Architecture Excellence and Environmental Performance

The Case of Broadcasting Tower, Leeds, UK

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ABSTRACT: Since its completion in 2009, the Broadcasting Tower in Leeds, designed for student accommodation, has been recognised for its architectural excellence and has won many prestigious local, national and international prizes, including a RIBA Award and Best Tall Buildings Overall Award from the Council on Tall Buildings and Urban Habitat. The asymmetrical façade was designed with the intent of achieving high levels of daylight without overheating. However, does architectural excellence denote good environmental performance? In this paper, the authors report on an investigation of the building's environmental performance regarding thermal and visual comfort, particularly with relation to the unique façade design of the tower. The qualitative and quantitative assessment included onsite observations, occupants' feedback through surveys and interviews, and a parametric study of the existing thermal and visual performance using computer simulations programs (TAS and Ecotect) for four perimeter zones, an east and west bedroom, and an east and west common room. The results suggest overheating issues mostly due to the window design, which determined natural ventilation levels, and the lack of shading devices which allows solar gains. In addition, the results illustrated daylighting performance did not achieve desirable levels in all studied spaces, with an average daylight factor below the recommended 2% and an uneven distribution of the daylight within the space. The issues presented in this paper demonstrate the importance of post occupancy evaluation and may inform future façade design for buildings of similar typology.

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

INTRODUCTION

The demand for student housing in the UK is increasingly growing as the country attracts national and international students [1]. However, little attention has been given to the design of energy efficient student housing, despite the fact that it composes an environmental challenge due to its high energy consumption, especially for space heating, ventilation, lighting and hot water [1]. Therefore, energy efficiency and comfort in student housing was set as the focus of this work.

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 [2]. The orientation of the building is equally important; each facade should be treated respectively according to its orientation to the sun [3]. 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 investigation was to understand the relationship between facade, window design, building orientation and the contribution of these elements to thermal and visual comfort.

THE 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 named the Broadcasting Tower, which provides 240 student rooms (Fig. 1, 2). Notably, the design has overcome several site difficulties, including an inner city motorway and low rise adjacent historical buildings [4].

Figure 1: Broadcasting Place, Leeds, UK (Source: [5])

The buildings form and facade were designed considering aesthetical and environmental issues. The rectangular plan of the tower faces west and east on its longer sides, while the short sides face north and south. According to the designers' intention, 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" [4] (Fig. 3). Unfortunately it was not possible to gain access to the report where the results of this software simulation were described in detail.

The south elevation was designed totally opaque to eliminate additional glass treatment and overheating as well as giving a sculptural impact since it is facing the city centre (Fig. 4). As shown in (Fig. 5), 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 [6]. 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. 6).
According to the architect's presentation in the CTBUH 2010 Conference [7], the Broadcasting Tower is highly insulated using infill panels for the exterior walls which support the passive heating strategy of the building and minimise heat loss through building fabric. Moreover, the structural concrete frame and concrete floors and roof provide thermal mass. In response to this, the U-value of the external walls was estimated at 0.25 W/m²K and the windows at 1.4 W/m²K. The ground floor, which contains the reception area, and the lifts' lobby in each floor are air conditioned and mechanically ventilated. On the other hand, all the student bedrooms and common rooms are equipped with radiators fitted with thermostat for winter heating and natural ventilation is the main cooling strategy. The ventilation strategy is single sided through the louvers panels which can be opened manually by the rooms' occupants (Fig. 7). The west and east facades glazing area is minimized to 20% in order to eliminate overheating from solar gains, which also eliminates the strategy of passive solar gain when needed in winter.

RESEARCH METHODOLOGY

The main concern of this investigation was to analyse the thermal and visual environment of the Broadcasting Tower in relation to the facade design, window type and building orientation. A qualitative analysis was conducted using surveys through questionnaires in correlation with quantitative analysis of the thermal and visual performance of the indoor spaces.

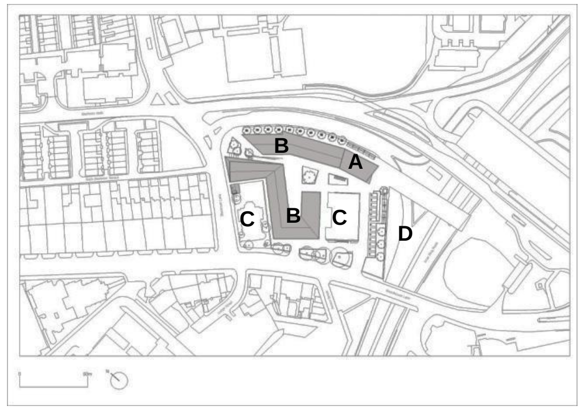

Figure 2: Site Plan. A- Broadcasting Tower, B- University buildings, C- Historical buildins, D- Motorway (Source: Feilden Clegg Bradley Studios LLP)

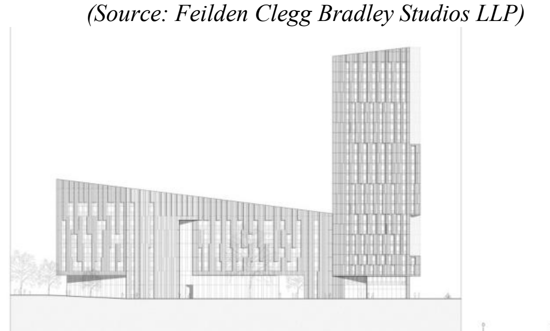

Figure 3: West elevation with 20% glazing ration (Source: Feilden Clegg Bradley Studios LLP)

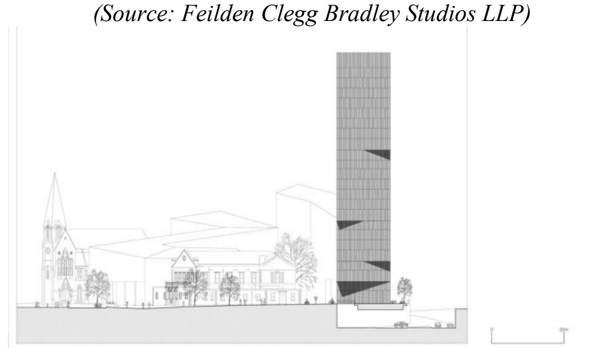

Figure 4: Solid south elevation (Source: Feilden Clegg Bradley Studios LLP)

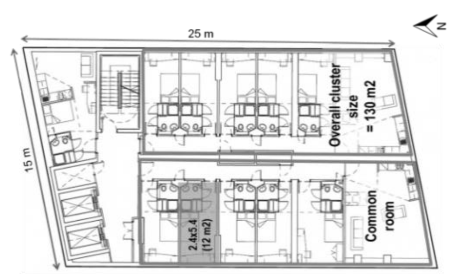

Figure 5: Typical floor layout (Source: Feilden Clegg Bradley Studios LLP)

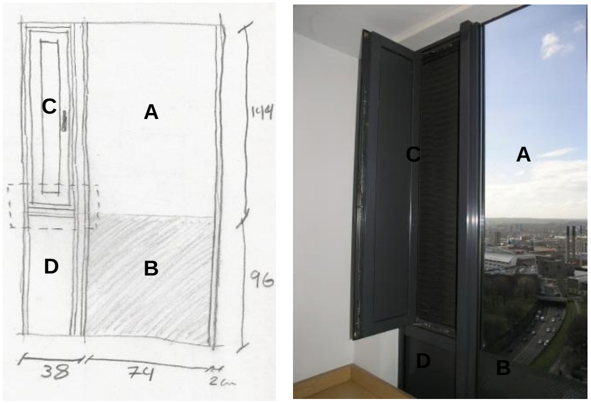

Figure 6: Window typology: A- Fixed transparent glazing. B- Fixed tinted glazing (About 40% of the total glazing area). C. Louvers Panels. D- Fixed solid panels

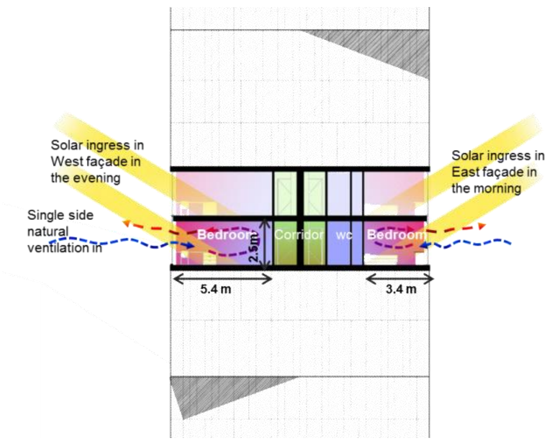

Figure 7: Section through typical floor illustrating the main environmental strategies in the students bedrooms

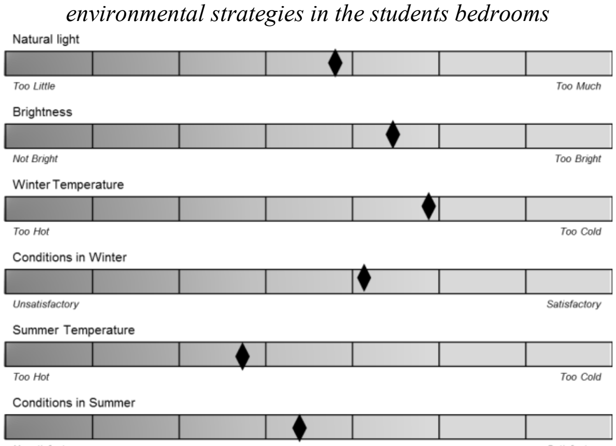

Figure 8: Occupants' POE survey results

Four main typical spaces where chosen for a comparative study, two bedrooms, one facing east and the other facing west, and two common rooms also one facing east and the other west.

In order to evaluate the existing visual environment, an empirical approach was conducted through on-site lux levels measurement. Furthermore, initial manual calculations for daylight factor where backed by computer simulations in Ecotect and Radiance renderings. A computer model of the building was used to calculate the incident solar radiation falling on the different facades of the building as well as investigating the solar penetration into the common rooms and bedrooms. As for the thermal evaluation, a TAS model of the building was used to determine the thermal behaviour of the building and its impact on the indoor thermal comfort. The ventilation strategy was initially tested in Optivent to determine how effective were the window size and type. All the findings were compared to the minimum recommended design criteria for lighting and indoor comfort temperature according to The Chartered Institution of Building Services Engineers (CIBSE) [8, 9]. With regard to the recommended thermal comfort criteria, dwellings building type were chosen since student housing are primarily dwellings. The CIBCE Comfort sets the summer indoor comfort temperature for non-air conditioned buildings as 25ºC for the living areas and 23ºC for bedrooms. The recommended lighting design criteria based on CIBSE standards are that the maintained illuminance (lux) level at the appropriate working plane or height in study bedrooms should be 150 lux at desk. Kitchens require 150-300 lux at working surface and from 50 to 300 for living room. Glare should be avoided by using smaller windows and vertical slats especially for east and west windows. The average daylight factor should be at least 2% which will require supplementary lighting [3]. This visual comfort criterion was used to assess the existing daylighting performance.

Finally, the author proposed different scenarios to improve the thermal and visual comfort levels and compared them with the existing building.

OCCUPANTS SATISFACTION

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) [10]. The surveys were answered by 20 students, and their level of satisfaction was recorded and analysed (Fig. 8). Since the surveys were conducted during Easter break when most of the students were in holiday, and due to time constraints, the population sample is relatively small which might affect the statistical analysis of the POE. However, the results were useful because they highlighted the main comfort issues in the building which were further validated through computer simulations.

It was observed from the survey results that the feedback on visual comfort was mostly positive and fell within the comfort range or slightly higher. However, the feedback for thermal comfort was less satisfactory especially in summer when overheating was described as an issue. 20% of the students commented that air conditioning should be provided to overcome the overheating problem.

THERMAL ENVIRONMENT

The thermal performance of the building was assessed by initial on-site monitoring and detailed analysis for the building's thermal behaviour through dynamic simulation using TAS. The natural ventilation strategy was assessed firstly using steady state calculations through Optivent, then through dynamic modelling in TAS.

On-site spot measurements were recorded twice in the 20th of March and 5th of April 2012 in a west common room in the 14th floor, and in a west bedroom in the 18th floor. Both measurements were on mid-afternoon time with the louver panels open for more than 2 hours. The external air temperature was below the comfort range (13ºC in 20 March and 8ºC in 5 April) while the internal air temperatures were within the comfort range between 18 and 20ºC. The relatively large different between internal and external temperature (10 to 12 ºC) - despite the fact that the louvers were open for a long time - indicates that overheating could be an issue in warmer weather.

The dynamic thermal simulations was developed to test three elements: the performance of the building fabric, the contribution of building orientation and glazed area in the east and west facades to solar gains, and the efficiency of the louvers panels system for natural ventilation. In order to run the simulations, 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) (Fig. 9).

The evaluation of the thermal performance was based on the percentage of occupied hours where indoor air temperature fall within the comfort zone (18-25ºC) in the bedrooms, and within the range of (18-28ºC) for the common rooms. 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 and study and leisure activities. In addition, the calendar was based on University calendar taking into account summer and winter holidays.

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 is introduced in summer time only during occupancy hours.

Case 2: Natural ventilation is introduced in summer and winter when the indoor air temperature reaches 24ºC during occupancy hours.

Case 3: The effective opening size for natural ventilation is increased to double.

Case 4: Vertical shading devices on the west and east windows were added.

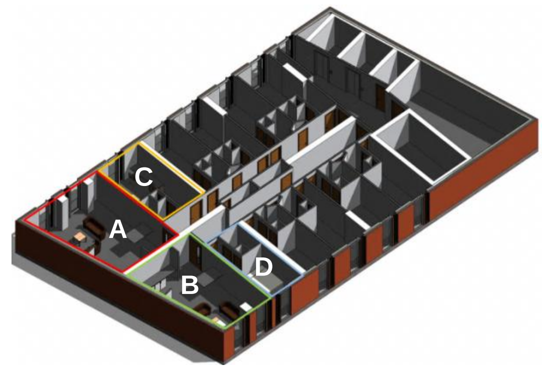

Figure 9: 3D for a typical floor plan showing the key rooms for the focus of the study. A- West Common room (WC), B- East Common room (EC), C- West Bedroom (WB, D- East Bedroom (EB).

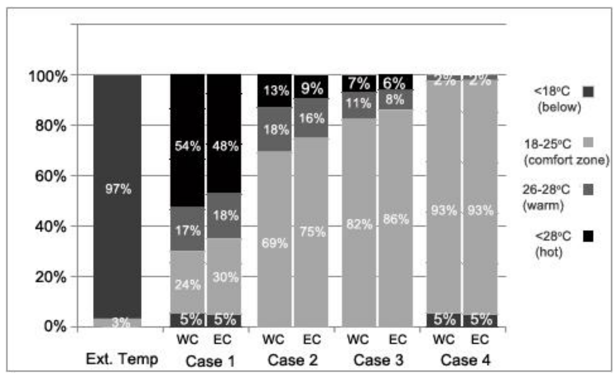

Figure 10: Annual percentage of occupied hours below, within and above the thermal comfort level (Common room occupation)

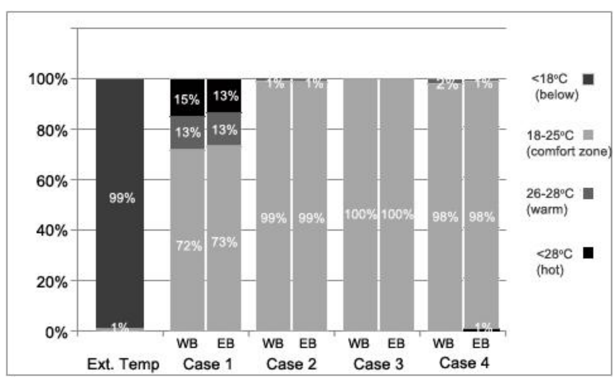

Figure 11: Annual percentage of occupied hours below, within and above the thermal comfort level (Bedroom occupation)

Fig. 10 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 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 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. 11), which also behaved very similarly, it was noticed that Case 3 provided the best solution where all the occupied hours fell within the comfort zone.
However, the high noise level from the major motorway adjacent to the building could prevent the occupants from opening the windows or allowing natural ventilation. Therefore, acoustic issues may jeopardise the achievement of a comfortable indoor environment.

THE VISUAL ENVIRONMENT

The daylighting performance was assessed using on-site spot measurements and a virtual model built in Ecotect and 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 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. 12), the uniformity ratio of the common rooms illustrates an uneven distribution of day lighting within the space, especially toward the kitchen area. To improve the lighting conditions in the common rooms, two scenarios where proposed and tested using Ecotect as following:

- Case 1: Removing the west and east windows and adding windows on the south elevation
- Case 2: keeping the west and east windows with additional south windows.

The results show that the distribution and quantity of glazing and shading in the façade and the vertical window design failed to achieve high and sufficient levels of natural light. When adding another south window (Case 2) especially in the kitchen area, the distribution of lights within the common area can be improved.

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

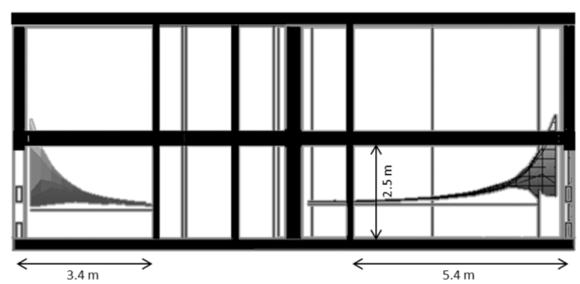

Figure 12: The uniformity ratio in section

CONCLUSIONS

The Broadcasting Tower, a student housing tower, was designed to achieve design excellence and high environmental performance through its unique irregular facade design and building orientation. The design won many awards, but did not win the users satisfaction completely. The post occupancy evaluation showed that many occupants expressed their dissatisfaction of the indoor temperature especially in hotter days. However, a larger sample is recommended for more significant results.

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 comfort zone (<28ºC) for nearly 50% of the occupied hours. The results illustrated that solar gain and insufficient ventilation are the prime reasons behind this overheating. Providing shading 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 can be glary due to the windows orientation, and the placement of study desk just next to the window or below it. Vertical slats could reduce the effect of glare but further investigation is required to confirm this suggestion. On the other hand, the deep plan for the common rooms resulted in an uneven distribution of daylight especially in the kitchen area, where it is most needed. Low daylight levels on the kitchen counter require the use of supplementary artificial lighting, which contradicts with the environmental approach of the design.

In conclusion, the building orientation and facade design are major factors in order to achieve visual and thermal comfort for the users. The placement of windows to face east and west is not necessarily the best approach, and further protection such as shading could be implemented to avoid glare and overheating. Moreover, a more effective ventilation strategy could be implemented to achieve better thermal indoor environment.

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