ASSESSING THE IMPACT OF OCCUPANT BEHAVIOUR ON ELECTRICITY CONSUMPTION FOR LIGHTING AND SMALL POWER IN OFFICE BUILDINGS

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ABSTRACT

Lighting and small power will typically account for more than half of the total electricity consumption in an office building. Significant variations in electricity used by different tenants suggest that occupants can have a significant impact on the electricity demand for these end-uses. Yet current modelling techniques fail to represent the interaction between occupant and the building environment in a realistic manner. Understanding the impact of such behaviours is crucial to improve the methodology behind current energy modelling techniques, aiming to minimise the significant gap between predicted and in-use performance of buildings. A better understanding of the impact of occupant behaviour on electricity consumption can also inform appropriate energy saving strategies focused on behavioural change.

This paper reports on a study aiming to assess the intent of occupants to switch off lighting and appliances when not in use in office buildings. Based on the Theory of Planned Behaviour, the assessment takes the form of a questionnaire and investigates three predictors to behaviour individually: 1) behavioural attitude; 2) subjective norms; 3) perceived behavioural control.

The paper details the development of the assessment procedure and discusses preliminary findings from the study. The questionnaire results are compared against electricity consumption data for individual zones within a multi-tenanted office building. Initial results demonstrate a statistically significant correlation between perceived behavioural control and energy consumption for lighting and small power

Keywords: Electricity consumption; occupant behaviour, offices, lighting, small power.

INTRODUCTION

Designing a building in a sustainable manner does not guarantee it will be energy efficient, as consumption is heavily influenced by the behaviour of its occupants (Derijcke and Uitzinger, 2006). This rationale carries great significance when investigating energy efficiency in buildings, and has been widely recognised in the building industry for many decades (Socolow, 1978). Post-occupancy data relating to energy use in office buildings has demonstrated significant variation in electricity consumption by different tenants occupying the same building (Menezes *et al.*, 2011). Such variations are largely influenced by the behaviour of occupants, yet current modelling techniques fail to account for the impact of behavioural elements on energy consumption of buildings. According to Haldi and Robinson (2011), building simulation programmes are now considered relatively mature, yet their ability to characterize reality is undermined by a poor representation of factors relating to occupants' presence and their interaction with environmental controls. If we are to ultimately achieve more realistic prediction of energy consumption in buildings, occupant-related factors must be better understood and represented in predictive models.

This paper investigates the impact of occupant behaviour on the electricity consumption of an 8-storey multi-tenanted office building located in Central London, UK. The building is split into 32 zones (4 per floor) allowing for the behaviour of the occupants in each of the zones to be correlated with their sub-metered electricity consumption. This covers electricity used for lighting and small power only, as these are the end uses occupants have direct control over. Energy used for heating, ventilation and air conditioning (HVAC), as well as server rooms are not included in the study. The assessment of occupant behaviour is undertaken through a survey based on the Theory of Planned Behaviour, and the methodology for developing the implemented questionnaire is explained in detail. The three precursors to behaviour are assessed individually allowing for conclusions to be drawn regarding their respective impact on energy consumption.

BACKGROUND

Occupant Behaviour in Buildings

Occupant behaviour plays a significant role in determining actual energy consumption in buildings, alongside physical building characteristics, local environment and systems servicing and commissioning (Steemers and Yun, 2009). According to Hoes *et al*. (2009), user behaviour can have a larger influence on the energy performance of a building than the thermal process within the building facade. Numerous studies have aimed to assess the impact of occupant behaviour and activities on energy consumption through the use of simulations. Yet such an approach can be complex because of the diversity and complexity of user behaviour. In order to obtain the full effects of user behaviour it is necessary to extract corresponding useful information from real measured data (Yu *et al*., 2011).

Several research studies have aimed to utilise monitored energy data to quantify the impact of occupant behaviour. In 2009, Ouyang and Hokao investigated the potential for energy savings in 124 households in China by improving user behaviour. Results demonstrated that, on average, effective promotion of energy conscious behaviour could reduce energy consumption by more than 10%. More recently, Gill *et al*. (2010) investigated the impact of occupant behaviour on the consumption of energy and water in a low-energy housing scheme in East Anglia, UK. The key intention was to enable quantification and apportionment of building performance to occupant behaviour, aiming to explain some of the variation often detected. Results indicated that energy efficient behaviours accounted for 51%, 31% and 11% of the variance in heat, electricity and water consumption, respectively, between the 26 dwellings in the housing scheme (Gill *et al*. 2010).

Focusing on commercial buildings, Masoso and Grobler (2010) highlighted the impact of poor occupant behaviour on electricity consumption during non-occupied hours in office buildings. The work was based on energy audits of 6 buildings in Botswana and demonstrated that 56% of the energy consumed by the building was used outside working hours because of poor occupant behaviour whereby lights and equipment are left on at the end of the day, as well as poor zoning and controls. More recently, Haldi and Robinson (2011) developed a bespoke model following extensive field survey data allowing for occupant behaviour to be considered at design stage. This novel modelling tool accounted for occupant presence, opening and closing of windows, as well as raising and lowering of blinds. A number of other research projects (Liao and Barooh, 2010; Smarakoon and Soberato, 2011) have investigated the impact of occupancy on energy consumption, proposing novel models for predicting occupancy patterns. However, the impact of holistic occupant behaviour on energy use in non-domestic buildings is still to be investigated in depth.

Theory of Planned Behaviour

Gill *et al*. (2010) successfully implemented a novel methodology for quantifying the impact of occupant behaviour on the energy performance of residential buildings based on the Theory of Planned Behaviour (TPB). Originally developed by Ajzen (1991), the TPB is one of the most widely applied behavioural models (Armitage and Conner, 2001). It proposes that human action is guided by behavioural attitude, subjective norms and perceived behavioural control, and can be predicted provided that the behaviour is intentional (Francis *et al*, 2004). In essence, TPB claims that, in order to predict whether a person intends to do something, it necessary to know (Azjen, 1991):

- Whether the person is in favour of doing it (‘behavioural attitude’)
- How much the person feels the social pressure to do it (‘subjective norm’)
- Whether the person feels in control of the action in question (‘perceived behavioural control’)

By adjusting these three ‘predictors’, the likelihood that the person will intend to carry out a desired action can be increased, thus increasing the chance of the person actually doing it. This concept is illustrated in Figure 1.

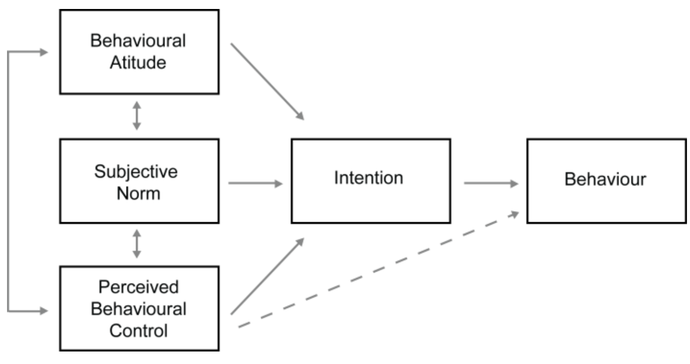


Figure 1: Theory of Planned Behaviour (adapted from Ajzen, 1991)

As shown, the three predictors are jointly responsible for shaping an individual's intention to perform a given behaviour. The TPB also suggests a direct link between perceived behavioural control and the achievement of a specific behaviour. This should not be confused with *actual* control (i.e. the availability of vital opportunities and resources such as time, money, skills, etc). Although the importance of *actual* control is indisputable, perceived behaviour control is of greater psychological interest, following the premise that people's behaviour is strongly influenced by their confidence in their ability to perform it (Azjen, 1991). Actual control is, strictly, irrelevant since if an individual does not also feel in control of an action they will not form an intention to do so. According to the TPB, perceived behaviour control can often be used as a substitute for a measure of actual control, providing a direct link to behavioural achievement.

It is worth noting that intentions are precursors to behaviours and although there is no perfect relationship between behavioural intention and actual behaviour, TPB relies on the assumption that intention can be used as a proximal measure of behaviour (Francis *et al*, 2004). This observation was one of the most important contributors of the TPB model when compared to previous models of attitude-behaviour relationship, allowing for the variables in this model to be used to determine the effectiveness of interventions even if there is no readily available measure of actual behaviour. This is both a strength and a limitation of the TPB, being a source of criticism by Martiskainen (2007) who suggests that the model is more applicable to measuring the relationships between behavioural constructs than the measurement of actual behaviour. However, a review of the TPB (Armitage and Conner, 2001) concluded that the TPB accounts for a considerable proportion of variance in actual behaviour, supporting the TPB as a predictive theory of intention and behaviours.

METHODOLOGY

This study was undertaken in an 8-storey multi-tenanted office building located in Central London, consisting mainly of open-plan office spaces. Each floor has a treated floor area of approximately 2,000m^2, and is divided into 4 sectors, providing 32 individual zones that can be let to different tenants. In order to assess the impact of occupant behaviour on electricity consumption, each of the 32 zones were regarded as individual data collection points. Two distinctive sets of data were acquired for each of the zones: one pertaining to the use of electricity for lighting and small power, and the other regarding the occupant behaviour, as described below.

Electricity Consumption Data

Electricity consumption data was acquired through the existing metering configuration of the building. This consists of two incoming meters: one for the landlord supply and one for the tenants supply. The landlord consumption includes all HVAC equipment and controls, as well as lighting throughout the common areas of the building, with no further sub-metering. Meanwhile, tenant consumption includes all the electricity supplied for lighting, small power equipment and server rooms throughout the building. A total of 36 sub-meters provide a further breakdown of the tenant electricity supply: one for each of the 32 zones in the building plus 4 separately metered server rooms (not considered in this study). Monthly electricity consumption data was recorded for each of the 32 sub-metered zones, yet only 27 of them were deemed appropriate for inclusion in the study. This was because 2 zones were unoccupied and 3 zones were reception areas consisting mainly of transitional spaces.

Assessing Occupant Behaviour

Francis *et al*. (2004) provides a thorough framework for survey development using the Theory of Planned Behaviour. The methodology characterises each contributing behavioural construct (behavioural attitudes, subjective norms and perceived behavioural control) and was used to develop the questionnaire used in this study. Figure 2 illustrates this methodology, highlighting key actions taken during the development and implementation of the questionnaire.

The first step was to define the population of interest, this being: *occupants in a multi-tenanted office building*. Defining the exact behaviour under investigation was not quite as straight forward, because occupants are able to affect electricity consumption in multiple and diverse ways. Considering the focus of the study involved electricity use only for lighting and small power, the key behaviour for investigation was defined as: *switching off lighting and appliances when not in use*. This behaviour was deemed appropriately representative of the key interactions between occupant and energy consuming devices in the workplace.

Prior to the development of the questionnaire, an elicitation survey was conducted with 30 people outside of the population to be surveyed (i.e. not working in the building under investigation). This consisted of six open-ended questions relating to each of the three predictors to establish the dominant factors that contribute to decisions regarding the target behaviour (as described in Figure 2). Respondents were asked to provide three responses to each question and caution was taken to ensure a wide range of backgrounds and age groups were included. The results for the survey were analysed and trivial responses were rejected, ensuring that at least 75% of all beliefs were accounted for. These were then used to develop a multiple choice questionnaire whereby each significant belief was transformed into a question couplet, in line with guidance from Francis *et al*. (2004). Once again, this process is illustrated in Figure 2, resulting in a questionnaire with six groups of six questions (i.e. two sections for each predictor of behaviour, with every question having an equivalent couplet).

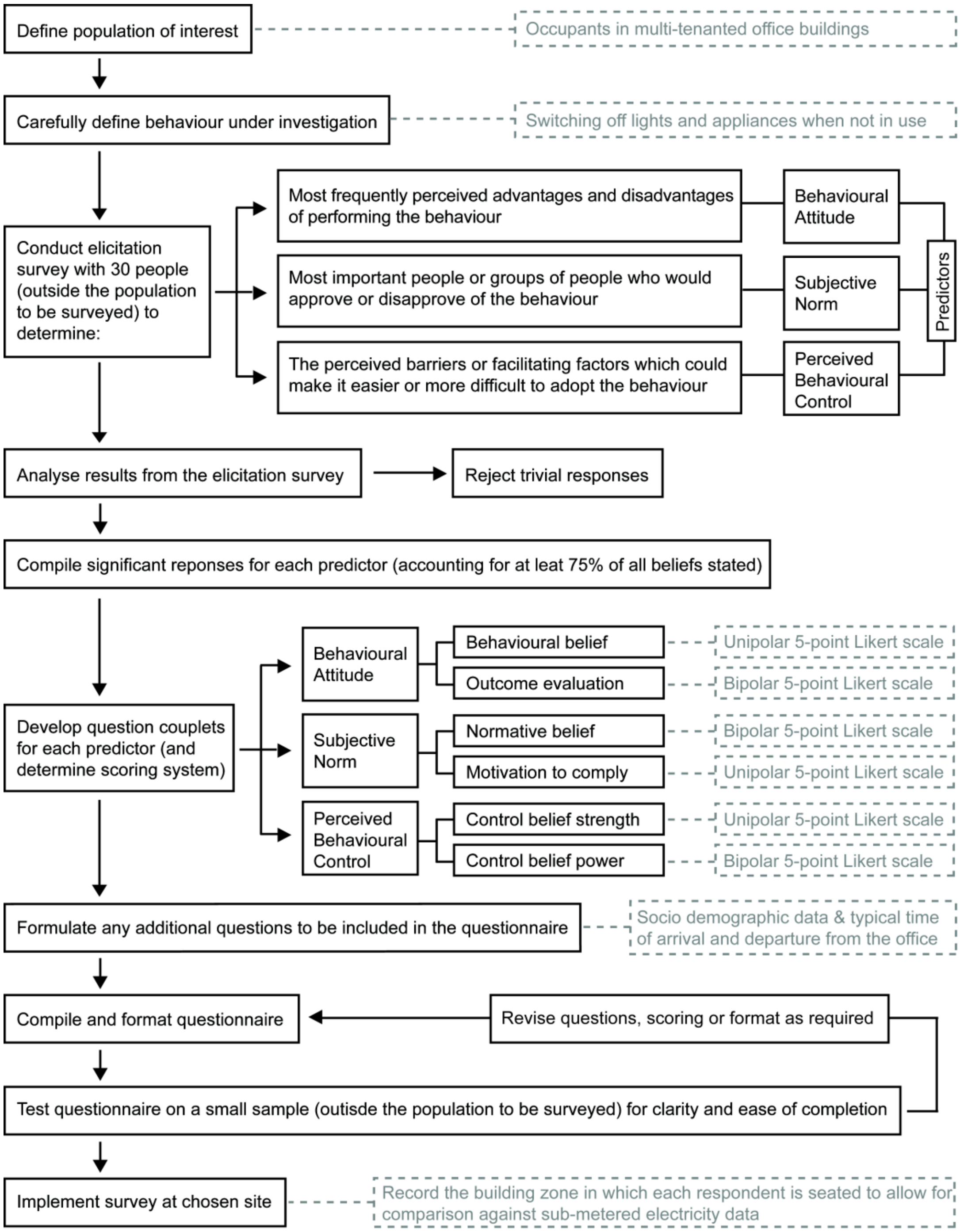
Scoring scales were established for each group of questions using a 5-point Likert scale as standard. The direction of the scale (i.e. bipolar or unipolar) was determined to suit each set of question groups appropriately, ensuring that each predictor had a unipolar and bipolar group of questions. This is to ensure consistency in the scoring for each predictor, as follows:

Behavioural attitude score: $\sum_{i=1}^{i=6} (\text{behavioural belief}_{\text{i}} \times \text{outcome evalation}_{\text{i}})$

Subjective norm score: $\sum_{i=1}^{i=6} (\text{normative belief}_{\text{i}} \times \text{motivation to comply}_{\text{i}})$

Perceived behavioural control score: $\sum_{i=1}^{i=6} (\text{control strength}_{\text{i}} \times \text{control power}_{\text{i}})$

The questionnaire was complied and piloted on five people (outside the population to be surveyed) to ensure clarity and ease of completion. Minor revisions were made in line with the feedback received. Additional questions were also added to capture social demographic data as well as typical time of arrival and departure from the office.



Note: Information within dashed boxes relate to choices / actions specific to this study.

Figure 2: Methodology flow chart for developing survey based on the TBP

Implementation of Survey

The questionnaires were distributed to all occupants in the building (approximately 800 people) between 08:00 and 10:00 hours on 1st November 2011. Respondents were informed that the questionnaires would be collected after 3pm on the same day. Care was taken to annotate each questionnaire with the zone in which the respondent was seated. This was crucial to allow for comparison against the electricity consumption data for each building zone. A total of 432 completed questionnaires were collected, representing a response rate of approximately 50%. Scores for each of the three predictors were calculated for each respondent and the median score for each predictor was determined for all 27 building zones included in the study.

RESULTS

Figure 3 illustrates the correlation between monitored monthly electricity consumption and the median scores of the occupants of each zone on each of the three predictors of the Theory of Planned Behaviour. Each individual has limited control over the electricity consumption within his or her zone, relative to the influence they may have on the average TPB predictor scores for their zone (particularly in more sparsely occupied zones) therefore median values were used to represent the behavioural scores in each of the 27 zones in order to reduce the possibility of results being distorted by individuals with extreme scores for one or more of these measures.

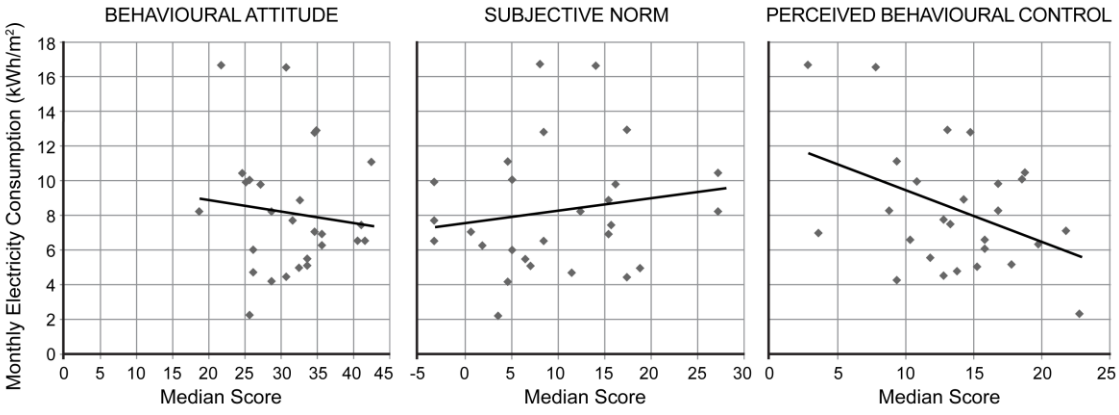


Figure 3: Scatter plots of electricity consumption vs. median scores

A multiple regression analysis was conducted to predict the monthly electricity consumption based upon the three components of the TPB. The predictors were entered into the regression analysis in the order: behavioural attitude, perceived behavioural control and subjective norms. This revealed that behavioural attitude alone did not account for a significant proportion of the variation in electricity consumption across the building, with R^2 = 0.013, F(1, 25) = 0.330, p = 0.571, where the F-statistic will tend to be smaller when the predictor does not account for variation in electricity consumption. Meanwhile, p indicates the calculated probability of observing these results, by chance alone, given no effect of the predictor on electricity consumption. By convention, $p < 0.05$ represents a statistically significant result. As seen, there is no statistically significant correlation between behavioural attitude scores and monthly electricity consumption. However, when perceived behavioural control was added to the model, this accounted for a significant proportion of the monthly electricity variance, with R^2 change = 0.168, F(1, 24)= 4.94, p = 0.036. Finally, when subjective norms were added as a predictor, these did not significantly add to the predictive value, with R^2 change = 0.01, F(1, 23)= 0.289, p = 0.596.

It is important to note that any variation that could be predicted either by perceived behavioural control or by subjective norms would, in this analysis, be ascribed solely credited to perceived behavioural control because this predictor was entered into the analysis first. Hence, to ensure that the already established effects of perceived behavioural control were not masking the effects of subjective norms, a second regression analyses was undertaken reversing the order in which the predictors were entered into the model. Results demonstrated that subjective norms alone did not account for a significant proportion of the variation in monthly electricity consumption, with R^2 = 0.029, F(1, 25) = 0.743, p = 0.397. However, when perceived behavioural control is added as a predictor, approximately 16% of the variation in monthly electricity consumption is now accounted for, with R^2 change = 0.156, $F(1, 24) = 4.61$, $p = 0.042$. Finally, as expected, adding behavioural attitude scores as the last predictor did not account for significantly more variation in electricity consumption than subjective norms and perceived behavioural control combined, with R^2 change = 0.006, $F(1, 23) = 0.181$, $p = 0.675$.

Based on the results from the multiple regression analysis, perceived behavioural control is the only predictor that has a statistically significant impact on electricity consumption. Using a linear regression analysis with perceived behavioural control as the sole predictor of monthly electricity consumption, it accounts for approximately 17% of the variation in monthly electricity consumption, with $R^2 = 0.169$, $F(1, 25) = 5.09$, $p = 0.033$.

DISCUSSION

Results from this study have demonstrated that, of the three predictors in the Theory of Planned behaviour, perceived behavioural control is the only one with a significant correlation to monitored electricity consumption. In the building under investigation, this implies that lower energy consumption can be expected in zones where occupants perceive themselves to have a high level of control over lighting and appliances. No correlation was found between either behavioural attitude or subjective norms, and monitored electricity consumption for the zones.

The structure of the TPB goes some way towards explaining these findings. As previously discussed, the TPB proposes a direct link between perceived behavioural control and behaviour, whereas the other predictors are linked only to intention. In this particular study, results suggest that perceived behavioural control could be used as a substitute for a measure of actual control, providing a direct link to behavioural achievement. This is understandable, as it is likely that occupants in the same zone would have a similar ability to adjust the physical controls that turn lighting and appliances off. While the scores for behavioural attitude and subjective norm would vary greatly between different individuals, the scores for perceived behavioural control would not vary as much, as this is heavily linked to actual measures of control.

Traditional attempts to reduce the influence of occupants on energy consumption revolve around the assumption that people's behaviour can be altered by providing them with information about their undesirable actions. However, there is evidence to suggest that while this approach may serve to influence attitudes, it often has a negligible effect on actual behaviour (McKenzie-Mohr, 2000). The results of this study support these findings by suggesting that the attitudes and subjective norms of the occupants have little discernable influence on their zone's electricity consumption. Instead it is their perceived level of control over lighting and small power that has a significant impact on their electricity use. This finding highlights the importance of considering how building users can control their environmental conditions during the design process, arguing against efforts to reduce the level of control users have over appliances and lighting. This would suggest a clear benefit in implementing usable and well located controls rather than technologies such as PIR (passive infra-red) detection and other automated services.

It is important to emphasise that TPB only considers planned behaviour, so for the purposes of this study it can only be used to explain the variation in electricity consumption caused by the conscious operation of lighting and appliances. The intangible nature of electricity use renders it likely that a certain proportion of electricity consumption in buildings is a result of unplanned or instinctive behaviour which will not be accounted for by TPB.

Following the completion of the survey some occupants highlighted that, in a number of questions, they might have given two different answers if lighting and small power had been dealt with individually. A subsequent survey will be undertaken to separately account for variations in behaviour for both end uses individually. This will be carried out in a building where lighting and small power are sub-metered separately, allowing for a more detailed analysis of the impact of occupant behaviour on electricity consumption for each end-use.

CONCLUSION

This study has investigated the impact of occupant behaviour on the electricity consumption for lighting and small power in a multi-tenanted office building in London, UK. The methodology used to undertake this assessment was based on the Theory of Planned Behaviour, dealing with each predictor to behaviour individually. Results demonstrated a statistically significant negative association between scores for perceived behavioural control and electricity consumption, suggesting that perceived lack of behavioural control can account for variations of up to 17% in electricity consumption in each of the building zones. The impact of behavioural attitude and subjective norms on electricity use were non-significant and may be deemed negligible in the specific building under investigation.

Findings from the study suggest that the more control people perceive to have over their surroundings, the less energy they consume. This premise goes against the current design trend for more automated buildings and will be investigated in further detail in a subsequent study to be carried out in a different multi-tenanted building. It is envisioned that further findings will be used to inform better predictions of energy consumption in office buildings allowing for occupant behaviour to be more adequately accounted for. Occupant behaviour is significantly more complex than is allowed for in current energy modelling techniques and this must be tackled if realistic predictions of energy performance are to be achieved.

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