Environmental Evaluation of an Active Façade in a Naturally Ventilated Office Building

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ABSTRACT: An active façade is often used to promote the flow of air through a building. However in order to ensure that this process is effective the façade should face a southerly orientation. This means that not only solar energy is transferred across the glazing but in warm periods shading is needed which can produce an internal environment where the luminance distribution may not comply with current lighting requirements. Also such buildings tend to have a high thermal mass to promote the use of night cooling; one consequence of this type of design is that there is a tendency for high reverberation times which can be acoustically distracting. This paper reports the initial findings of an internal assessment of the daylighting, acoustic and thermal comfort conditions of such a building. The results have 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 that the air flow paths are maintained and reasonable precautions taken to reduce reverberation times.

Keywords: Energy, Daylight, Natural Ventilation, Comfort, Acoustics

1. INTRODUCTION

An active façade is often used to promote the flow of air through a building. However in order to ensure that this process is effective, the façade should face a southerly orientation. This means that not only solar energy is transferred across the glazing but in warm periods shading is needed which can then produce an internal environment where the luminance distribution may result in some local visual discomfort or not comply with current lighting requirements.

Moreover, such buildings tend to have a high thermal mass which is used to absorb daytime heat gains which are then dissipated via night time ventilation which gives passive cooling. A building with a high thermal mass is also prone to having long reverberation times which can be distracting to occupants working in a predominantly open plan situation.

The building being investigated was constructed in 2004/05 and uses the 100% glazed south façade as a means of heating the air which then rises and is vented out at the top. The replacement air is supplied via openings on the north façade. Figure 1 shows the design concept for the ventilation regime. Figure 2 shows the south façade of the building and the internal shading devices. The initial monitoring of this building was aimed at establishing if the south façade was operating as expected with respect to drawing the air through the building and that the lighting of the work spaces was appropriate.

The main issues of concern were: were the air drawn upwards and the replacement air drawn from the north; is the south façade capable of providing appropriate daylight; and are the luminance distributions acceptable and finally are the thermal conditions within accepted comfort limits.

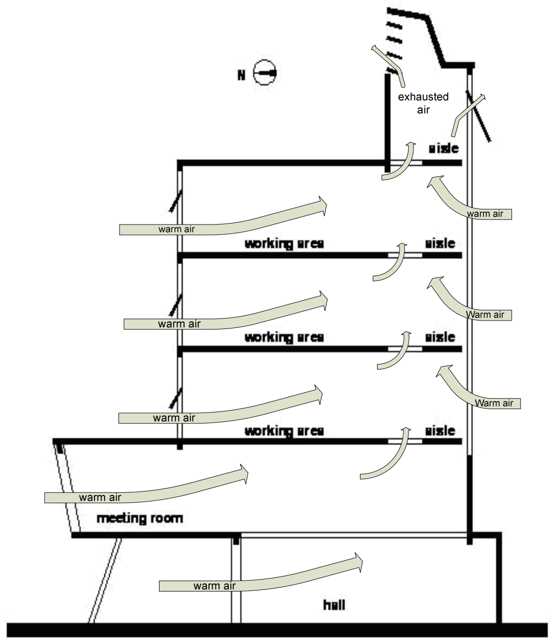

Figure 1: The planned operation of the ventilation strategy.

Figure 2: Investigated office building.

2. MONITORING PROGRAMME

A monitoring programme has been initiated in order to establish if the design meets the aspirations of both the designers and occupiers in terms of the below aspects:

2.1 Internal Working Environment

These include satisfaction with air temperature, air humidity, air movement, noise levels, and the visual environment.

2.2 Energy Use Issues

The building was designed to be a naturally ventilated building with the south façade acting as 'the solar chimney' driving the ventilation. It is controlled by a Building Energy Management System (BEMS).

The monitoring programme undertaken (and is continuing) has helped in establishing if the building is performing as intended and could form a benchmark for other similar building types. Of particular interest is the effectiveness of the south façade in driving the ventilation.

3. MEASUREMENTS

3.1 Temperature Measurements

The initial spot measurements presented in this paper were taken on a sunny sky day early February 2006. Table 1 shows the measurements for two floors during this time along with the corresponding external conditions. The measurements were taken at the positions shown in figure 3.

Table 1: Measured outdoor and indoor conditions.

Outdoor conditions:	Air Temperature: 8.3°C Noise Level: 53 dB Exterior Illuminance: 5400 lx

Indoor conditions: 2nd floor

Pos	T_{air} [°C]	RH [%]	SL [dB_a]	I_{hor} [lux]
4	26.1	23.2	42.5 - 54.4	1165
5	28.5	23.0	26.6 – 40.1	510
8	28.7	22.6	30.6 – 48.6	392
10	28.0	21.2	33.0 – 46.0	672
11	28.3	21.1	36.0 – 45.0	492
12	26.8	22.3	25.2 – 45.7	952
14	27.5	21.8	32.7 – 41.5	680

Indoor conditions: 4th floor

Pos	T_{air} [°C]	RH [%]	SL [dB_a]	I_{hor} [lux]
10	30.8	21.3	33.2	387
11	31.7	21.8	35.0	370
12	31.2	19.6	26.3	852
13	30.5	20.4	39.4	470

Pos: Position
T_{air}: Air Temperature [°C]
RH: Relative Humidity [%]
SL: Sound Level [dB_a]
I_{hor}: Horizontal Illuminance [lux]

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 reached 40°C. These measurements were taken on the 4th floor which is near the top of the shaft. The airflow 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 m^3/s which taken over the volume of the building produced an air change rate in the region of 4 per hour.

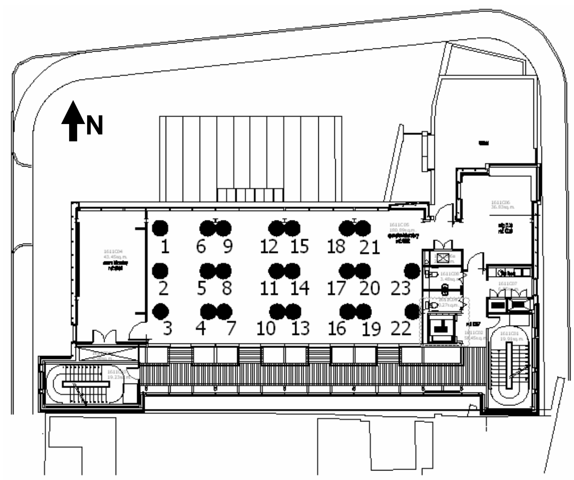

Figure 3: Typical floor plan where measurements were taken.

3.2 Luminance Measurements

The illuminance on horizontal surfaces is usually taken as the requirement for performing a visual task and according to the CIBSE Lighting Design Guide [1], [2] and [3], a value of 300 Lux is recommended as the minimum for the type of work being carried out in this office environment.

From the measurements shown in table 1 the space seems to be adequately lit. However the design of the blind system on the south façade resulted in gaps being seen between the blinds on different floors (see figure 4). These gaps allowed sunlight to penetrate in narrow shafts to the working positions and there was some evidence from some of he occupants that they found this situation disturbing. Therefore measurements of the luminance distribution at various locations were carried out.

Figure 4: The blinds on the south façade.

The results of the measurements for various working positions are shown in table 2 along with the maximum range in luminances observed within the occupants view. An example of the distribution on luminance on a working position is shown in figure 5. These ratios do seem a little high which prompted further investigations using Radiance lighting simulation.

Table 2: Luminance measurements.

Luminance	2nd floor
Position 1	
Max luminance:	362 cdm^{-2}
Min luminance:	121,6 cdm^{-2}
Window-south view (with a blind):	6112 cdm^{-2}
Window-north view:	3114 cdm^{-2}
Maximum Ratio	25:1
Position 4	
Max luminance:	3461 cdm^{-2}
Min luminance:	16.57 cdm^{-2}
Maximum Ratio	194:1
Position 5	
Max luminance:	138 cdm^{-2}
Min luminance:	26 cdm^{-2}
Window-south view (with a blind):	5250 cdm^{-2}
Windows without a blind:	14870 cdm^{-2}
Window-north view:	3007 cdm^{-2}
Maximum Ratio	571:1
Position 8	
Max luminance:	100 cdm^{-2}
Min luminance:	30,76 cdm^{-2}
Monitor off	16.26 cdm^{-2}
Window-south view (with a blind):	5796 cdm^{-2}
Windows without a blind:	14220 cdm^{-2}
Window-north view:	3610 cdm^{-2}
Maximum Ratio	874:1
Position 10	
Max luminance:	12100 cdm^{-2}
Min luminance:	80 cdm^{-2}
Window-south view (with a blind):	6006 cdm^{-2}
Maximum Ratio	151:1
Position 11	
Max luminance:	222 cdm^{-2}
Min luminance:	54 cdm^{-2}
Window-south view (with a blind):	4715 cdm^{-2}
Windows without a blind:	11760 cdm^{-2}
Window-north view:	3940 cdm^{-2}
Maximum Ratio	217:1
Position 12	
Max luminance:	247.1 cdm^{-2}
Min luminance:	98 cdm^{-2}
Window-south view (with a blind):	5955 cdm^{-2}
Windows without a blind:	11550 cdm^{-2}
Window-north view:	3646 cdm^{-2}
Maximum Ratio	117:1
Position 14	
Max luminance:	118.2 cdm^{-2}
Min luminance:	69 cdm^{-2}
Window-south view (with a blind):	5524 cdm^{-2}
Windows without a blind:	15140 cdm^{-2}
Window-north view:	3882 cdm^{-2}
Maximum Ratio	219:1

Luminance	4th floor
Position 10	
Max luminance:	204 cdm^{-2}
Min luminance:	121 cdm^{-2}
Monitor off	12,27 cdm^{-2}
Window-south view (with a blind):	3208 cdm^{-2}
Window-north view:	2220 cdm^{-2}
Maximum Ratio	261:1
Position 11	
Max luminance:	213.2 cdm^{-2}
Min luminance:	28.5 cdm^{-2}
monitor off	4 cdm^{-2}
Window-south view (with a blind):	3316 cdm^{-2}
Window-north view:	1781 cdm^{-2}
Maximum Ratio	829:1
Position 12	
Max luminance:	164 cdm^{-2}
Min luminance:	52 cdm^{-2}
monitor off	6.05 cdm^{-2}
Window-south view (with a blind):	722 cdm^{-2}
Window-north view:	294 cdm^{-2}
Maximum Ratio	120:1

3.3 Radiance Lighting Simulation

The measurements of the distribution of brightness (luminance) of the working environment indicated that under certain situations the ratio between the brightest and dullest part of the view the occupants had within their field of view was excessive which could give visual discomfort. To establish if this could be a problem in other environments the computer simulation programme Radiance [4] was run to establish the likely ranges in brightness over the working positions. Some of the results of this work are shown in figures 6, 7 and 8.

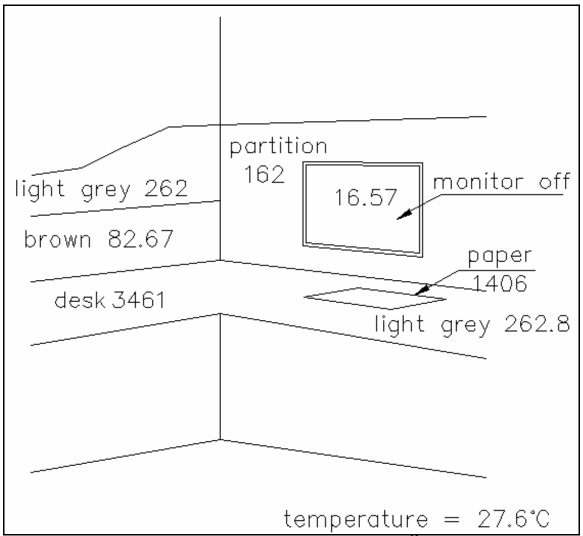

Figure 5: Luminance values [cdm^{-2}] at working position 4 on 2nd floor.

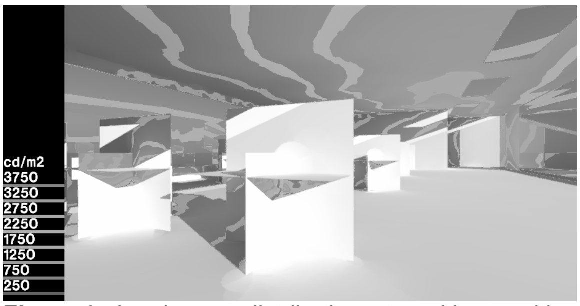

Figure 6: Luminance distribution at working position 4.

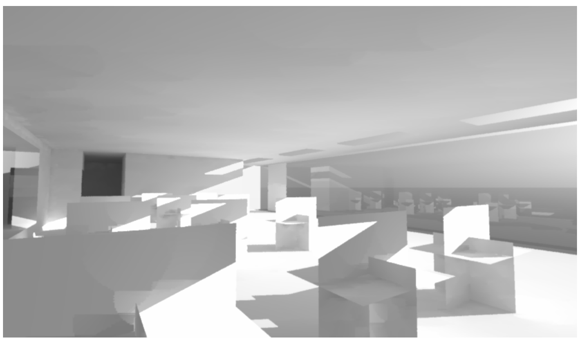

Figure 7: Luminance distribution at working position 1 looking south east.

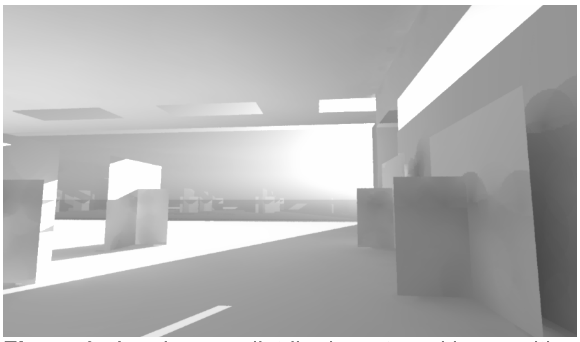

Figure 8: Luminance distribution at working position 1 looking south.

These simulations clearly demonstrate that there is wide range in brightness's within the working environment, which may cause visual discomfort to occupants.

4. MONITORED INSIDE TEMPERATURES AND NATURAL VENTILATION STRATEGY

Part of the monitoring programme involved observing the way in which the natural ventilation louvers operated to maintain the correct internal temperature. 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 temperature. Also there was the intention that during the night the louvers would open to cool the building.

The monitored data is available for the autumn and early winter of 2005/06 and extracts are shown to illustrate how the system was operating.

The trends in internal air temperature are clearly illustrated in figure 9, which shows for the 17th to 23rd November how the internal temperatures varied. It is clear from this figure that there was a significant difference between the ground floor temperature and the temperature on the 4th floor.

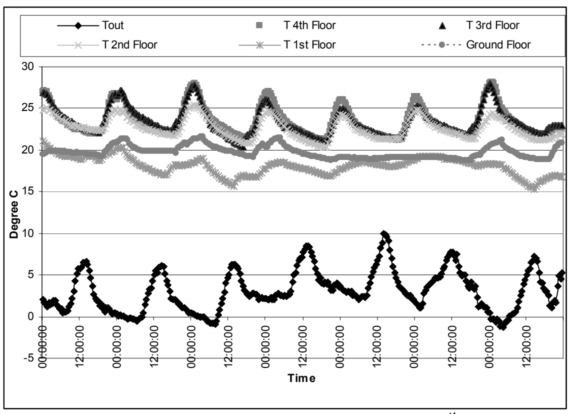

Figure 9: Inside temperatures for 17th to 23rd November.

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 figure 10).

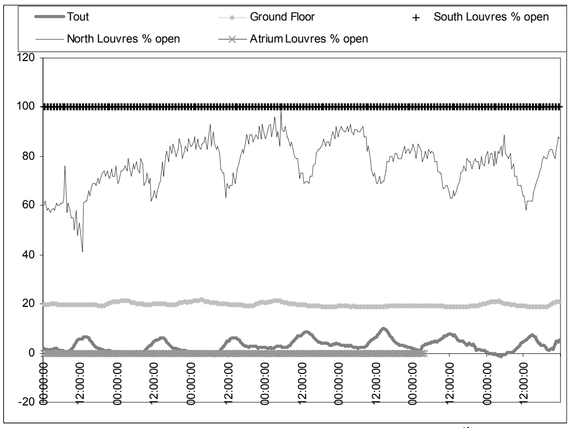

Figure 10: Position of louvers for 17th to 23rd November.

Looking at a period of time when the outside air temperature was a little higher than in November showed that the operating pattern was completely different, as shown in figure 11 for the 3rd to 6th October.

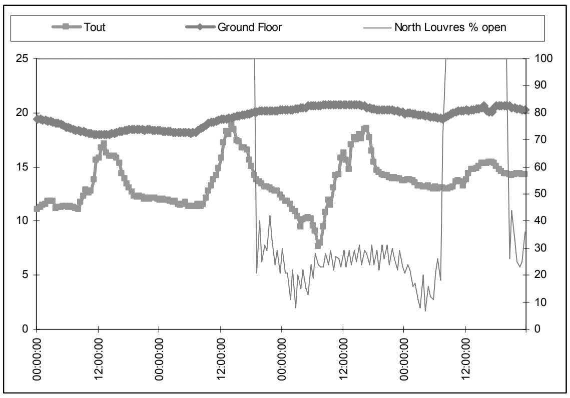

Figure 11:Operation of the louvers in early October.

Before the winter heating schedule was activated the louvers were operated to control both night cooling and day ventilation rate. Figure 12 illustrates how the systems responded to the demands of the building. It is interesting to note 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.

5. ACOUSTIC ENVIRONMENT

From the measurements taken during the survey there appeared to be little problem with the acoustic environment. A full test of reverberation times was carried out by the designers [5] and this concluded that the times were well within accepted values.

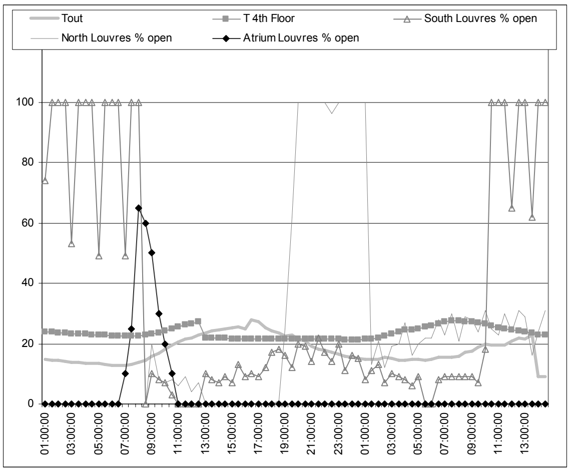

Figure 12: Operation of the louvers in early October before the winter heating schedule was in operation.

6. CONCLUSION

The results of this initial study on the operation of the building have 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 that the airflow paths are maintained and reasonable precautions taken to reduce reverberation times.

Further observations include:

- The brightness distribution did seem to give some cause for concern.
- At the time of this survey the louvers controlling the ventilation rate appeared not to operating but the calculated air change rate (about 4 per hour) seemed reasonable. It was not sure how this was achieved when the louvers appeared closed.
- High internal air temperatures measured again indicated a lack of control of the natural ventilation rates.

This work is continuing with a view to providing an operating manual for the BEM system more in keeping design concepts and user behaviour.

REFERENCES

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[2] THERMIE, Daylighting in Buildings, PUCD-OPET, UK, 1994.
[3] British Standards, BS 8206-2 Lighting for Buildings - Part 2 - Code of Practice for Daylighting, UK, 1992.
[4] Radiance Simulation Programme, http://radsite.lbl.gov/radiance/
[5] Arup Internal Report on Commissioning of the ICOSS Building, Private Communication.