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Simple prompts reduce inadvertent energy consumption from lighting in office buildings

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ABSTRACT

Building designs regularly fail to achieve the anticipated levels of in-use energy consumption. The interaction of occupants with building controls is often cited as a key factor behind this discrepancy. This paper examines whether one factor in inadvertent energy consumption might be the appearance of post-completion errors (when an intended action is not taken because a primary goal has already been accomplished) in occupants' interactions with building controls. Post-completion errors have been widely studied in human-computer interaction but the concept has not previously been applied to the interaction of occupants with building controls. Two experiments were carried out to examine the effect of incorporating two different types of simple prompt to reduce post-completion error in the use of light switches in office meeting rooms. Results showed that the prompts were effective and that occupants switched off lights when leaving the room more often when presented with a normative prompt than with a standard injunction. Additionally, an over reliance on PIR sensors to turn off lights after meetings was observed, which reduced their intended energy savings. We conclude that achieving low carbon buildings in practice is not solely a technological issue and that application of user-models from human-computer interaction will encourage appropriate occupant interaction with building controls and help reduce inadvertent energy consumption.

1. Introduction

Concerns surrounding anthropogenic climate change and energy security have compelled governments across the globe to impose strict targets for CO_2 emissions abatement. The UK government has committed to an ambitious 80% reduction, on 1990 levels, by 2050 [1]. As the operation of non-domestic buildings is thought to be responsible for as much as 18% of total UK CO_2 emissions [2] it represents a key area where substantial reductions will need to be made if these targets are to be met. One of the main policies which the UK government is employing to stimulate reduction within the built environment is through the introduction of gradually stricter CO_2 emissions targets in Part L building regulations. This has led to an increasing demand on the construction industry to deliver energy efficient buildings.

However, an established (and growing) body of evidence suggests that many supposedly energy efficient buildings do not, in practice, meet their intended levels of energy performance. In fact, associated CO_2 emissions are frequently more than twice the design expectations [3], a discrepancy which has been termed the 'performance gap' [4]. This situation is unsurprising as typical energy modelling calculations focus on compliance with Part L building regulations which was never intended to consider the actual in-use performance of a building.

The actual energy performance of a building can be considerably influenced by the actions of the building users, for example the introduction of additional plug loads [5], the operation of building service controls [6,7], or failing to switch of lighting and equipment when not required [8]. In general the construction industry has considered the delivery of low carbon buildings to be largely a technological issue and has focused on reducing the performance gap through improving thermal performance, increasing the efficiency of building services, and incorporating low/zero carbon

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technologies. From this viewpoint, occupants are often regarded as a hindrance to the building's performance and measures (such as automated controls) are taken to reduce the level of control that they have over their environment. For example, lighting accounts for around 16% of total electricity used in office buildings [9], so controls such as passive infra-red sensors (PIRs) are often employed to automatically switch off lighting when no occupancy is detected [10]. However, the results of occupant satisfaction surveys frequently indicate that their use in meeting rooms can be a source of occupant dissatisfaction as poorly calibrated PIRs will often inappropriately turn off lights during meetings [11]. A common alternative, to specify manual lighting controls for meeting rooms, provides users with an opportunity to adversely influence electricity consumption by leaving lights on when they are not required.

Efforts to reduce occupant related energy consumption in buildings either explicitly or implicitly subscribe to a '*rational choice*' model [12] which assumes that people will both interpret information as intended and act rationally to modify their behaviour in line with this. Energy-reduction campaigns therefore encourage the deliberate conservation of energy rather than aiming to reduce inadvertent energy consumption. This somewhat simplistic approach to the behaviour of the building users, which ignores the automatic and habitual nature of much behaviour, has been shown to be incomplete at best [13] and ineffectual at worst [14,15].

An alternative approach, adopted here, is to assume that building occupants are generally well-disposed towards energy conservation but are prone to inadvertent energy use from actions made (or not made) in error. Consider the common experience of sending an email and not realising that an intended attachment was not included until after the email is sent. This *post-completion error* [16] is a systematic, non-random error, a consequence of the routine, almost habitual, nature of the procedure, and the fact that the desired outcome (sending the email) is actually achieved before all the intended actions are accomplished. Further examples of errors of this type include leaving an original document on a photocopier, forgetting to replace the petrol-cap when refuelling a car, and failing to press "vote" after registering a preference on an electronic voting machine [17]. Such errors have been the subject of study in human-computer interaction for a number of years [e.g., [16],[18]]. However, the concept has not previously been applied to the interaction of occupants with building controls.

One reason for the neglect of post-completion errors in the study of the built environment is straightforward: in most studies of post-completion error there is an identifiable goal (the email is sent) embedded within a circumscribed task and the error can often be eliminated by restructuring the task and/or redesigning the relevant piece of machinery. For example, cash-machines (ATMs) dispense cash only after the user has retrieved their card. The goal (obtaining the cash) cannot therefore be achieved without first retrieving the card, eliminating this post-completion error [16]. Leaving the cash behind remains possible but is a rare occurrence because obtaining the cash was the goal of the transaction and – unlike leaving the card – forgetting the action which leads directly to the intended outcome only occurs under exceptional circumstances. Occupant behaviour within buildings, in contrast, is seldom so structured or as susceptible to analysis in terms of simple tasks with definable intended outcomes. The activities of occupants within non-domestic buildings can vary considerably, often in ways which could not be anticipated by the designers. Nonetheless, in the context of occupant use of building controls, post-completion errors could impact on building performance by increasing inadvertent energy use. For example, turning the lights on in a room in preparation for a meeting but then forgetting to turn them off as the room is vacated, or opening a window to ventilate a room but neglecting to close it afterwards. These basic features are common to almost all buildings, and reducing inadvertent post-completion errors of these types could help to reduce the impact that the occupants have on energy performance.

In the studies reported here, we assume that failing to turn off an energy source – in this instance lights in a meeting room – is a post-completion error. Individuals are aware that to do so would be of financial and environmental benefit and it is a low-cost physical operation (literally, flicking a switch) however they fail to do so, in part, because once the meeting is over the "goal" is completed. Failing to switch the light off may therefore be a post-completion error rather than a simple consequence of poor motivation. As such, a simple visual reminder present at the point at which the room is vacated should significantly reduce the incidence of lights remaining on in empty meeting rooms, and such a reminder should remain effective over a period of time. Although such interventions are cheap and easy to implement – and are often done informally – it is perhaps surprising that their effectiveness over both the short and the longer-term has not previously been evaluated.

2. Previous research findings

2.1. Occupant interaction with lighting controls

There has been much interest in developing models to predict occupant interaction with lighting controls in single-occupant rooms, such as cellular offices. Hunt [19] and Love [20] proposed functions for the probability of occupants switching on lights based on illuminance level. They concluded that artificial lighting is more likely to be switched on when illuminance at the working plane drops below approximately 100 lux and once on it is unlikely to be switched off until the occupant leaves at the end of the working day, although the reasons for this were not clear. Pigg et al. [21] studied light switching behaviour in 63 cellular university offices with different lighting configurations including manual switching only and manual switching with PIR sensors to turn lights off when no occupancy was detected for a 10 min period. Their results showed that length of absence (people were more likely to switch off lights when away for extended periods) and presence of PIR sensors (people were about half as likely to switch off lights when leaving a room with a PIR sensor than when leaving a room without one) were both strongly related to light-switching behaviour. These data suggest that, for cellular offices at least, not all failures to switch off lights are unintentional, as forgetting to do so is unlikely to be affected by these factors but there are also reasons to believe that this picture is incomplete.

A sophisticated and influential lighting algorithm called Lightswitch-2002 was developed by Reinhardt [22] to predict the probability of occupants switching lights on and off when arriving and leaving cellular offices. The algorithm was informed by field study data [23] and broadly collaborated Hunt's and Pigg et al.'s findings. In related work, Fabi et al. [24] also drew a distinction between 'active' and 'passive' situations for occupant interaction with lighting controls and they proposed different models for these different situations. Results from their field study showed that a range of environmental variables had a significant impact on light-switching behaviour including different illuminance levels and ratios within the room, but also indoor temperature. Interestingly, Fabi et al. also suggested that occupants are generally less likely to switch lights off than on because they are cued to switch lights on by poor visual comfort whereas there are no analogous cues for switching lights off. This result is consistent with the idea that providing appropriate visual cues to switch off lights will reduce the number of lights left on unnecessarily.