Energy and Buildings 104 (2015) 73–86

Contents lists available at ScienceDirect

Energy and Buildings

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

A case study on the individual energy use of personal computers in an office setting and assessment of various feedback types toward energy savings

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ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 13 June 2015
Accepted 4 July 2015
Available online 8 July 2015

Keywords:
Desktop computers
Energy savings
Office
Eco-feedback
Case study
User behavior

ABSTRACT

There is evidence that occupants' energy use holds a large fraction of the total energy consumed at the office. Our work, motivated by a relevant study investigating the effect of individual feedback on energy use at the workdesk, exploits earlier findings to design a six-month field trial that monitors occupants' energy use and provides individual feedback to 18 office employees in a university setting. This paper presents the research design and methods used, employing data analysis to assess how office workers responded to the feedback provided, and to examine their impact on the energy consumption of their desktop computers. The main findings were: the behavior of occupants affected the energy consumption of their computers in a large extent; emails were considered better communication channels than posters and leaflets; a combination of feedback messages was more useful, with personal advice, self monitoring and education being the most powerful; finally and most importantly energy reduction and proper use of equipment continued for 13 weeks after the feedback was removed.

1. Introduction

Commercial buildings are responsible for around 20% of the total primary energy consumed in the USA today [1], and this percentage is expected to increase by 36% in the next 15 years [2].

Miscellaneous electric loads (MELs) involve all non-main electric loads in offices, including desktop computers, printers, scanners etc. [3]. MELs consume more than one fifth of the electricity used in offices, and this figure is projected to reach 27% by 2035 [4]. Hence, MELs constitute one of the fastest growing sectors of energy consumers [5].

Although there is an abundance of literature on energy consumption been done on households, little research has yet investigated the energy use of MELs by employees in offices. The activity of occupants affects the overall office consumption, mainly by controlling personal equipment (computers, monitors and printers). The impact of occupants has been estimated to be around 20–50% of the total building's energy use [6,7]. Desktop computers (and their monitors) or personal laptops are the devices used most during the day by office workers [1].

Five field trials in offices, performed in southern Africa, discovered that 56% of the building's total electricity consumption happened during non-working hours [8]. A similar experiment in a university setting revealed that 10% of regularly used desktop machines were constantly powered on, 68% had night-time activity and 53% weekend activity [9]. Patterns of electricity wastage at night-time were observed, representing 5–6% of the school's total consumption. Webber et al. [10] calculated possible savings of 56% for desktops/monitors and 96% for printers by means of proper power management. These observations indicate that the appropriate use of desktop machines by office occupants has a large potential for energy savings in the offices.

2. Related work

Related work spans two dimensions: eco-feedback strategies used in offices for motivating occupants to reduce their electricity footprint; and studies on energy conservation interventions and campaigns.

2.1. Eco-feedback strategies

In the context of buildings, occupants' behavior is generally stochastic and complex [11]. Multi-faceted factors exist, which influence this behavior in the office space. These factors include

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http://dx.doi.org/10.1016/j.enbuild.2015.07.010
0378-7788/

comfort, culture, organizational norms, economy, physiology and psychology [12]. Barriers also exist, defined as "*internal and external factors prohibiting people from engaging in pro-environmental actions*" [13–15]. Finally, there are challenges such as the fact that office workers are not held accountable for paying their energy bills and difficulties in understanding organizational cultures and norms [7].

Exposure to eco-feedback impacts occupants differently in offices than in houses [16]. Well-accepted individual determinants of energy use at the office include (among others) attitude and knowledge, personal experience, locus of control (i.e. the extent to which individuals believe they can control events affecting them), self-efficacy, commitment, responsibility, perceived norms (i.e. perception of what others do and what others think) and environmental attitudes and beliefs [17–20]. Demographical determinants (gender, age, income) and external determinants on organizational activities and norms also relate in certain extent to energy use [16,21,22]. Multiple feedback types are better for generating positive response, activating different motives, beliefs and norms [23–25].

Instructional interventions (attitude and knowledge, environmental beliefs) are effective to change one's attitude and intentions while motivational and supportive interventions (self-efficacy, commitment) can be more effective to influence people when their anti-environmental behavior has become a habit [26]. Combining instructional and supportive interventions is generally more effective [23,27].

Regarding communication channels for giving eco-feedback to occupants, email seems to be an effective medium [23,28,29]. Other promising channels with encouraging results include desktop and web applications such as MyEco-Footprint [13] and BizWatts [16], social media [30] and peer-based dissemination of information [28,31].

2.2. Energy conservation campaigns

Two practical energy conservation interventions typically used in commercial buildings are advice and education [29,32]. Educating occupants can be accomplished by conducting workshops, or by assigning certain occupants with the task of promoting energy conservation practices amongst their colleagues [31]. These methods tend to be less effective than other methods such as eco-feedback [13,28,33,34].

The positive effect of frequent feedback to office workers in order to avoid wasting energy at their workplace was demonstrated through two methods applied in a research center [28]. The one involved group-level feedback presented to employees via e-mail monthly, while the other used peer educators to disseminate information and to encourage colleagues to reduce their energy use. Both interventions were compared to an information-only control strategy, designed to educate employees about how and why to conserve energy. Results indicated that feedback and peer education resulted in 7% and 4% reduction in energy use, respectively. The positive effect of eco-feedback was further demonstrated at the study in [33], in which employees who were provided with information on their energy expenditure and costs, reduced their energy use more than twice that of their colleagues.

Comparative feedback seems to be another important motivational factor for office occupants, as showed during the study in [34]. In this study, employees who compared their collective consumption with that of another group of workers had less energy-wasting behavior in regard to switching off lights and shutting off machines.

Foster et al. [7] concluded that the engagement in energy-saving campaigns at the office is strengthened by pecuniary incentives. In general, regarding persuasive technologies, incentives are stronger when they are tangible and realistic [35]. Moreover, social media can be used as improved communication channels between building occupants and operators [30].

Previous studies have been limited in measuring individual behavior in terms of consumption. For most of them, only the building's total monthly consumption was available, and hence only infrequent, group-level feedback was possible, leaving the role and behavior of individuals unexamined. However, frequent eco-feedback on personal consumption has the potential to influence people to reduce their consumption by fractions of 4–15%, at least in residential settings [36].

In one of the few studies measuring individuals' consumptions continuously in offices [16], a web-based eco-feedback application was used to demonstrate that organizational network dynamics can significantly impact energy conservation among occupants.

In a similar setting, Murtagh et al. provided important insights on the reasons why employees do not save energy at work, investigating their motives and perceptions [13]. In this study, 83 office occupants were provided with real-time feedback on their energy expenditure for 18 weeks. Reasons for energy-wasting behavior included a lack of motivations and personal goals. Reductions in energy consumption were recorded at the third and fourth month of the field trial.

The aforementioned study motivated the work of this paper, aiming to address its limitations and exploit its findings in order to influence office occupants to change their behavior when using their personal computers toward energy savings.

A main limitation of the relevant study was that it provided personal consumption feedback only, omitting to include other feedback strategies such as general education on good energy practices, personal targeted advice and social comparisons. Also, the study phases did not include a post-observation period after the interventions had been applied, hence the long-term changes in occupants' behavior could not be observed. Another limitation was the difference in hours of attendance due to the inclusion of post-graduate students (52%), researchers (34%) and lecturers (10%) in the sample, having different teaching duties and work deadlines each month. This difference was restrictive to assume a realistic office setting. Finally, the sample was more culturally diverse than a nationally representative sample, a fact that may have introduced variations in the findings.

3. Method

The study was performed in a recently built building called Ventus, hosting the Office of Environmental Sustainability at the National University of Singapore. It has total gross floor area of 5335 square meters with about 50 occupants working there in typical office hours. Its primary facilities include offices, meeting rooms and a resting lobby. Occupants include mainly administrative and technical support staff as well as employees providing managerial or supervisory tasks.

3.1. Research questions

The research questions of this study were:

1. To consider whether and how office workers affect the energy consumption at their desk.
2. To identify potential energy savings in the use of desktop computers by the occupants.
3. To understand which eco-feedback strategies (interventions) or combinations of interventions are more effective.
4. To assess various communication channels for providing feedback.