An internal assessment of the thermal comfort and daylighting conditions of a naturally ventilated building with an active glazed facade in a temperate climate

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1. Introduction

The naturally ventilated high thermal mass building with an active glazed facade is located in Sheffield, North of England, and the building was chosen as a case study for investigation of indoor environment due to its passive design strategies such as the use of natural lighting and cooling. ICoSS building is the first large scale dedicated facility for Social Sciences Research in the UK and designed for the University of Sheffield. It is a naturally ventilated and daylit building, and achieved an award not only for its iconic design, but also for its green aspects such as the selection of building materials and the use passive solar design strategies [1–7].

The glazed southern facade faces to a buffer zone with the stack natural ventilation service. Solar radiation transmitted through the glazed facade heats the air which then rises and is vented out at the top, and the replacement air is supplied via openings on the north facade which provides cross ventilation across the building. Fig. 1 shows the north facade of the building.

With such designs where the active facade drives the air upwards and the replacement air is supplied by the north facade openings in order to drive the passive cooling (natural ventilation) in the building, the research questions posed are that:

- Is the south facade capable of providing appropriate daylight into the working environment?
- Are the luminance distributions acceptable?
- Are the thermal conditions within accepted comfort limits?
- Are there potential overheating periods during warm seasons?

In order to answer these questions, a post-occupancy evaluation programme was put in place and consisted of measuring the internal environment conditions including indoor air temperatures and humidity levels in the working environment, natural ventilation shaft, and the luminance distributions at selected positions of the work stations in a typical floor plan.

The design concept for the facade ventilation regime in the context with the ventilation strategy of the whole building is presented in Fig. 2. The initial monitoring of the building which is reported here was aimed at establishing if the south facade (active facade) was operating as expected and the daylighting levels through glazed facades were sufficient. There are shading roller blinds on the southern glazed facade and the ventilation louvers are used on the top of the roof as a control device for the thermal regime in the investigated building (see Fig. 2).

2. Results of the thermal measurements

The first part of the post-occupancy monitoring programme about the effectiveness of the active facade involved observing the way in which the natural ventilation louvers operated to maintain
the correct internal temperatures [8,9]. The design criteria were that when the inside air temperature rose due mostly to the incidence of solar radiation then the louvers on both the north and south elevations would open to control the air temperatures. Also there was the intention that during the night the louvers would open to cool the building.

The measurements were concentrated in the working area but in order to estimate if the shaft was producing air at temperatures sufficient to set up a convective current temperatures were taken in the shaft and also between the glazing and the internal shading devices. On average, the temperature in the shaft was in the region of 35 °C, and between the blinds and the glazing it raised to 40 °C. These measurements were taken on the 4th floor that is near the top of the shaft. The air flow at this level was also measured and found to be in the region of 0.4 m/s. Aggregating this flow rate over the area of the shaft produced a flow rate in the region of 7 m³/s which taken over the volume of the building produced an air change rate in the region of 4 h⁻¹.

The monitored data is available for the autumn and early winter of 2005, spring and summer 2006, and extracts are shown to illustrate how the system was operating. The trends in internal air temperatures for 17–23 November 2005 are clearly illustrated in Fig. 3 and also show how the internal temperatures varied. It seemed clear from this figure that there was a significant difference between the ground floor temperatures and the temperatures on the 4th floor.
For the corresponding time period, it was shown that the south louvers were open while the north louvers changed their opening pattern in response to the inside air temperatures (see Fig. 4).

Looking at a period of time when the outside air temperature was little higher than in November 2005 showed that the operating pattern was completely different, as shown in Fig. 4 for the 3rd to 6th October 2005.

Before the winter heating schedule was activated the louvers were operated to control both night cooling and day ventilation rate. Fig. 5 illustrates how the systems responded to the demands of the building. It is interesting to see that in this operation mode the louvers at the top of the south glazing were not operated for most of the day, and the control of ventilation was mostly under the influence of the south louvers. Furthermore, the thermal
operation of the facade system in spring 2006 was also monitored and the following figures present the results of temperature profiles and measurements for a characteristic sunny and cloudy cold spring day (see Figs. 6 and 7).

Results from the spring measurements provided information about the temperature difference between the first and the top floor which is more than 8°C on a sunny day and less than 2°C on a cold day. This indicates that the natural ventilation effect of the glazed facade is limited during cold cloudy climatic conditions.

In addition, for the comparison of the results mentioned above, Sheffield (England) outdoor temperature profile from the Met Office Statistics for year 2006 is presented in Fig. 8.

3. Lighting measurements and daylighting simulations

The measurements of the luminance distribution at various locations were carried out and the positions of the work stations from 1 to 23 are clearly marked on typical floor plan, and shown in the following figure (see Fig. 9).

The lighting measurements of the distribution of brightness (luminance) of the working environment indicated that under the clear sky condition with direct solar radiation the ratio between the brightest and dullest part of the view where the occupants had within their field of view was excessive, which could give visual discomfort. Moreover, to find out if this could be a problem in other
environments, luminance analysis was carried out in the administrative part of the building on a typical floor. The evaluation of visual conditions in the working areas was required in order to investigate areas with very high and very low luminance that could be a possible cause for unwanted interior glare effects. The luminance distribution on the working areas including work-

Fig. 8. Outdoor temperature profile, Sheffield, year 2006.

Fig. 9. Typical floor plan where the measurements were taken in positions of the work stations 1–23.

Fig. 10. (a) Luminance distribution over the working area close to the southern glazed facade (radiance lighting simulation). (b) Luminance distribution over the whole working area (radiance lighting simulation).
stations was evaluated with the use of the computer simulation programme Radiance \[10\], to establish the brightness levels over the working areas, and some of the results of the study carried out are shown in Fig. 10a and b.

The southern facade is an objective of the investigation due to the fact that it is one of the possible causes of glare effects and direct solar gains which is also the cause of overheating.

However the design of the blind system on the south facade resulted in gaps being seen between the blinds on different floors. These gaps allowed sunlight to penetrate in narrow shafts to the working positions and there was some evidence from some of the occupants that they found this situation disturbing, which indicates visual discomfort, i.e. glare effect.

The computer simulations clearly demonstrated that there is a wide range in brightness within the working environment which may cause visual discomfort to the occupants (see Fig. 10).

The results of the luminance measurements for various working positions (work stations) are shown in Table 1, which contains values along with the maximum range in luminance observed within the occupants view. These ratios do seem a little high which prompted further investigations using Radiance lighting simulations.

The illuminance on the horizontal surfaces is usually taken as the requirement for performing a visual task and according to the CIBSE’s Lighting Design Guide \[11\], a value of 300 lux is recommended as the minimum for the type of work being carried out in this office environment, which is also supported by the British Standards \[12\].

Furthermore, the results of the illuminance distribution on the working plane (850 mm over the floor level) are presented in the following figure (see Fig. 11) with predicted variations for both summer overcast and summer clear sunny sky conditions, by the use of Ecotect software \[13\].

4. Determination of overheating periods

In order to investigate and determine the overheating periods in this naturally ventilated office building, a longitudinal thermal data (inside temperature profiles) was required. As part of the ongoing post-occupancy evaluation programme, the measurements of the indoor air temperatures in selected positions were already obtained in the building during an annual period for the whole year of 2006, and as a result by the use of chosen method \[5\], overheating analysis were conducted. The overheating periods were determined for the season between July and October 2006 (in two parts; July, August and September, October), and under the conditions that an indoor air temperature reaches and/or goes above 27 °C for a duration of 2 consecutive hours (time interval)
Table 1
Results of the luminance measurements at working positions on the 2nd floor

<table>
<thead>
<tr>
<th>Position</th>
<th>Max luminance:</th>
<th>Min luminance:</th>
<th>Window-south view (with a blind):</th>
<th>Window-north view:</th>
<th>Maximum ratio:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>362 cdm(^2)</td>
<td>121.6 cdm(^2)</td>
<td>6112 cdm(^2)</td>
<td>3,114 cdm(^2)</td>
<td>50:1</td>
</tr>
<tr>
<td>Position 4</td>
<td>3,461 cdm(^2)</td>
<td>16.57 cdm(^2)</td>
<td>5,710 cdm(^2)</td>
<td>10,175 cdm(^2)</td>
<td>636:1</td>
</tr>
<tr>
<td>Position 5</td>
<td>138 cdm(^2)</td>
<td>26 cdm(^2)</td>
<td>5,250 cdm(^2)</td>
<td>14,870 cdm(^2)</td>
<td>571:1</td>
</tr>
<tr>
<td>Position 8</td>
<td>100 cdm(^2)</td>
<td>30.76 cdm(^2)</td>
<td>16.26 cdm(^2)</td>
<td>6,796 cdm(^2)</td>
<td>874:1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14,220 cdm(^2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,610 cdm(^2)</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1 (Continued)

<table>
<thead>
<tr>
<th>Position 10</th>
<th>Max luminance:</th>
<th>12,100 cdm²</th>
<th>Min luminance:</th>
<th>80 cdm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window-south view (with a blind):</td>
<td>6,006 cdm²</td>
<td>Window-north view:</td>
<td>3,422 cdm²</td>
<td></td>
</tr>
<tr>
<td>Maximum ratio:</td>
<td>151:1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Position 10 | Max luminance: | 222 cdm² | Min luminance: | 54 cdm² |
| Window-south view (with a blind): | 4,715 cdm² | Windows without a blind: | 11,760 cdm² |
| Window-north view: | 3,940 cdm² | Maximum ratio: | 217:1 |

| Position 12 | Max luminance: | 247.1 cdm² | Min luminance: | 98 cdm² |
| Window-south view (with a blind): | 5,955 cdm² | Windows without a blind: | 11,550 cdm² |
| Window-north view: | 3,646 cdm² | Maximum ratio: | 117:1 |

| Position 14 | Max luminance: | 118.2 cdm² | Min luminance: | 69 cdm² |
| Window-south view (with a blind): | 5,524 cdm² | Windows without a blind: | 15,140 cdm² |
| Window-north view: | 3,882 cdm² | Maximum ratio: | 219:1 |
during the times between 9:00 a.m. and 6:00 p.m. The scheme of the building with thermal sensors distribution is presented in Fig. 12.

Results of the overheating periods investigation is summarised in the histogram in Fig. 13.

Monitored data were sorted with respect to the minimal and maximal daily temperature profiles. There were evaluated daily indoor air temperature profiles and these were classified with their minimal and maximal values during the monitored period from June to July and October to November 2006. In addition of the investigations, the histograms of hourly average temperatures were completed for the same monitored period. The graphs of minimal and maximal daily profiles and temperature histograms are presented in Figs. 14–28.

Fig. 12. Scheme of the building with HOBO thermal sensors distributions.

Fig. 13. Comparison of 2 h intervals of the overheating periods recorded between July and October 2006.
Fig. 14. Temperature profile of logger HOBO/02; day with minimal indoor air temperature profile—15th October 2006.

Fig. 15. Temperature profile of logger HOBO/02; day with maximal indoor air temperature—1st November 2006.

Fig. 16. Histogram of hourly average indoor air temperature; logger HOBO/02—October–November.
Fig. 17. Temperature profile of logger HOBO/03; day with minimal indoor air temperature—7th July 2006.

Fig. 18. Temperature profile of logger HOBO/03; day with maximal indoor air temperature—17th July 2006.

Fig. 19. Histogram of hourly average indoor air temperature; logger HOBO/03—June–July 2006.
Fig. 20. Temperature profile of logger HOBO/04; day with minimal indoor air temperature—5th November 2006.

Fig. 21. Temperature profile of logger HOBO/04; day with maximal indoor air temperature—1st November 2006.

Fig. 22. Histogram of hourly average indoor air temperature; logger HOBO/04—October–November 2006.
Fig. 23. Temperature profile of logger HOBO/13; day with minimal indoor air temperature—15th October 2006.

Fig. 24. Temperature profile of logger HOBO/13; day with maximal indoor air temperature—1st November 2006.

Fig. 25. Histogram of hourly average indoor air temperature; logger HOBO/13—October–November 2006.
Fig. 26. Temperature profile of logger HOBO/15; day with minimal indoor air temperature—22nd October 2006.

Fig. 27. Temperature profile of logger HOBO/15; day with maximal indoor air temperature—2nd November 2006.

Fig. 28. Histogram of hourly average indoor air temperature; logger HOBO/15—October–November 2006.
5. Conclusion

The paper focused on an evaluation study of a glazed facade (active facade) and its influence on the indoor climate comfort and working environment. It also reported the initial findings of an internal assessment of the thermal comfort and daylighting conditions in such a building, and some of the results are listed below:

- There are obvious advantages of passive solar designs with various techniques such as using a fully glazed facade to both drive the natural ventilation and maximise the daylighting with high indoor illuminance in buildings.
- In contrast, high intensity of solar radiation transmitting through the glazed areas can also cause unwanted glare effect and interior overheating during warm and sunny days, and therefore the efficient shading system should be in permanent operation [6].
- The existing blinds do not create complete solar protection and the part of the facade in the uncovered strip close to the soffit of the floor structure does cause bright pathway for sun patches, which again influences many working positions [7] (findings from walk round survey).
- The findings from the indoor climate study focusing on the operation of the building has indicated that such designs are to be commended for their passive use of solar energy and can provide a high quality working environment provided that care is taken to ensure the natural ventilation strategy concept is monitored continuously, and is also not compromised due to maximising daylighting in the working areas or vice versa (in other words; optimising efficiency for not only natural ventilation but also for natural lighting).
- At the time of this survey the louvers controlling the ventilation rate appeared not to be operating but the calculated air change rate (about 4 h

Further study

This study is continuing with a view to providing an operating manual for the building energy management system (BEMS) more in keeping design concepts and user behaviour.

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References