Building and Environment 92 (2015) 75–85

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Identifying behavioural predictors of small power electricity consumption in office buildings

Richard M. Tetlow [a, e, *], Chris van Dronkelaar [b, f], C. Philip Beaman [c], Abbas A. Elmualim [d], Kevin Couling [e]

[a] Technologies for Sustainable Built Environments, University of Reading, UK
[b] The Bartlett School of Environment, Energy and Resources, University College London, UK
[c] School of Psychology & Clinical Language Sciences, University of Reading, UK
[d] School of Construction Management and Engineering, University of Reading, UK
[e] AECOM, Bristol, UK
[f] BuroHappold Engineering, London, UK

ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form
22 March 2015
Accepted 5 April 2015
Available online 22 April 2015

Keywords:
Electricity consumption
Occupant behaviour
Offices
Small power
Habits

ABSTRACT

It is widely accepted that there is a gap between design and real world operational energy consumption. The behaviour of occupants is often cited as an important factor influencing building energy performance. However, its consideration, both during design and operation, is overly simplistic, often assuming a direct link between attitudes and behaviour. Alternative models of decision making from psychology highlight a range of additional influential factors and emphasise that occupants do not always act in a rational manner. Developing a better understanding of occupant decision making could help inform office energy conservation campaigns as well as models of behaviour employed during the design process.

This paper assesses the contribution of various behavioural constructs to small power consumption in offices. The method is based upon the Theory of Planned Behaviour (TPB) which assumes that intention is driven by three factors: attitude, subjective norms, and perceived behavioural control, but we also consider a fourth construct: habit measured through the Self-Report Habit Index (SRHI). A questionnaire was issued to 81 participants in two UK offices. Questionnaire results for each behavioural construct were correlated against each participant's individual workstation electricity consumption.

The intentional processes proposed by TPB could not account for the observed differences in occupants' interactions with small power appliances. Instead, occupants were interacting with small power "automatically", with habit accounting for 11% of the variation in workstation energy consumption. The implications for occupant behaviour models and employee engagement campaigns are discussed.

1. Introduction

According to calculations based on UK energy consumption statistics, in 2013 the operation of non-domestic buildings was responsible for around 12% of total UK CO_2 emissions with commercial offices alone representing about 1.1% [14]. To promote large scale reduction of emissions in this sector, the UK Government has tended to rely on legislative tools. For instance, successive revisions of Part L since 2002 have seen the introduction of gradually stricter targets for CO_2 emissions abatement [15]. Whilst this has led to greater demand for energy efficient commercial properties, evidence from post-occupancy evaluations (POE) routinely show that this low carbon design intent only rarely results in low carbon operation. For example, data from CarbonBuzz indicate that office buildings can consume as much as 1.8 times more energy than indicated by the initial design calculations [52].

The failure of this legislative approach to deliver the anticipated energy reductions is partly due to its one-dimensional nature. Carbon emissions abatement is primarily sought through the promotion of "technological" solutions such as improved building

* Corresponding author. Technologies for Sustainable Built Environments, University of Reading, UK.
E-mail address: r.m.tetlow@pgr.reading.ac.uk (R.M. Tetlow).

http://dx.doi.org/10.1016/j.buildenv.2015.04.009
0360-1323/

fabric efficiency, increased efficiency of building services, and incorporation of low/zero carbon technologies [4]. This focus on technology addresses only part of the problem as it does not adequately account for the behaviour of the occupants which is regularly cited as a key determinant of actual in-use building energy performance [17,25,26,61] and can considerably reduce the effectiveness of some technological interventions intended to reduce CO_2 emissions [32]. Post-occupancy investigations routinely reveal examples of occupants using technological systems contrary to the building's original design intent. For example, Passive Infra-Red (PIR) sensors to automatically switch off lighting do not necessarily attain the anticipated energy savings because occupants can modify their behaviour as a direct result of their implementation [49], unanticipated small power loads are introduced [37], and carefully designed heating, ventilation, and air-conditioning (HVAC) strategies are compromised [45]. The designers of any technological system often assume that the intended end-users will possess the same conceptual model of how the system operates as they do, neglecting the fact that the end-users were not privy to the original design decisions. When the end user's conceptual model of operation differs from that of the designer there is a “communication gap” [42]. In the case of building systems and controls there is often little or no direct communication between the designer and the end-user (either the facilities manager or occupants) to indicate appropriate use. Consequently, the occupants in particular are left to infer the operation, and the design intent, of any technological system installed. This oversight directly contributes to instances of users operating building systems “inappropriately” (i.e. contrary to the design intent) and inefficiently, significantly contributing to the observed difference between anticipated and actual energy levels.

In an effort to predict the energy impact of occupant behaviour numerous models have been developed (e.g. Refs. [23,33,40,41,50,62]). In general these have taken a fairly superficial approach to modelling behaviour, assuming that action is triggered primarily by physical changes in environmental variables such as external temperature or illuminance level. To account for the high level of variability of occupant behaviour observed during field studies many models also propose categorising building occupants into different “user types” which regularly include explicit or implicit reference to the occupant's environmental attitudes [8,17,25,50,57]. However, from a psychological viewpoint this representation of attitude alone as determining behaviour is demonstrably insufficient. Indeed, the fallacy that a given individual's behaviour is determined by their attitude is known within social psychology as the “fundamental attribution error” [51] and it is noteworthy that this attribution is far more frequently applied to others than to one's own behaviour – for which situational variables are more frequently cited [54]. Similarly, there is a documented “intention-behaviour gap” (reviewed by Ref. [53]) whereby positive intention to act does not perfectly predict future action.

This paper attempts to apply insights from psychology to assess occupant interactions with small power appliances and resulting energy consumption. It reports on an investigation to assess the relative importance of four behavioural predictors (highlighted as important factors in the decision making process by psycho-social models of behaviour) on average daily workstation electricity consumption in two open plan office buildings in the UK, one in Bristol and one in London. The assessment method is through an online questionnaire, the development and implementation of which are described in detail. The implications of the results for both the modelling of occupant behaviour during the design of new buildings and for influencing occupant behaviour in existing buildings are discussed.

2. Occupant behaviour models

Although building simulation software programmes for modelling thermal and building service performance are now relatively mature [22] the interaction of occupants with the building's systems and controls, which can arguably have an even greater influence than thermal processes, is considered only simplistically [24]. For example, current energy modelling during the design stage makes the rather crude assumption that certain systems are consistently in operation during default occupancy profiles [24,36]. While this is currently acceptable engineering practice, in reality occupant interactions with building systems and controls are much more dynamic and, consequently, occupant behaviour is the most significant cause of uncertainty in the prediction of building energy use [25].

In an effort to improve this situation, various models capable of predicting occurrences of occupant related energy use have been developed which are compatible with existing building simulation tools (e.g. Refs. [23,33,40,41,50,62]). While these models have advanced the understanding of occupant interactions with the built environment, to date none have achieved any traction within the construction industry. One reason for this, as [57] highlight, is that these models have been developed by different research groups focussing on different variables and employ a wide range of data collection and analysis techniques. Consequently, the resulting models are difficult to compare to one another.

This variability amongst built environment models of occupant behaviour also reflects the high variability of behaviour observed amongst occupants in field studies. To address this, there have been many attempts to distinguish between different *types* of occupants. For example [50], developed a sophisticated and influential lighting algorithm, “Lightswitch-2002”, to predict the probability of occupants switching lights on and off when arriving and leaving cellular offices. Building on [33] initial reference to different levels of use between occupants, Reinhardt conceived of four different “user types” based on whether the occupant's use of artificial lighting was dependent or independent of daylight. Bourgeois [8] created an expansive model for predicting interaction with both windows and lighting based on [41,50] earlier work. This further developed Reinhardt's distinction between different user types with Bourgeois proposing that occupants can be represented as “active” (i.e. use these systems a lot) or “passive” (i.e. never use these systems). More recently [25], categorised occupants in private offices into three different work styles: “austerity” – *occupants are proactive in saving energy*, “standard” – *represents the average energy use of the majority of occupants*, and “wasteful” – *occupants have no motivation to save energy*. When these categories were used as inputs during an energy modelling exercise, the results showed corresponding increases or decreases in energy consumption. Leading on from this [57], stated that an occupant's energy attitude is an important driver for any behaviours which result in energy consumption. They suggested that occupants can be usefully categorised as “energy frugal”, “energy indifferent”, or “energy profligate”. Fabi et al. [17] also claimed that it is possible to differentiate between users' behaviours typologies depending on how they interact with a building. For instance, from an energy perspective occupants could be classified as “energy saving users” or “energy wasting users”. In later related work [18], also drew a distinction between “active” and “passive” situations for occupant interaction with lighting controls and they proposed different models to account for these different situations.

These models then have attempted to broadly categorise occupants in a way that seems to implicitly assume stability of user-type as a physical parameter across time, building type, and system. Models can also be viewed either as purely behaviouristic,