# Post Occupancy Evaluation of University Buildings in the UK

# (Case Study: The Diamond, Sheffield)

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**Abstract:** The Diamond, housing teaching and research space for the Faculty of Engineering, represents the largest ever capital investment for the University of Sheffield. Costing £81m, construction began in 2013 and the building was officially opened on 28th September 2015. The building employs a complex Building Management System to manage the internal environment. It is an example of a modern building that has been designed to take control away from occupants and use automated systems to control environmental conditions and mitigate interventions by occupants.

This relies on the Standard Effective Temperature model to assign comfort temperatures. This is based on the PMV thermal comfort model derived from extensive laboratory experiments to establish mean thermal comfort scores (Fountain et al., 1996). However, beginning with a range of field studies in the 1970s, Humphreys and McIntyre have shown that the range of temperatures that building occupants report as 'comfortable' is wider than reported in controlled laboratory conditions.

Leaman and Bordass (2001) define Post Occupancy Evaluation (POE) as a process for creating a dynamic, continuous and improving knowledge base that can be used to continuously improve a building's performance over its life time. (Bordass et al., 2001). As many design stage decisions are based on broad assumptions of how a building will perform, conducting POE provides an opportunity for gathering real information to improve and inform future projects (Zimmerman and Martin, 2001).

The aim of this research is to investigate the relationship between the use of automated systems for indoor environmental control and user satisfaction in the Diamond building, contributing towards improving building performance and the quality of the indoor environment for users. The research employs POE as a strategy for investigating the building, including a bespoke survey to gather information about user perceptions of comfort and satisfaction with the environment.

**Keywords**: Post Occupancy Evaluation, Thermal Sensation, Occupant satisfaction, Building evaluation

## Introduction

The further and higher education sector in the UK, with a wide range of building types, user occupancy patterns and research activities, provides a challenge for the energy manager to meet all the users' needs with the minimum energy consumption (CIBSE 1997). User's needs vary, and people's behaviour is considered one of the most important significant factors that effects energy consumption. Mechanical ventilation systems (HVAC), used to maintain the quality of the indoor environment, can consume up to 50% of total energy use during operation (Vargas et al. 2014)

Normally people behave in a way that makes them feel comfortable while doing their main activities (Barbu et al. 2013). However, people's thermal sensation and perception are not always the same. Comfort temperature is changeable, as people will adapt to a range of temperatures by adjusting their clothes and/or activities or the environmental conditions according to the weather. Many attempts have been made to predict and assume the optimal indoor temperature and determine the environmental strategy that should be used in a given situation. (Nicol et al. 2002).

But, as predicting people's behaviour is a challenge, designers may prefer using automated systems to control the indoor environment (rather than giving people the opportunity to adapt to their conditions) using HVAC systems and comfort standards as the only design parameters. Often this employed the "Standard Effective Temperature" (SET) model to assign comfort set-point temperatures. SET is based on the Predicted Mean vote (PMV) thermal comfort model which is derived from extensive laboratory experiments on groups of people in which the mean responses for feeling satisfied were recorded as set points (Fountain et al. 1996).

However, there are many cases in which a building does not perform as expected, despite the ubiquity of design standards. In addition, people's responses towards these standards vary. These problems are exacerbated in a university building like the Diamond, with a wider range of space types, user occupancy patterns and activities than other non-domestic buildings. The Building Performance Evaluation (BPE) programme was recent a four-year UK study examining how well real buildings perform. The study included schools, apartments, supermarkets, offices, health centres and houses. The end results of this study indicated that buildings were using 3.6 times as much energy as they were designed to use (Connect.innovateuk.org 2017). In order to understand the reason being this gap, known as the performance gap, tools can be used to learn from past buildings in order to improve future buildings' functionality and efficiency in terms of energy performance and user satisfaction. The need to conduct POE of the Diamond is based on: a lack of evidence about: 1) the performance of the advanced systems designers use for operating university buildings, and 2) the variety of users and their different perceptions of experiencing the same space with automated environmental controls.

## Post Occupancy Evaluation

Building performance can be defined as the degree to which a building can meet any or all users' expectations. Many tools have been developed to evaluate building performance, guarantee occupant requirements and save energy use. One of these is Post Occupancy Evaluation (POE) (Tookaloo et al. 2015). Zimring and Reizenstein (1980) defined POE as 'examinations of the effectiveness for human users of occupied design environments' (Hadjri et al. 2009) Leaman and Bordass (2001) define POE as an implemented process for creating dynamic, continuous improving knowledge base that can be used to continuously increase the building performance over its life-time (Bordass et al. 2001).

POE is a continuous process and should not stop as long as the building is in service. The main goal of POE to meet users' needs, then help to improve current and future buildings. The POE process should also be published and accessible to everyone as it provides systematic continuous studies for occupied buildings, sharing knowledge in order to improve building's efficiency, meet users' needs, mitigate energy use as much as possible and continuously assess current design standards.

POE emerged in the 1950s as part of a trend to apply science as an investigatory tool to solve problems arising from the building industry. It started with care facilities such as hospitals and nursing homes (Preiser et al. 2006). It has been marginalised for a period of time until it started to be taken more seriously with many clients more interested in improving the performance of their facilities and meeting occupants' needs and satisfaction (Leaman et al. 1999). During the development of POE methods, the study and evaluation of educational environments in academic institutes has always played a main role. Since the 1960s universities have been at the forefront of POE development partnering with design practitioners (Tookaloo et al. 2015), but, there is currently no agreed strategy for POE of HE buildings in the UK, and the most up to date available guidance was published by the Higher Education Funding Council for England in 2006 (Barlex 2006).

## Research Methodology

100 students were surveyed to understand occupants' feelings and their satisfaction for the indoor thermal and lighting conditions inside the Diamond. The survey was conducted in June – July 2017, in different types of study spaces, including open spaces and silent rooms of various sizes. All survey responses were recorded with the corresponding date, temperature, humidity, lighting levels and clothing conditions of the participants. The survey recorded users' thermal sensation votes (AMV), thermal preference votes and the background environmental parameters for the calculation of the Predicted Mean Vote (PMV).

According to Barlex (2006), POE may be conducted with three different levels of benefits (Barlex 2006); the short-term benefit for this study is to investigate user satisfaction with the interior environment. The medium-term benefit is to develop a POE plan for the University of Sheffield. The longer-term benefit is to spread the word about the importance of performing POE in higher education buildings, and the greatest benefits will be achieved when the information is made available to everyone who can make a good use of it.

### *Post-Occupancy Survey*

The survey was divided into four main parts. The first part collected general information about the participant, his/her age, country of origin, the period of stay in the building and clothing conditions. The second part was about thermal sensation and preference, in which the participants were asked to rate their thermal sensation on the ASHRAE seven-point scale. This was to gather the quantified thermal sensation of the participants, which is known as Actual Mean Vote (AMV), which is compared with the Predicated Mean Vote (PMV) calculated from the CBE Thermal Comfort Tool, to assess the extent to which the building is meeting peoples' needs. The third part was about lighting conditions. It included two questions, the first about current lighting levels, all the on-the-spot measurements were taken during the daylight. The second question is about how much control people prefer to have over the lighting. The last part of the survey included readings of temperature, lighting intensity and indoor and outdoor humidity. All the indoor readings were measured simultaneously while people completed the survey. Spaces were divided into two groups; open and closed spaces.

## Introducing the Case Study

As a 24/7 facility, the Diamond (Figure 1) consists of six levels, hosting students and staff from across the university. The building hosts a range of lecture theatres, seminar rooms, open plan study spaces, library, IT services, spaces for informal study and a café at the ground floor. In closed spaces the building employs a mechanical ventilation system, however, in the main atrium, it employs a natural ventilation system. The building depends on both natural and artificial lighting. Each of the building zones has a presence detector. If no movement is registered for a specific amount of time, the system will turn off the main lights, and in return will turn it on if it detects movement.


Figure 1 The Diamond exterior (East facade) and interior view (Main Attrium)
Source: http://www.twelvearchitects.com/portfolio/item/the-university-of-sheffield/(accessed:5th, July,2017)

The building was designed by Twelve Architects, and won many awards, including the 'Design through Innovation' award in the 2016 Yorkshire and Humber Region Royal Institute of Chartered Surveyors (RICS) awards, and was also shortlisted for the Yorkshire awards from the Royal Institute of British Architects (RIBA). The building was designed as a 'smart' building, with automated control of energy management. The central atrium is naturally ventilated.

***Technical information***

*The Ventilation system*

The building operates in a mixed mode. It has two different ventilation systems; in its closed spaces it uses a mechanical ventilation system. however, in the main atrium, it uses natural ventilation systems; the openable automated glazed louvers at the top of the interior atrium, east and west façade are automated to provide the building with natural ventilation and extract smoke. They are controlled by indoor and outdoor conditions and will not open during high winds and rains. Typical but adjustable set points for operation are; the outside air temperature has to be between 17 and 25C. The indoor space temperature in the atrium should reach 24C to begin opening.

*Lighting*

The building depends on natural and artificial lighting. Most of the study spaces have a desk lamp overhead, which can be turned on, off, or dimmed by the user. This supplements the background lighting. Each of the building zones has a presence detector. If no movement is registered for a specific amount of time, the system will turn off the main lights and in return will turn it on if it detects movement. Lighting of corridors cannot be controlled by the end users but building managers have manual control over it. In other places, especially closed bookable silent rooms, users can control the light by turning it on or off. Projection units located at a higher level project lights toward celling mirrors which in return provide artificial light to all different levels in the atrium and a large room on the second level.

**Survey Outcome**

One hundred occupants were surveyed over several days, including 55 females and 45 male students. Mostly subjects wore medium clothing (53 persons) followed by 44 persons wearing light clothing and only three people wearing heavy clothing. The Clo. values were estimated by the researcher according to observation. Suggested values for clothing conditions from the ASHRAE standard are 1.0 and 0.5 Clo, representing typical winter and summer clothing, however no evidence is given that these are typical values. Estimating clo values is therefore one of the key uncertainties that researchers face calculating PMV (Nicol et al. 2011).

***Thermal comfort***

The measurements show that the minimum temperature inside the building during the period of the research was 20 ◦C at the open space at the ground floor, and the maximum temperature was 25◦C, with a mean temperature of 23.1◦C. At the same time the lowest temperature outside the building was 15◦C, and the highest temperature was 28◦C, with a mean temperature of 21.1◦C. After applying all the values of temperature, clothing conditions, metabolic rates, humidity and air speed using the CBE thermal tool and the preference votes from the users, Figure 2 represents the AMV on the ASHRAE Thermal Sensation Scale in relation to the PMV.

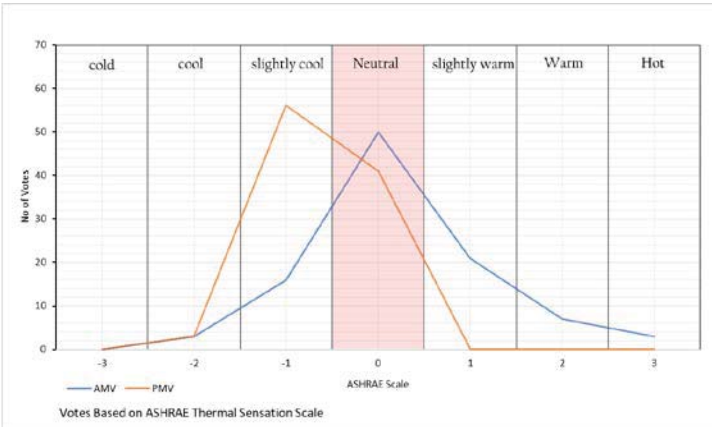


Figure 2 AMV and PMV compared
Source: Researcher

According to the AMV, around 50% of the participants feel neutral, with 19% feeling slightly cool and cool, and 31% feeing slightly warm, warm and hot. However, the PMV suggested that 56% of people may feel slightly cool and 42% may feel neutral. This shows that the range of comfortable temperatures is wider than suggested by the PMV model, supporting similar findings as demonstrated by Humphreys and Mclntyre (Leaman et al. 1999). One of the reasons that may explain the discrepancies between AMV and PMV could be the phenomenon revealed by previous studies that in naturally ventilated buildings, comfort is found to extend beyond the temperatures predicted by the PMV model. Half of the interviewed occupants were sitting in the open space, which is naturally ventilated, and standards like ASHRAE 55 were originally introduced with an assumption that centralised HVAC technology would be employed (Fountain et al. 1996). This finding implies that building users may demonstrate some forgiveness for temperatures outside of the comfort range implied by the PMV model, as the AMV demonstrates that most of the occupants are feeling neutral, and are thermally satisfied.

Figure 3 also shows the preference votes for the environment plotted over the AMV and PMV. It shows that the numbers of people who preferred no change or to feel slightly cooler are slightly greater than the numbers who were satisfied (no change) and slightly cool according to the AMV. However, the numbers of people who preferred to feel slightly warmer and warmer are slightly less than the AMV. This might be explained by occupants' expectations of the season, as occupants may prefer to feel cooler inside the building during the summer.

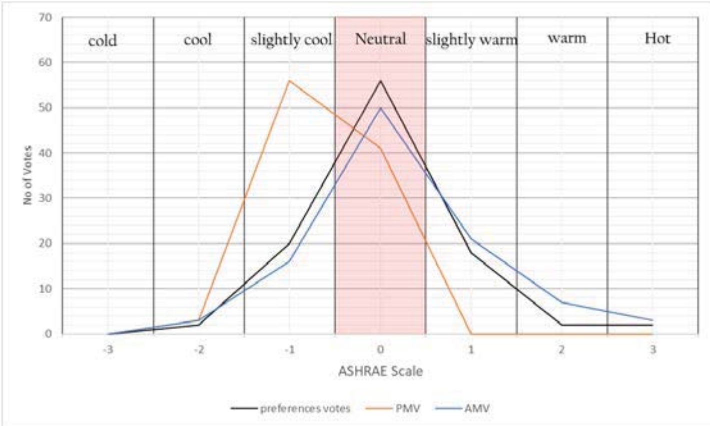

Figure 3 AMV, PMV and preferences votes plotted overlapped
Source: Researcher

However, there is broad agreement among researchers that individual control of local thermal environments is by far the best solution from a comfort and satisfaction standpoint (Fountain et al. 1996). The survey shows that 41 subjects are satisfied with the automated control system, whereas 43 subjects stated that they want a bit more control. On the other hand, there are people who do not express any desire to have more control over the environment (Figure 4).

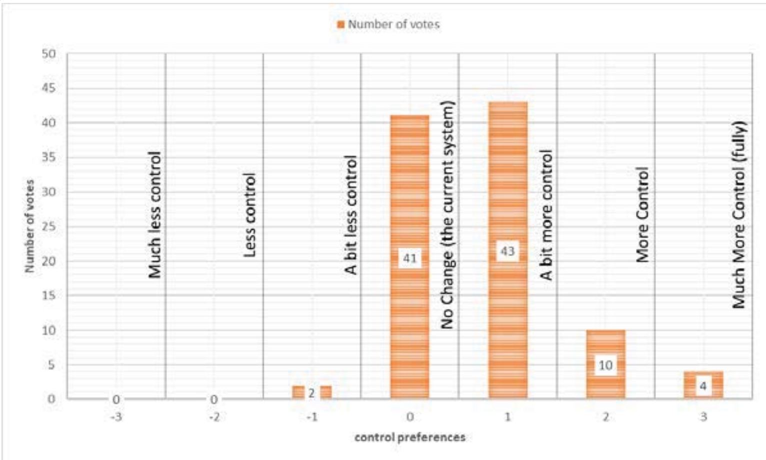

Figure 4 preferences over controlling the environment
Source: Researcher

***Lighting conditions***

Figure 5 represents people's responses and the mean corresponding lighting levels for each preference. 48 users had a neutral response to the lighting when the mean level was about 500 lux, meeting the European standard for Indoor lighting (BS EN 12464-1); 29 users wanted it to be slightly lighter when the mean level was 450 lux; and 11 users wanted it to be lighter when the mean level was 400 lux. Four people wanted the light to be much lighter when the mean level was 321 lux. However, it was noticed that seven people preferred it to be slightly darker and one person wanted it to be much darker when the lighting levels were 346 and 315 respectively.

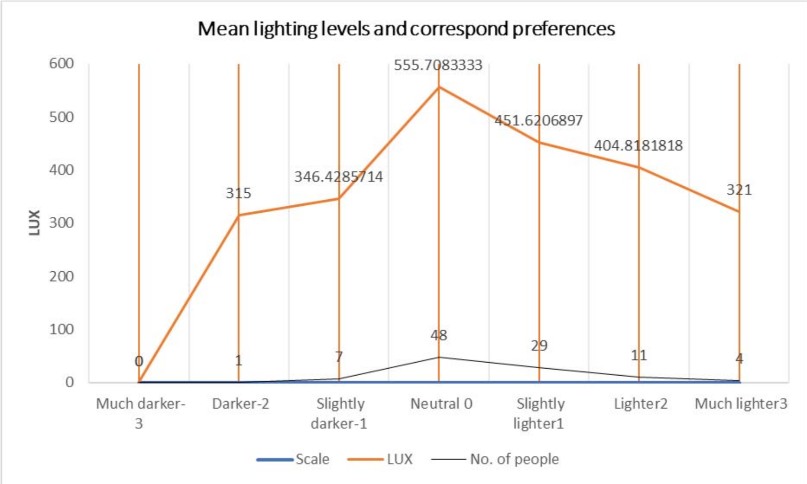


Figure 5 Preferences votes for the current lighting conditions
Source: researcher

Most people were already using laptops and PCs which do not require much light in the background. However, students pointed out the problem of glare caused by suspended lights in the open spaces and light reflectors, especially when these were facing people sitting at higher levels. Reflections were another issue mentioned by students and observed in different places around the building.

Regarding people's preferences in controlling the lighting conditions, 42% of people stated that they were satisfied, 38% of people wanted to have a bit more control and 15% wanted to have more control. Only 5 people reported that they want to have full control of the lighting conditions. However, the questionnaire did not enquire what kind of control was desired (such as turning on, off, dimming or even changing colour, which could be considered in future research).

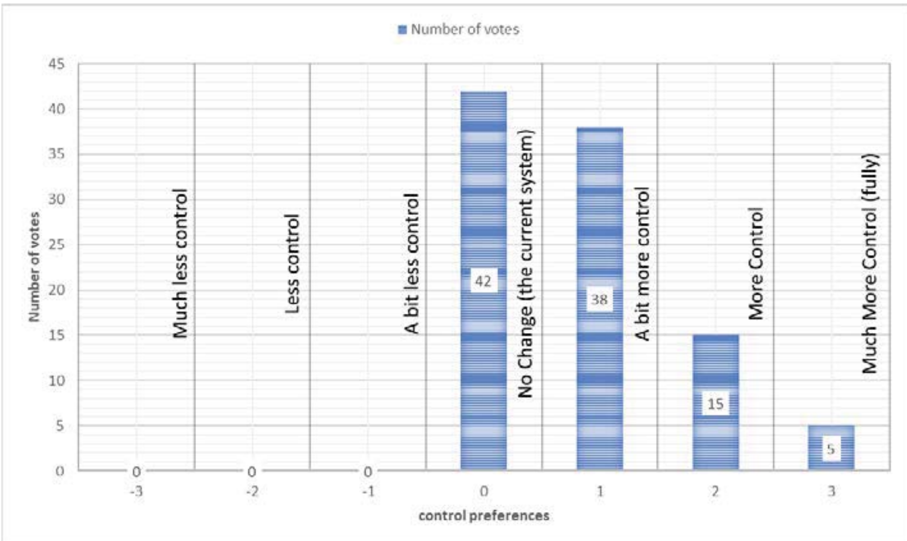


Figure 6 preferences over controlling the light
Source: researcher

***Energy consumption***

Figure 7 represents the amount of energy used for the heating demand. The heating energy consumption for the Diamond in 2015 was 153.28 kWh/m2. This is 5% below CIBSE-Part F standards for typical practice (a figure of 161 kWh/m2for a naturally ventilated library). The highest consumption is in winter from December until March.

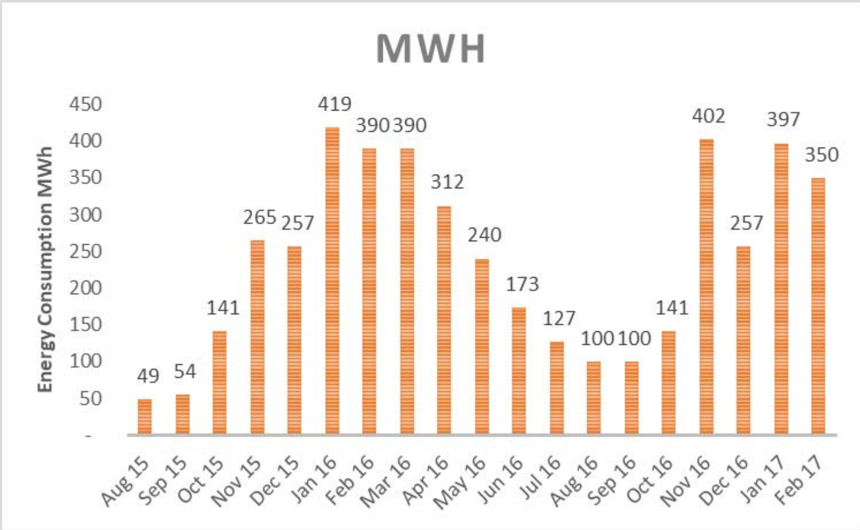


Figure 7 Monthly Energy Consumption for heating
Source: adapted from University Facility Management

Figure 9 compares the energy consumption of the Diamond with two other university buildings in Sheffield and the CIBSE standard. These two buildings are the Arts Tower, and the Information Commons (Figure 8), Sheffield's largest library. The three buildings are different in terms of design and ventilation strategy, but are similar in terms of use patterns, with students using all three buildings throughout the day/academic year to carry out desktop study (Lawrence et al. 2016).

While this is not a full representative sample it offers anecdotal evidence that the Arts Tower, as a building with more opportunities for users to control the indoor environment, is using less heating energy than the Diamond. The Arts Tower is using more heating energy than the Information Commons, but it provides users with an easy way to control their environment by opening the windows.

Figure 8 Information Commons to the left, The Arts Tower to the right
Source: To the right: https://www.sheffield.ac.uk/polopoly_fs/1.248578!/image/ATforCMSsmall.jpg

In terms of electricity consumption, the Diamond as the highest tech building appears to use less energy than the Information Commons. The consumption values for the Diamond are from December 2015 to December 2016, and have not been corrected for average degree-days. The Arts Tower as a traditional building with low technology uses less energy than the Diamond and the Information Commons.

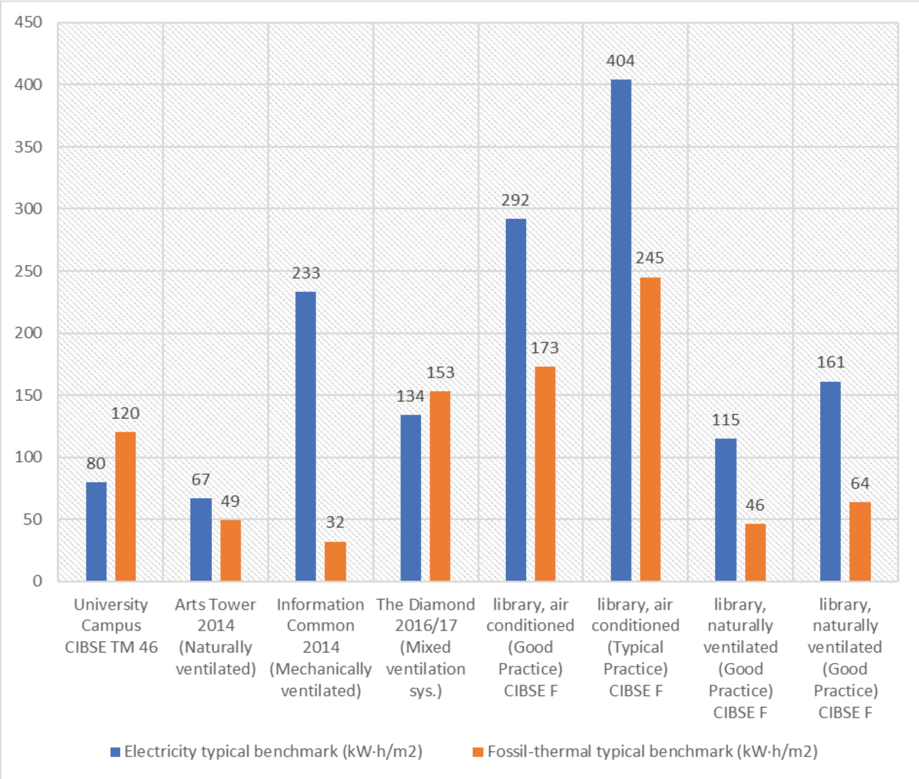


Figure 9 Energy consumption comparison

Source: Information adapted from CIBSE guide F, University State Department and (Lawrence et al. 2016)

## Conclusions and Further Research

### *In terms of thermal satisfaction*

The research was based on the hypothesis that "Mechanical solutions give a superior outcome, and people's perception of control over their environment affects their comfort and satisfaction"(Leaman et al. 1999). However, 50% of the sample felt neutral without having control over the environment, and 41% were satisfied with the current automated system. Nevertheless, it is not a definitive proof or disproof of the hypothesis. Providing personal control in large interior open spaces usually costs more money and is often not the most efficient way of ensuring adaptability (Myerson et al. 2010). In addition, not everyone will accept the conditions resulting from individual interventions, as it was clear from individual users' responses for the environmental preferences and feelings.

The outcome of this research shows that occupants have a level of forgiveness even if they cannot control the environment, so long as they are satisfied with the interior conditions. Further research should analyse in depth the energy use of the Diamond, as it is critical to know exactly how much energy the building is using to achieve comfortable conditions for different end uses (heating, cooling, ventilation, lighting). While the results show that the users are mostly satisfied, POE is a continuous process, so the results in this research should not be taken as final, and should be considered as a one step in the POE process.

### *In terms of lighting*

Despite 48% of the people feeling neutral, the other half of the sample desired more light, and this can be justified by the measurement readings represented in Figure 5. Most of the lighting levels at spaces located near the envelope meet the European standard for indoor lighting (BS EN 12464-1). Meanwhile, all values below the standard were measured in the core of the building and away from the outer envelope. It was also noticed that the artificial light is turned on all of the time on most days in the inner spaces, Figure 10. This could reflect an issue with the design in terms of achieving the required levels of natural lighting, but, as there was a lack of information about the standard and sensors used in the building, further investigation is required.

Figure 10 Artificial light turned on in the morning
Source: Researcher

The researcher noticed the majority of users are not familiar with all the lighting control options. For instance, most of the lighting units have a dimming option, but users did not know about this feature, so it is recommended that these options should be made clearer for the user. People who were using laptops mentioned that sometimes glare from lighting reflecting on their screen was annoying, and they cannot control the light as it is operated by automated sensors. People who were studying around the outer envelope found it annoying not to be able to blind the direct sunlight if it is hitting their face or computer screens.

The researcher also observed that as users become familiar with the automated lighting they assume that the manual controlled desk lighting (fitted to all study desks) is also automated, so they leave without turning it off, causing higher energy consumption. It was also noticed that the lighting for each space is centrally controlled, so all of the lights in a space could be turned on without full occupation of the space.

Figure 11 All the lights are turned on in the library at morning without the full capacity
Source: Researcher

***In terms of energy consumption***

Energy consumption readings should be considered in more detail, but this research indicates that the use of auto-controlled systems in combination with natural ventilation can be a good solution for providing thermal comfort as well as saving energy in university buildings, characterised by a wide range of space types, user occupancy patterns and activities. The research also demonstrates the importance of performing POE for university buildings to understand alternative servicing strategies and examples of good practice, and then to employ these precedents to improve the performance of current and future buildings.

***Further Research***

Previous surveys indicate that only 3% of British-based architectural practices regularly undertake POE on housing projects, only 9% of chartered practices offer POE to clients, and none generate revenues from POE services (Hay et al. 2017). This research has highlighted the need for people who are working in the construction sector to think again about considering and undertaking POE for current and future buildings in general, and education building in particular.

This study only focused on students' thermal comfort and lighting satisfaction for the indoor environment at the Diamond. Future research for the Diamond may consider other attributes like the design of the building itself, acoustic problems, colours, furniture, internal and external views, and could also consider different study spaces such as research laboratories, cafeterias and lecture theatres.

The difference between the Diamond and other university buildings is that, the Diamond is a 24/7 facility. It hosts varies activities including lectures, seminars, and presentations. This kind of university building is growing in popularity in order to attract students through the improved range and quality of facilities provided, and so it is important that researchers develop a thorough understanding of the unique challenges that they present. Involving the staff in the survey would be beneficial as they are working on the building regularly, doing their job within the same space. They experience the building during the full year and often over more than one year. Thus, their feedback may include comments about issues that students are not aware of, such as local problems and maintenance issues.

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