Daylight, Solar Gains and Overheating Studies in a Glazed Office Building

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***Abstract*—**The Glazed envelopes represent a possibility to use solar radiation for reduction of energy consumption in buildings, which is very important especially in regions with temperate climatic conditions. Then again, glazed facades are potential sources of unwanted overheating and glare effects that cause indoor discomfort and result in necessity for ventilation and cooling services which again increase energy consumption in buildings. The paper discusses the analysis of an overheating issues occurred in a naturally ventilated office building in Sheffield, England. The building is designed with a south facing fully glazed facade where solar energy is utilized to provide cooling within the building. In this study, indoor thermal conditions have been measured in order to determine the overheating periods during warm spring and summer months and the findings of thermal discomfort levels are examined on each floor level including open plan floor spaces. The overheating periods are determined in a duration where indoor air temperatures reach to 27ºC or above for more than two consecutive hours between 9am and 6pm, and the results of the analysis are presented with a series of overheating studies. The paper also reports the findings of monitoring carried out for indoor environment in such an office building with glazed facades during their summer performance in temperate climatic conditions and presents a comparison study with computer simulation results, and discusses the further solutions suggested for optimization of indoor comfort on the basis of the investigations..

***Keywords*—**Computer simulation, Daylighting, Glazed facade, Overheating, Solar gains, Thermal comfort.

I. Introduction

THE architectural trends of glazed facades have brought more daylighting and transparency into buildings, although with large glazed areas come a large amount of solar radiation which can be wisely utilized for better environmental building design. This is mainly related to areas connected to the energy consumption and indoor environmental comfort, and their evaluation is equally important particularly in such regions with temperate climatic conditions, where the probability of overheating and glare effect arises accordingly with the area of glazing.

These problems are resulting in necessity for ventilation and cooling services and in demand for increased energy consumption in buildings [1], [2].

With the increasing demand for building cooling in temperate climates due to increased outdoor air temperatures as a result of global warming, overheating has become a real issue considering thermal comfort conditions of work environments, particularly in naturally ventilated office buildings. Climate change is a known fact and adapting buildings for climate change is the only survival guide for such buildings due to their climate sensitive designs [3].

Passive solar design techniques likely to be simple and inexpensive and night time ventilation is one of the known techniques used to cool the exposed thermal mass of a building as a passive cooling strategy. Night time ventilation again is a significant potential for energy savings and therefore naturally ventilated office buildings in particular can benefit from this technique whenever outdoor air temperatures are low enough to provide sufficient cooling into the building.

Although there isn't a very clear definition of overheating in office buildings, all buildings do overheat to some extend depending on the definition of thermal comfort conditions.

The building investigated is a naturally ventilated office building in Sheffield, England where passive solar design techniques share a crucial part of the building design, and the use of solar energy as a means of ventilation strategy to drive passive cooling within the building as well as night time ventilation to minimize potential overheating throughout warm summer periods (see Fig.1).

The monitored data in the selected building during summer operation under temperate climatic conditions has shown that such building design is likely to show optimal variations with respect to the indoor comfort and energy savings [4], [5].

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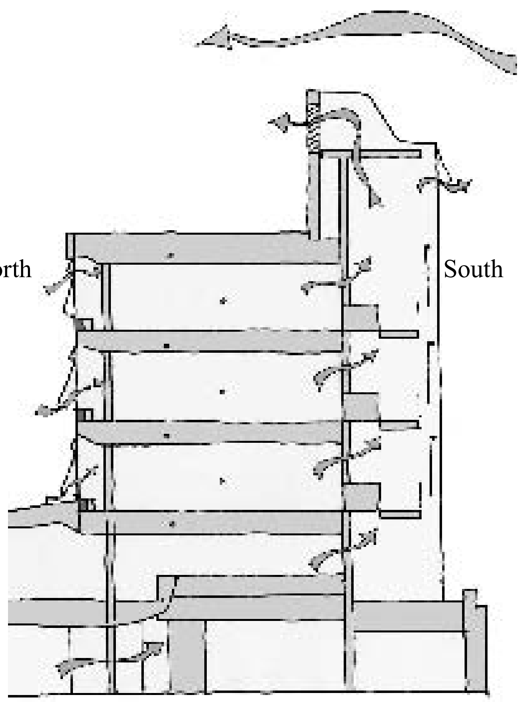

Fig.1 The scheme of natural ventilation strategy

II. THE INVESTIGATED BUILDING

The glazed facades of the ICoSS building at Sheffield University campus were investigated (see Fig. 2). The building's south facing glazed facade was designed and constructed as part of the natural ventilation scheme where its south facade is acting as a 'solar chimney' driving the ventilation.

The building was constructed in 2004 as a new interdisciplinary research facility for the Social Sciences faculty in the university campus. It is approximately 1850 m^2 of new build on 5 floors with is iconic design that forms a landmark.

The open space is animated by an elevated, sculptural conference room, which opens views across the site and forms a dramatic marker for the building's entrance. The laboratory floors are to be aligned against a south-facing atrium which contains the primary vertical and horizontal circulation, and acts as a thermal collector to drive the passive stack natural ventilation.

The building was internationally recognized at the Green Apple Awards 2006 and won an environmental and architectural award [6].

Main characteristics of the building:

- Built up area approximately 1850 m^2
- Areas of glazed facades are:
  North - approx. 300 m^2
  South - approx. 320 m^2

Description of building envelopes constructions:

- Both southern and northern facades are fully glazed in alumina fames with a U-value of 1.8 $Wm^{-2}K^{-1}$; both facades glazing is with a U-value of 1.5 $Wm^{-2}K^{-1}$. The southern glazed facade has white roller blind solar shadings.
- Eastern and western facades are constructed of cavity walls with cavities fully utilized by insulation and metal studs.
- Flat roof is incorporated as a green roof with benefits to building insulation and rainwater run-off control.

Fig.2 Investigated building ICoSS: south glazed facade with the natural ventilation system (top); northern facade with the main entrance and large windows (bottom)

The research-oriented investigation of indoor comfort during the initial years was conducted by the Building Energy Analysis Unit (BEAU) in the School of Architecture at the University of Sheffield, where the building indoor temperatures were monitored in selected parts. The most important part monitored was the internal open space vertical shaft close to the southern glazed facade, which is controlled by a Building Energy Management System (BEMS). The monitoring program undertaken has helped to establish if the building is performing as intended and could also form a benchmark for other similar building types. Mainly of particular interest was the effectiveness of the south facade and solar gains, and daylighting evaluation.

In addition, daylight computer simulations and illuminance measurements were completed. The study focused on concerns related to overheating periods and thermal discomfort conditions in the building over the past three years (post occupancy evaluation) on open plan office floors was also carried out.

A. Evaluation of Daylighting

In the investigated building, the spaces located on the ground and first floor are dedicated for facilities like conference events, the rest of the building is dedicated for administrative purposes and that is why the investigation was carried out in levels consisting primarily of open plan office spaces such as the second floor.

Daylight factor as a ratio between internal illuminance on the working plane 850 mm over the floor level and external illuminance on non-shaded horizontal plane was determined under overcast sky conditions [7][12][14]. The daylight factor calculations were carried out with the use of computer daylight simulation program WDLS [8] (see Fig.3).

The illuminances at selected working positions close to the glazed south facade are presented in Fig.4. During sunny summer days the large glazed facade causes glare effect in this open plan office space.

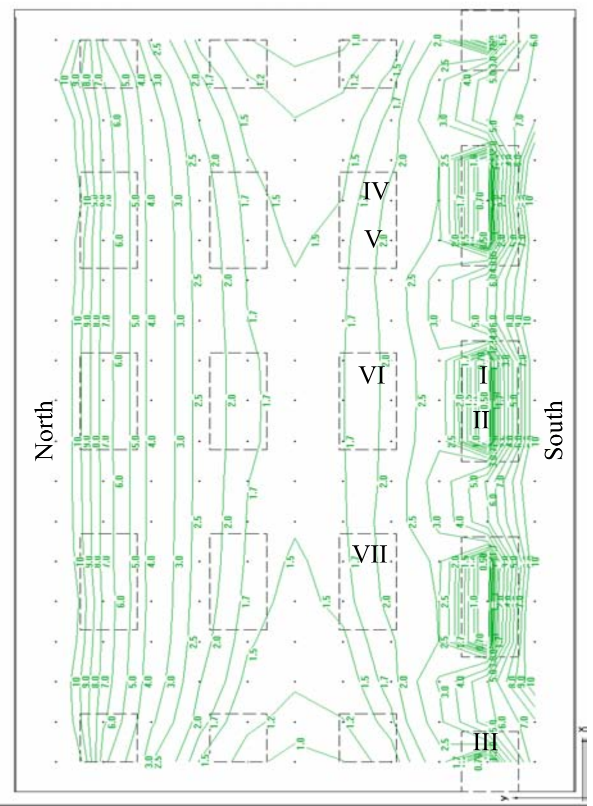

Fig.3 Daylight factor distribution in an open plan office space; the second floor space

High differences in internal illuminance on working positions during the time of intensive sunshine cause discomfort. Monitoring of luminance distribution on computers and working desks was completed and results were confronted with responses of staff occupants of the open space office (see Fig.3).

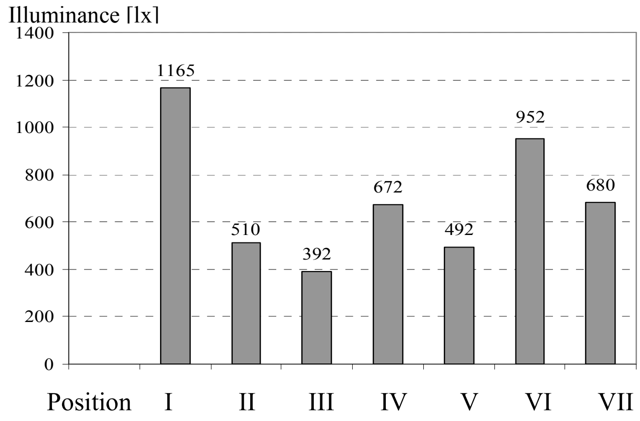

Fig.4 Illuminance at the selected working positions

B. Evaluation of Visual Comfort

The reason for conducting observations was to be able to assess visual comfort conditions and compare findings with computer simulations undertaken, and also to inform both the occupiers and designers of any shortcomings in the design or good points which could then be incorporated in future developments.

The following figures (see Fig.6 to Fig.14) show observation photos of the interior daylighting conditions in this office building floors, atria and other spaces observed throughout the walk around survey.

Fig.6 South façade - blinds are open on a sunny winter day

Fig.7 South façade - blinds are closed on a sunny spring day

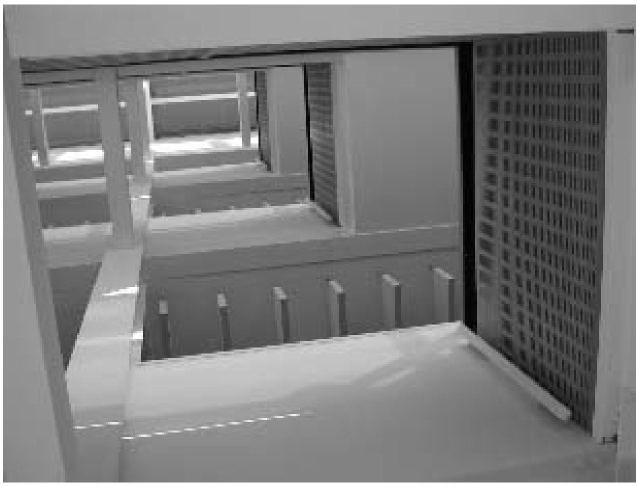

Fig.8 Atria space under clear sky conditions

Fig.9 Entry foyer with direct sun/daylight through the mezzanine floor

Fig.10 North façade conference room with clear sky conditions

Fig.11 North façade open plan office space while south façade blinds are closed and electrical lighting is switched on during a sunny summer day

Fig.12 South façade while blinds are 70% closed on a sunny day

Fig.13 Passive solar design feature (skylight) for maximizing natural daylighting on the north side (left), while preventing sunlight glare effect on the south side (right) during a sunny clear sky conditions

Fig.14 Foyer display (LCD) screen with reflections from sunlit windows and bright wall surfaces during a sunny summer day

Analysis of the observation photos:

Fig.6 illustrates sufficient daylighting through the south facade due to having the window blinds open during a bright sunny winter day. This is a passive solar technique, maximizing natural daylighting throughout the open plan spaces in office buildings.

Fig.7 shows the use of shading elements, such as window blinds, during a day when excessive sunlight is available to prevent unwanted solar gains through the south façade during hot summer days. This is a very common situation when one needs to compromise between daylighting and solar gains.

Fig.8 shows the atria space in this office building under clear sky conditions when sufficient natural daylighting is present and electrical lighting loads can be minimized throughout the most office spaces (PSD technique).

Fig.9 illustrates a sufficiently lit foyer space via direct sun/daylight where again artificial lighting can be minimized, yet there may be a potential glare effect, reflections on display (LCD) screens (see Fig.14).

Fig.10 also illustrates a sufficiently lit conference room where artificial lighting is in use although this is unnecessary and could be avoided in order to increase energy savings.

Fig.11 shows a situation where the daylight savings can be compromised due to preventing unwanted solar gains, particularly in open plan office spaces where the artificial lighting could also be seen as a side effect.

Fig.12 shows a situation where occupants positioned window blinds in a way (60-70% closed) that can help to overcome glare effects caused by direct sunlight.

Fig.13 illustrates two passive solar design features; (one) a skylight maximizing natural lighting in spaces facing north and (two) a shading element preventing direct solar gain and glare through the south facing spaces.

Fig.14 shows an example of glare effect on a display (LCD), which is not directly located in the sunlight path, and is instead caused by the reflections of sunlight from bright surfaces (walls, ceiling and glass).

Additionally, computer simulations were carried out to examine some of the findings of observations throughout the walk around survey conducted. The computer simulations were undertaken with the use of various lighting simulation software such as Radiance [10], Ecotect [9] and Daysim [11] to determine the likely daylight illuminance distributions and daylight factors across open plan office spaces, which could then be compared with some of the findings of observations. For this, computer models [15] of the office building were created (see Fig.15) in order to carry out the simulations of the likely ranges in interior lighting levels and conditions across open plan office spaces.

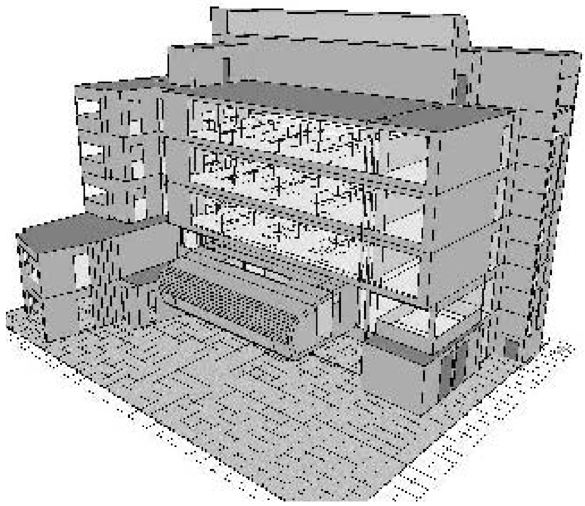

Fig.15 Computer simulation model

The following figures are the results of the computer simulations (Radiance) showing the likely outcome of illuminance distributions (lux) from daylight across open plan office spaces (see Fig.16 to Fig.23).

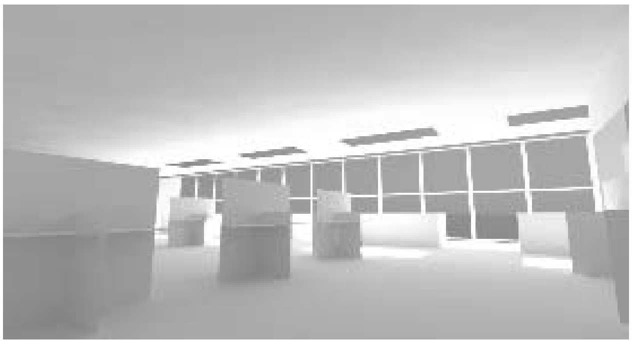

Fig.16 Lighting simulation across an open plan office floor in July under sunny sky conditions, window blinds closed (southeast view)

Fig.17 Daylight illuminance distributions (lux) across an open plan office floor in July with sunny sky (southeast view).

Fig.18 Lighting simulation across an open plan office floor in July under sunny sky conditions, window blinds closed (southwest view).

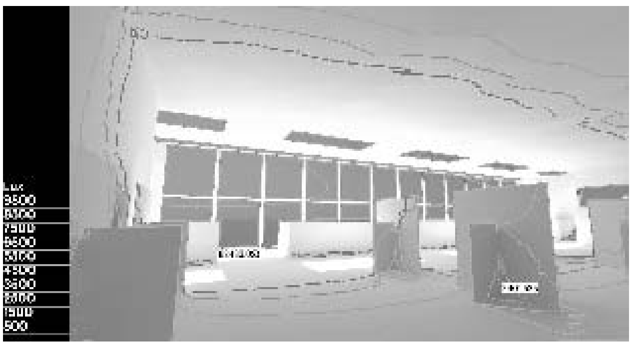

Fig.19 Daylight illuminance distributions (lux) across an open plan office floor in July with sunny sky (southwest view)

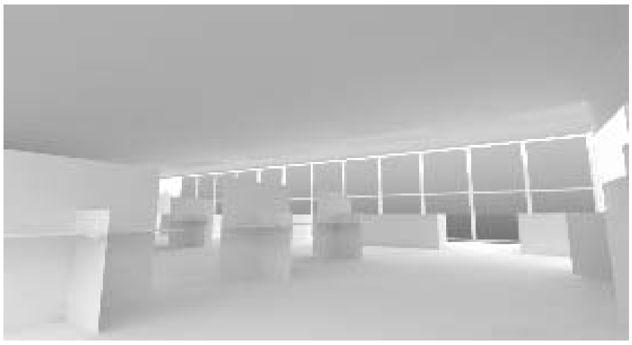

Fig.20 Radiance lighting simulation across an open plan office floor in December under overcast sky conditions, window blinds closed (southeast view)

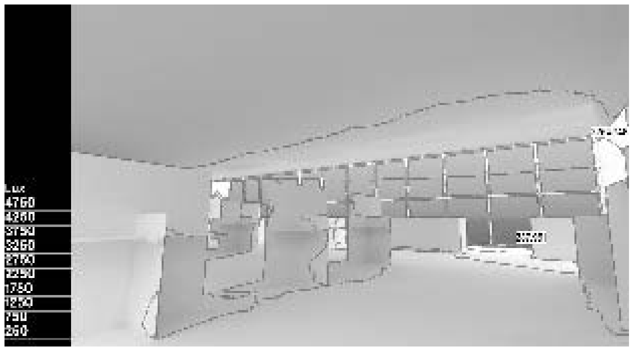

Fig.21 Illuminance distributions (lux) across an open plan office floor in December with overcast sky (southeast view)

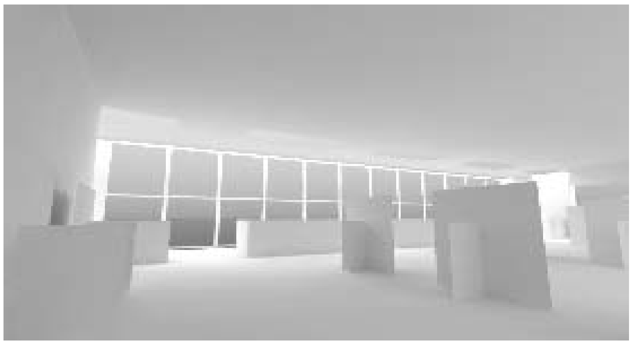

Fig.22 Radiance lighting simulation across an open plan office floor in December under overcast sky conditions, window blinds open (southwest view)

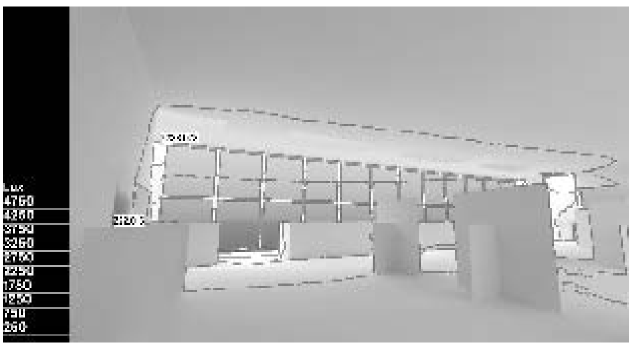

Fig.23 Illuminance distributions (lux) across an open plan office floor in December with overcast sky (southwest view)

The results have shown that there is adequate daylighting throughout the office building due to its passive solar design features; particularly with its south facing active facade under bright and clear sky conditions by maximizing natural daylighting over the open plan office spaces.

The control of shading elements such as window blinds during hot summer days (where there is excessive sunlight in present) can help to prevent unwanted solar gains through the south facades in such buildings. The atria space designed is providing a good distribution of natural daylighting in the building under clear sky conditions where electrical lighting loads can be minimized throughout the most office spaces.

Typical cases such as having an unnecessary artificial lighting in use can be avoided with better occupant understanding of adequately lit spaces with direct sun/daylight. Nevertheless, if there are effects of glare and reflections, further assistance should be required.

Additionally, the following figures are the results of the computer simulations (Ecotect/Daysim, [9]/[11]) showing the likely illuminance levels (lux) and daylight factors (%) on working planes across open plan office floors (see Fig.24 and Fig.25).

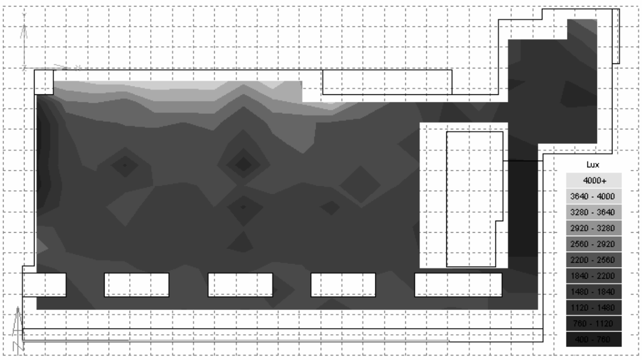

Fig.24 Daylighting levels across an open plan office floor in July

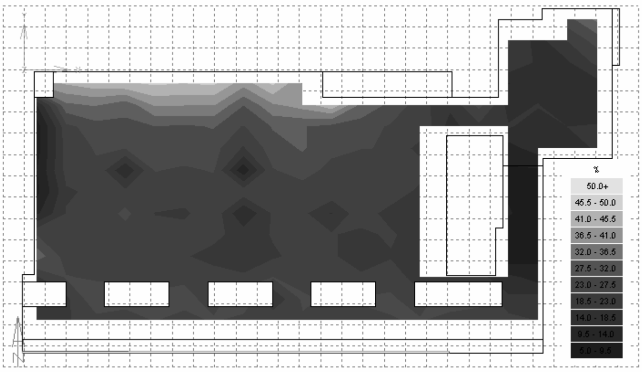

Fig.25 Daylight factors across an open plan office floor in July

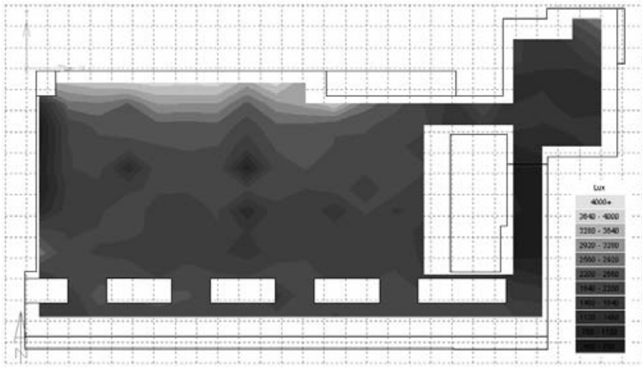

Fig.26 Daylighting levels across an open plan office floor in December

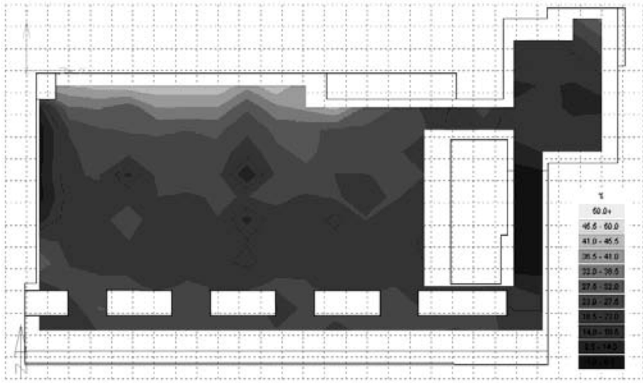

Fig.27 Daylight factors across an open plan office floor in December

Overall, the results of computer simulations have supported the findings of observations, and therefore are reliable to inform such building designs at the early design stages as well as when a refurbishment is required.

C. Evaluation of Solar Gains

Intensity of solar radiation Wh.m-2 Sheffield:

- South facade – glazed area about 315 m2, glazing solar
- North facade – glazed area about 230 m2, glazing solar
- Light transmittance of the facade glazing is □=0.78, value total solar transmittance g-value is 0.65.

Total global solar radiation intensity in Wh.m-2 per months during the reference year in climatic locality Sheffield, UK [3] is presented in Table 1. The following is the estimated solar gains of the south facade (see Fig.28).

On the basis of the solar data, the solar gains can be estimated through the glazed south facade system as can be seen in Fig.5. It is obvious that during a summer season solar gains are very high.

Table 1 Solar radiation intensity - Sheffield

Month	Solar radiation intensity [Wh.m-2]
January	599
February	1319
March	2058
April	3483
May	4362
June	4775
July	4089
August	3119
September	2943
October	1657
November	872
December	511

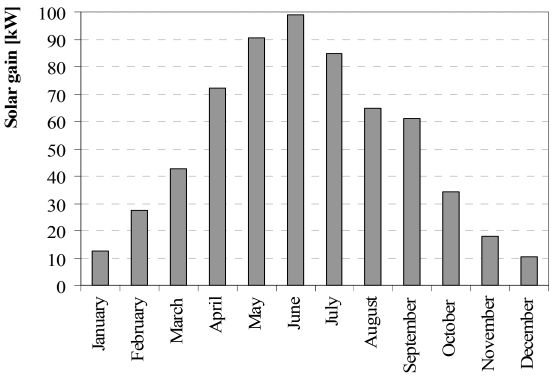

Fig.28 Estimated solar gains through the south facade

D. Monitoring of Temperature Profiles

Daily temperature profiles were monitored at individual floors close to the glazed south facade, system HOBO and HOG were used for the thermal monitoring.

The overheating time was investigated on the basis of measured air temperatures inside the building in the central area of open plan office floors. There is a scheme with the positions of temperature sensors located inside of the investigated building (see Fig.29).

To investigate the overheating periods, the following sensors were selected from the whole measurement data obtained:

- HOBO/07 on the ground floor entrance hall;
- HOBO/11 first floor meeting room and conference hall;
- HOG/08 on the second floor;
- HOG/12 on the third floor;
- HOG/09 on the fourth floor open plan administrative offices.

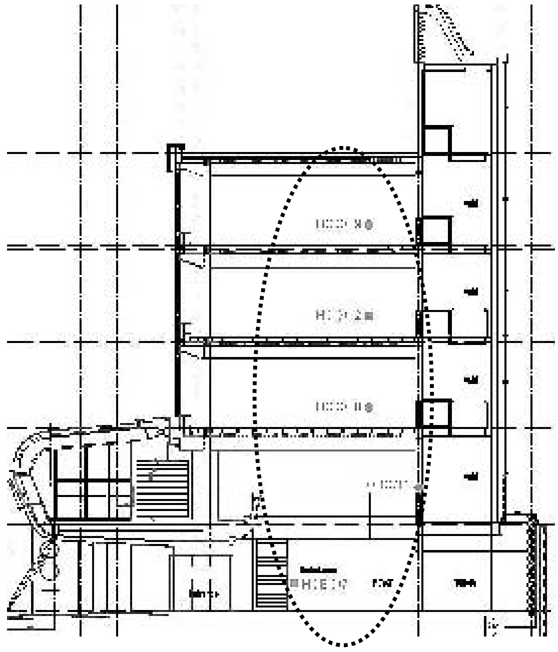

Fig.29 Position of air temperature measurements;

An example presentation of the temperature profiles monitored is showing for 5th May 2006 in Fig.30. There is a significant temperature difference which is also obvious from the profile shown below (d). Temperatures inside the building have risen on upper floors where overheating was also measured during the late spring and summer periods in these floors.

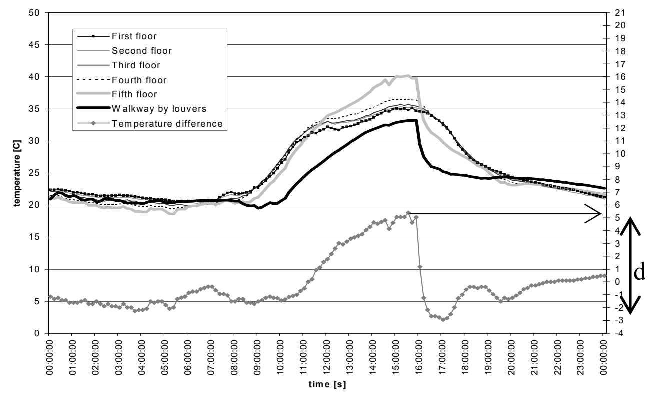

Fig.30 Individual floor day temperature profiles inside the investigated building; where d is the temperature difference between temperature profiles at lowest and highest floors.

Overheating is a major problem in the investigated building and the following figure presents the histogram of number of hours with the average temperature monitored during spring and summer of 2006 (see Fig.29). It is obvious that the time period when indoor temperatures increased above 25°C could not be disregarded – about 219 hours. During this time, due to the thermal environment in the building, there was serious indoor thermal discomfort. Results of questionnaire for indoor comfort confirm occupant discomfort as too hot dry environment.

To eliminate excessive overheating, the ventilation system in the building should be in permanent operation which would consume higher energy for ventilation. The temperature on the facade rises with height of the building but it diminishes as it gets close to ventilation outlet. This temperature difference is reduced via natural ventilation system located directly outside the glazed shell.

On the basis of the monitoring of indoor air temperatures, the results were completed in histograms summarizing the time of temperature intervals during a monitored season and the thermal profiles in characteristic days (see Fig.31).

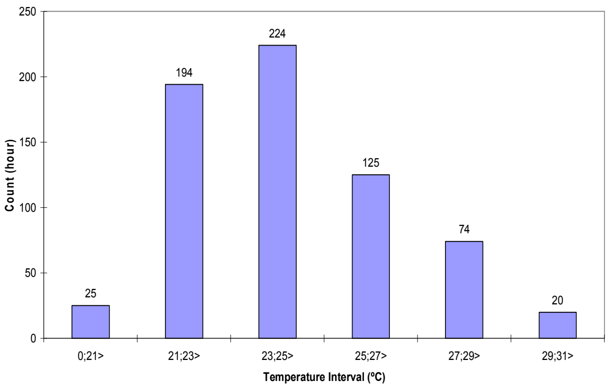

Fig.31 Hourly average indoor temperature histogram

Temperature profiles are completed with histograms which gave information about indoor air temperatures during the monitored seasons. Fig.31 is showing a histogram of the indoor air temperature profiles recorded during summer 2006.

Examples of the results are presented in Fig.32 and Fig.33. The figures present thermal profiles monitored within the open plan offices close to the glazed ventilated facade.

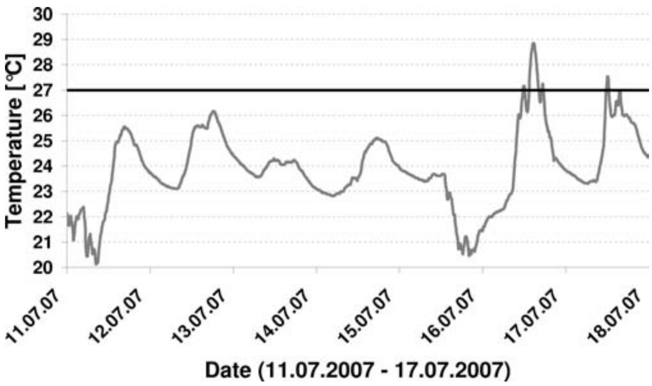

Fig.32 Temperature profile over a period where overheating was recorded during the summer 2006

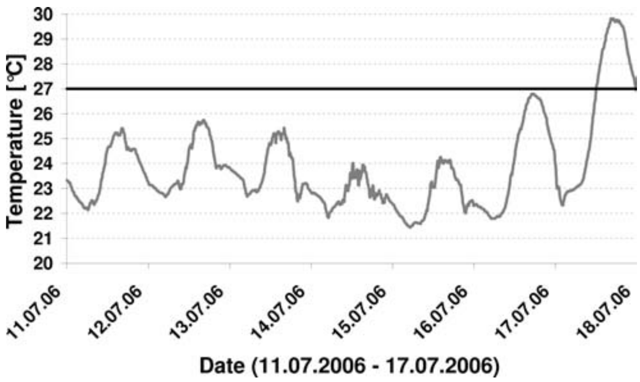

Fig.33 Temperature profile over a period where overheating was recorded during the summer 2007.

III. Improvements to Indoor

There are several potential tasks that can be aimed at improving indoor climate in the investigated building:

The first task is to the retrofit the shading system installed on the south glazed facade. The shading consists of vertical roller blinds in white color. The existing blinds do not create complete solar protection and the part of the facade that can be seen as an uncovered strip (see Fig.34, Fig.35) close to the soffit in line with the floor structure does cause bright pathway for sun patches, which again influences many working positions.

The second task is to monitor the thermal regime in the building as well as the design of the hybrid natural ventilation in order to force ventilation with minimal energy consumption for eliminating overheating problems.

The third task is to utilize solar energy, via solar gains towards energy demand in the building. In addition, with the installation of solar thermal collectors and photovoltaic panels on the roof and/or facade, the building could benefit from reducing its energy demand and consumption of the building, significantly.

Fig.34 Existing shading of the glazed facade (south orientation) - roller blinds

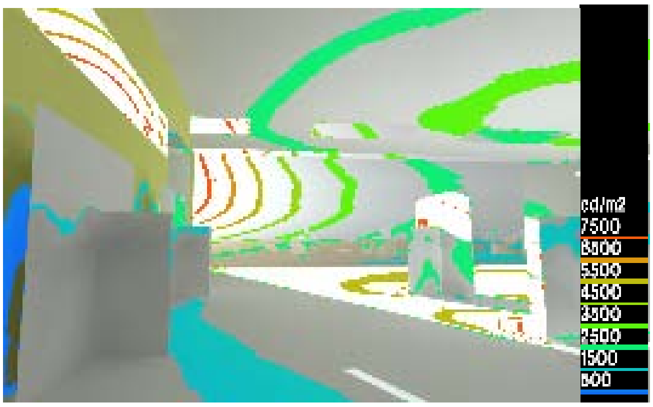

Fig. 35 Luminance distribution in the open office space on the second floor.

IV. Conclusion

The building indoor climate comfort was investigated with respect to solar gains and daylighting through the glazed facades.

The findings have indicated that such designs are to be recommended for their passive use of solar energy and can provide a high quality thermal environment provided that care is taken to ensure the effective use of the natural ventilation strategy in place. Moreover, it is important that in such buildings optimization is achieved for not only natural ventilation but also for natural lighting which is also necessary.

There are known advantages of passive solar designs with various strategies such as using glazed facades to drive the natural ventilation and maximize the daylighting with high indoor illuminance in open plan floor spaces in buildings. However, in contrast, high intensity solar radiation transmitting through the glazed areas can cause unwanted glare effect and interior overheating during warm and sunny days, and therefore a more effective solar protection system should be in permanent operation.

The architectural concept behind this buildings design in terms of its ventilation strategy was to construct a building that would operate with natural ventilation to maintain the indoor air temperature at a level between 20°C to 22°C. In reality, excessive solar gains through the southern glazed facade cause unwanted overheating which then leads to thermal discomfort which is not easily eliminated by the natural ventilation effect.

The building is currently under ongoing monitoring of indoor air quality (in addition to indoor air temperatures and relative humidity levels in selected parts) which should help to modify the design strategy used as means of ventilation system in the building and to suggest a more efficient solar shading system for the glazed active facade.

To conclude, the investigation of indoor air temperatures in such buildings with glazed facades is very important for the building design and operation, particularly for solar shadings and efficient ventilation systems, which will decrease summer overheating and its unwanted effects.

The investigated building is monitored for more than two years now. The final analysis of thermal and visual environment in this building will therefore help to inform the design of more efficient heating and ventilation system [13] as well as functional shading devices during eco-refurbishment.

Acknowledgment

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