}^2\text{K}$</td>
<td></td>
</tr>
<tr>
<td>Layers:</td>
<td>0.002 Linoleum</td>
</tr>
<tr>
<td></td>
<td>0.02m Cement mortar</td>
</tr>
<tr>
<td></td>
<td>0.28m Reinforced concrete</td>
</tr>
<tr>
<td></td>
<td>0.02m Plaster</td>
</tr>
<tr>
<td>Partition walls: lightweight panels, $U=0.275 \ W/\text{m}^2\text{K}$</td>
<td></td>
</tr>
<tr>
<td>Layers:</td>
<td>0.01m Plaster board</td>
</tr>
<tr>
<td></td>
<td>0.06m Glass wool</td>
</tr>
<tr>
<td></td>
<td>0.01m Plaster board</td>
</tr>
<tr>
<td>Internal doors: wood</td>
<td></td>
</tr>
<tr>
<td>Transparent structural elements:</td>
<td></td>
</tr>
<tr>
<td>Fenestration:</td>
<td>Double glazing of clear glass and aluminium frame with thermal cut. $U=2.9\ W/\text{m}^2\text{K}$</td>
</tr>
<tr>
<td>g=0.80</td>
<td>$T_\circ=0.80$</td>
</tr>
<tr>
<td>Sun protection: Adjustable</td>
<td></td>
</tr>
<tr>
<td>Internal blinds, $F_c=0.50$</td>
<td>$g_1=0.50\times0.80=0.40$ [10]</td>
</tr>
<tr>
<td>External blinds, $F_c=0.30$</td>
<td>$g_2=0.30\times0.80=0.24$ [10]</td>
</tr>
</tbody>
</table>
The summer period included the months, during which the mean 24-hour temperature outdoors is higher than 18°C ($\theta_{\text{mean}} > 18^\circ$C). For the local climatic data this period corresponds to the interval between May and September [12].

4. THE INDOOR THERMAL CONDITIONS

4.1. The in situ measurements

The in situ measurements of the air temperature were carried out right after the end of the renovation works (May 2001). Temperature and humidity sensors were positioned at the offices of the Observatory (south, west zone) and monitored the indoor conditions for 3 days at the end of May 2001, before the fitting of the internal blinds and the occupation of the space by the users. During the monitoring, every office was ventilated from 9 p.m. to 9 a.m. through the opening of the windows. At the time, the air temperature of the ambient environment and in the hall of the lower floor was also recorded.

The results of the in situ measurements are presented in Figure 3. The diagram shows that there is a difference of 3K between the maximum air temperatures prevailing in the south and the west zone of the offices. For both zones the daily temperature distribution is wide (~10K). The ambient air temperature exceeds the limits of thermal comfort to a great extent ($\theta_{\text{mean}} = 25^\circ$C) [9], as well as the values of ambient air temperature. On the lower floor the fluctuation of the daily air temperature is smoother (~4K) and the peak values ($\theta_{\text{mean}} = 24^\circ$C) are lower than the criteria set for thermal comfort. The great variation of the daily air temperature in the interior of the Observatory is typical for spaces of lightweight structure. On the contrary, on the lower floor, which is a heavy construction and has a lower proportion of glazed apertures on the façade's surface, the temperature does not reach such high values and is distributed over a more confined range. Due to the lightweight construction of the Observatory, the maximum daily temperatures are observed one hour earlier compared to those of the lower floor.

4.2. The parametrical analysis of the criteria of evaluation

In order to study the parameters that influence the thermal conditions of the space, the reliable computer program for dynamic thermal analysis SUNCODE was used. The input data included the local climate in the form of a Test Reference Year (TRY) [8].

The factors taken as variables in the optimization of the indoor conditions are the sun shading of the façades and the ventilation (Table II).

Under the frame of the parametrical analysis of the thermal comfort conditions, the effect of the exterior wall characteristics and the interior construction type on the formation of the maximum air temperature profiles was also investigated. The glazing to façade ratio of the Observatory was considered as given; therefore it was not taken into consideration as a variable.

4.3 Indoor conditions

**Use of space**: Monday to Friday, 08:00-20:00.

**Occupants**: 2 persons, who offer internal gains equal to 250W.

**Ventilation**: variable (Table II):
- a) 24-hour infiltration through the joints.
- b) Controlled night ventilation 22:00-08:00.

The ventilation is activated as soon as the indoor air temperature exceeds 24°C and only when it is higher than the ambient temperature.

**Sun shading**: variable. Louver blinds fitted on the interior or the exterior side of the openings (Table II).

The mechanical cooling is activated during the working hours (08:00-20:00), when $\theta_i > 26^\circ$C.

It must be noted that the users of the offices have personal control on the sun protective devices, in order to screen windows from solar radiation [10].

4.4 Validation of the simulation results

For the confirmation of the input data and the modeling of the indoor thermal conditions with regard to the in situ measurements, simulations were conducted. The simulations referred to May 25th, since there were also in situ measurements available for that date. The daily distribution of air temperature in the offices with south and west orientation as regards the measured and the simulated values are presented in Figure 4. It emerges that for both spaces the daily temperature profiles resulting from the measurements as well as the simulations coincide.

4.5 The simulation of summer conditions

4.5.1 The case of non air-conditioned offices

In order to study the peak indoor air temperature of the spaces and the effect of night ventilation, a rich in solar radiation day of the summer (July 17th, max$\theta_i = 32^\circ$C) was considered as a critical period. The temperature fluctuation within the offices under the
effect of the examined parameters (Table II) is presented in Figures 5, 6.

For reasons of comparison, every figure also includes the daily distribution of ambient air temperature. It emerges that temperature profiles within the two spaces, for both types of sun protection and for all ventilation rates (Table II) remain above the curve for ambient temperature and exceed the criteria set for thermal comfort (θ_{igrenz}=25°C) [6].

It is also concluded that there is a 2-hour lag in the appearance of maximum temperature values in the southern and western zone (15:00-17:00). The difference of maximum temperature between the two orientations (S, W) equals 2K when interior blinds are used (g=0.40) and 1K with external blinds (g=0.24). For each orientation the decrease of temperature due to the use of external blinds equals approximately 2K.

The effect of night ventilation is significant in keeping the air temperature of the spaces at lower levels. The installation of internal blinds (g=0.40) and a ventilation at a rate of 15AC/h cause a reduction of 6K in peak indoor air temperature in the western office. As the sun control increases, the air temperature differences between zones of different orientation decrease.

- The effect of lightweight exterior envelope
  The substitution of the vertical lightweight envelope (insulating panels, U=0.275 W/m²K) with heavy brickwall of the same U-value resulted in a slight difference of 0.15K on the maximum indoor temperatures of the western zone. The reduction of the absorbance of the exterior envelope by 0.10 caused the decrease of the indoor temperature in the western office by 0.20K.

- The effect of the type of internal structure
  The case of heavyweight structural components in the interior was also tested as an alternative solution in the formation of thermal comfort conditions. This was achieved by substituting the lightweight panels of the partition walls with heavy brick walls, resulting in double active thermal mass capacity. The distribution of daily temperature for this case of heavy structure (C>130Wh/Km²) is also presented in Figures 5, 6.

In the case of heavyweight interior structure with internally fitted blinds and a ventilation rate of 15AC/h, the maximum temperatures of the southern space coincided with the values of the exterior temperature. For the respective case of the western zone, the difference accounts for an increase by 1K.

By incorporating external blinds (g=0.24) the maximum temperatures in all zones range below the maximum values of exterior temperature [10]; however, they still exceed the limits for thermal comfort.

- Thermal comfort during the summer period
  The time interval during which critical values of interior air temperature (θ>θ_{igrenz}=25°C) were observed was calculated for the case of strong sun protection (g=0.24) and night ventilation (AC/h=15) during the whole summer period. It has resulted that the total time of occurrence of the critical temperatures for the offices of all orientations exceeds 10% of the total duration of use of the spaces during the specific period [9].

4.5.2 The case of air conditioned offices
  From the above it is concluded that there is need for the integration of a mechanical system for providing cooling to all offices. The total loads for cooling during the summer period under the effect of the two types of sun protection and the various rates of ventilation are presented in Figure 7. For the case of infiltration through the joints (0.5AC/h) the required cooling loads are equal to Q=40.05kWh/m²a and Q=28.04kWh/m²a for each type of sun protection respectively. The impact of more effective sun protection on the total cooling energy is obvious.

Taking into account that there are no significant sources of heat in the interior (internal heat gains <30W/m²), the further decrease of cooling loads can be achieved by ventilation conducted during the night and early morning hours [2], given the fact that the temperature of the ambient environment at the time is much lower than 22°C even during the hottest summer months [12].

The position of the fenestration on the offices’ facades, as well as the arrangement of the spaces, contribute to natural night ventilation, which was in effect accomplished during the in situ measurements on May 25th (Figure 3) through the opening of the windows (AC/h=15). The cooling loads and the decrease ratio for different ventilation rates is presented in Figure 7. More specifically, a night ventilation rate of 15 AC/h in conjunction with external blinds (g=0.24) results in decreasing the initial cooling
THE VISUAL COMFORT CONDITIONS

The evaluation of visual comfort provided in the offices of the Observatory was based on the estimation of daylight levels and the possibility of glare occurrence. The study was conducted by means of the simulating computer program ADELINELINE [3]; the input data included the geometrical characteristics of the space and the conditions of the ambient environment prevailing on the most critical day of summer period (June 21st).

The different types of sun shading were taken into account in the visual transmittance of the glazing, on the basis that the existing glazing has high spectral selectiveness on the range of visual radiation and very low absorptance of thermal radiation. For that reason, it was assumed that the visual transmittance $T_v$ practically coincided with the g-value of the glazing (0.80). Furthermore, the internal louver blinds were considered to be of high reflectivity and low absorptance; therefore, the visual transmittance of the system (internal louver blinds and glazing) is practically equal to the g-value of the system. For the simulation of external blinds, it was also assumed that the absorptance of the blinds is low and that the gap between the glazing and the slats is ventilated [5].

The above assumptions for the considered values of transmittance were confirmed by means of in situ measurements. More specifically, the vertical illumination on the exterior side of the glazing and the interior side plane of the blinds was monitored for various outdoor conditions and their ratio was calculated [13]. The results of the experimental study showed that the transmittance of visual radiation was very close to 0.40 (0.38), while in the case of external blinds the respective value was found equal to 0.24.

5.1 The daylight levels

The daylight levels were assessed through the estimation of daylight factor for the two types of sun shading devices. The daylight levels prevailing on the working plane without the presence of sun control devices was considered as the reference case for the study. As expected, the daylight factor is significantly higher when no sun control is used. The high levels of daylight illumination are attributed to the high ratio of window to façade area (60%), as well as to the relatively small depth of the offices (3.05m). These characteristics ensure daylight autonomy on the offices even during the overcast days of winter. In the case of internal blinds the average daylight factor reaches 3.89%, which complies with the acceptable range for daylight adequacy [1]. The installation of blinds on the exterior side of the façade results in further decrease of the daylight factor (1.72%); however, this value accounts for overcast sky conditions and it is unlikely to be observed in reality, since the device is adjustable and the users have personal control over its operation.

5.2 Glare

Under clear sky conditions the daylight illumination on the ambient environment reaches much higher levels. Therefore, under the specific conditions, it is not necessary to study the adequacy of daylight indoors. On the other hand, it is recommended that the possibility of glare occurrence caused by excessive contrast of luminance between the various indoor surfaces should be estimated.

The possibility of glare occurrence in the offices of the Observatory was assessed by the estimation of the Daylight Glare Index (DGI) [1]. In the case of no solar protection, DGI was found equal to 27.28, which exceeds the acceptable limits for the specific use of the spaces (DGI(max)=23 [1]). Through the use of internal blinds the DGI is reduced to 22.6; for the external blinds the value is even more confined (20.9). The qualitative estimation of glare in the
offices of the Observatory showed that the contrast among the luminance of the interior surfaces becomes smoother with the use of external blinds [1]. Therefore, acceptable conditions for visual comfort during the summer period can be achieved only by sun-protected openings; actually, especially for the elimination of glare occurrence, the visual comfort conditions are optimized by the use of external blinds.

6. CONCLUSIONS-PROPOSALS

i. According to the results of the study, it is concluded that mechanical cooling is necessary in order to accomplish thermal comfort conditions within the offices of the Observatory during summer.

ii. The installation of blinds for sun control leads to considerable reduction of the required cooling load and contributes significantly to the improvement of the thermal and visual conditions indoors. Moreover, external ventilated adjustable blinds are necessary for the offices with “critical” orientation (E, S and W).

iii. The contribution of ventilation during the night and the early morning hours is also essential to passive cooling and thus to the reduction of cooling loads.

iv. The effect of orientation is reduced with effective sun protection and extensive night ventilation.

v. The structure of the exterior wall does not influence the indoor temperature fluctuation significantly, as long as the U-value is low. The enhancement of the characteristics of the exterior surface of the envelope as regards the solar radiation (i.e. low absorptance) acts positively. The influence of considerable thermal mass indoors is more effective.

vi. Optimal results are achieved by combining a heavyweight internal structure with efficient sun protection devices and night ventilation. In that case, the interior spaces comply with the recommendations of DIN 4108 for the summer period and for that reason the indoor temperature does not exceed the ambient temperature even during the hottest days.

vii. The use of double glazing with clear glass has offered satisfactory visual transmittance and has contributed to the formation of visual comfort conditions. Taking into account the requirements for an envelope of a very low U-value and the presence of a lightweight construction, a lower U-value (U<2.0) of the glazing would further improve the thermal protection offered by the building’s shell.

viii. The assessment of the visual comfort in combination with the evaluation of the thermal conditions showed that the use of external adjustable sun protective devices in the offices with “critical” orientations (East, South and West) result in significant energy conservation and does not have negative effects on the adequacy of daylight levels indoors. On the contrary, the externally fitted blinds provide better protection against glare.

ix. Finally, the role of the users is of great importance. The control of the shading devices for the total screening of direct radiation as well as the operation of night ventilation have a remarkable effect on the reduction of the cooling loads, the formation of comfort conditions and the enhancement of air quality within the space.

REFERENCES


