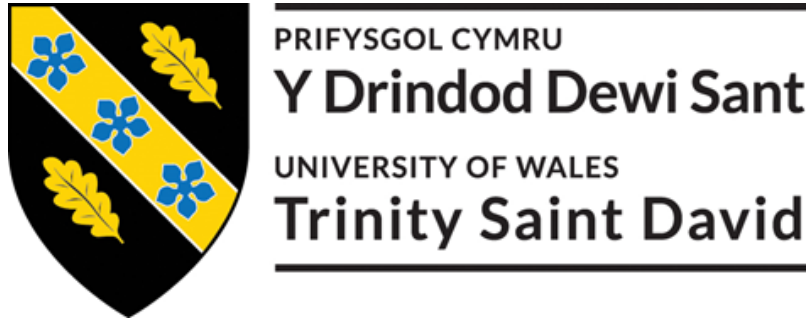




School of Architecture, Built & Natural Environments

An Analysis of Behavioural Adaption to Climate Change in Higher Education Establishments

A Dissertation for the partial fulfilment of an MSc study in Sustainable Construction

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The Author

Abstract

It is well documented in literature that the global climate has changed over the lifetime of the Earth's existence. However, until more recently this has been a natural process, with many climate scientists suggesting that the current trend of global warming is now caused by human activities. Although adaption to the changes caused by the climate is considered to be vital to ensure resilience, behavioural adaption is viewed by many as an emerging discipline. In this research, behavioural adaption in the context of the built environment is examined, including how this is interrelated to changes in the climate. Multiple methods are utilized including; professional interviews, opinion-based building occupant surveys, as well as an observational study enabling verification of results. Based on a knowledge gap found in reviewed literature, demonstrating a call for more climate related research at universities, the setting for the project relates to a new build higher education facility, which encompasses multiple internal environments & facilities.

Major findings of the project include but are not limited to; a lack of occupant training in relation to building use, poor communications between staff & student populations, as well as the identification of adaptive behaviours which have the potential to cause devastating side effects in the event of an emergency scenario. In certain circumstances, occupant behaviour was found to be not only wasteful in terms of energy consumption, but also likely to be actively contributing to anthropogenic climate change. Conclusions derived from findings suggest that full Post Occupancy Evaluation would be beneficial to the facility, with potential for the results & lessons learned from such processes to be of value to the wider industry.

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Glossary

Anthropogenic – referring to something that is influenced or caused by humans

Awnings – An external solar shading device

Biomimetic – See biomimicry

Biomimicry – The design and build of an item or component (such as part of a building) based on how issues are overcome in the natural environment

BREEAM – Building Research Establishment Environmental Assessment Method

Brise-soleil – An external solar shading device

Carbon Sequestration – The storage of Carbon in a medium that prevents its release into the earth's atmosphere

Disseminated – To distribute

Displacement testers – A device which measures force v distance

Emeritus – Refers to a person retaining their career designation after retirement as a sign of respect

Evapotranspiration – The natural process of water transitioning from its physical state into the atmosphere in the form of water vapour

Flectofin – A biomimetic external solar shading device

Holocene – Referring to the modern epoch of time

Hydrology – The study of water & its movements

Intumescent Strips – A fire & Smoke protection system commonly inlaid into fire doors which activates in emergency fire situations

Magnetic Induction – Refers to an object being capable of becoming magnetised

Multi Criteria Analysis – Is the comparison of different criteria in the same analysis for complicated issues

Permeable paving – A form of Sustainable Urban Drainage System, which is porous allowing water to pass through its surface

Photovoltaics – A device capable of capturing and converting the energy emitted from the sun into a form useful to humans

PPM – Parts Per Million

Sustainable Urban Drainage System – A drainage system which aids in the management of water in a sustainable fashion, such as a green roof

Trickle Vents – A ventilation system used to regulate air flow in buildings when major components such as doors or windows are not used

1. Introduction

It is well documented in literature that the global climate changes naturally. Evidence from factors such as geological records suggest that the climate over course of the Earth's existence has altered between great extremes. However, there is a consensus in modern times that the climate is now rapidly altering due to human intervention (Committee on Climate Change, 2017). Not only is this a great cause for concern, but it brings to light the seriousness of the issue, and how we as a species are to reduce our influence on climatic issues as well as adapt to these changes in the interim.

In 2006, adaption was suggested to be critical to ensure resilience to the implications of climate change, for which the global population has already subjected itself to (Stern, 2006). Yet, in the modern era, there is literature to suggest that understanding of behavioural adaption to climate change in buildings is an emerging discipline, still in its youth (Filho et al, 2018). Such findings point to a gap in social research, specifically associated with a link between occupant behaviour & climate adaptation. There is also investigation in the scientific community into occupant understanding climate change phenomenon at the university level, as well as the quality of available climate related studies for student, identified in the works of Nam & Ito (2011) & Hess & Collins (2018). The identified social research gap, as well as the ongoing exploration of occupant awareness in higher education institutions, defines a clear path requiring further academic study, associated with occupant behaviour & how its occurrence is related to change in the climate. To compliment these findings, this study examines behavioural adaption in relation to the climate, within the context of the interior of a building.

The building selected for this study was a new-build, constructed at a higher education institution in Wales, UK, commissioned in 2018. The interior of the building encompasses a wide variety of internal environments, where different building control systems were necessary in individual areas. Occupant behaviours common to these different areas specifically relating to adaption were identified. In addition, how these behaviours either positively or negatively affected the internal climate is examined, contributing to the growing body of knowledge in the behavioural field. Occupant behaviours were captured in a multitude of mechanisms building on previous studies including:

- Professional interviews with facilities staff & project managers associated with the build of the facility
- Opinion based surveys of a representative student & staff population relating to adaption & comfort
- An observational study, where validity of survey & interview results could be verified in practice.

In addition, analysis relating to how occupant behaviour potentially contributes to anthropogenic climate change is provided in connection with their actions in the built environment. Main findings included; a lack of occupant training & communication, as well as identification of adaptive behaviours that have potentially detrimental side effects in the event of emergency situations. The overarching Aim & Objectives of this research are clearly defined in the following sections.

1.1 Aim

To understand if the awareness and behaviour of building occupants impacts upon the effectiveness of adaptations for climate change and is acting as a barrier to their implementation in higher education establishments.

1.2 Objectives

- To establish if there is a need to adapt to present and future climate change in UK buildings whilst reviewing potential adaptation strategies
- To assess if awareness & building occupant behaviour influences the efficacy of climate change adaptation methodologies, amongst staff & students in higher education establishments via professional interviews & student surveys.
- To draw conclusions from data collected & make recommendations as to how behavioural adaptation can improve resilience to climate change in buildings.

1.3 Research Approach

Following the introduction, this research consists of:

- An extensive review of relevant literature, including; what climate change and its causes? How are buildings affected by these changes? A review of behaviour, education & previous adaption studies
- A detailed review of the methodologies used, as well as justification for their use – including; the research context, case study overview, data collection mechanisms, as well as ethical considerations
- Results & Analysis, including; discussion and in-depth analyses of the findings, with recommendations from these findings.
- An overall conclusion of the research project, with proposals relating to future research areas

The study is a form of attitudinal research, based on occupant adaptive behaviour and was conducted at a new build higher education facility, at SA1, Swansea, at the University of Wales Trinity Saint David. It was carried out between October 2018 – April 2019, in what is considered a heating season in terms of the internal building environment, following recent commission. Therefore, any conclusions drawn are specific to this time frame, and not those throughout a summertime period (cooling season).

2. Literature Review

2.1 What is Climate Change?

Climate change is the ongoing transition of the Earth's temperature & weather systems. This self-regulation of the global climate usually occurs naturally, over thousands to millions of years, with evidence demonstrating that the last three decades have been the warmest on record (Met Office, 2018) (NPS, 2015). However, there is a consensus in the scientific community that this average temperature increase is not caused by the Earth's natural weather systems alone. 97% of climate scientists claim that the current global warming trend is caused by human activities (NASA, 2018). Impacts of human activities which contribute to climate change are discussed in the works of Schlesinger (2011), suggesting that at the time of writing the increase of atmospheric CO² was around 1.9ppm annually. By comparison, data from the Mauna Loa Observatory has found that the global annual average has now increased to 2.36ppm between October 2017-2018 (CO₂.Earth, 2018). Since the end of the last ice age, the Earth's climatic conditions have been relatively stable up until the point of the industrial revolution, where anthropogenic carbon emissions have since increased by 40% from 1950 onwards (Schlesinger, 2011) (NPS, 2015). By comparison, far more recent research expanding on the findings of Schlesinger, suggests that the rate of increase in global temperature measured across the last 45 years, is now warming at a rate of 170 times that of the Holocene baseline, at approximately 1.7 degrees per century (Gaffney & Steffen, 2017). However, not everyone in human society agrees with the phenomena of rapid climate change. Although it is a significant branch of social science, there are those who find the prospect of climate change being influenced by humans unbelievable (Lombardi et al, 2013). For example, there are well studied individuals, such as the emeritus professor Les Woodcock, who provided the view that global warming is complete rubbish, which is not linked to humans, carbon emissions, and is reversible (Hudson, 2014). Therefore, although there is a plethora of evidence suggesting that global warming is a real threat to the planet, not everyone agrees. It could then be argued that the efficacy of any climate change related research could be influenced by a predisposed bias of the reader, based on which side of the argument they reside on.

2.2 What Causes Climate Change?

In the normal course of the Earth's atmospheric warming patterns, energy from the sun is passed through space into the Earth's upper & lower atmosphere, warming its surface. Excess heat is then re-emitted back into space. However, increasing amounts of greenhouse gasses in the Earth's atmosphere, result in this redirected heat becoming trapped. Such gasses are measured for their concentrations in the atmosphere in either parts per million, billion or trillion, and can remain there for a duration ranging from years to thousands of years (EPA, 2018) (NASA, 2018). Examples of these gasses include:

- *Carbon Dioxide*
- *Methane*
- *Water Vapour*
- *Nitrous Oxide*
- *Chlorofluorocarbons* (NASA, 2018)

Although these gasses are also produced through Earth's natural processes, it is generally accepted that humans contribute to their excessive production in today's climate. This takes place through processes such as; burning fossil fuels, deforestation, land change use, domestic livestock management, using certain fertilizers, as well as other industrial processes (NASA, 2018) (WWF, 2018). Although there are individuals in human society that would simply dismiss such information, evidence that our species contributes to accelerated climate change through our daily actions such as the above is widely available and easily accessible.

2.3 How are Buildings Affected by Climate Change?

In the built environment, building materials are selected for both their structural properties, as well as their unique climatic abilities. An example of this includes the use of traditional building products in historic buildings such as lime-based mortars. Such materials are often utilized in churches and other historic structures (dependent on region). This material when used correctly in conjunction with other vapour permeable materials, allows for a vapour open building fabric which enables the passage of moisture in and out of the structure as the weather changes (Williams, 2014). The use of this technique in historic structures clearly demonstrates that in the past, building materials have been selected with consideration given to how they will behave in their specific environments. It is therefore unsurprising that with rapid anthropogenic climate change, there are expected implications for our building stock. Directly attributable impacts as detailed in the IPCC's Fifth Assessment Report, state that effects for buildings will and already include; Increased risk of wildfire & floods, precipitation & frost risks, wind loading & damage, as well as being situated in an environment with a higher temperature since construction (IPCC, 2014). By comparison however, other authors claim that the

true extents of these risks are not fully understood (Aysha & Mani, 2017) . The IPCC also identifies that unless resilience to these factors is improved, the likelihood of issues arising from these events increases. Suggested strategies to adapt to these issues include; Decarbonisation in the electrical sector, increased efficiency & demand reduction of service technologies in the built environment, as well as improving building fabrics both new and old to increase their efficiency (IPCC, 2014). Similar issues are also identified by Johns & Fedeski (2001). It is therefore evident that there is a level of awareness & discussion of these issues in literature, with a comparison between authors demonstrating the subject to be an ongoing development of knowledge. Although such aspects have been known for an extended period of time, the behavioural side of climate adaption in buildings, as identified by Filho et al (2018), is still considered to be a form of climate science in its infancy.

There is also literature to suggest that the age of buildings, may also affect their resilience to climate change. For example; Mosoarca et al (2017), examines a case study in Romania, which is rich in built assets of historical significance. Climate change related events such as increased precipitation, flooding and wind loading are discussed in relation to their impact on heritage buildings. The research finds that historical buildings could be considered as extremely vulnerable to the effects of anthropogenic climate change and suggests that protection strategies need to be developed and implemented to help protect these structures. Although this is mainly a Romanian based study, the research is swift in indicating that these climate related phenomena are also a threat to UK heritage buildings, such as the flooding of Abergeldie Castle in 2016. Here, remedial action was necessary to protect the asset from becoming structurally compromised (Mosoarca et al, 2017).

Phillips (2015), also states that cultural heritage assets are exceptionally susceptible to rapid climate change. In these works, climate related adaptive capacity is investigated amongst three UK heritage sites, via a survey of heritage site managers. Findings suggest that factors which effect the adaptive capacity of heritage sites include; understanding & education of managers in relation to climate adaption needs, limited availability of information & limited resources. However, conclusions suggest further research is necessary as there is lack of knowledge in the subject (Phillips, 2015). It is therefore evident that heritage assets are at risk from climate change, as well as the identification that greater education is necessary for persons responsible for implementation of climate adaption mechanisms. This demonstrates the magnitude of such issues, as many of these assets have existed for great periods of time already in some cases. It is only in more recent years that humans have caused the great acceleration of this issue in a short timespan as identified in the research of Gaffney & Steffen (2017), which in turn, hastens the necessity of adoptions systems in the built environment.

There is also research to suggest that the full effects of climate change on current building stock are not yet known in their entirety. Due to this fact, the ability to adapt to future scenarios is now expected

of buildings (Aysha & Mani, 2017). The expectation of adaptive capacity for climate resilience is also expressed in earlier research by Chow & Levermore (2010). It is therefore evident that alongside their historic counterparts, modern buildings are also likely to be susceptible to the implications of climatic change. In contrast however, there is literature emerging which highlights some of the potential implications for these buildings. For example, Vardoulakis et al (2015) suggest that 1 in 6 UK buildings may be susceptible to an increased chance of flooding in future climate scenarios. The cause of this expected risk can be attributed to increasing temperature, resulting in melting ice caps and higher precipitation levels, as well as tidal, surface and river flooding (Vardoulakis et al, 2015). Overheating is also identified as an issue for new-build structures. Marsh (2012), explores future scenarios in relation to overheating risks for new build houses. The study finds that new homes constructed after building standards released in 2012, are likely to experience overheating problems in the future, linked to increasing global temperatures associated with anthropogenic climate change. The suggestion is also made that for buildings which are designed with high levels of insulation, as well as physical orientation to capture solar energy passively, overheating is likely to be even more severe. This overheating risk is then likely to cause an increase in energy loads for cooling purposes. The study concludes that these issues should be considered now to reduce future overheating risk (Marsh, 2012). The evidence presented by these studies, demonstrates conflicting opinions between authors. Aysha & Mani (2017), suggest that these factors are at least in part unknown, however, authors such as Marsh (2012), have proposed multiple issues. It is therefore evident that there is a gap in knowledge of the true extent of these impacts, with some authors suggesting there could be more done at the present time to consider such impacts well in advance to minimise future risks for buildings.

2.4 Climate Change Adaption Studies

Previous studies into how climate change is likely to impact the built environment, have covered a wide variety of topics. These include the analyses of Weng (2017), which assess how the comfort levels of a semi-detached building are met during summertime in the UK. This research was carried out on a predictive basis using established datasets, observing patterns of window operation in different locations. (Weng, 2017). The study finds that for the UK, the use of behavioural adaptations such as opening windows only at daytime, will not be suitable by the year 2080. Findings suggest window opening will also be required at night in order to maintain comfort, although the study acknowledges this could pose a safety issue for the inhabitants of the building (Weng, 2017). This study therefore identifies that not only will behavioural adaptation be necessary in the near future, it also hypothesises that such adaptation has the potential to cause negative security issues in terms of occupant safety.

Previous research has also analysed the importance of behavioural adaptations in relation to climate change related impacts. Coley et al (2012), define these as behavioural factors as soft adaptations and building fabric changes as hard adaptations. This study reviewed two different buildings; a domestic dwelling and a larger educational structure, in relation to expected scenarios for emissions and weather patterns. The results of this research detail that using a combination of both physical and behavioural adaptations can contribute to reducing the timescale for overheating in buildings. Although this research also utilizes predictions in the datasets used, it is a key study as it begins to highlight the importance of human behaviour and the impact it has on a buildings ability to keep the internal climate comfortable. This study also points towards the potential to explore in greater depth the social elements of climate change adaption and enable the production of actual datasets for human influenced factors.

2.5 Occupant Behaviour

There is an emerging body of research which places emphasis on how occupant behaviour impacts upon a buildings ability to deal with the effects of climate change. Examples of this include studies carried out by Vardoulakis et al (2015). This study highlights that building improvements for the purposes of increasing the thermal performance, may lead to an increase in indoor air pollutants. This can be dealt with by the introduction of Trickle Vents. However, analysis of the behaviour and knowledge of occupants has found that up to 75% of similar ventilation systems are not used correctly (Vardoulakis et al, 2015). Such findings are of great concern when compared to the results of studies such as Coley et al (2012), as a combination of both behavioural and building adaptations are necessary to enable buildings to adapt to future climate (Coley et al, 2012). As there are findings that occupant behaviour is already negatively impacting the performance of buildings, this implies that there is a need to educate occupants as to how their actions effect building performance, and research this factor at the academic level. Additional literature is also available which supports the view that occupant behavioural changes will be required to adapt to climate change. For example, Lim & Yun (2017), suggest that the utilization of behavioural factors such as lighting systems which operate based on occupancy, alongside nocturnal ventilation, can cause a reduction in the energy required to cool buildings. This literature also states that the education of building users is necessary to adapt to the negative implications of climate change in buildings (Lim & Yun, 2017).

Similar research was also carried out in 2017 concerning the education level of building occupants, and how this affects their behaviour and resilience to extreme climate related events. Pisello et al, (2017) utilized the methodology of a detailed questionnaire, disseminated in person and online to 316 respondents in Italy. This research criteria including; the background of the respondent, building

information, education level, as well as age, income, gender and whether active, passive or a combination of the two adaptive strategies were used by the respondents during extreme events. This study was carried out during both heating and cooling seasons, and highlights in its results that even when there is no specific extreme climatic event taking place, persons with a higher education level are still interested in the changing climate, regardless of less publicity in the media. The study concludes that the education of building occupants could therefore be a critical factor in improving resilience to climatic related events (Pisello et al, 2017). This work clearly identifies that an improved awareness of climate science amongst building occupants, has the potential to their increase their ability to adapt to extreme climatic events.

Research into how building occupants interact with building systems, is also presented in the works of Gilani et al (2017). This study utilized data collected from built-in building sensors, data loggers and time lapse cameras that were analysed to understand occupant behaviours. However, the study identifies that other methods can be employed to research the same issues, such as surveys and questionnaires. The suggestion is also made that these methods allow for the capture of the causes and effects of behaviours, which are not easily observed in the method they elected to use. The study also highlights that when under observation, persons may alter their behaviour from what would be considered normal, as they are being watched. This is known as the *"Hawthorne Effect"*, and it is conveyed that this phenomenon can be minimised by restricting the information provided to participants. The findings also suggest that analysing aggregated data may lead to incorrect cause and effect relationships being identified, and that analysing scenarios where individual room controls are available may be of more value (Gilani et al, 2017). This study identifies a key issue when observing the behaviour of any persons, in this case building occupants. Consideration of the Hawthorne Effect would be of critical importance when conducting any social research into behavioural patterns as there is potential for it to cause a great bias to results. The study also suggests a potential remedial action to rectify this issue, however it does not convey that it can be eradicated completely.

Similarly, there is also literature available which has investigated occupant behaviour at the individual level. Yao & Zhao (2017), present research into the window opening patterns of 19 residencies in Beijing. Their study uses a combination of methodologies (similar to the approach of Gilani et al, 2017) utilizing a questionnaire, as well as monitoring; temperature, indoor CO₂ concentration, relative humidity, and recording the position of openable windows using Magnetic Induction Devices. The results of the study highlight how window opening patterns were found to have longer durations during summertime. Of the environmental factors analysed, outdoor temperature was found to be causing the greatest influence on occupant behaviour (Yao & Zhao, 2017). As could be expected from this study, more window opening was found to be necessary during the summer to maintain comfort,

as opposed to other times of the year. However, what is key in this study is that outdoor temperature was found to be the most influential factor for occupant actions, instead of issues with the building fabric or personal preference. This study could be replicated in different locations and buildings to ascertain if outdoor temperature remains the greatest issue affecting this phenomenon. Comparable research has also observed window opening patterns in a commercial setting, for offices at a university. The works of Pan et al, (2018) also took place in Beijing, monitoring passive cooling behaviours through heating and cooling seasons. The study used a combination of devices to measure data including; indoor temperature sensors, portable weather stations, infrared sensors to detect heat emitted by occupants, and the position of windows via displacement testers using magnetic induction. The study finds that there is potential for a multitude of factors to be able to influence window opening behaviour, including internal & external temperature, personal preference, seasonal change, as well as windspeed, humidity and time of day. The study concludes that more research is needed into each of these factors to establish their individual influence on occupant behaviour (Pan et al, 2018). This work clearly identifies that occupant behaviour is not simply influenced by any singular definitive factor, which is different from the view suggested in the works of Yao & Zhao (2017). The study also conveys that window opening behaviours have the potential to be unique to each individual based on preference. Therefore, there is a difference in opinion amongst climate change researchers as to what influences this behaviour.

Research into the perceptions of thermal comfort has also been carried out amongst vulnerable persons. Tartarini et al, (2018) explore the perceptions of thermal comfort and the adaptive behaviour of staff and residents across five care homes in New South Wales. Data was collected through questionnaires, interviews, and devices to monitor indoor environmental conditions. In total, 509 participants contributed to this research throughout both heating and cooling seasons. The results of this study find that in these locations, the most common adaptive behaviours were to adjust the local air velocity as well as clothing level. It was also found that thermal comfort was not always achieved for all residents, and the study highlights a distinct lack of research in the care sector regarding thermal comfort. (Tartarini et al, 2018). Not only does this study identify yet another sector in which climate change-based research is lacking, it also suggests a potential human rights issue in the care industry as the resident's comfort was found to be inconsistent. As adjustment of air velocity was found to be one of the most frequently adopted adaptive behaviours in these buildings, further study into the benefits of different mechanisms to regulate the internal air movements & quality could be of benefit to the sector.

Similarly, research into thermal comfort has also been carried out in a residential setting for subtropical climates. Dear et al, (2018), explore thermal comfort across 42 homes in Sydney Australia,

using a modern take on an established methodology. The study utilizes data logging devices to record environmental data for the indoor climate of the homes, however it uses a novel approach to capture occupant data, disseminating a questionnaire through smartphones. The main finding of this study is that residential occupants are typically better suited to adapting to the temperature of their environments, by comparison to those in a commercial setting such as offices. (Dear et al, 2018). This research not only provides an understanding of the thermal adaptive capabilities of occupants in a residential setting, but is also significant in its advancement of existing research methods by incorporating new technologies such as smart devices, in social based climate research.

Literature also suggests that assumptions concerning occupant behaviour in building simulation, can lead to inaccuracies in the energy requirements for heating and cooling buildings. The work of Yao (2018), investigates the behaviour of residential occupants in China, in relation to the duration of air conditioning usage. The data used in this study was collected via devices monitoring internal temperature, as well as smart plugs which monitored energy usage linked to smartphones. Similar to the study of Dear et al (2018), this work also incorporates a rapidly evolving technology into its research method. The results of this study highlight that utilization of behaviour models in building simulation, in accordance with the building energy standard for the associate geographical region can lead to an overestimation of cooling energy loads by up to 113% (Yao, 2018). This identifies the seriousness of acquiring a true interpretation of the influence of occupant behaviour in buildings, and how a misrepresentation can lead to inaccuracies in calculated energy demands. This area could also be expanded upon in different regions to ascertain if the same results are observed.

2.6 Climate Change & Education

There is a growing body of social research, relating to education & climate change adaption. For example, the works of Siegner (2018), express the importance of utilizing both behavioural & technological adaptations to ensure resilience to climate change and suggest that the education of persons is vital to the adoption of these behavioural changes in society. This American study examines the impact of changes to the learning curriculums of various school students to include climate change related teaching. How this then impacts their awareness and understanding of the subject is assessed. The level of confidence and ability of staff to provide climate related learning was also analysed. On site observations, interviews with teaching staff, and pupil surveys, were used to capture data. Findings suggested an improved knowledge in students regarding the implications of climate change, as well greater staff preparation to teach in this subject area (Siegner, 2018). This clearly demonstrates the value in further developing climate change-based education, as it has the potential to expand the knowledge of the subject within the minds of students, who will become the next generation of adult

building users. Such results therefore contribute to the education needs identified in the works of Lim & Yun (2017).

There is also literature exploring the potential barriers of conducting climate change related research in universities. Filho et al (2018), provide insight into the complexities of climate-based research, suggesting that simple predictive modelling for future scenarios is insufficient to gain a true understanding of the subject. The complex nature of the social factors, and the actions of humans which influence climate change adaption also need to be understood, as these are generally viewed as a modern emerging form of climate related science (Filho et al, 2018). This study produced an international survey of universities & higher education establishments, across 48 countries. Its purpose was to source experts in the field of climate change and identify the main barriers of research at these institutions. Percentages of the main barriers identified by respondents are shown below:

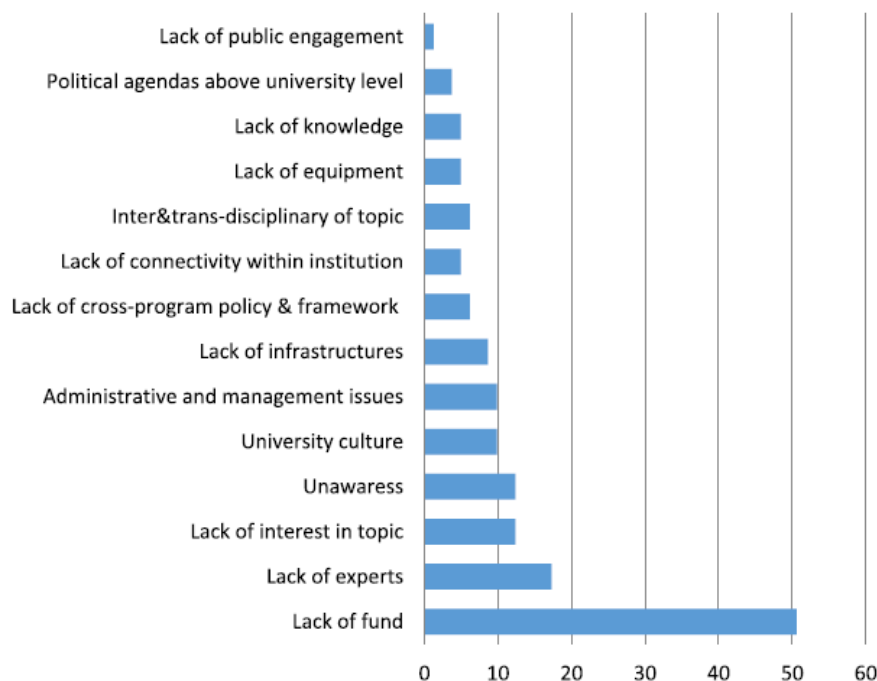


Figure 1 – Results from the study of Filho et al (2018) expressing main barriers to climate change related research at universities.

As detailed in Figure 1, the main barriers to climate change research at higher education level are; lack of funding, followed by lack of experts and interest. The study also highlights that less than half (46%) of universities surveyed have an ambition to circulate research in the topic area, with only 54% conveying that their institution had a dedicate climate change research facility. Conclusions suggest that wider interdisciplinary approaches to research are required in this topic, and that future studies could include investigations into the perceptions of both students and staff regarding climate change adaption and mitigation strategies at higher education establishments (Filho et al, 2018). The justification of the need for more social-based climate research amongst occupants of higher education establishments begins to emerge in this research, with suggestions for future investigations that are directly attributable to the current study. Notably, findings suggest that some universities are

simply disinterested in contributing to climate change research, which could therefore be a prudent area to explore in more detail.

Exploration of the efficacy of dedicated climate change educational courses, when offered university students is also available in literature. Nam & Ito (2011), detail the importance of student knowledge relating to climate change, as they will likely be involved in future environmental decisions. For this research, a specific educational course was provided to improve the information literacy and knowledge of undergraduate students in relation to climate change, and its connections to human society. Data & evidence was gathered using multiple methodologies including; questionnaires, interviews with students, observations, and an after-course survey, providing both quantitative & qualitative analyses. An improved climate knowledge was observed in students, including human influence on the phenomenon as well as improved information literacy skills. However, the study also suggests that a change in environmental behaviour was not witnessed amongst participants, demonstrating that this could have been caused by; exposure to uncertainties surrounding climate research, predisposed lifestyle choices, or the possibility that no personal carbon environmental impacts were covered in the course (Nam & Ito, 2011). This therefore identifies the potential positive impacts of advancing climate change education at university level and is also critical as it provides insights into the potential flaws of such education, that could be considered and amended in future educational courses.

Similarly, research has also been carried out examining the probability of students attending a course at university, that is related to climate change. Hess & Collins (2018), conducted a study into the curriculums of what could be considered the elite 100 Universities in the United States, to establish the likelihood of climate change being part of university level education. This research was not exclusive to a subject and encompassed a variety of topics such as; natural & social sciences, mathematics, writing, history and philosophy. The results of the study found that there was a 0.17% probability of a student studying a course related to climate science, with the suggestion that it is possible for a student to obtain a bachelor's degree without any introduction to climate change (Hess & Collins, 2018). This suggests a serious climate related issue at higher education institutions. As identified by Nam & Ito (2011), there is potential for students to become future decision makers, who according to Hess & Collins (2018), could then be oblivious to the subject. It is unlikely that this would yield beneficial results for the natural environment, and this study provides opportunity to improve education curriculums for future students.

In relation, earlier literature specifically investigates the knowledge and awareness of climate change amongst higher education students. Wachholz et al (2014), explores the views & attitudes towards the prevention of further accelerated climate change, amongst 338 American university students

studying multiple disciplines including; social sciences, business, humanities, as well as other topics. This research utilized a questionnaire to gather data, which was presented to students before and after lectures, during different years of their studies. The findings conclude that of the students surveyed, 75% believed that the current trend of climate change is caused largely by humans. However, it also highlighted that there was only slight evidence amongst respondents that any proactive personal intervention to minimise contributory emissions caused through their lifestyle choices was taking place (Wachholz et al, 2014). This finding therefore agrees with the works of; Hess & Collins (2018) & Nam & Ito, (2011) as it suggests that there is potential for future decision makers to play an inactive role in the prevention human induced climate change.

In literature, specific climate change adaption strategies have been developed for higher education institutions. Owen et al (2013), established a study at Dalhousie University, Canada, with the aim of providing strategies for the institution to adapt to a future climate. The study highlights a lack of information at university level for climate change adaption planning, finding that the majority of such guidance is aimed at a regional or national level. Data & evidence gathering was conducted in this research through a campus survey, allowing staff and students to voice their views on the facility in relation to vulnerabilities they thought were relevant to the institution, as well as a workshop to expand upon findings. The study established three main areas of concern for this particular institution in the face of extreme climatic events, these were; the existing built environment, energy supply and method of transportation. A wide range of options are also suggested for the institution to adapt to extreme events. These include; installing backup generators, considering the use of green infrastructure, burying powerlines, using alternate building materials and including adaption strategies in emergency plans. The work concludes that although such measures may be suitable for this institution, and that it is possible for the method used to be utilized by other facilities, individual campus research is required to make facilities more resilient to a future climate (Owen et al, 2013). This study not only adds to the emerging body of literature relating to climate science, but also begins to investigate adoptions strategies suitable for higher education establishments.

2.7 What can be done to adapt to climate change in the built environment?

To begin assessing which adaption strategies are available in the built environment, to counteract climate change, it is useful to have an appreciation of its impacts. These include but are not limited to:

- *Rising Temperatures*
- *Rainfall Change*
- *Sea Level Rise*
- *Melting & Shrink of Glaciers & Artic Sea Ice*
- *Effects to Nature & Behavioural Patterns*

(Met Office, 2017)

How then does this cause issues in the Built Environment? As development occurs, construction activities generally cause a decrease in size of natural landscapes, as areas become urbanized. This can then lead to issues such as flooding, as natural land available to manage surface water runoff becomes compromised (Vardoulakis et al, 2015). This view has also been reflected in earlier works, highlighting that effects of climate change for the built environment are likely to include; increased flooding & storm damage, greater thermal discomfort, as well as increased demand for cooling of buildings (Roberts, 2008). In relation, there is research to suggest that in locations with alternating hydrology, excess water may be managed through the development of Green Roofs. Using these systems provides much needed green areas in an otherwise urban landscape. These systems regulate water through the process of evapotranspiration, much like that of the natural landscape (Viola et al, 2017) (CIRIA, 2007).

Another method which allows for the management of surface water in the built environment is through the use of permeable paving. This can be used for both roads and walkways, and it allows water to soak below its surface for further management or back into the ground. (susDrain, 2012). Although these systems can provide benefits such as the reduction of peak flow surface water, they can also contribute to the pollution of groundwater. This can occur when contaminants as well as surface water, pass through into the ground below, which means that their use requires careful consideration (Jiang et al, 2015).

The increasing temperatures associated with accelerated climate change are also likely to be a concern for the future built environment. In this context, shading techniques may be beneficial to help overcome this issue, such as external & internal shutters including Brise-soleil systems and Awnings (BRE, 2016). There also an emerging design discipline known as Biomimicry which could contribute to climate change adaption. Examples can include biomimetic building skins which are adaptable to the climate, as well as shading systems like the Flectofin (Pawlyn, 2016). In addition, further benefits of biomimetic design, can include carbon sequestration as well as enabling energy production (Aanuoluwapo & Ohis, 2017). These forms of adaption are a selection of some the innovative ways of

improving resilience in the built environment to climate change through building design, fabric and material selection.

However, there is more to adaption than building alterations alone. As building users, we also adapt to the climate via behavioural adaption, which can include the use of both passive and active mechanisms. Examples of such behaviours include but are not limited to;

- Window Opening
- Changing Local Air velocity
- Adjustment of clothing level

(Yao & Zhao, 2017), (Tartarini et al, 2018)

These behaviours can potentially influence the perception of comfort within a building from the view of the occupant, in addition to the composition of a building's fabric. Such behaviour also impacts upon the energy use in buildings, and there are studies which examine the extent of these influences in the built environment, many of which are detailed in section 2.5 such as the works of Tartarini et al (2018).

3. Methodological Review

3.1 Methodology Introduction

Following a review of literature, it is evident that physical & behavioural adaptation to future climate change in buildings is a relevant, emerging form of research amongst higher education institutions. This section therefore proposes an area within the field of climate adaptation to further investigate and contribute to knowledge for the sector. This includes an in-depth account of methodology utilized in the study, as well as its various strengths & limitations. Justification and evaluation of the choice of methodology is also provided (USC, 2018). As identified in the literature of; Hess & Collins (2018) & Filho et al (2018), there is opportunity to explore perceptions of climate adaptation and mitigation strategies amongst university staff & students, as well as the extent of student understanding of climate change. Therefore, as this gap has already been identified by other authors, it is the area within the broader subject of climate change adaptation, which is the focus of the study. As part of the evaluation process, any issues with the methods employed are identified, as well as how these factors were resolved, or reduced to an acceptable level.

3.2 Research Context

As identified in the aim of this research, its purpose is to provide an understanding of; if there is a relationship between building occupant behaviour & climate adaptation strategies at higher education institutions, and if occupant behaviour impacts upon the efficacy of such strategies. For this study, the new build development at the University of Wales Trinity Saint David, SA1 Campus, was the focal point of the research. To build upon the methodologies of greatest significance to study identified in reviewed literature, such as Pisello et al (2017), this research consisted of a mixed method format, of both a qualitative & quantitative nature. Initially, qualitative data collection took place through in-person staff interviews, as well as through an extensive occupant survey, which enabled the capture of attitudes, opinions, viewpoints and perceptions in the research (Naoum, 2013). The collected data then lead to quantitative data generation, as well as complimentary qualitative analysis through the analytical process. Therefore, the format of the methodology for this study consisted of:

- Interviews with staff members in their professional capacity, to ascertain a true interpretation of the building's facilities, fabric and services
- A survey of pupils & staff to define their opinion of the new buildings' internal climatic performance in relation to their own adaptive behaviour at the same facility
- An observational study to examine if behaviour identified through the above two mechanisms is viewed in practice

In relation to the aim of this study as set out in section 1.1, the proposed intent of selecting these methods was to;

1. Assess awareness of building occupants through the survey
2. Examine behaviour of occupants through the observational study,
3. Understand if there is a link between occupant behaviour, and the ability of a building to adapt its internal climate through analysis of data from interviews and occupant survey.

This selection of data collection methods satisfies objective point 2 of this study, as established in section 1.2.

3.3 IQ Overview

In 2018, the University of Wales Trinity Saint David, completed the construction of its new campus buildings at SA1, Swansea. Following discussion with senior members of staff at the institution, it was identified that this development could be a valid setting to contribute to the climate adaption research field. Reasons for this include that students and staff have all been relocated to a brand-new facility, where it could be argued that considerations such as future adaptive capability should have been considered from inception to protect the building from future climatic impacts (IPCC, 2014). Although there are multiple buildings at this facility, for this study, the IQ building will be of focus, as it encompasses a wide variety of internal environments required for multiple disciplines.

The IQ building, is a new build higher educational facility, commissioned in 2018. The construction type could be considered a modern method of construction and comprises of; A structural steel frame, with metal decking, concrete floor & roofing systems. The wall fabric consists of a steel & brickwork façade with curtain wall window systems. It is worth noting that in terms of environmental considerations, the building was specified to be produced at a BREEAM Excellent Standard. The finished build is depicted in the following images:



Figure 2 – The IQ Building at UWTSD SA1 Swansea (UWTSD - Photographer - Adam Davies, 2018)



Figure 3 – The IQ building in relation to the rest of the SA1 campus (UWTSD, 2019)

The approximate size of the building is 10149m². As could be expected with a modern building, it utilizes a selection of heating & cooling mechanisms, energy sources, and also has systems in place to monitor its internal environment. More information on this built asset is available in the results section of the professional staff interviews, chapter 4.1. In relation to the building's surroundings, the following climate data represent typical values for the external environment:

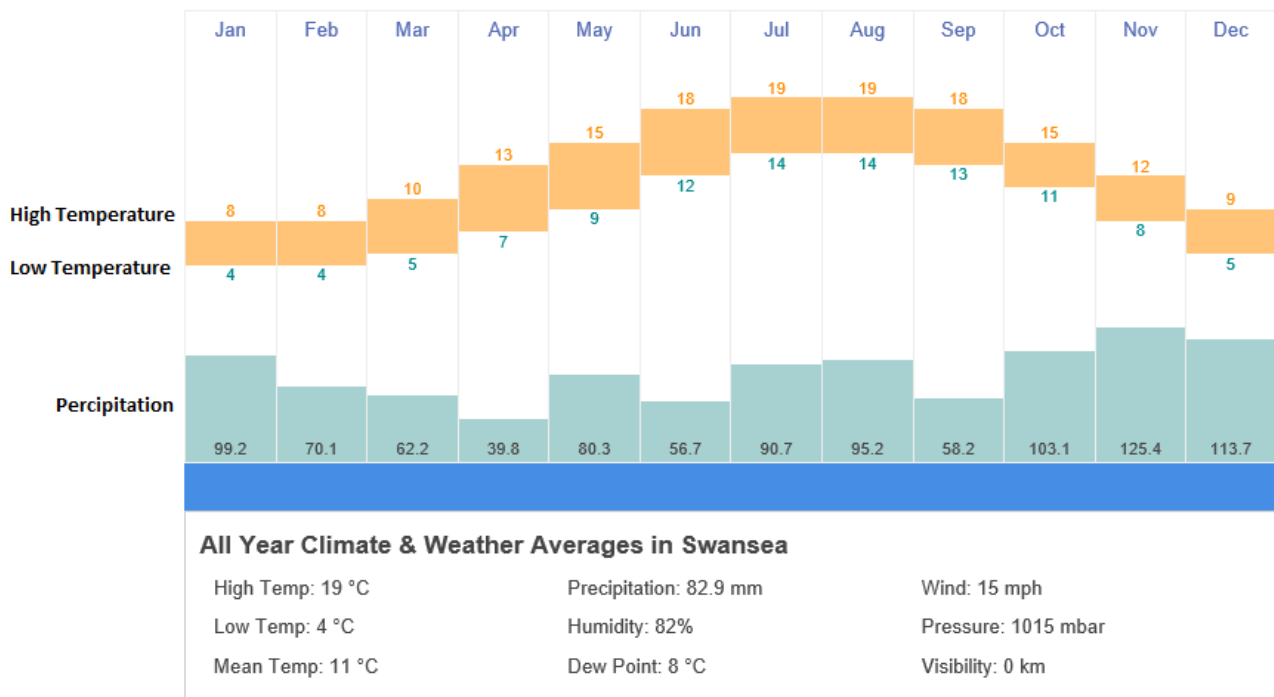


Figure 4 – Climate Data for Swansea (Time and Date, 2019)

The data presented in Figure 4 are representative figures for the average climate likely in the external surrounding environment of the IQ Building, and are based on weather reports taken for the area

between 2005-2015. As shown, the temperature can vary greatly between 4-19°C, with average temperatures of 11°C. Average relative humidity & precipitation are also high at 82% & 82.9mm respectively.

3.4 Data Collection Part 1 – Staff Interviews

To ascertain potential challenges faced by the IQ building, interviews were conducted by the Author with staff members of the institution, providing their unique insight in their professional capacities. Interviewees relevant to the study were identified through open discussion between the researcher and senior staff members at the institution. These persons included members of the facilities management team as well as sustainability leads, however, names and exact titles are omitted intentionally for the purposes of confidentiality. A Project Manager from the design & build stages of the project was also included in the interviews, providing a specialist viewpoint into the expected performance of the building. The participants selected for interviews were considered to be the most appropriate for the study based on their level of understanding of not only the fabric of the building, but also its day to day running & maintenance. In total, 3 interviews were carried out with the facilities team at the institution. A potential limitation of this method is the quantity of staff interviews carried out. Initially, more potential interviewees were identified for the study, however, upon making repeated contact with them, they were unavailable to take part in the research.

When conducting interview-based research, there is guidance available which details the different forms available to the researcher, as well as their uses. These include structured, semi-structured & unstructured interview styles. Unstructured refers to an interview which utilizes open ended questions in an unassigned order, which are broad and generalized. Structured interviews can begin with open style questions initially, but quickly takes the form of a closed question survey, where the interviewer then has more control, and the survey questions have a predetermined order. Semi-structured however, use both open and closed questioning styles, and although questions are predetermined prior to carrying out interviews, they are not prescribed to a schedule or order. The intent of using this style is to capture as much data as possible about a specific topic and are as such suitable for scenarios where respondents have gained direct experience in the research area (Naoum, 2013). It was therefore evident that the interview technique most suited to this study was the semi-structured interview style, as the interviewees were likely to have the greatest level of experience in the appropriate use and maintenance of the IQ building.

A set of interview style questions were developed by the author, based on similar studies found in the literature review such as Pisello et al (2017), prior to commencement. Interviews were carried out in person, at a private meeting room at the institution marketing suite. The advantages & disadvantages

of face to face interview styles are evident in literature. Main advantages can include; flexibility & adaptability, as well as observation of the respondent & use of physical stimulus, for example body language can be observed. However, as with any approach disadvantages are also witnessed including increased time constraints on respondents, as well as geographical issues & greater costs (Szolnoki & Hoffmann, 2013). In the case of this study, costs were reduced to zero through the use of space available at the facility, and issues with time keeping were overcome through high quality communication with the respondents by the author, as well as allowing additional time when planning the interview structure. The initial contact with participants took place via email to ascertain if they were willing to take part in a thirty-minute interview, and if so to arrange a further date and time of commencement. Prompt responses were received from most recipients in this case, demonstrating the method to be highly successful. However, a potential limitation could have included later responses from participants, which could have greatly delayed the project. During interviews, valuable information was imparted to the Author enabling an understanding of inner workings of the building, and all questions were fully answered by participants. The responses clearly defined factors that were critical to the study, and the information provided to the Author guided the production of content for the staff & student survey.

3.5 Data collection Part 2 – Survey

Following the response of interviews, a series of questions were specifically developed to be disseminated to staff and students of the IQ facility, to include the following content:

1. Adaptive occupant behaviour
2. Internal temperature & air flow/quality
3. Comfort

To satisfy the aim and objectives of this research, a survey was carried out at the IQ facility in person, to capture information relating to occupant awareness & behaviour. Survey questions for both staff & students are available in Appendix A. Due to the extensive population of occupants which use the facility on a daily basis, it was considered impractical to include every occupant within the survey. To resolve this issue, a representative sample was selected. There is literature to suggest that the issue of sample size is complex, and consultation must be carried out with the department requesting research, to ensure they are involved with the decision (Bryman, 2008). Through discussions with staff at UWTSD, it was made evident that there will be constraints to this data collection, such as time, cost & availability of individual respondents. In consideration of these issues as well as comparison with similar studies identified in the review of literature such as Tartarini et al (2018) & Pisello et al (2017) which range from 100-500+ respondent's, the survey was extended to a representative population of 120 individuals. For this study, 100 students and 20 staff completed the survey in total.

As with any form of research, there are different variables to consider, such as those which are dependent & independent of each other. Dependent variables are usually measured, which are often considered an effect caused by another factor. Whereas independent variables are a constant, and are unaffected by other factors, often thought of as a cause of another variable (USC, 2019). For this study, there would appear that there are three variables to consider, these are:

1. The Independent Variable – External Climate Change
2. 1st Dependent Variable – The internal comfort level achieved in the IQ facility
3. 2nd Dependent Variable – Occupant behaviour in response to comfort levels achieved

For this research there were two dependant variables, as occupant behaviour & comfort were both analysed. Although these are different, individual factors at work and therefore are different variables, they are intrinsically linked by nature.

Students were selected for the study based on consultation with UWTSD staff. At the institution, mixed group lectures were held, which encapsulated the greatest number of disciplines within a single session (enabling greater representation of the overall student population). 10-minute periods of time were kindly donated at these sessions to allow students to participate. However, a disadvantage of using these sessions included attendance by individuals at a single session. This was overcome by the Author attending multiple sessions with different students to capture data. However, this also increased time required for the process. Due to the attendance issue of these sessions, there is also potential for a bias in the population of the sample based on discipline of study, i.e. more students could attend the class from one discipline than another. This was overcome through a secondary process where random participants were allowed the opportunity to participate in communal areas of the facility, where the presence of the surveys was made known to students. This greatly increased the representative disciplines within the sample. Staff participants were also selected via consultation with senior members of the institution, as staff with different roles were not always available at the same time. This was also overcome through multiple visits to the facility by the author, to enable a wider spread of staff participants. However, a slightly different survey was issued to staff to include factors related to teaching, which would not be relevant to student participants.

Costs of the survey included printing, at a total of £20 (borne by the Author). This was necessitated by the use of the in-person method. As highlighted in section 3.8, submission of the survey for ethical approval, caused an approximate 3-week delay to the project. Although this is a beneficial and necessary process, it affected the options available to the Author for dissemination of the survey to occupants. It was therefore considered prudent to carry out the surveys in person, as this was likely to reduce the rate of non-responses, as well as collecting high quality data, as identified in the works of Lavrakas (2008). The costs incurred could have been avoided through digital dissemination.

However, as a prompt response was required due to the afore mentioned delay, it was considered more feasible to carry out the research in person.

3.6 Pilot Study

Literature suggests that for the utilization of a questionnaire as a data collection tool, it is first prudent to carry out a pilot study. A pilot study is essentially a trial of the method on a small group to check the suitability of questions and identify problems to be solved before the main study (Hassan et al, 2006). Therefore, a decision was made by the Author to carry out a pilot study prior to dissemination of the main survey. This was carried out with a small group of 10 persons at the institution, studying & lecturing in environmental sciences. The pilot study provided the opportunity to examine the suitability of questions used, identified errors, and suggestions were also made by participants as to how the survey could be improved. This proved to be an invaluable process as it greatly increased the scope of survey. Based upon the findings of the pilot, additional research areas were included in a revised version of the survey such as; tuition mechanisms for occupant training purposes. This potentially increases the value of the study, as such information may then be of greater significance to the institution (post analysis), by comparison to the original survey.

3.7 Data Collection Part 3 - Observational Study

As suggested previously, this research also consisted of an observational study conducted by the Author. Its purpose was to ascertain if the behaviour & adaption mechanisms brought forth through interviews & surveys are witnessed in practice. There is guidance available in literature, relating to carrying out observational studies in the built environment, specifically for the means for observing behavioural adaption. Gunnay et al, (2013) highlight the need to document certain parameters for such studies, including observed state (what is being observed), sample interval (how often a recording takes place), and change of state (what is observed to happen). Various mechanisms are also described which can be useful to the researcher, such as the use of time lapse photography. However, it is made clear that some methods do not enable true capture of the indoor environment. The suggestion is also made that to overcome this issue, continuous desktop indoor monitoring may be used in practice (Gunnay et al, 2013). Therefore, based on this guidance the intended parameters for this study are as follows:

1. Observed state – Behavioural Adaption
2. Sample Interval – Hourly
3. Change of State – What behaviour is witnessed & Why

Additional parameters that were also adhered to for this study include the observational timeframe in relation to the occupancy pattern of the staff & student population. More information relating to these patterns is available in section 4.3.

As it was the intent of this observational study to capture internal building occupant behaviour, continuous desktop monitoring was a suitable option to utilize. A limitation of this method is that it does not fully capture information relating to the position of building elements, for example how long a window has been opened for, or the angle of which it is open to. For this reason, the results section for the observational study consists of qualitative analysis, which is complimented and compared with quantitative from the survey section. It is also suggested in literature that there are different forms of observational study. For example, Allen (2017), suggests that an observational study is a form of qualitative research where the observer notes real life actions as they exist in their natural setting. They can take the form of a study where certain subjects are viewed with consent, or they can be carried out as a covert study (Allen , 2017). In the case of this research, the intent of the observational study was to witness actual adaptive behaviour. Therefore, a covert study was the more suitable as this enabled capture of actions as they occur naturally, and minimised factors such as the Hawthorne Effect, where persons change their behaviour for a more socially acceptable option when under observation (Gilani et al, 2017). However, limited insight into the reasoning behind adaptive behaviours was captured; i.e. opening a door for access. Therefore, commentary analysis was also necessary to compliment findings. This was provided from the building occupants after observations took place, which then either supported or disproved the observer's reasoning behind witnessed behaviour. This process not only added value to the study but was also used to check the validity of found results, reducing bias. The inclusion of the observational study within this research confirmed if the actions suggested through the staff and student survey, were actually observed and therefore acted as a mechanism to verify and improve the validity of external results produced from the responses of the survey. It could therefore be suggested that the cross examination & comparison of findings from the observational study, was critical to the success of the overall research.

3.8 Ethical Considerations

As part of this study, issues of ethics were at the forefront of consideration for the data collection methods. Prior to commencement of interviews & the survey, question sets were presented to senior members of the institution, to enable internal discussion & exploration of ethical concerns. This process generated a 3-week delay for the project, whilst ethic deliberation took place. However, this was a necessary step, as a basic demographic was included in the survey, with items such as gender & age. As detailed in literature, the importance of ethical considerations in research, ensures a mechanism to protect participants from any unwanted harm, whilst reinforcing the integrity of the

methodological approach (McKenna, 2018). Research participants were ensured of confidentiality through a written statement at the beginning of questions (explaining the research purpose), as well as no questions capturing information which could reveal identity, such as names e.g.

Anonymity was also assured through the inclusion of a prefer not to answer section for sensitive demographic items such as age & gender. Upon submission of questions to senior staff for approval, no additional ethical concerns were found by relevant parties.

4. Analysis & Results

4.1 Professional Interview Results

As discussed in section 3.4, initial data collection for the study, consisted of professional interviews with members of facilities staff at the IQ facility. These interviews were carried out by the Author, to gain an understanding of the inner workings of the IQ facility, prior to carrying out surveys with staff and students relating to adaption & comfort. The information produced from these interviews provided invaluable insight for the Author and was critical in the design of the survey. Results & interview questions are shown in the following table:

Interview Question	Response Received
Q1) - In the IQ Building at SA1, Swansea, what heating and cooling systems are in use? Are they Active or Passive?	As part of the design & construction of the building, Thermal Modelling was carried out to assess which rooms were the most likely to overheat. This resulted in the introduction of both active and passive heating and cooling systems including; natural ventilation & heat recovery systems as well as mechanical air conditioning and heating in other areas. Server rooms & technical study areas for specific studies require air conditioning to allow for the nature of work for course programmes.
Q2) - What considerations have been made to adapt to future climate change for the IQ Building during design?	As part of considering adaptations for future climate change, the building was constructed 7.2m above sea level in accordance with current standards. The thermal model was also used to forecast 3 years into the future, with regards to the changing climate. Project requirements were often challenged during production of the facility in relation to costs, to ascertain feasibility of different factors, for example the incorporation of district heating. Space has also been left intentionally spare in the building to adapt to future requirements such as heating. Space is also left for more renewables, restricted by finance, including options for more wind and solar.
Q3) - Are any monitoring systems in place for internal comfort & air quality, energy usage & waste production?	Yes - The building has systems in place to monitor the internal environment. This includes a breathing building system which notifies occupants if windows need opening to refresh airflow based on CO² concentrations. This system is integrated with mechanical air pumps for some rooms. Energy usage is monitored through the buildings management systems, which is in the process of optimisation at the time of writing, due to recent building commission. Waste production is monitored through collection notes. Appropriate metering systems have been put in place— which does not only relate to the building itself but is also beneficial to post occupancy evaluation (which at the time of writing has not been carried out). Systems in the building are provided with meters to ensure that 90% of energy consumption of each fuel can be assigned to the various end uses in the building. A water leak

	detection system is also in place to monitor water usage.
Q4) - Where is energy sourced from for the building? Are there any renewables in energy mix, and is consideration of source presented in tendering process or is it based on cheapest deal?	As of April 2018, Energy sourced for the building is guaranteed to come from renewable energy sources, so consideration is given to the energy mix used, not just a cost driven agenda. There is also a photovoltaic array on site and combined heat and power boilers are also utilized. Details for the solar array include: Large pitch roof: 88 modules at 270W = 23.76kWp Pop-up roof 2: 30 modules at 270W = 8.10kWp Pop-up roof 3: 36 modules at 270W = 9.72kWp Flat roof: 139 modules at 270W = 37.53kWp Total = 79.11kWp Estimated annual energy yield = 71,633kWh
Q5) - Are there any periods where you believe internal comfort is not achieved and why?	Yes – comfort levels have not always been achieved at all times, as some rooms were found to be overheating. The issue is now thought to be solved and was caused through optimisation and setting up the new building services. Staff training was initially delayed for around 3 months which resulted in a lag and catchup period.
Q6) - Have any issues been experienced with the building since commissioning?	Yes - Noisy ventilation systems have been identified as an issue by building occupants. There is remedial action currently in progress to rectify this issue, with a mechanical engineer working on adjusting units. Optimisation of heating and cooling building management systems has affected what would be a suitable level of clothing for occupants for the internal environment, as extremes between hot & cold have been experienced.
Q7) - Since commission, have you witnessed any adaptive behaviour in the occupants of the building to compensate for any building issues?	Yes - Adaptive behaviour has been observed, these have included; window opening, manual occupant thermostat changing, adjustment of clothing level, as well as wedging doors open.
Q8) - In your opinion, what do you feel the greatest issues will be for the building to be able to adapt to a changing future climate and why?	1 - Extreme rain & sea level rise - due to the location of building in relation to sea level 2 - Ensuring building operators are educated to ensure the correct operation of the building, as well as occupants being educated to use the facilities services appropriately.

	The rising cost of utilities – The institution will either have to pay rising costs or explore more sustainable solutions – this in turn will then affect the availability of services - if bills increase, it would be sensible to increase the efficiency of the building where possible.
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Table 1 – Original Staff Interview questions & responses

As can be seen in Table 1, Q1-Q4 relate to the design and mechanical control systems incorporated into the IQ Building, which include various comfort control systems. Of particular interest to the study was that the building has also been part of an exercise to allow for adaptations to climate change through the implementation of the advanced thermal model. However, what was found to be of the greatest significance to the study was the results of Q5-Q8.

Q5 demonstrates that since commission, comfort has already been identified by facilities staff as a concern for the building, with overheating issues experienced by occupants. It was suggested by interviewees that this issue had been rectified prior to interview commencement. Other issues which also have the potential to affect comfort in the building such as excessive noise generation from mechanical building systems was also identified, with remedial action being taken.

Both Q6 & Q7 identified critical factors for the study, including aspects of occupant behaviour & adaption. Staff expressed the view that the optimisation process for the buildings management systems since commission, has negatively influenced occupant behaviour, as adjustment of clothing level was often witnessed. However, it has varied greatly at different areas of the building. Additional adaptive behaviour has also been observed at the facility, as shown in Table 1.

However, certain adaptive behaviour identified such as “wedging doors open” for the purposes of comfort, also carries with it risks such as increasing fire spread or worse should an emergency occur. The process of using fire doors to block the path of fire in a building is known as compartmentation, as these doors are made of materials which take a set amount of time to burn in fire situations. In addition to this, intumescent strips are also used at the edges of doors which react to smoke & fire and seal the door, as well as specialized fire door closers to ensure that doors remain in the closed position to allow these mechanisms to work correctly (UK Fire Service Resources, 2018). The inherent fire risks of such common adaptive behaviours are therefore obvious, demonstrating the need of further occupant education. Such commentary was also expressed by staff during interviews in Q8 suggesting the needs to educate not only students, but staff to reduce the risk & occurrence of such issues.

4.2 Occupant Survey Results

Following successful professional interviews with staff, a survey was disseminated to a wider selection of building occupants. The survey was prepared around the concepts brought forward during interviews. In total, 120 responses were received, representing 100 students & 20 staff members, all of which are available alongside the questions utilized in the research in Appendix A. A basic demographic was utilized to provide an idea of the structure of the population. Initially, this included additional options such as marital & employment status. However, upon reflection & development of the project, some of these factors were found to be irrelevant to the research. The decision was therefore made by the Author to not utilize this data. The selection of persons largely took place via the mixed group sessions at the facility and were therefore based on availability, as opposed to a bias such as gender or age. It is worth noting that over half of the student population (57%) were aged between 18-21, which is thought to be related to the attendance of students following completion of secondary school education. For the student sample, occupants were more than willing to participate, however, some staff were hesitant to take part, many of which refused as they were unsure if it was appropriate to participate without permission of their line manager. However, with good communication, a staff sample was eventually generated.

Analysis of the results took place with the aid of MS Excel. As the largest expected population at the IQ building is likely to be during term time for students, attendance patterns were the first data captured by the student survey. This information was captured across many study disciplines shown below:

Study Discipline	Percentage Representation
Automotive Engineering	41%
Logistics and Supply Chain Management	2%
Building Surveying	3%
Architectural Technology	13%
Quantity Surveying	5%
Construction Management	6%
Civil Engineering	5%
Psychotherapeutic Practice	4%
Psychology & Counselling studies	5%
Education Studies	2%
Software Engineering	3%
Computer Engineering & Cyber Security	11%

Table 2 – Representative study disciplines of survey

As can be seen in Table 2, there are some disciplines which represent a far greater proportion of the student sample than others. This was not determined by the researcher, as selection of participants took place mainly through mixed group study sessions as discussed previously. Persons were therefore selected based on availability of individuals and any percentage representations were coincidental.

Analysis suggested that the most common daily occupation of the IQ facility over a weekly basis was a four-day period for students (28%), with the greatest percentage of these (45%) attending the facility for 5-8 hours per day, closely followed by 41% of the sample between 1-4 hours daily. It is therefore likely that the greatest quantity of adaptive behaviour will occur across a 4-day week, ranging between 1-8 hours a day. More information on the occupancy pattern of students at the facility is shown below:

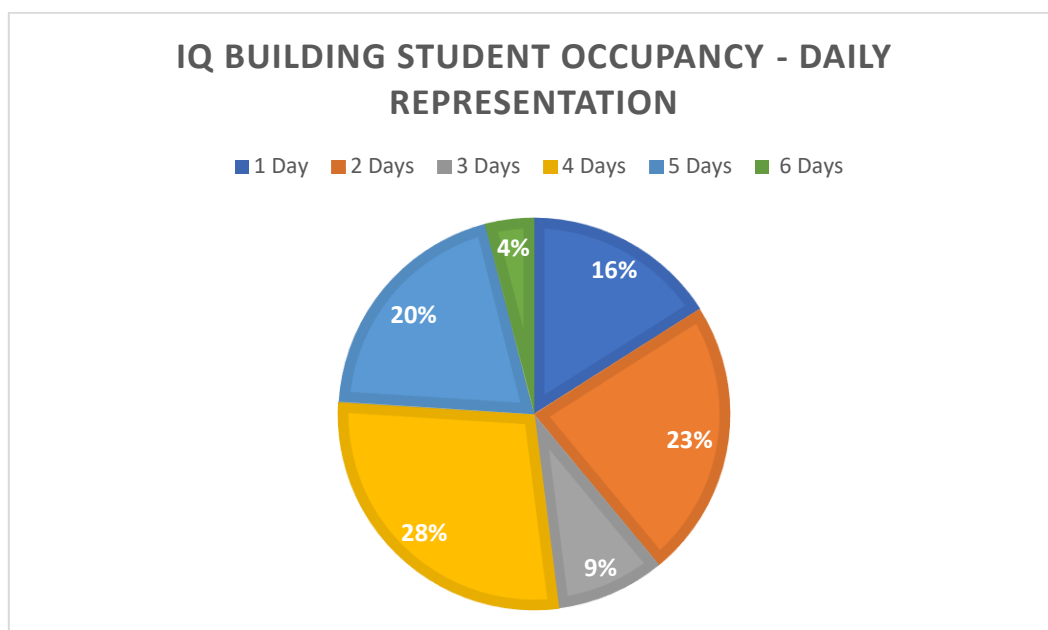


Figure 5- Student daily occupancy pattern at IQ

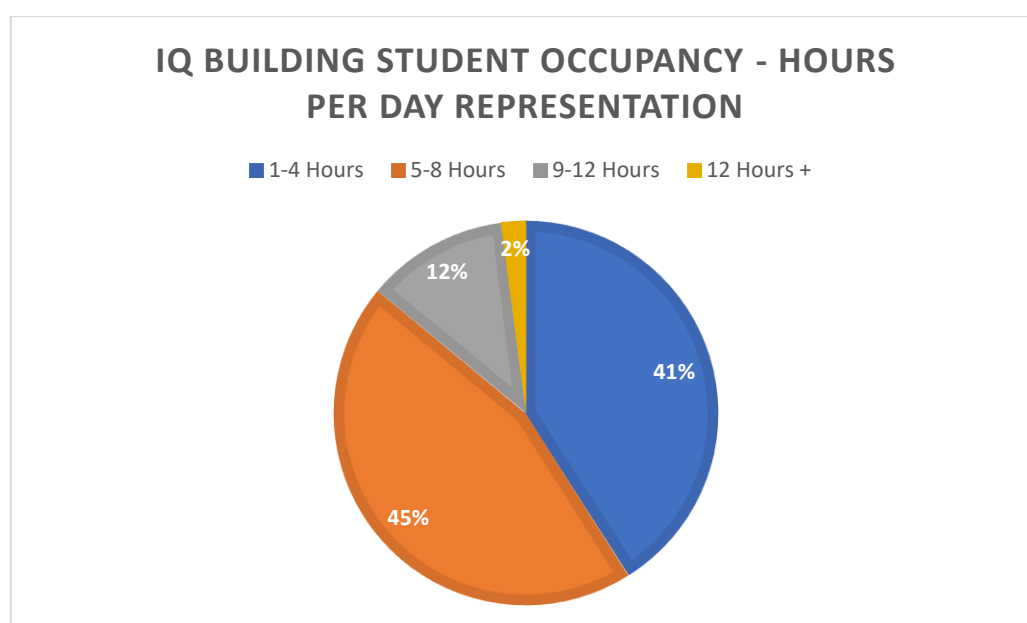


Figure 6 – Student hourly occupancy pattern at IQ

Interestingly, although adaptive behaviour has already been observed by staff members, as demonstrated through the professional interviews, 47% of the student population expressed in the survey that thermal/atmospheric comfort was a concern to them, with the remaining 53% feeling less concerned about the issue. In demographic terms, 16% more female students found comfort to be of concern to them, compared to those which did not. In addition, 22% more male students were found to be unconcerned with comfort in relation to those which were. By comparison, 80% of staff at the facility were found to be concerned by thermal/atmospheric comfort. Of the 80%, 69% were female, with the remaining 31% representing male staff. These results would suggest that for both students and staff, there is a greater proportion of the population which are having difficulties with such comfort currently at IQ, and also that at least in the case of this study, comfort is generally of more concern to female occupants. The survey also allowed the provision of comments for this issue, with 11% of female & 16% of male students writing comments such as; *"the building is too cold in some areas, and I have to wear a coat in lectures"* & *"many rooms are too cold"*. Similar commentary was also provided by staff occupants, ranging from *"I find IQ most comfortable"* to *"A bit like Goldilocks- too hot or too cold, never just right"* & *"heating at times is an issue – too cold"*. This evidence suggests that some occupants are aware that they carry out adaptive behaviours whilst using the facility, with both staff & students expressing the environment can be too cold in a heating season. In terms of the overall student sample, 23% expressed additional commentary that the environment is currently too cold, 1% suggested it is too hot, and 10% suggested that it can quickly change from one extreme to the next. Similarly, 60% of the overall staff population expressed comments suggesting issues with heating, many of which were too cold. Based on this additional commentary information, it would appear that the opinion of many occupants is that they find the average temperature too cold.

As the IQ facility encompasses a wide range of environments, the survey considered temperature separately between lecture & open access areas. When occupants were questioned regarding the average temperature of the facility, the most common response of the student sample was "it varies" for both open access & lecture areas, at 44% & 40% respectively. This response is consistent with the findings from professional interviews, where optimisation of building services was identified as an issue impacting occupant adaptive behaviour, specifically appropriate adjustment of clothing level to cope with inconsistent internal ambient temperature. By comparison, the most common single response of staff (35%) was that open access areas are too cold, whilst suggesting that temperature in lecture areas varies between extremes at 60% of the sample. However, it is also worth noting that for open access & lecture areas a significantly greater percentage of the student population, found the facility to be too cold (25% & 19% respectively). Demographically, none of student female participants suggested that the facility was too hot for either open access & lecture areas, instead the most common answer of the sample suggested that it was too cold at 12% & 15% respectively. By

comparison, 46% of female staff found open access areas to be too cold, and 69% found lecture areas to vary. For male students the most common response was that temperature “varies” for open access & lecture areas at 34% & 32% respectively, with 42% of male staff suggesting the same for lecture areas, and 57% finding open access areas ambient. The comparison between the two genders for both students and staff suggest that male occupants find the temperature to be generally inconsistent, whereas female occupants’ perception of temperature trends towards the environment being too cold. It is important to note here that this study was conducted in the heating season only, and the same study could also be conducted in a cooling season to compare results. Further results relating to occupant opinion of average temperature are shown below:

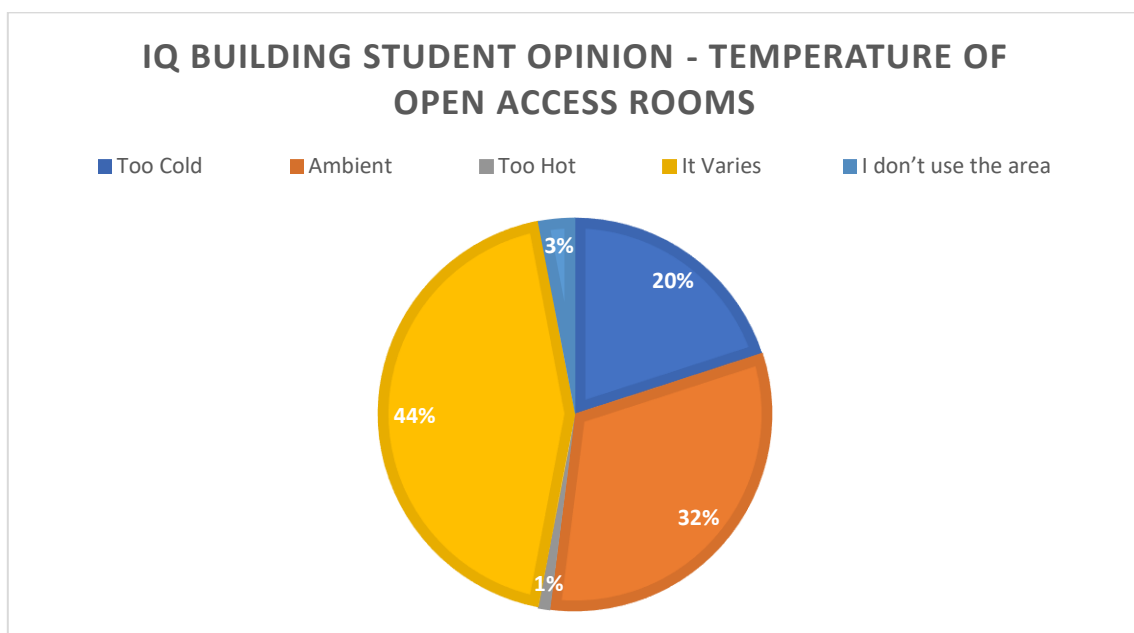


Figure 7 - Student opinion of temperature at IQ for open access

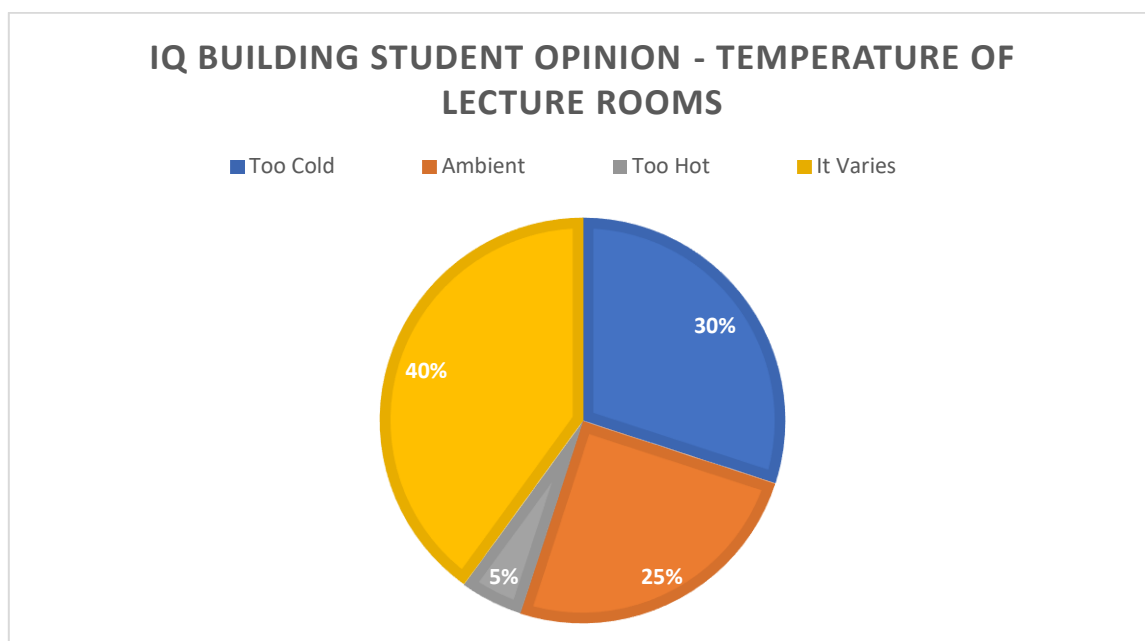


Figure 8 - Student opinion of temperature at IQ lecture areas

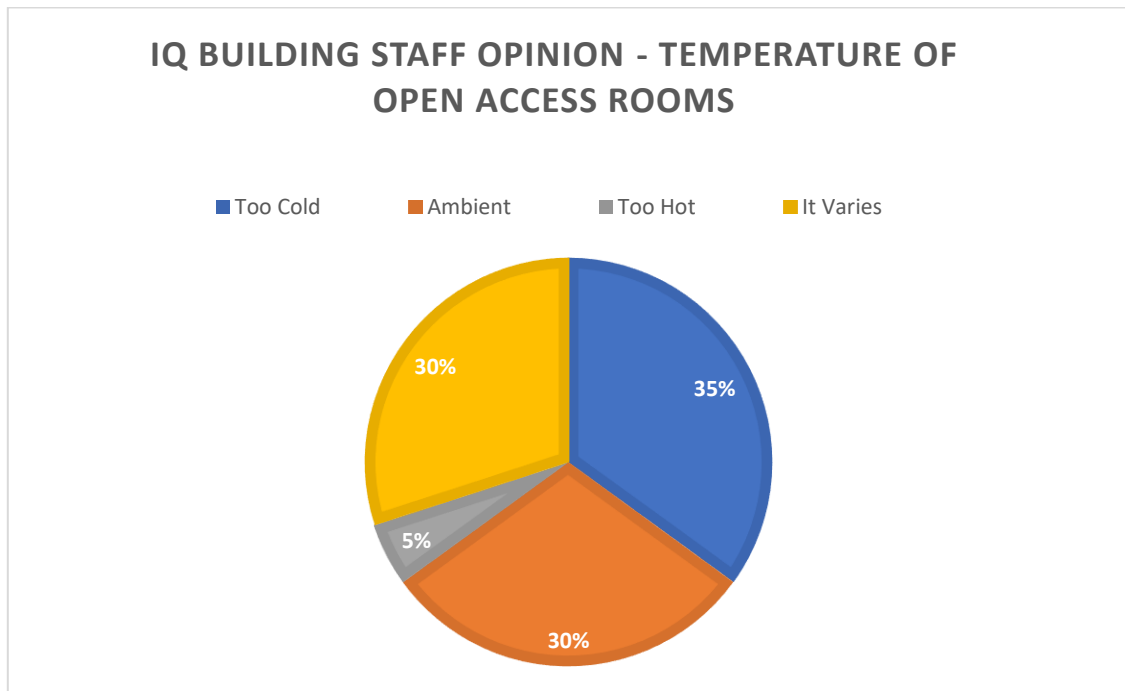


Figure 9 - Staff opinion of temperature at IQ for open access areas

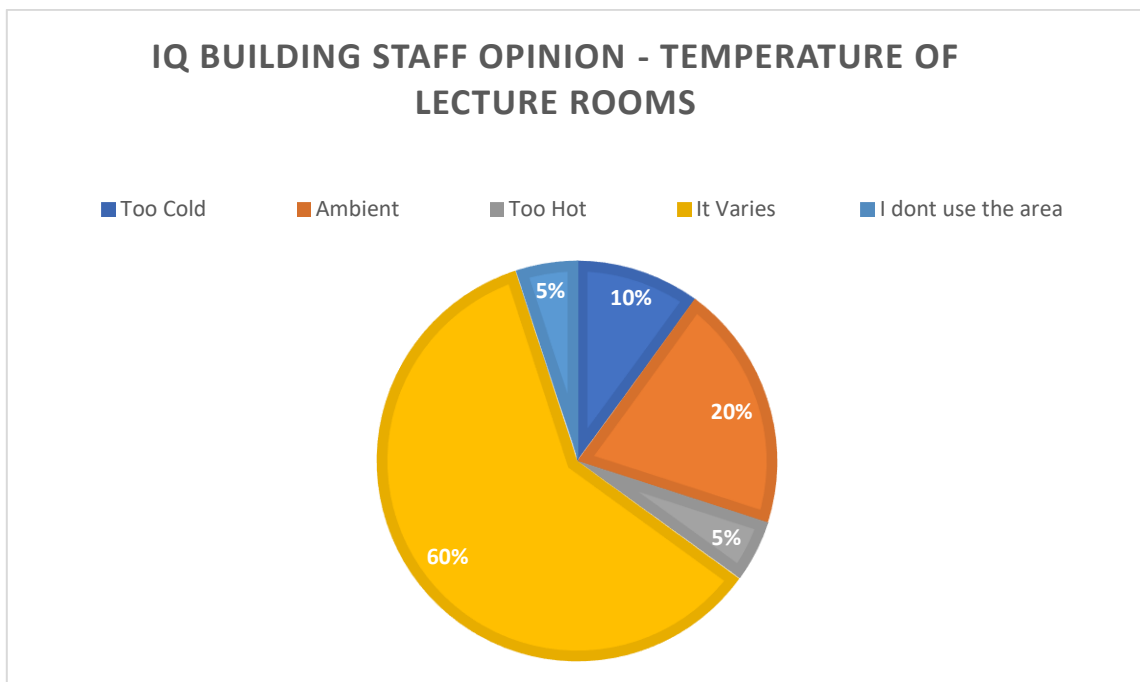


Figure 10 – Staff opinion of temperature at IQ lecture areas

From an educational point of view, staff opinion relating to the internal lighting provision & acoustic properties of the IQ facility was also captured. For lighting requirements, in the case of both open access & lecture areas, the majority of staff (75%) suggested that lighting was “good”, with 5% more of the staff population suggesting that it was “excellent” in lecture areas by comparison to open access. Only 15% of the sample suggested it was poor in open access areas, with no participants suggesting the same for lecture areas. Comments were also allowed for this section, with 25% of staff

providing anecdotal evidence such as *“the lighting in lecture areas is great, and the option to have three pre-set levels is excellent”*. These results suggest that staff view lighting to be superior in lecture areas by comparison to open access, and there is therefore scope to potentially improve provision in open access areas.

Analysis of staff opinion relating to IQ’s acoustic properties suggests that as is the case with lighting, the majority of the population view it as “good”, at 70% & 50% for open access & lecture areas respectively. For both areas, 10% of the sample suggested the acoustics were “excellent”, however, 25% more staff suggested that it was poor in lecture areas by comparison to open access. This is also confirmed in commentary analysis for this issue, suggesting it is; *“difficult to project voice in certain areas”* & *“lecturers often suggest there are issues playing videos with sound”*. Such results suggest that there is potential to investigate sound transmission for lecture areas to improve the facility for tuition purposes.

Occupant opinion relating to the supply of air into the building was also captured in the survey. For both open access & lecture areas the majority of the student sample suggested that a “good” supply of air was available in both areas at 83% & 74% respectively. Notably, analysis of data suggested that 10% more students felt that the air supply in lecture rooms was poor by comparison to open access areas. Such findings present potential to investigate air supply further for lecture areas. However, it is important to note that 3% more of the student population suggested that lecture area air supply was excellent by comparison to open access. Comparatively, there was also 6% more of the student sample who felt that lecture area air supply was poor, by contrast to those who suggested it was excellent. Similarly, analysis of staff opinion also found that the majority suggested both open access & lecture area air supply was “good” at 80% & 85% respectively. In addition, 5% less of the staff population suggested air supply in lecture areas was poorer than open access areas, which also leads to potential to implement improvements for air supply in lecture areas. Further analysis of results relating to occupant opinion of air supply for IQ are shown in the following charts:

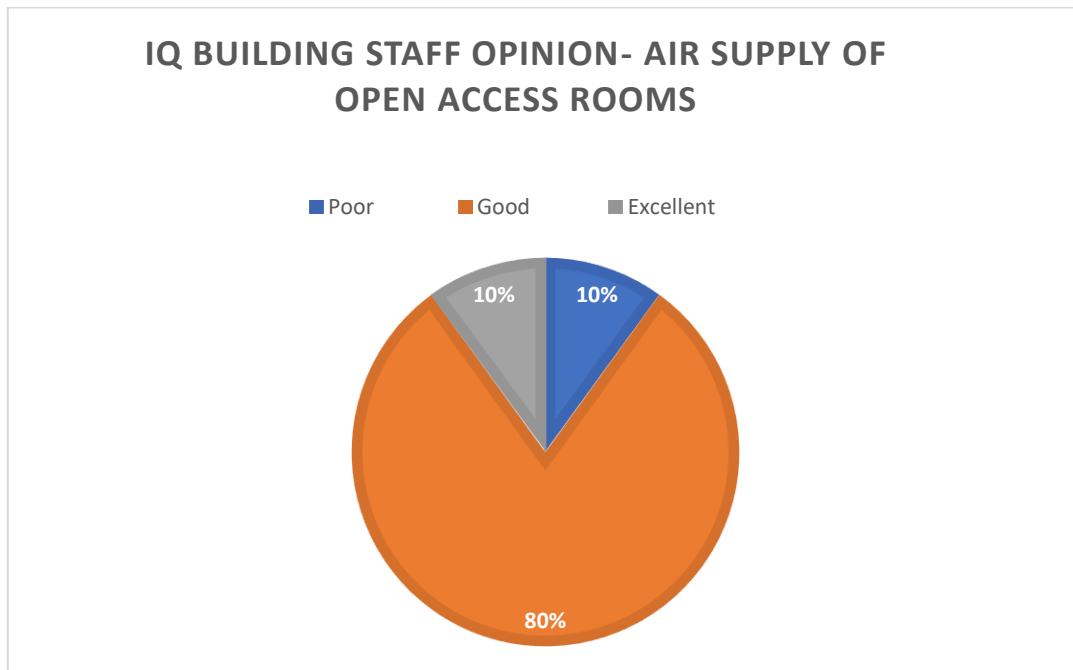


Figure 11 – Staff opinion relating to air supply at IQ for open access areas

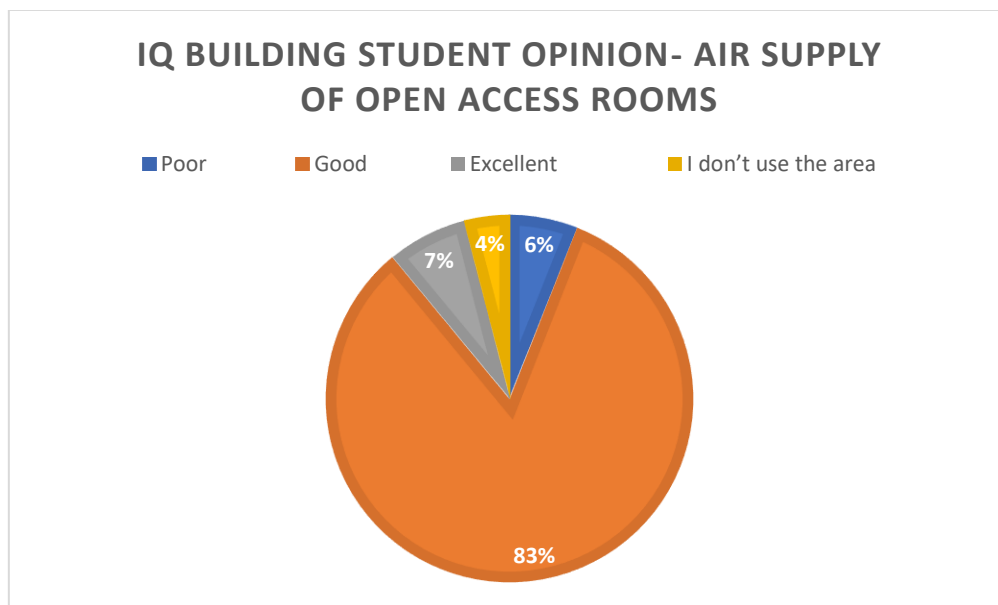


Figure 12 – Student opinion relating to air supply at IQ for open access areas

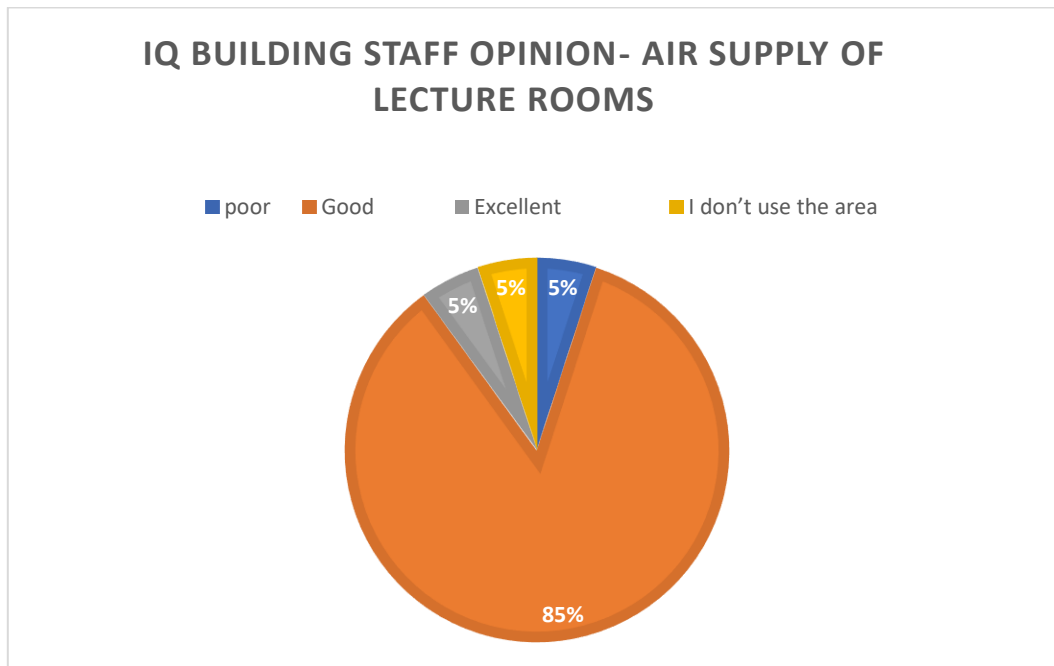


Figure 13 - Staff opinion relating to air supply at IQ for lecture areas

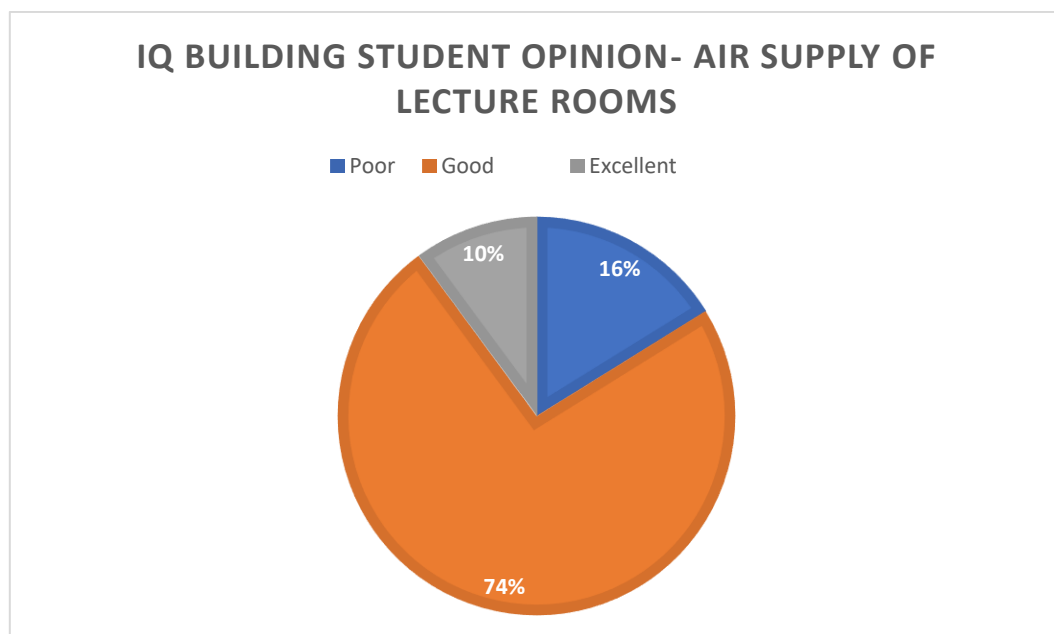


Figure 14 – Student opinion relating to air supply at IQ for lecture areas

Before capturing information relating to adaptive behaviours, to minimise factors such as the Hawthorne Effect as identified by Gilani et al (2017), students were questioned relating to how much training they had received in the appropriate use of the building & its systems since commission. The majority (82%) of students had received no training at all, with the remaining 18% receiving varying durations of training in hours. Similar results were also found from analysis of staff responses, with 70% receiving no training, 25% receiving <1 hour, and 5% between 1-3 hours. Such responses from both staff & students would suggest that there is a form of training procedure in place at the facility.

However, it appears to be reaching less than 20% & 30% of students and staff respectively. This corresponds with a training delay for staff as identified earlier through the interview processes. It could be argued that such issues have the potential to cause significant changes to how adaptive behaviour occurs. For example, with little training, occupants may be more inclined to carry out behaviour such as opening windows based more on personal preference, as opposed to reasons of energy conservation or sustainability. This has the potential to contribute greater to rapid anthropogenic climate change, as resources could be being wasted unnecessarily, such as those used to generate energy. In turn, such behaviour could be exacerbated as change to the climate occurs, trending towards a hotter external environment, increasing adaptive behaviour, similar to the reasoning of Yao & Zhao (2017). When such issues are considered, the value in occupant education & training begins to emerge. To add to these findings, student & staff opinion relating to the most preferential mechanisms to receive such training was also captured. Such information may be of significant value to the institution, should it intend to provide additional training in the future. The results of preferred training mechanisms are shown below:

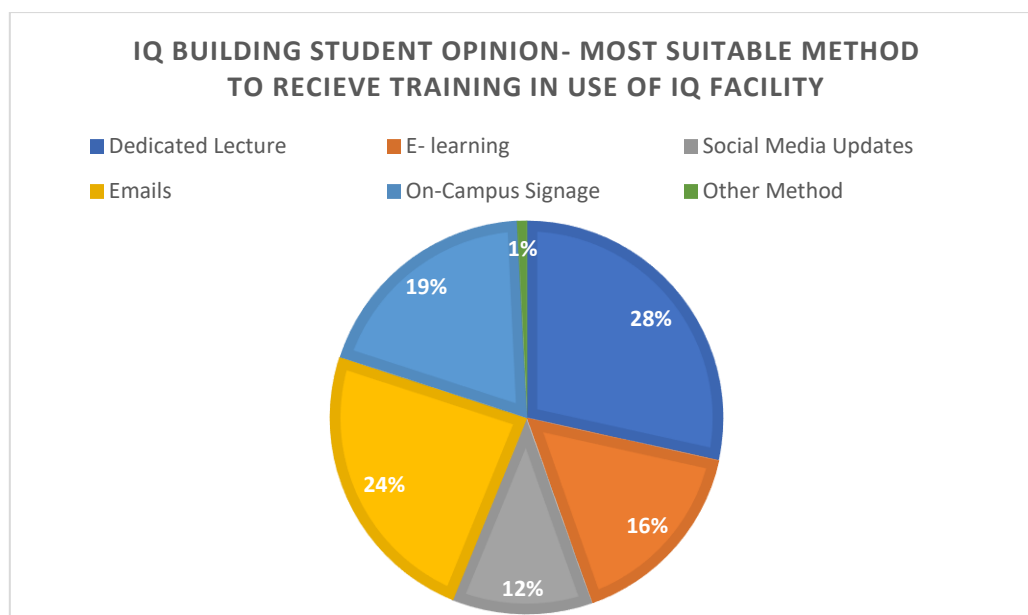


Figure 15 – Student opinion – Preferred mechanism for receiving training in appropriate use of IQ

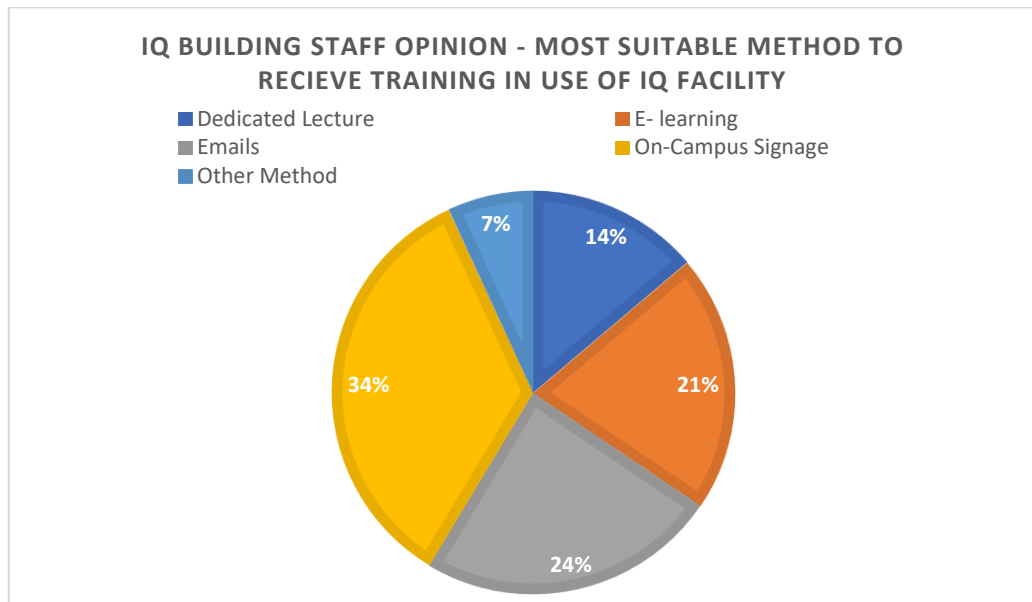


Figure 16 - Staff opinion – Preferred mechanism for receiving training in appropriate use of IQ

As can be seen in Figure 15, the most common response of the student population (28%), would prefer a specialized dedicated lecture to train them in efficient use the IQ building. This was closely followed by preference for digital information provided through emails at 24%. However, on campus signage was preferential by students at 19%, by comparison to all other digital methods (excluding emails). Further results shown in Figure 16 suggest that 34% of staff would prefer on campus signage, 24% prefer emails & 21% electronic learning. Although these results do not rule out other means to disseminate training, it does suggest that a combination of lectures, emails and improved campus signage would be the most appropriate means to provide training for students, with increased signage, emails & electronic learning sessions more suitable for staff members. Notably, 1 student participant completed the comments section for additional mechanisms, suggesting a walk & talk would be suitable, with 2 staff members also suggesting instructional videos & practical demonstrations would be beneficial. It is possible that these additional mechanisms could become part of a dedicated lecture scenario and be used to greatly improve its efficacy.

Critically, opinions relating to adaptive behaviours were also captured during the survey. Occupants were asked how they were most likely to achieve a suitable comfort level at the facility, with response options based on common adaptive behaviours found in previous literature including the works of Pisello et al, (2017). Additionally, the option to suggest other adaptive behaviour was provided via a comments box. Unfortunatley this was not utilized by students, however, staff did provide additional commentary. The overall results for adaptive behaviour amongst the samples are shown below:

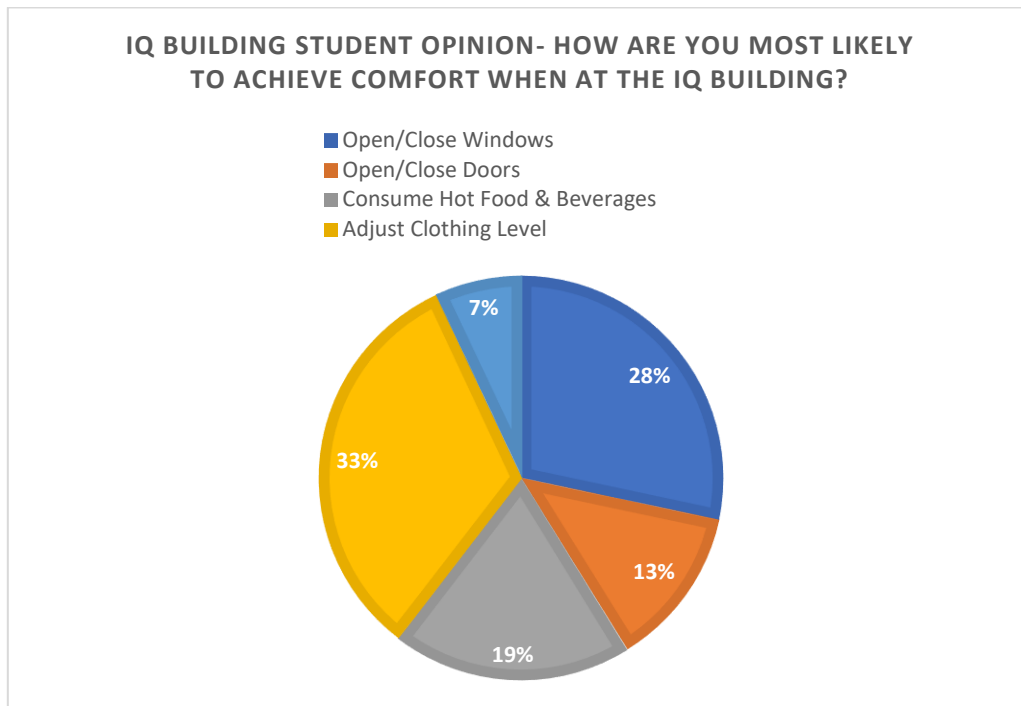


Figure 17 – Adaptive behaviour amongst student occupants

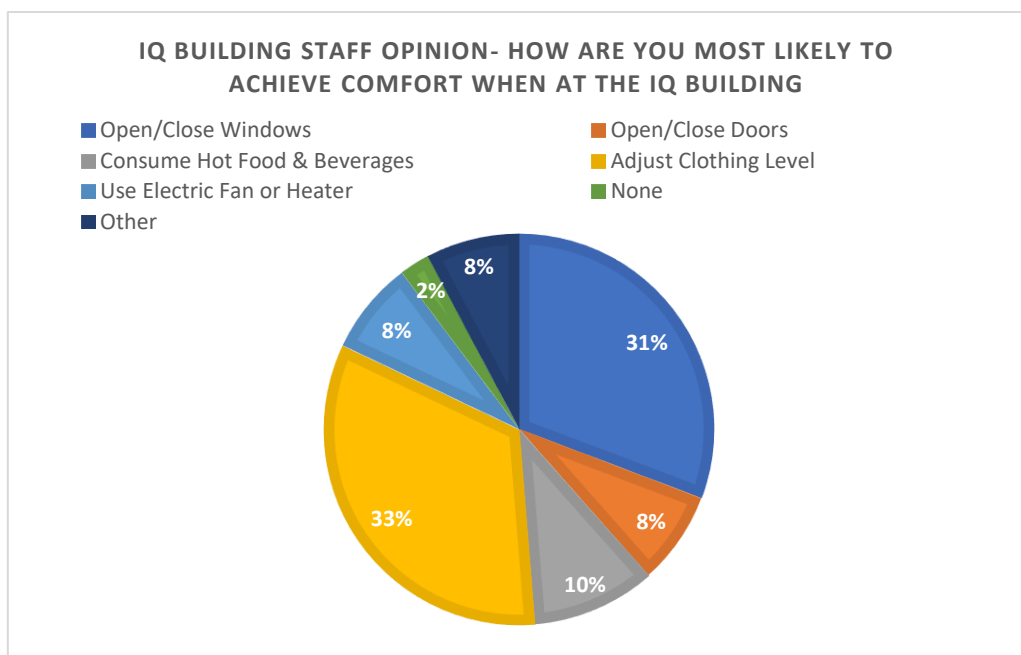


Figure 18 – Adaptive behaviour amongst staff occupants

As shown in Figure 17, 33% of students suggested that change in the level of their clothing was the most commonly utilized adaptive behaviour, closely followed by the regulation of air supply & temperature via window opening at 28%. These results suggest that such common adaptations account for over 60% of student behaviour. Similarly 33% of staff suggested adjustment of clothing level was the most common form of adaptive behaviour, followed by window opening at 31%. However, due to being questioned, participants of the survey could have completed this with a bias attitude, for a more socially acceptable option (The Hawthorne Effect). Therefore, these results shall be particularly

relevant for the completion of the observational study, to ascertain if these behaviours are viewed in practice.

The survey also found that 19% of the student population & 10% of staff suggested consumption of hot foodstuffs was a preferred mechanism to obtain comfort. However, in some cases, such behaviour could be based on personal preference.

As identified by facilities staff, survey analysis also suggested 13% of the students & 8% of staff indicated they would alter the position of doors (wedging open). The risk in the event of an emergency situation is therefore self evident, as discussed previously as such behaviour hinders the process of compartmentation & stops intumescent strip systems working correctly in the event of an emergency. The remaining 7% of students suggested that the introduction & use of externally sourced electrical heaters was also utilized for comfort purposes, with 8% of staff suggesting the same. It could be argued that this adaptive behaviour is consuming additional energy at the facility, which its design should be compensating for. This evidence suggests that there is scope for further optimisation of building services in relation to ambient temperature. Notably, when students were asked if they had been made aware of the procedure to report comfort issues to members of staff, the majority of the sample (67%) responded that they were not aware, by comparison to (33%) who were. This suggests that there is dialog occurring between students & staff in relation to comfort concerns at the facility, however, there is also room for improvement in terms of communication.

Additional adaptive behaviours were also provided by staff commentary during the survey including; the issue of blankets, attempting to adjust locked heating controls & moving to colder rooms. Not only could such behaviour cause issues in terms of lecture scheduling but it could also have the potential to cause damage to heating control systems in place.

From a demographic perspective, just over 58% of female students suggested that their most likely adaptive behaviour was to adjust clothing level, followed by window opening behaviour at 50%. It is worth noting that for this question, participants were able to select more than one answer if they wished, meaning that percentage values in this case are mutually exclusive. The least common behaviour in female students was found to be use of electric fans & heaters. However, it is possible that this behaviour could be affected by availability of devices. The most common behaviour in student male participants, was also found to be adjustment of clothing level, at 61% of the sample, followed by window opening at 54%. As is the case with female participants, male participants also suggested that the least likely behaviour was to use electrical heaters. Such correlations between gender groups would suggest that the opinions provided, relate to actual behaviours and that factors such as the Hawthorne Effect have been minimised.

To add additional value to the survey, occupant opinion was also captured in relation to how they would rate their knowledge of climate change. The responses are detailed below:

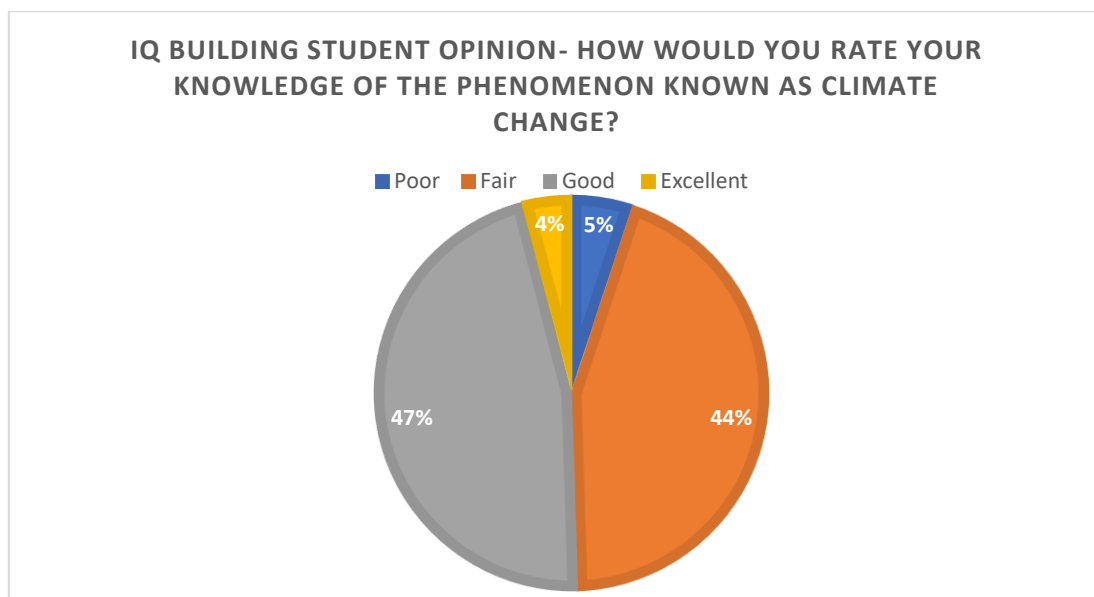


Figure 19 – Student opinion – Knowledge of climate change

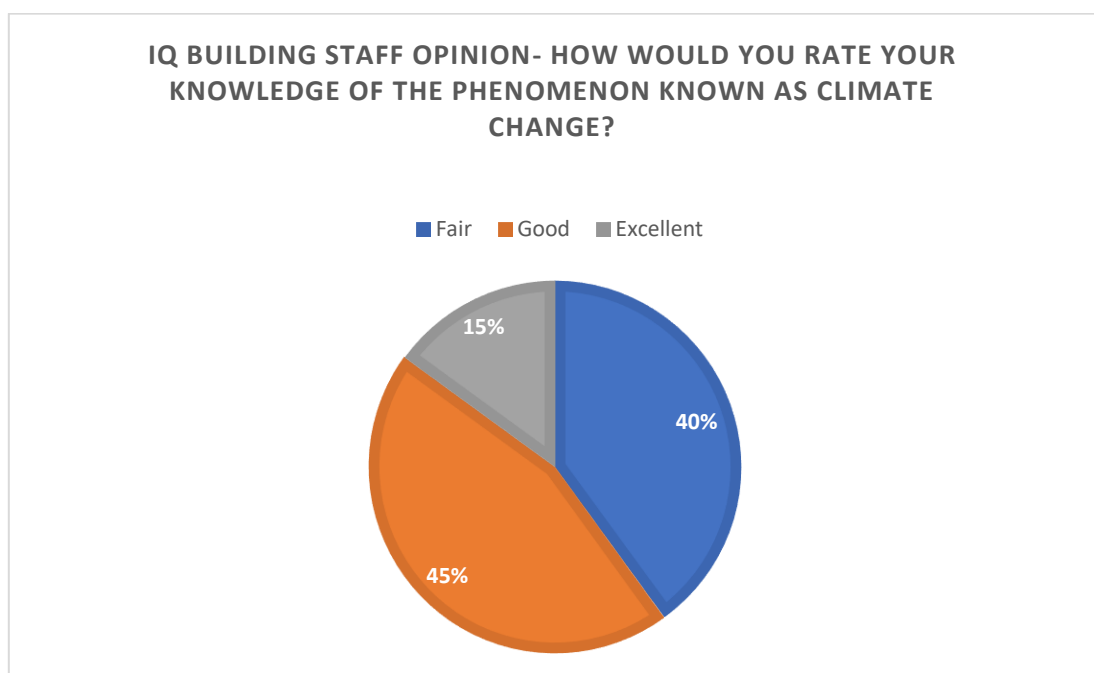


Figure 20 – Staff opinion – Knowledge of climate change

As can be seen in Figure 19, The most common student response (47%) stated that in their opinion they have a “good” knowledge of the subject of climate change, followed by 43% of students suggesting slightly less knowledge, categorized as “fair”. However, 5% of the student population feel that their understanding of the issue is poor, with even less at the other extreme at excellent (4%). By comparison, 45% of the staff population suggested their knowledge was “good”, with 40% suggesting a “fair” knowledge. 15% of staff suggested an “excellent” understanding, which is 11% more than the student population. These results identify awareness of climate related phenomenon amongst the

population of IQ occupants, however, there also appears to be potential to increase instruction in the subject, for both groups. Further instruction in climate change at the institution may improve awareness amongst occupants and may influence their adaptive behaviour. It could then be possible to repeat this same study later at the institution to ascertain if the same results are found, therefore further contributing to climate-based research.

To conclude, the survey also allowed the provision of an end comments box, intentionally left plain, to ensure that any comments provided were not bias relating to any form of leading questions. By including this section in the survey, it allowed participants to contribute their opinions regarding the facility, in any capacity they wished. This enabled insight into areas which may not have been covered, or not specifically related to the scope of the study. Results from this section included:

- Comments regarding no training provided as to how to operate room lighting, as well as requests to reduce energy consumption, but with no instruction as to how
- Suggestion of rooms being too hot & too cold
- Room controls being locked
- Dissatisfaction with chairs & whiteboards
- Awareness of adaptive behaviour, such as bringing layers of clothes to the facility as well as blankets
- Suggestion that main entrance doors let in draught in winter
- Praise of the quality of the overall result of the IQ Building – “The IQ building is vibrant & exciting to work in”

Not only do these comments suggest further adaptive behaviours, but they also express that the institution has a sustainable agenda, with awareness of global issues such as climate change. This is due to dissemination of requests among staff to conserve energy at the facility. However, based on the opinions that in many cases training received has been minimal, there appears to be a call for more in-depth training at the facility, beneficial to occupant awareness regarding both climate change & building operation.

Additionally, adaptive behaviours which could be considered extreme for a new build facility, with integrated heating systems in place were identified, such as the use of blankets. Such factors suggest that there is more optimisation required of the building systems at present. However, what was also made clear through the additional comments was praise of the facility, which would not otherwise have been enabled without this section. This evidence suggests that any issues identified are not necessarily affecting all persons using the building, and that there were occupants included in the data collection process who find the new facility fit for purpose.

4.3 Observational Study Results

As identified through the occupant survey, the most common occupation of the IQ facility by the student population was across a 4-day period, ranging between 1-8 hours daily. Therefore, these were the parameters adhered to by the Author to conduct the observational study. Its purpose was to ascertain if adaptive behaviours suggested by occupants though the wider survey are viewed in practice, as a mechanism to check validity & truthfulness of responses. Observations took place in a multitude of locations within the IQ facility, with special permission obtained from senior staff members to attend certain areas at specific times. In total, 15 hours of observations took place across a 4-day period. Results are shown in Table 3:

Day	Start Time	Hour of Observation	IQ Location	Observations
1	10:00 AM	1	Open Access Area	Many adaptive behaviours witnessed; these include; Hot beverages consumed as well as clothing adjustment ranging from scarfs & overcoats to t-shirts & shorts. It is possible that consumption of hot beverages is linked to personal preference, however, currently this is occurring in excessive quantities.
		2	Open Access Area	Many hot beverages still being consumed. Clothing level varies between long sleeves & hoodies to t-shirts; however, this could relate to personal preference. Typically, male occupants are wearing lighter clothing, compared to female occupants dressed in far heavier layers.
		3	Refectory Area	The doors are left intentionally open in refectory, enabling an increased air current with the purpose of allowing access to outside area. Adaptive behaviour included wearing woolly garments & long sleeves next to doors. Anecdotal commentary was provided in area suggesting it is too cold. This suggests 1) personal preference at work, or 2) training need to be implemented. Typically, more female occupants find area too cold.
		4	Open Access Area	Mixture of clothing level adjustment witnessed; some commentary also provided pointing towards the areas being too cold. Hot beverage consumption increased during this period, which is likely to be adaptive behaviour at least in part, due to commentary. However, this could be due to preference at lunch hour.
2	9:00 AM	5	Open Access Area & Lecture Area	There appears to be a lot of hot beverages consumed, as well as nearly all persons wearing very thick clothing. This would suggest that this is adaptive behaviour, as both are occurring simultaneously. However, undoubtedly some will be personal preference. Lecture area occupants appear to be wearing significantly lighter clothing (as well as less adjustment). This is possibly of personal preference, or the potential that these areas are more ambient.

		6	Open Access Area & Lecture Area	In open access areas, adjustment of clothing level has been observed in excess to thinner garments, however hot food & drink also being consumed – this combination suggests that beverage consumption is now more preference based, whereas clothing adjustment is likely adaptive behaviour. In lecture areas, door wedging behaviour has also been witnessed, and as it is occurring at a similar timeframe to adjustment to thinner garments, it is likely that this is due to temperature regulation of rooms by occupants.
		7	Open Access Area & Lecture Area	In lecture areas, door wedging behaviour has been observed again – including placement of waste bins between doors at computer areas – clothing level varies as midday approaches, although a distinct temperature increase is felt. It is therefore possible that clothing adjustment is based on a combination of adaptive & preferential behaviour. However, door wedging behaviour is likely due to the temperature increase.
		8	Open Access Areas	Various clothing adjustment observed ranging from scarfs to t-shirts – many hot beverages being consumed. Anecdotal commentary observed regarding the temperature being ambient. This would suggest that this behaviour is personal preference based as opposed to adaptive behaviour. However, in one space the clothing level ranged between thin garments to thick woollen coats, which would suggest that not all persons find the temperature ambient, and adaptive behaviour is therefore also taking place.
		9	Open Access Area & Lecture Area	It appears to be far more common to see thinner garments at this time of day. Occasional consumption of hot beverages, suggesting these are being used less as an adaptive behaviour, and more as personal preference. Adaptive window opening observed in lecture areas, as well as communal areas, and heating remains on, effectively heating a building mechanically, with occupants letting it straight out of building wasting energy. Not only would such behaviour needlessly contribute to climate change, but also as the climate continues to change due to other external factors, such behaviour has the potential to increase, demonstrating the need for occupant education. In some cases, windows were found to be open directly above the facility's active radiator heaters.
3	1:30 PM	10	Open access & Meeting Room Area	Observer was able to sit in meeting areas, while in use, with permission obtained prior to commencement. Many hot beverages being consumed, and the majority of occupants wearing very thick garments in open access areas with the same also occurring in areas where meetings were taking place, with large groups of occupants. This would suggest that this adaptive behaviour is caused through regulation of temperature as opposed to fashion reasons, suggesting areas are likely too cold.
		11	Open Access Area & Office Areas	Door Wedging behaviour has been observed in various areas, sometimes for obvious reasons such as access. However, there could be other contributory factors also at work such as the internal temperature. Upon carrying out observation, anecdotal evidence was provided for some areas of the

				building by occupants, suggesting that certain areas have an intake and outtake ventilation system for work areas with large amounts of IT equipment. However, it was suggested that this system is not operational, and the room is generally too hot, causing door wedging behaviour.
4	10:15 AM	12	Open Access Areas & Lecture Areas	Nearly all occupants are observed to be wearing thick, heavy garments, including coats, bobble hats & scarfs. Although it is possible that this is linked to the entering from the external climate, upon observation, only a few occupants were adjusting clothing level after extended periods of time. Door wedging behaviours are also being observed, with paper bins forced into doors, to prevent them from closing. This is stopping the intumescent strip systems working as they remain out of alignment & also stops fire door closures from functioning correctly, thus effectively stopping compartmentation of the building in some areas. Anecdotal evidence provided by occupants that in this case suggests it is due to an ongoing consistent issue with access cards for certain students, who are unable to use some areas unless this behaviour occurs.
		13	Lecture Areas	Observer was able to sit in on active lectures with permission obtained from institution staff prior to commencement of study. All participants found to be wearing heavy clothing, despite the lecture taking place in an IT lab, where it could be expected that there would be extra heat. Hot flasks present, with consumption of contents taking place. The potential is then obvious for damage to facilities due to adaptive behaviour. It is possible that this is an individual case, related to personal preference. However, it is also likely that this is associated with temperature regulation instead of personal preference, due to heavy garments worn by occupants at the same time.
		14	Refectory Area	In this area, heat is being generated from catering processes. Many occupants are observed to be wearing high levels of clothing in the area. This is consistent with anecdotal commentary provided by occupants that cooking staff often open external doors to reduce heat and trapped moisture. There is potential for research into this area specifically relating to improvements for heating, moisture & air circulation control.
		15	Open Access Area	A significant amount of the population is observed to be wearing heavy garments. However, as the lunch hour passes more persons are starting to reduce clothing level, with a significant drop in consumption of hot beverages. This suggests adaptive behaviour is taking place as means to regulate comfort, specifically temperature.

Table 3 – Results of Observational Study

Day 1 – As can be seen in Table 3, observations took place across a 4-hour period. Occupant adaptive behaviour included; external door opening & wedging, consumption of hot beverages and adjustment of clothing level. The majority of the population was observed to be wearing thick garments through

the day, as well as anecdotal evidence provided that the environment was too cold. Interestingly, the majority of female occupants were found to be carrying out more adaptive behaviour than male occupants, which is consistent with the findings of the survey; that a greater percentage of female occupants found comfort an issue with temperature by comparison to males. From an adaptive perspective, these observations are also consistent with the fact that students suggested that the most common form of adaption carried out was adjustment of clothing level. However, additional adaptive behaviour was also noticed being carried out by staff in the refectory area. Not only does opening external doors alter internal temperature & air velocity, it also allows for the escape of energy used to heat the facility. Therefore, such behaviour would suggest that either occupant education is required regarding building use, or more likely a form of Post Occupancy Evaluation (POE) is required to ascertain if there are any possible improvements necessary. POE is a procedure to gather information relating to a building in live use. Amongst other benefits the process enables the identification & if necessary remedial action of any issues in recently produced construction projects (BRE, 2009).

Day 2 – During the second day of the study, 5 hours of observations took place. Typically, lots of hot beverages were consumed, however it is possible that this behaviour is a preference as opposed to adaptive. In open access areas, heavy garments were commonplace amongst all students. However, adjustment to lighter clothing was observed in lecture areas, suggesting the environment was more favourable. As the day progressed more adjustment of clothing to lighter garments was noticed in open access areas, as well as door wedging behaviour in more than one lecture area. Window opening behaviour was observed in both lecture & open access areas, and in some cases, windows were being opened directly above active heaters. This behaviour essentially causes a direct waste of energy used for heating purposes, which would therefore cause an additional cost for the institution, as well as needlessly contributing to climate change. In this instance, a combination of further occupant education in conjunction with greater communications between persons responsible for regulating building services and occupants may be beneficial. This would also aid in the deficit in communications identified through the survey, where 67% of student occupants were unaware of a procedure to discuss such issues with staff.

Day 3 – Occupant behaviour was observed for a 2-hour period. Special permission was obtained for this day for the observer to attend meeting rooms when in use to cover observations in these areas. For both open access areas & meeting areas the most common behaviour appeared to be consumption of hot beverages, in combination with wearing very heavy garments. This behaviour is consistent with the findings of the survey that these behaviours account for over 60% & 40% of overall adaptive behaviour of students & staff respectively. This suggests that the responses received through the survey process were genuine and therefore found to be more valid following the observational

process. In addition, multiple instances of door wedging behaviour were found to be occurring, with evidence provided that this is caused by overheating issues from IT equipment, where ventilation systems are present but non-functional. This identifies that there is scope to assess all such areas to identify where improvements to these systems is possible.

Day 4 – For the final day, 4 hours of observations also took place. Nearly all occupants were found to be wearing very heavy garments including woollen items typically reserved for winter conditions. Upon observation, this behaviour did not change over extended periods of time, suggesting the temperature to be too cold as opposed to this behaviour occurring for reasons of preference. Door wedging behaviour was also observed in lecture areas, and although in some cases this was thought to be for adaptive purposes related to comfort, evidence was also provided which suggested it was linked to building services. For one area in particular, wastepaper bins were found to be wedged in fire doors, with evidence suggesting that this was related to access issues for certain occupants, and without such behaviour access was not possible to work areas. This suggest that there is more than one area of the facility that would benefit from POE. Permission was also obtained by the observer to attend lectures on this day to carry out observations. During lectures utilizing IT equipment, heavy garments were worn despite heat produced by machines. In addition, hot flasks were being used in the area, despite this being against common rules for the occupants in these areas. Evidence of adaptive behaviour relating to reduction in moisture was also provided for refectory areas, where staff are finding the need to open external access doors to reduce this issue. This identifies the potential to review the ventilation systems for such areas.

The observations across the span of the 4-day study appear to be consistent with the opinions provided through the survey, in terms of the most common adaptations used, and it is the view of the Author that these were therefore provided accurately, contributing to the validity of results. In addition, further adaptive behaviours have been uncovered by the process, as well as many reasons behind adaptations, which were not evident through the survey or professional interview processes. It is therefore obvious that the observational study has been of great benefit to the overall research project. However, there was an issue relating to capturing data. Initially there was potential to extend the study, however this was offset through collection of surveys, in connection to periods of time where students leave the facility at end of the term. This is therefore a factor to consider, should other authors decide to carry out a similar study at this institution or any others, to gain maximum benefit from the process.

5. Conclusion

To conclude, there is a great deal of literature & evidence to suggest that the actions of humans contribute to climate change, such as the works of Gaffney & Steffen (2017) & Schlesinger (2011), as well as evidence provided by the Committee on Climate Change (2017).

Specifically, this study has examined the link between adaptive behaviour & the efficacy of climate adaptations for the internal environment of a case study building, with acknowledgment that behavioural adaptation is a newly emerging field of climate science (Filho et al, 2018). How our existing and future building stock are already and are likely to be affected by climatic change is also discussed with findings that the heritage sector is particularly vulnerable, and a lack of information & education for responsible heritage managers is affecting the efficacy of adaptations (Phillips, 2015), (Mosoarca et al, 2017). Extensive review of previous adaptive, behavioural & educational studies relating to climate change is also included. Through these previous works, a gap in behavioural adaptation was identified, with emphasis on a call for research at higher education institutions, which developed the basis for this study (Nam & Ito, 2011), (Filho et al, 2018). A review of adaptive mechanisms for buildings as well as behaviour is also discussed. Through review of this literature it is evident that adaptation is necessary in the built environment, which would suggest that objective 1 of this research is satisfied.

Behavioural adaptation was also examined for this study at UWTSD's IQ facility, at SA1, Swansea. Methods included; a collection of professional interviews with onsite staff, an opinion-based survey with the staff & student populations, as well as an observational study examining actual adaptive behaviour. The methods employed in this study hold distinct similarities to other author research approaches in this field, such as Tartarini et al (2018) & Lim & Yun (2017), but were used in this case to observe different factors.

Upon reflection, the overarching research aim appears to be achieved, as evidence was found during the study of a link between occupant adaptive behaviour & the efficacy of adaptations to deal with changes in the climate. An example of this was demonstrated during the observational study, where facilities staff had set the building to provide heat during the day, however at the same time, occupants had carried out window opening behaviour directly above active heaters. Such behaviour potentially causes negative implications for the environment, as energy is wasted for heating purposes. In turn this could also cause greater inconsistency in the internal environment of the building, likely to be causing more adaptive behaviour. Such evidence very clearly shows that behavioural adaptation does have an effect on climate adaptations in buildings, and in some cases, it renders them completely inefficient. Documentation of this evidence contributes to the achievement of research objective 2. In previous studies, such as that of Yao & Zhao (2017), during summertime

external temperature was found to be the greatest cause of window opening behaviour. However, as this study was carried out in a heating season (winter) the explanation of Yao & Zhao for this behaviour is not necessarily valid. What was made clear through evidence provided by occupants of the facility, is that as the temperature changes rapidly in some areas, it is necessary to open windows. This would suggest that in the case of this project, the behaviour is linked to a fluctuation in the internal temperature as opposed to external temperature. Emphasis is therefore placed on the need for stronger communications between staff and student populations at the facility, as well as suggesting scope for further optimisation of building services. Adaptive behaviours were also found to be causing other negative implications for the facility, in relation to risk for emergency fire situations.

For this research the main findings are as follows:

- Identification of occupant awareness of comfort – specifically thermal comfort in a heating season
- Identification of occupant awareness of adaptive behaviour
- Evidencing that the majority of students & staff had received no training in the appropriate use of the IQ building at 82% & 70% respectively.
- Identification of the most appropriate mechanisms to disseminate building use training to staff & students.
- Suggestion of the value in further occupant education – as adaptive behaviour was observed which was counterproductive to climate adaptive building systems (window opening in multiple areas, directly above active heating systems)
- Recognition of adaptive behaviours which significantly increase the risk of fire spread in the event of an emergency situation (door wedging behaviour)
- The recommendation that there are multiple areas of the IQ facility that would benefit from the occurrence of Post Occupancy Evaluation
- Discovery of a lack of communications between staff & students in relation to comfort
- Identification of areas where improvements in building systems are necessary, such as inactive ventilation & card access systems

As discussed above, adaptive door wedging behaviour was frequently observed at the facility, often forcing common office items such as paper bins into fire door sets. This behaviour eradicates the effectiveness of design measures intended to protect life in the event of a fire (compartmentation & intumescent strip systems). Such behaviour has the potential to cause very serious issues in the event of an emergency scenario, and it is therefore evident that further occupant education is required to control & stop such issues. This suggestion agrees with the views of a multitude of other behavioural authors expressing the need for greater occupant education, including the works of Phillips (2015), Lim & Yun (2017), Pisello et al (2017) & Siegner (2018). In this case, the comparison between these expressed views & the findings of this research not only suggests occupant education in buildings it is beneficial to ensure resilience but also adds to knowledge in this field as it is possible that further training for occupants at this facility could minimise such negative behaviour. This finding also suggests that occupant behaviour does indeed influence the efficacy of adaptations, intended to manage a

changing climate at higher education facilities, as in some cases, the cause of this behaviour was found to be linked to temperature regulation, as well as the access issues identified above. This result would then also contribute to the achievement of research objective 2.

However, the findings of this research differ from other studies in two key areas. Firstly whereas many other studies suggest that further occupant education is needed to achieve various aims (in this case to reduce behaviour which is stopping building systems from operating correctly) many do not investigate or suggest the most appropriate mechanisms for providing training to occupants. For this study, these mechanisms were discovered as part of the data collection process, for both student & staff populations. Surprisingly, the second area where the findings differ from other studies was the communicational aspect. It was found that the majority of the student population at the facility (67%) were not aware of a mechanism to discuss comfort issues with staff. This suggests that there is room for improvement in relation to communications. If this area were to be improved, there is potential for common occupant behaviour to change from current practices, as building systems could be altered to suit more preferential conditions, reducing scenarios such as the heating being active, with occupants opening windows.

In addition, findings of the project also indicate a change in opinion of the ambient temperature of the facility. During interviews, staff suggested that overheating issues were experienced by occupants. However, through the survey and observational study, underheating now appears to be a greater concern to building occupants. This could be an area to monitor technically using temperature sensors to verify these results. Based on occupant opinion, there would also appear to be a need to increase education of the subject of climate change with both staff & student populations. This has potential to effect adaptive behaviours currently observed, and a similar study to this may be carried out at a later date to compare findings after a scheme to increase climate related education has commenced.

In the context of the utilizing the findings of this research, there are both local & wider benefits. For the institution itself, identification of a need for greater occupant training was found, as well as the most preferential mechanisms for dissemination of training. This is potentially of significant value to the institution, should a decision be made to carry out further training. In addition, there have been several issues identified through the research such as non-operational heating systems, issues of excessive moisture in refectory areas, as well as access issues with key cards (also found to be contributing to door wedging behaviour). All of these factors lead to the potential to carry out Post Occupancy Evaluation at the institution, to put remedial actions in place to solve found issues.

With such evidence in mind, it is also important to note that there many persons involved in the project who were pleased with the results of the new build facility, expressing complimentary evidence such as; *'the option for different levels of lighting was a great idea'*, ranging to *'the IQ facility*

is exciting & vibrant to work in'. Therefore, it is important to retain that some of the issues expressed through the data collection methods may relate to individual circumstances, and some of these could be considered as 'teething issues' due to commission of a new facility. It is therefore possible that some concerns such as access cards, or inactive ventilation could be solved through a Post Occupancy Evaluation scenario.

From a wider more international perspective, or indeed at this institution, the identification of potentially hazardous occupant behaviours, such as forcing fire doors to be open on a semi-permanent basis, suggests that there is scope to review such behaviours in a much greater context than of this study. This could occur across a range of other higher education facilities, as well as other publicly accessible buildings to ensure that such behaviour is minimised, as it is likely that such behaviour is not isolated to the case study facility alone. It is worth noting that such behaviour was not found by the Author during the literature review process. This does not necessarily mean that it does not exist, however, it is possible that there is less publicity relating to the issue, demonstrating value in the findings of this project. The identification of other factors, such as a lack of internal communications, as well as training in the appropriate use of the facility, may also be of use to other institutions with a sustainable agenda. This is due to the research demonstrating that occupant behaviour has serious potential to reduce the efficacy of building systems designed to regulate the internal climate, and can lead to energy being wasted directly through heating processes.

Finally, this study could be considered a form of attitudinal research, as opinions were gathered, and observations took place. Other authors have identified the *Hawthorne Effect* in such research, whereby a bias is created when persons are observed, as they tend to change their common behaviour for a more socially acceptable options, usually solved by restricting information (Gilani et al, 2017). To solve this issue survey participants were provided with minimal information as to the nature of the project, and the observational study was used to verify the common behaviours provided through the survey. Upon reflection, it is the view of the Author, that the behaviours suggested by occupants were genuine, as the same behaviour was commonly seen during the observational study. Therefore, this issue was minimised as much as possible, providing validity to the found results.

5.1 Recommendations

Based on the above findings, recommendations to enable improvements at the facility to increase resilience to climate change include:

- Development & implementation of a widespread building occupant education scheme in the efficient use of the building, through the most appropriate mechanisms as identified
- Full Post Occupancy Evaluation for the entire facility, to enable remedial actions for any identified issues

- Development of mechanisms to increase communications between the staff & student populations to enable discussion relating to building issues & comfort

It is suggested that areas for further research could include; 'a similar study carried out in a cooling season at the facility to compare findings' or 'further research into the reasoning behind some of the adaptive behaviours identified in this study'. Although in some cases, the observational study provided insight into these areas, such as issues with access cards for door wedging behaviour, this is not an extensive proof of reasoning behind such actions. It is however, linked to specific systems within the case study building, which could therefore make this a prudent area to research further.

It is the view of the Author that there is potential to implement small changes at the facility, which have the potential to create large gains in terms of occupant comfort, and the Author would like to express thanks for the co-operation & time of all persons involved in the research project.

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7. Appendix A – Survey Responses

The following are the original responses from the survey data collection process.

Note: a tick was place on each response by the Author, during data analysis, as a mechanism to ensure that duplication of data did not occur.