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The Contribution of Facade Design and Building Orientation to the Indoor Environment
Case Study: Broadcasting Tower in Leeds, UK

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Abstract
Since its completion in 2009, the Broadcasting Tower in Leeds has won many prestigious local, national and international prizes. But as a students' residence tower, do these recognitions for architectural excellence reflect a comfortable indoor environment? To answer this question, the author has investigated the building's environmental performance regarding thermal and visual comfort in particular relation to the unique irregular facade design of the tower. The qualitative and quantitative assessment included onsite observations, occupants' feedback through surveys and interviews, and a detailed comparative analysis of the existing thermal and visual performance using computer simulation programs (TAS and Ecotect). The results showed that the contribution of the window design - which affected the natural ventilation system- and the solar gain due to the building orientation toward west and east without shading devices; all led to overheating and affected the daylighting performance inside the building. It is hoped that further investigations regarding different facade designs and building typology as well as different climatic conditions can be obtained based on this research.

Keywords: Facade Design, Window Type, Thermal Comfort, Visual Comfort

1. Introduction
The demand for student housing in the UK is growing steadily due to the increased participation of higher education from both national and international students. However, little attention has been directed to student housing, despite the fact that it composes an environmental challenge due to its high energy consumptions, especially for water and space heating, ventilation and lighting (Clegg, et al., 2007). Therefore, student housing was set as focus of this research.

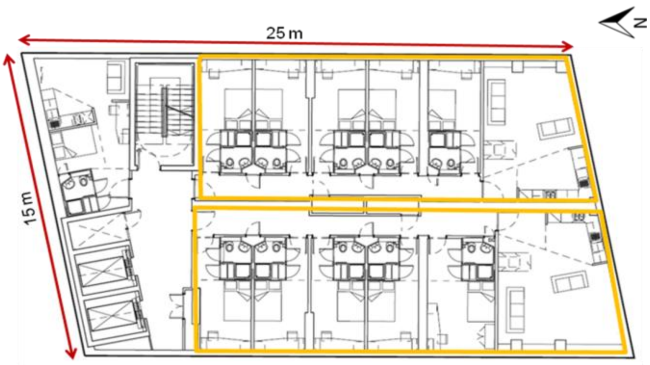
When considering environmental principles in building design, energy efficiency is usually a driving factor; while the prime factor should be to provide delightful comfortable indoor environment for the building's users. The building envelope, including the fenestration systems (windows, skylights, and door systems within a building) has a major impact on the indoor environment. Bessoudo (2008, p.2) states that: "*A well-designed, high-performance envelope can improve building energy performance, provide a higher quality thermal and visual environment, and reduce peak thermal loads in perimeter zones*". The orientation of the building is equally important; each facade should be treated respectively according to its orientation to the sun (Rennie and Parand, 1998). Carefully designed facade should exclude excessive direct sunlight in order to avoid overheating while allow sufficient levels of natural daylight and ventilation. The main objectives of this research are to understand the relationship between facade, window design, building orientation and how they contribute to the thermal and visual comfort, in regard to overheating, natural ventilation and daylighting, with particular reference to student housing.

2. Case Study: Broadcasting Tower

Broadcasting Place is a mixed-use development located in Leeds, UK, designed by Alex Whitbread from FCBS. The development consists of academic buildings for Leeds Metropolitan University in addition to a 69m high student residence tower which provides 240 student residences (Fig. 1). Notably, the design has overcome several site difficulties, including an inner city motorway and low rise historical buildings (CTBUH, 2011).

Figure 1. Broadcasting Place, Leeds, UK
(Source: www.archdaily.com, 2010)

The buildings form and facade were designed in respect to aesthetical and environmental considerations. The rectangular plan of the tower faces west and east on its longer sides, while the short sides face north and south. The west and east elevations were "*tailored to optimize daylight and reduce solar penetration. The proportions of the glazed facade were carefully examined and derived using special software. An innovative analysis of the building facades were undertaken, which calculated the optimum quantity and distribution of glazing/shading at all points on the facade in order to ensure high levels of natural daylighting without overheating*" (CTBUH, 2011). The south elevation was designed totally solid to eliminate additional glass treatment and overheating as well as giving a sculptural impact since it is facing the city centre (see Fig. 1). As shown in (Fig. 2), the typical floor plan for the Broadcasting Tower consists of one individual studio room and two clusters. Each cluster is around 130 m² and contains five individual rooms and a common living area (Feilden Clegg Bradley Studios LLP). All the rooms are facing either east or west orientation and are naturally ventilated from one side. The window typology is the same but the distribution of windows within the façades varies. Each window is 2.4 x 1.1 m and consists of four elements: 2.4 x 0.75 m fixed double glazing with the lower half being tinted, and 0.3 x 1.3 m openable louvers panels with wire mesh (Fig. 3).



3. Window Typology

Figure 2. Typical floor layout, A- West Common room, B- East Common room, C- West Bedroom, D- East Bedroom

D B (EB) C A (WB) (WC)

3. The Broadcasting Tower Post Occupancy Evaluation (POE)

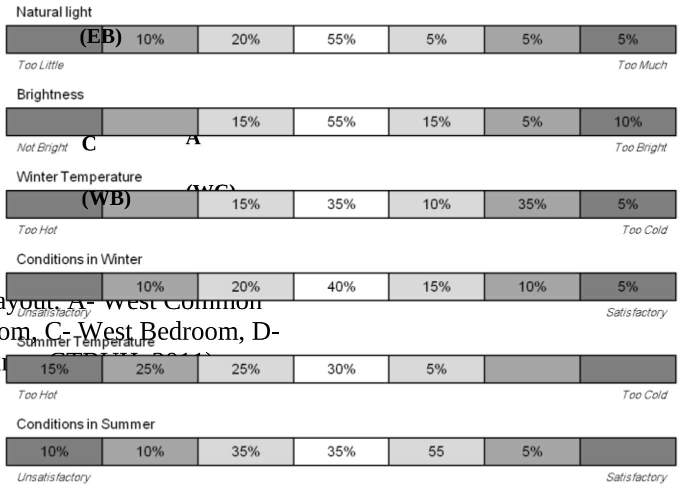


Figure 4. Occupants' POE Survey Results

The quality of the indoor environment in Broadcasting Tower was evaluated by its occupants –the students- using surveys through questionnaires. The questionnaire was composed following the "Guide to Post Occupancy Evaluation" provided by the Higher Education Funding Council for England (HEFCE). The surveys were answered by 20 students, and their level of satisfaction was recorded and analysed (Fig. 4).

It can be observed from the survey that the outcomes regarding natural lighting perception were mostly positive and fell within the comfort range or slightly affected with minor extreme ratings. However, regarding user perceptions of temperature, it can be noticed that users' satisfaction was less achieved especially in summer and that overheating might be an issue. 20% of the students commented that air conditioning should be provided to overcome the overheating problem.

4. The Broadcasting Tower Environmental Performance

4.1 Thermal Performance Prediction

In regard to the recommended comfort criteria, dwellings building type were chosen since student housing are primarily dwellings. The CIBSE Comfort sets the summer indoor comfort temperature for non-air conditioned buildings as 25ºC for the living areas and 23ºC for bedrooms. When setting the maximum indoor temperature according to CIBSE and ARUP, the Design for Future Climate report states that:

"Two thresholds were used to define discomfort - 'warm' (25ºC) and 'hot' (28ºC) – representing the band in which most people currently start to feel uncomfortable. The 'warm' (25ºC) temperature was used for bedrooms, because people tend to be less tolerant of higher temperature when trying to sleep. Otherwise 28ºC was used. A building was said to have overheated if temperature exceeds the threshold for more than 1% of occupied hours." (Gething, 2010, p.13).

The indoor thermal performance of the Broadcasting Tower was tested against the previous benchmarks. The assessment was carried out by initial on-site monitoring and detailed analysis for the building's thermal behaviour through dynamic simulation using TAS. Moreover, the natural ventilation strategy was assessed using computer calculations using Optivent software. The spot measurements revealed the internal air temperature exceeding the external temperature by 10 to 12 °C. The relatively large different between internal and external temperature - despite the fact that the louvers were open for a long time - indicates that overheating could be an issue in warmer weather.

In order to run the dynamic thermal simulations using TAS, a typical floor plan – assumed to be on the 11th floor- was modelled in TAS and four spaces were analysed: a west common room (WC) and a west bedroom (WB), an east common room (EC) and an east bedroom (EB) (refer to Fig. 2). As for the assumptions they were as following: The occupied hours for both the bedrooms and common rooms were assumed according to the occupancy patterns for students allowing for sleeping hours, lectures times, study and leisure activities. The calendar was based on University calendar considering summer and winter holidays but the simulations were run during the open university days both in summer and winter, assuming that students usually travel on holidays. The building fabric assumptions were based on the high level of insulation suggested by the architect, the U value for the external walls (0.25 W/m²K) and the windows (1.4 W/m²K). The internal conditions were set based on the space function (bedroom or common room), occupancy pattern, as well as the calendar and season. In winter, the heating depends on radiators while in summer cooling was achieved by setting aperture type for the openable louver panels to be functioned when the internal air temperature reaches 24ºC. The effective opening area for the aperture was set as 50 %. The simulations compared between four cases:

- Case 1: The existing building case in order to analyse the thermal behaviour of the building and investigate what can be improved. Natural ventilation in summer time only.
- Case 2: Natural ventilation used in summer and winter when the indoor air temperature reaches 24ºC.
- Case 3: The effective opening for natural ventilation is increased to the double.
- Case 4: Vertical shading devices on the west and east windows were added.

Fig. 5 illustrates the air temperature prediction results for the west and east common room (WC and EC) in the different cases. Generally, both rooms behaved similarly regardless of the opposite orientation, giving into account that the west common room (WC) is slightly overheated than the East common room (EC) due to the solar gain especially from the low evening sun. When assessing the existing case (Case 1) with summer natural ventilation only, it is apparent that though the external temperature is below the comfort zone for 97% of the hours, the indoor temperature is reaching the 'hot' zone for more than half of the occupied hours with only 30% within the comfort range. This excessive overheating is gradually decreasing as natural ventilation was allowed in winter when the indoor temperature reaches 24ºC (Case 2). In (Case 3) the effective ventilation opening was increased to the double since the current louvered panels has a small effective opening due to the close spaces between the louvers blades in addition to the wire mesh. This option increased the comfort zone hours to more than 80%. This option was also tested in Optivent and the results showed that the existing opening is not sufficient to achieve the required air flow for cooling and when increased to the double the required air flow rate was successfully achieved. In (Case 4) the proposing shading device on the east and west windows has eliminated the overheating problem completely and increased the comfortable hours to more than 90% of the occupied time. Compared to the bedrooms (Fig. 6), which also behave very similarly, it was noticed that (Case 3) provided the best solution where all the occupied hours fell within the comfort zone.

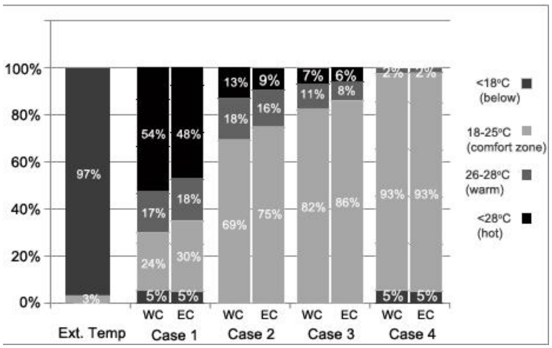


Figure 5. Annual Percentage of occupied hours below, within and above thermal comfort (Common Rooms Occupation)

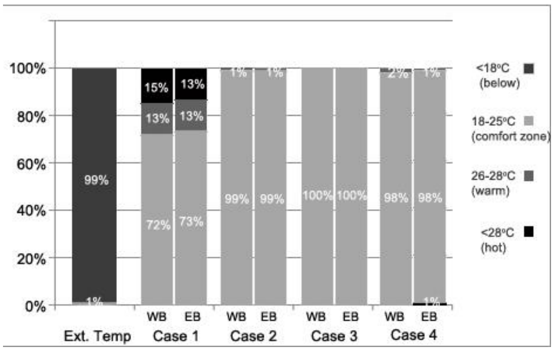


Figure 6. Annual Percentage of occupied hours below, within and above thermal comfort (Bedrooms Rooms Occupation)

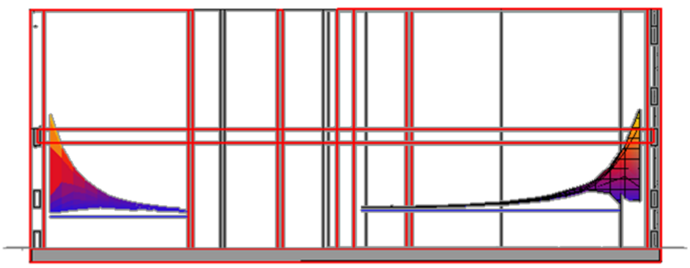
4.2 Daylighting Performance Prediction

The daylighting performance was assessed using on spot measurements and building model in Ecotect and simulated by Radiance. The same four spaces previously analysed were tested. In the bedrooms, the working plane was considered at 750 mm from the finished floor level (study desk height), while the kitchen counters of 90 mm high were set in the common rooms.

Table 1. Daylight prediction results for each analysed space

	West Common Room (WC)	West Bedroom(WB)	East Common Room (EC)	East Bedroom (EB)
Average DF (%)	1.7%	1.9%	1.2%	1.7%
Uniformity Ratio	0.12 (borderline)	0,66	0.02 (too dark in the back)	0.44
Illuminance (lux) based on spot measurements	130 (Kitchen counter top)	1169 (Study desk top)	120	488

Table 1 shows the low lux levels on working surfaces in the common rooms, with illuminance levels reaching below the recommended 150 lux. Moreover, the location of the windows on the opposite wall of the kitchen results on self shadow when a person is standing over the kitchen counter. In the bedrooms the high lux levels on the desks can cause a discomforting glare. The average daylight factor in all the spaces is below the



recommended 2%, which indicates low illuminance levels and poor day lit rooms. By looking at (Fig. 7), the uniformity ratio of the common rooms illustrates an uneven distribution of day lighting within the space, especially toward the kitchen area.

West Bedroom (EB)

East Common Room (EC)

Figure 7. Uniformity Ratio in section

5. Conclusion

The Broadcasting Tower, a student housing tower, was designed to achieve design excellence and high environmental performance through unique irregular facade design and building orientation. The design won many top awards, but did not win the users satisfaction completely. Many occupants expressed their dissatisfaction of the indoor temperature especially in hotter days. Subsequently, the environmental evaluation of the building performance through computer simulations showed that overheating is indeed an issue regardless of the low exterior temperature. The indoor air temperature rises above the discomfort zone (<28ºC) for nearly 50% of the occupied hours. The results illustrated that solar gain and insufficient ventilation openings are the prime reasons behind this overheating. Providing shading device on east and west windows as well as increasing the effective area for ventilation can significantly increase the level of thermal comfort inside the tower.

Based on the daylighting performance analysis, the daylighting in the bedrooms are glary due to the windows orientation to east and west, and the placement of study desk just next to the window or below it. Vertical slats could eliminate the effect of glare but further investigation should confirm this suggestion. On the other hand, the deep plan for the common rooms resulted in an even distribution of daylight especially toward the kitchen area - where it is most needed- , low illuminance lux on the kitchen counter require the use of supplementary artificial lighting, which contradict with the environmental approach of the design.

In conclusion, the building orientation and facade design should complement the environmental strategies approached in building design, in order to achieve the delightful visual and comfort level for the users. The placement of windows to face east and west is not necessarily the best approach, and further protection regarding shading should be implemented to avoid glare. Moreover, good ventilation strategy and window openings should be carefully analysed to achieve the best thermal indoor environment.

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