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A review of occupant-centric building control strategies to reduce building energy use

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ABSTRACT

Building Energy Management is identified as a key part of the move towards localised energy generation and control. The significant discrepancy between building energy use as designed and during actual operation shows a need to evaluate the relationship between building occupants and energy requirements. The need to better account for the influence of occupants on building energy use has been established through post-occupancy studies, highlighting the characteristics needed for more successful building control systems. This paper provides an overview of current building control systems technology and discusses existing academic research into more advanced occupant-centric controls. The potential for application of various methods is compared. It is found that study into occupant-centred control systems covers a wide array of approaches, ranging from simple presence-based switching of lighting systems to full model predictive control. Studies suggest an optimum point balancing the complexity of a system against its potential for saving energy.

1. Introduction

As energy generation for buildings becomes increasingly localised thanks to advances in renewable technologies, the mismatch between real-time energy generation and use leads to a need for effective localised energy control. The use of Building Energy Management Systems (BEMS) to cater building energy use directly to occupant needs has an important role to play in this system. This paper seeks to provide a review of approaches to energy management that place specific emphasis on collecting and reacting to real-time occupant data. This work builds upon the detailed review of the impacts of occupancy on energy and current capability of Building Energy Management solutions established in [1], with an emphasis on the methods and hardware used to accurately detect occupant data and a broader review on how this data is implemented intro building control. Through cross-review of the existing body of work in these fields, this study aims to highlight current issues/complicating factors in occupancy detection, emerging techniques/technologies and potential routes to improving the robust performance of occupant-centric building controls.

Data collected during building operation typically shows a significant difference between designed and actual energy use in buildings across multiple sectors, as shown in Fig. 1-1. Discrepancies between predicted and real building performance are caused by: underestimation of predicted values for reasonable building use during the design phase, potential construction defects causing deviation from the designed build quality, and excessively wasteful use of resources during actual operation. Both the design and operational issues are affected by the "inability of current modelling methods to represent realistic use and operation of buildings" [2]. Menezes et al. highlight the fact that occupant behaviour is one of the major factors contributing to excessive energy use during building operation, alongside effectiveness of services control and deviations from designed build quality.

The contribution of occupancy/occupant behaviours towards final energy use in buildings has been assessed in several studies. Simulation of different schedules and behaviours within commercial buildings has shown an occupant-dependent variation of from 30% [4] to 150% [5] of final energy use. Studies of control systems and real buildings have shown high variation in domestic electrical loads depending on occupant behaviours [6,7]. In commercial buildings, it was found that building services have poor response to occupant presence patterns [8], noting that energy used on HVAC was sometimes higher in unoccupied spaces than occupied [9]. This suggests the need for more occupancy-centric control systems.

Most research looking specifically at behavioural impact on building energy use shows that there is significant potential for energy saving through greater understanding of building use. The field of detailed exploration into occupant behaviour is relatively young, meaning that there is currently a lack of large-scale in-use data for buildings in the UK

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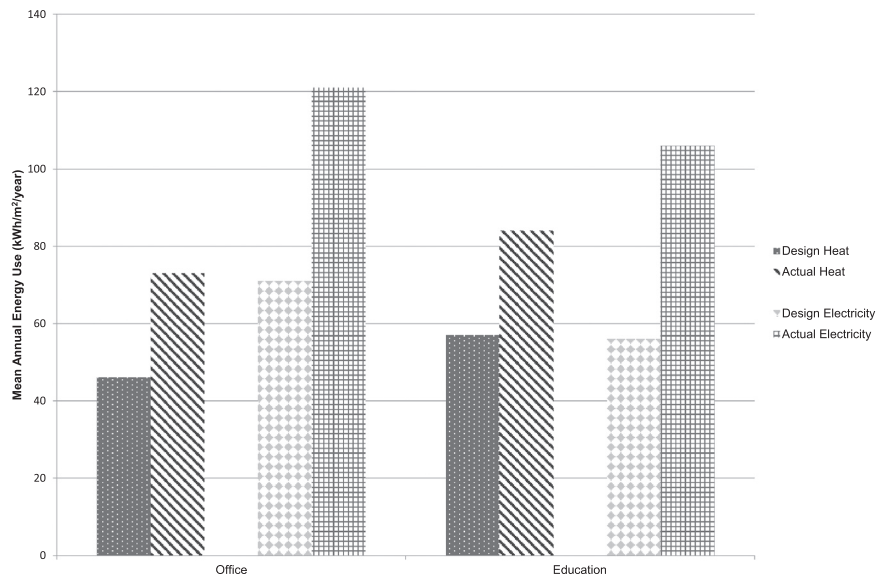

Fig. 1–1. Predicted versus actual energy use in commercial buildings [3].

Table 2-1
Comparison of major domestic heating controls packages available in the UK as of Q4 2017.

	Hive active heating 2 (2016) [17]	Nest v3 (UK) (2017) [18]	Heat genius (2016) [19]	Tado (2016) [20]	Honeywell evohome (2015) [21]
Multi-zone control	Up to 3 zones if boiler allows, no TRVs	Per thermostat if boiler allows, no TRVs	◆	Per thermostat, no TRVs	◆
Remote Control	◆	◆	◆	◆	◆
User Motion Sensing		◆	◆		
User Geolocation	Limited - prompts manual alterations	◆		◆	
Learning heat response		◆	◆	◆	◆
Weather data use		◆	◆	◆	
Additional features	• Security Integration	• Self-learning schedules[a] • Security Integration	• Modular • Further home automation	• Distance dependent temperature setback	• High control granularity

[a] Reviews indicate effectiveness of learning can vary [22].

[10].

2. Energy management systems – current state

As it has been seen that occupancy and occupant behaviours can significantly affect the way a building operates, it must be addressed whether current building control systems are operated sensitively in response to changing occupant needs. The automated control of buildings encompasses an array of different technologies and is described using many different terms. In this publication, the term Building Energy Management Systems (BEMS) is used.

2.1. Commercially available technology

Application of BEMS is highly variable in both commercial and domestic buildings. The general structure of BEMS can be defined as: a centralised management layer where general policies and decision making is applied, a field layer of local devices to measure and actuate changes to the indoor environment, and an automation layer interfacing between the two with localised controllers [11].

The area of energy and comfort management in buildings has received significant research interest over the last decade [12]. Despite this interest, an estimated 90% of current HVAC control systems do not run optimally [13], showing the need for an improvement in the way that controls are designed and implemented. Commercial systems tend to rely on pre-set working schedules, based on the occupancy patterns estimated at the building design stage. It has been found that such schedules can differ dramatically from actual use patterns, causing energy waste [14].

The last few years have seen a dramatic rise in commercial interest in energy management software and hardware, typically procured as a retrofit to existing or recently completed buildings. Often the retrofitted solution can only control the building's energy consumption so far as the existing sensing/actuation system allows; requiring the major overhaul of a full BEMS and significant physical changes for more comprehensive control. Due to increasingly cheap hardware including wireless sensors/actuators, and the availability of configurable software, the barriers to entry for more sophisticated energy management solutions have lowered in recent years.

Commercial reports hint towards the importance of the software intelligence and data analysis side of the BEMS business in the near future [15]. In the domestic field in particular, recent years have seen a large increase in the sophistication of occupancy-related tools in energy management: Table 2-1 summarises the capability of popular ‘smart’ domestic heating control systems. It can be seen that many major controllers are adopting learning algorithms and occupancy-responsive technology, facilitated by the wider availability of easily installed wireless sensors etc. Trends towards occupant-responsive systems and integration with personal devices for remote control can also be seen in popular home automation management hubs and software. These ‘central hub’ solutions typically offer a more open system compatible with third party hardware using multiple communication protocols