278: Building Energy Performance Considering Post Occupancy: A Case Study of an Innovative Academic Research Building

Ji Young Song [1], Eirini Tsianaka [2]

The Martin Centre for Architectural and Urban Studies, Department of Architecture, University of Cambridge [1]
RMJM London Ltd., Cambridge [2]

Abstract

Often the post occupant's behaviour differs from the original assumption, thus the building tends to perform differently from the initial design intention. The working style of people has dramatically changed allowing more flexible time and space use. The William Gates Building at the University of Cambridge has been designed as a low-energy building by cutting heating and cooling energy to half of the consumption of many contemporary buildings. However, the behaviour and working style of each occupant may differ, resulting in different amounts of energy consumption. We aim to investigate the energy performance of the building with changing occupants' behaviour compared with the initial brief. For the methodology, we perform an occupant's pattern survey and a building energy simulation using ESP-r applying two different occupancy scenarios. From this study, we expect to attain a better understanding about this new working style and thus provide a new occupancy pattern in academic research buildings. From this it can then be identified whether the changed occupancy has an effect on the building energy consumption.

Keywords: energy performance, occupant's behaviour, working style, post-occupancy

1. Introduction

Working patterns have been changing with the knowledge economy in developed countries, allowing people more flexibility in their use of time and space in the workplace [1, 2, 3]. The changes in working environments lead to different occupancy patterns in office buildings [4, 5]. This may cause discrepancies between the real occupancy and the original hypothesis. As a result, the building performs differently from the initial design intention.

The William Gates Building at the University of Cambridge is designed as a low-energy building by cutting heating and cooling energy to half of the consumption of many contemporary buildings. However, are the post-occupancy levels similar to the initial brief? If not, what is the effect on energy consumption?

The purpose of this study is initially to identify the occupancy levels of the above academic building and then to investigate its energy performance, comparing the initial design assumptions with different occupancy patterns based on the questionnaire survey.

The paper consists of five sections. The first section introduces the investigation and states the purpose of the study. Section 2 describes the selected academic building explaining its main environmental characteristics. Section 3 illustrates the survey which was done to explore the occupancy pattern and thermal comfort of the users of the building. Section 4 demonstrates the energy simulation using the ESP-r program to compare the energy consumption, based on the occupancy pattern uncovered by the survey and the original design brief. Finally, Section 5 concludes the investigation by discussing its own limitations and suggesting further directions for the above research.

2. Description of the case study

The William Gates building (Fig. 1,2,3) is a RIBA award winning building which has many environmental friendly features designed by RMJM Architects [6].

Fig 1. External view of the Williams Gates Building (Computer Laboratory), University of Cambridge [6].

It is located at the West Cambridge campus of the University of Cambridge, which is a high-profile site in the north-west area of the Cambridge city centre. The Computer

Laboratory, which is located in this building, is an academic department which encompasses Computer Science, along with many aspects of Engineering, Technology and Mathematics. It consists of 35 full-time academic staff, 25 support staff, 35 post-doctoral research workers and 140 PhD students [7].

The 10,000 sqm space includes research, teaching, library and catering facilities. The more ‘public’ teaching areas are separated from the research space by a three-story ‘street’ with connecting galleries and bridges for informal circulation and meetings. Small offices for either one to two people and larger offices for three to five people were designed along with meeting rooms and social spaces throughout the building.

Fig 2, 3. Views of the courtyard and the main café area on the ground floor [6].

The brief for the project essentially provided two challenges to the multidisciplinary design team: the need to develop a low-energy solution and the requirement to accommodate highly specialist computer equipment ensuring that it is flexible enough to adapt to possible long-term changes in use.

The architects’ approach was to develop an extremely well insulated building envelope, within which artificial heating and cooling systems could be minimized based on the client’s occupancy schedule mentioned above. The criteria of the energy brief has been met by simple passive construction, where possible, and careful consideration of how the building fabric will perform.

The external walls, roof and ground floor are insulated well in excess of building regulations. In addition the fabric has been designed to be airtight to $3m^3/hr/m^2$ at 50 Pa test pressure. This super-insulated building envelope gave the design team the opportunity to omit the heating system serving research offices. Instead the heat emitted from occupants, computer equipment and lighting is used to keep the building warm during the winter. The benefit in summer is that heat can be kept out, so the cooling provided by chilled beams is kept to a minimum and free air cooling is utilized for much of the season.

Air quality is optimized by delivering air through a floor diffuser displacement system with no re-circulation. Energy is recovered between the supply and extract using thermal wheel technology. Although not required with the current ventilation strategy, windows can be opened to allow future use of simple natural ventilation.

3. Questionnaire Survey

3.1 Introduction

Before describing the questionnaire survey in detail, this introductory section provides some background information on the design and construction of the questionnaires.

Each questionnaire consisted of three parts: the first being a demographic survey, the second querying the working habits of the occupants, and the third containing key questions of thermal sensation in the offices. The form combined both fixed-response and free-response questions depending on the survey aims. Clear and concise questionnaires were designed to target a higher number and better responses by the users of the building.

Forty survey forms were distributed in person to the occupants on different wings and levels of the building. The sample was chosen randomly but we tried to represent each occupant group (PhD students, research and academic staff). In total, 35 users completed and returned the questionnaires to the research team (Table 1). This sample corresponds to about 15% of the occupants of the Computer Laboratory. The conclusions of the questionnaire survey are thus interpreted qualitatively because of the relatively small number of participants.

Table 1: Distribution of the participants in accordance with sex and occupation.

	Female	Male
Administration	3	0
Research Associates	0	8
Academic Staff	0	2
PhD Students	3	19

Due to the large percentage of students and smaller percentage of the permanent staff that prefer working anywhere than the office building as explained further on Section 3.3 (Working Style), the responses of the questionnaires represent workers who regularly go to the office and use the building. In order to identify more accurately the percentage of people who frequently use their offices for work, we conducted further interviews with a number of people from one of the ten research groups, the Digital Technology Group (DT Group).

3.2 Demographic Data

As the male population is found to dominate the area of sciences, 29 of the participants were men and 6 were women (mainly working in the reception). Most age groups took part in the survey but the majority were young people between the ages of 20 and 29 years. This was expected due to the large number of PhD students occupying the building. The majority of the respondents were Europeans (British 11, South Europeans 5, Central Europeans 3 and North Europeans 3) with a few representatives from other continents, mainly from Asia. Last but not least, most of the occupants have lived in

Cambridgeshire for three years or more and being familiar with the weather conditions of the area.

3.3 Working Style

The second part of the questionnaire queried the working style of the users including key questions on how they work, where they work and how many hours they spend in the office environment.

The way users of the Computer Laboratory carry out their daily work, think or concentrate, and solve problems, depends on their role at work. In particular, the support staff (reception and IT workers) almost always work at their offices in order to be available to the rest of the employees.

Academic staff and research associates carry out research across a broad range of subjects within Computer Science. This work is conducted primarily in small research groups. There are currently 10 research groups in the building [8]. Due to the nature of their work, the use of one or sometimes more than one computers to run simulations is inevitable. On the one hand, the permanent personnel, academic and research associates, usually work in their offices during normal working hours, with the exception of the visiting fellows, managing the research projects and maintaining active dialogue with their PhD students. Without exception, all the academic and research workers who were questioned on the working hours and place confirmed the above hypothesis. On the other hand, the PhD students, who are the majority of the occupants, are working long hours but not always following a specific working hour pattern.

The University policy on flexible working, which incorporates the statutory right to request flexible working provided for by the Flexible Working Regulations, includes the provision for flexible working hours (including reduced hours to eligible staff) and working from home scheme, also known as 'teleworking', under terms and conditions [7] in order to achieve a better work/life balance. For those holding a University office, leave to work part-time is currently granted for a specified period. The above policy is well known to both staff and PhD students of the Williams Gates building. 97% of the users responded positively that they are aware that the University is flexible on both working hours and place of work.

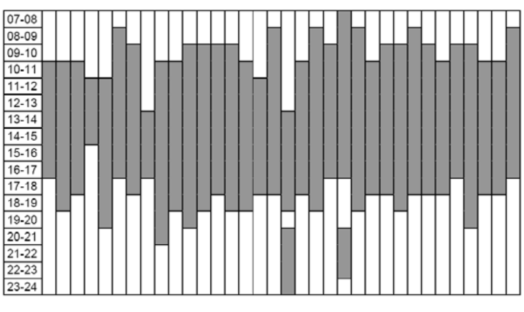

Fig 4. Flexibility of working hours for a typical working day in the Williams Gates Building

The flexibility on working hours for a typical working day is reflected on Figure 4 ranging from 07:00 to 21:00. However, the majority of the respondents who work in the building are available from 11:00 to 17:00.

As already explained above, our research to identify the percentage of people who rarely use the building for work was principally focused on the DT Group on the second floor of the North Wing. The scope of research conducted within this group ranges from analysis of communications media at the physical level to development of novel devices and their applications [8]. The Group consists of 41 people of which 5 are Visiting Fellows and they do not have a dedicated workstation. Six are academic staff, 6 research associates, 23 PhD students and 1 support staff. On average, 19 out of 36 desks are occupied. Hence, a percentage of 52.8% occupies the offices as shown on Figure 5. The fact that one out of two people occupies the offices is far from the original brief and building services assumptions.

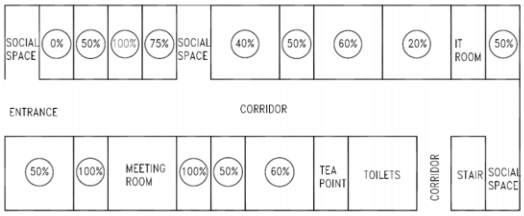

Fig 5. Schematic diagram of the occupancy levels in the DT Group.

Most of the respondents (40%) occasionally go to the office during the weekend while 37% do not go at all. A small percentage (6%) goes every weekend and 9% go quite often. The percentage of people working during the weekend in the building is important for energy consumption consideration.

Though the data is statistically insignificant, it is worth noting that 24 out of 35 respondents specified 'home' as an alternative place for work. This number is quite high bearing in mind that 8 out of 35 workers do not work anywhere outside of the office. A few other people prefer to work in the libraries or other laboratories related to their work. Apparently, computer scientists do not work in the cafes or other leisure places. This is mainly due to the nature of their work and the use of high performance computer equipment used for simulations as opposed using laptops.

Regarding the provided office layout with offices of 1 to 2 desks or 3 to 5 desks, most of the users replied positively expressing the view that the smaller open plan offices are better than the larger ones consisting of 5 or more people. During the interviews with the DT Group, we also noticed that the meeting rooms are very useful spaces in contrast to the social space which is rarely used for work or leisure. The main Café area on the ground floor is primarily used during the lunch break.

3.4 Thermal Comfort

The third part of the survey questioned the thermal conditions and the thermal sensation of the staff using the building regularly.

Most respondents expressed the view that they are generally satisfied with the thermal conditions of their offices as illustrated on Figure 6. In particular, 51% of the participants replied 'Somewhat Yes', 23% 'Definitely Yes', 11% 'Probably Not' and 11% 'Definitely Not'. The design team encouraged people to specify the main reason of being unhappy with the temperature in their office. Seven out of eight participants complained of cold temperatures and one complained about the ventilation system. No one has complained regarding hot temperatures or overheating. The occupants who expressed their dissatisfaction on the cold environment were mainly British or Southern Europeans.

It is worth mentioning that three of the respondents replied that they are satisfied with the temperature in their office when they use additional electric heaters during the winter to keep them warm. In addition to the above, three other occupants stated that they are happy with the thermal conditions of their office since they have switched off the air supply.

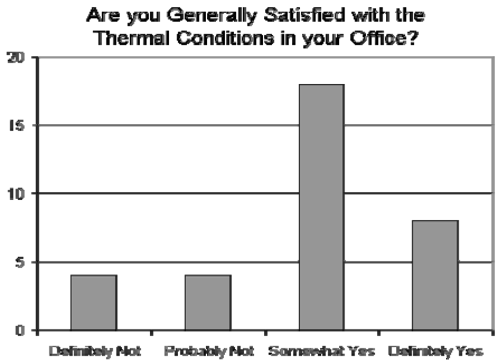

Fig 6. Distribution of the answers to the question 'Are you generally satisfied with the thermal condition in your office?'.

A notable percentage (14.3%} of the participants had to relocate their place of work due to dissatisfying thermal conditions within the building. Most of them moved to warmer offices. One of them decided to work from home or the college library.

Most of the occupants are aware that they can have their windows unlocked. However, a high percentage of users almost 43% think that it is not possible to open them or they are not allowed due to the building services management of the building. In reality, all the windows can be opened to some extent (approximately 5cm) but the management advise the users to close the corridor door before they open the windows in order not to affect the average temperature of the building and make the cooling system inefficient. However, a high percentage of the users are not fully aware of the above fact primarily due to the bad communication or the lack of induction package for the newcomers. Besides, many occupants expressed their desire to open the window more than the allowed 5 cm opening.

Regarding the use of the thermostats in the offices, 86% know how to operate it but some of them expressed concerns for indicating heat and cooling options rather than indicating temperature figures.

4. Building Energy Simulation

4.1 Simulation Design

As seen in the previous section, the actual occupancy pattern in the William Gates building is different from the assumption made the design brief (Fig. 4, 5). The computer simulation below aims to define the impact of occupancy factors on the building energy performance.

Many integrated modelling tools were considered for the building energy simulation, such as Ecotect and IES. ESP-r [9] was chosen for the simulation, because it is an open source program associated with the environmental control systems and constructional materials, and has the function of defining the operational schedule in detail. In ESP-r, the internal gains from occupants and equipment can be controlled according to the operational schedule.

The questions to be explored in the ESP-r simulations include;

- How the thermal condition is different according to different occupancy scenarios?
  - The casual heat gain in each case
  - Indoor temperature in each case
- How much energy is consumed for cooling and heating?
  - The cooling load for both cases
  - The heating load for the monitored case

The outputs from the ESP-r simulations in this study are obtained in a csv format as well as a graphical/text formats for the further analyses.

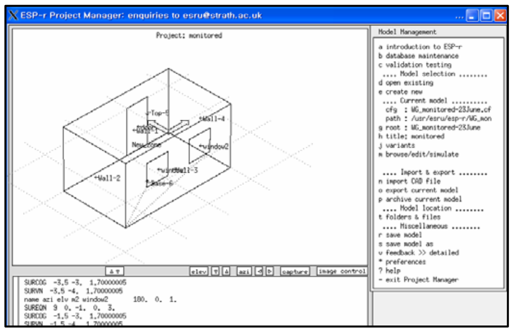

Fig 7. Computer Simulation using ESP-r [9]

4.1.1 Building geometry and weather data

For the sake of simplicity, one of the offices with five desks, in the William Gates building, is used for the simulation. Figure 7 shows a cubicle office with the dimension of 3m depth, 5m length and 2.7m height which has two double glazed windows (1x1m) and an internal door.

Where the geographical and weather data are concerned, 52.2˚ longitude, 0.12˚ latitude for

Cambridge in the UK are set and default UK climatic data is used for the simulation.

4.1.2 Construction materials

As an extremely well insulated building, the following low U-values are used which have much better values than the recommended Building Regulations requirements [10] (Table 2).

Table 2. U-values

	Building Regulation [10]	Cases
External wall	0.35 W/m^{2}K	0.14 W/m^{2}K
Roof	0.25 W/m^{2}K	0.13 W/m^{2}K
Floors	0.25 W/m^{2}K	0.18 W/m^{2}K
Glazing	2.0|2.2 W/m^{2}K	1.0 W/m^{2}K

4.1.3 Operational detail

For the purpose of comparison, two models were built – a base case model and a case model which uses monitored occupancy information.

For a base case model, it is assumed that the occupancy is 100%. Five researchers occupy the five desks of the office, working from 9am to 5pm during the weekdays. The lights are assumed to be on from 8am to 6pm for cleaning and building management purposes. Also, five computers are on from 9am to 5pm during the weekdays. The sensible heat gain from occupants is assumed to be 100W per person and the latent magnitude 50W per person. The sensible heat gain from lighting is set to 10W/m^2 and, from computer equipment 100W per machine.

As for the monitored case model, one case is chosen arbitrarily from the survey data; a researcher occupies the office from 7am to 9am and then two researchers from 9am to 2pm and three researchers from 2pm to 5pm. From 5pm to 6pm, one member of the cleaning staff is in the office and from 8pm to 11pm, one researcher works during the weekdays and on Sunday from 2pm to 5pm. Figure 8 shows the casual heat gain from occupants, lighting and equipment in each case.

4.1.4 Plants and systems

The William Gates building has no central heating system in the cellular offices. Instead the combination of low U-values used and the heat emitted from the occupants, lighting and computer equipment keep the building warm in the winter. For cooling, chilled beams are used for summer and free air cooling for the other seasons.

For the estimation of the cooling load, a maximum set-point of 24ºC is used [11]. As for ventilation, a fixed infiltration rate of 1ac/h is used during occupied hours, while the ventilation rate of 0.5ac/h is assumed for out of hours [11].

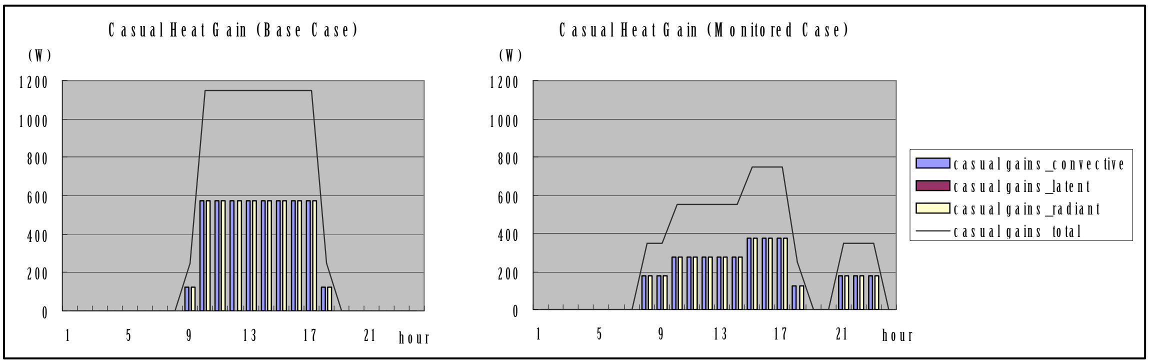

Fig 8. Comparison of the casual heat gain (a base case and a monitored case)

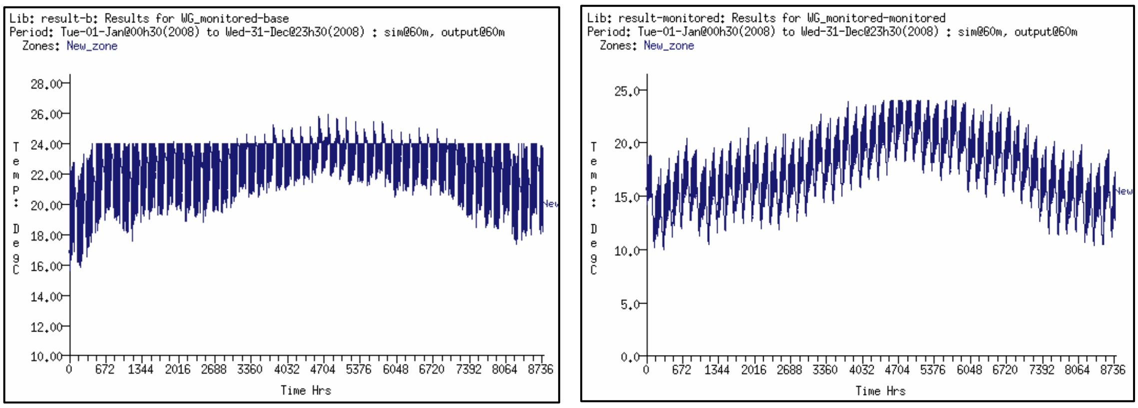

Fig 9. Comparison of indoor temperature over the year (A base case & a monitored case)

4.2 Results

The simulation was performed to examine thermal condition and energy consumption for cooling in William Gate Building. Figure 9 shows the indoor temperature over the year of the base case and the monitored case. It is seen that the indoor temperature of the monitored case is usually lower than the base one (20.6°C of the average temperature in the monitored case and 22.5°C in the base case). Therefore, cooling load for summer is less in the monitored case (7.7kW in the monitored case, 387.8kW in the base case). This difference is due to relatively less casual heat gains during the day time of the monitored case. However, because of less casual heat gains, the average indoor temperature during cold seasons is much lower of the monitored case than what is assumed in the base case.
The lower temperature for cold seasons can be considered as the main reason why some of the occupants expressed dissatisfaction with the thermal condition during the winter and thus the use of additional electric heaters. The additional heaters were not planned to be used from the design brief but in reality, the thermal discomfort caused the use of them. To estimate the heating load for the monitored case, another simulation was conducted regulating a minimum set-point of 21ºC during operational hours [11]. The simulation results show 599.1kW of heating loads over the year. This tells that more energy for heating/cooling is consumed in the monitored case rather than the base case.

Table 3. The average temperature and heating/ cooling loads in both cases

	Average temperature	Cooling load	Heating load
A base case	22.5 ºC	387.8kW	-
A monitored case	20.6 ºC	7.7kW	599.1kW

5. Conclusion

In academic buildings, there is a considerable difference on the occupancy levels compared to the original design brief and building services assumptions. In the Williams Gates building, the survey concluded that one out of two people occupies the offices.
The architects' approach and design is based on the client's original brief and requirements which is proved to be different from the real occupancy. However, the building design should reflect the actual work characteristics and working pattern of the building users.
The building energy simulation using the ESP-r program concluded that the sporadic occupancy leaded to less casual heat gains over the year resulting in less cooling load and more heating load thus more energy consumption in total.
It is proven that the discrepancy between the assumed initial occupancy and the post occupancy leaded to different energy performance of the building from the original design.
However, this simulation exercise has its own limitations; only one typical office was chosen without considering the actual whole building scale and without including all the construction details.
For academic research buildings, it is suggested that the Universities should consider providing offices with dedicated desks to employees who normally work at their office and 'multi-functional offices' for short and long stay to those who usually prefer to work elsewhere or out of their office.
This paper could be the preliminary study of setting up new ideas and guidance for innovative academic buildings. Further simulation with various occupancy patterns for each office type could be used for more detailed estimations.

6. Acknowledgements

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