User Perceptions and Adoption of Plug Load Management Systems in the Workplace

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ABSTRACT

Smart energy management systems incorporate advanced sensing and control technologies that enable users to monitor and reduce their energy consumption through interactive visualisations and automated control features. Plug load management systems (PLMS), in particular, are applications of such systems targeting electrical devices found in homes and workplaces. While past studies have mostly focused on PLMS adoption in homes, past literature indicates several key differences in user motivation as office users typically do not bear the cost of their consumption. This reduces their motivation to embrace such systems, resulting in low adoption rates. In our research, we examined user perception of adopting PLMS in the workplace through a series of focus group discussions and an online survey guided by findings from the focus group discussions. By analysing the quantitative and qualitative responses from 101 participants, we identified six design implications to guide the development of future PLMS in the workplace.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **HCI theory, concepts and models**.

KEYWORDS

Smart Energy Management Systems, Office Workplace, Office Equipment, Plug Loads

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1 INTRODUCTION

Energy wastage in the workplace has become a critical social issue due to increased social awareness of the impacts of environmental pollution, accelerated by the rapid urbanisation in modern cities [1, 14]. While the growth in electronic device usage in the workplace has increased worker productivity over the last 20 years, the combined energy contribution of these devices now stands at over 30% of a standard office building's total energy consumption [17]. Based on the survey findings released by the Alliance to Save Energy (ASE) coalition, over 50% of office workers who use a desktop at work typically do not switch off their devices at the end of the day, resulting in an estimated cost of $2.8 billion every year in the United States [12]. Nevertheless, 20-38% of this consumption can be reduced by implementing smart energy management systems (SEMS) within existing workplaces [19].

Recent advancements in SEMS incorporate advanced sensing and IoT technology to help users monitor their energy usage and empower them to reduce their consumption through different control and automation features [29]. SEMS for office equipment uses smart power meters to track the energy consumption of individual devices and allow users to control the operation of their devices either remotely or based on a predefined schedule. These systems are known as plug load management systems (PLMS), where plug loads refer to electrical devices that draw power from the electrical sockets and excludes conventional heating, cooling, and lighting loads in the building [21].

Different intervention strategies have been proposed in the past and implemented within PLMS to encourage positive behavioural change among system users. These interventions include implementing eco-feedback systems that provide feedback to the user or a group of users on their energy footprint [9], introducing extrinsic or intrinsic incentives to encourage the adoption of sustainable practices [8], and the use of interactive games to increase user knowledge of different energy-saving strategies [15].

While past literature have mostly focused on studying PLMS within the context of residential homes [3], the study of the system's adoption in commercial workplaces remains relatively less studied. Furthermore, there are several stark differences between the residential and commercial contexts, such as the composition of plug load types found in both settings and office workers not having to bear the cost of their energy consumption. The latter reason poses a significant challenge in motivating users to accept and adopt PLMS within the workplace [19]. This issue is exemplified during a recent NREL study where they reported limited success during a field implementation of a PLMS as users were observed not using the system as initially intended [11]. Apart from not utilising the dashboard interface to monitor their energy consumption, some users were even observed to unplug the system's sensors from the electrical sockets, thereby limiting the system's ability to monitor and manage the plug loads in the study area. Therefore, the overall effectiveness of PLMS depends heavily on users' acceptance and perceptions towards the technology.

The objective of this study is to gain a better understanding of users' perception of adopting PLMS in the workplace. A 2-stage data collection approach was adopted, consisting of a series of focus group discussions followed by an online survey. The responses collected from a total of 101 participants were analysed using thematic analysis and combined with the qualitative results from the online survey to identify six design implications for future PLMS in the workplace.

2 RELATED WORK

This section provides a thorough review of prior studies investigating the adoption and implementation of SEMS in homes and workplaces.

Starting with the studies conducted in residential homes, Shuhaiber and Mashal [18] attempted to identify the significant factors influencing user acceptance of smart home systems by proposing a theoretical model based on the Technology Acceptance Model (TAM) [5]. The study concluded that perceived usefulness, attitude, and trust were significant factors influencing people's intention to adopt such systems, while perceived risk and lack of awareness negatively impacted technology adoption. Using a modified version of TAM, Whittle et al. [27] conducted a similar study by considering other factors such as subjective norms, image, perceived voluntariness, environmental world, and goal internalisation. The study found that the participants were generally positive about adopting smart home systems and suggested using practical design elements to improve their relevance within existing homes. Another study conducted by Jensen et al. [10] also identified ten desirable characteristics of a smart home system to ensure a pleasurable user experience and encourage users to reduce their energy consumption by adopting such systems. Castelli et al. [20] highlighted the importance of presenting information relatable to the users by proposing a flexible smart home interface that allowed users to build customisable dashboards to suit their diverse information needs.

As compared to residential homes, relatively few studies can be found investigating the adoption of SEMS in the workplace. A case study conducted by Coleman et al. [4] found that office users were generally optimistic about adopting wireless technologies in the workplace to monitor their energy consumption but preferred the information to be presented in the appropriate units, increases their energy awareness, and allows for historical comparison. Papagiannanidis and Marikyan [16] also highlighted several barriers to smart technology adoption in the workplace, such as limited monetary budget, low labour force skills, lacking compatibility with existing technological infrastructure, and organisational distrust. Finally, one of the most relevant works is a study conducted by Foster et al. [7], which investigated users' perception of energy use in the workplace by conducting a series of workshops where participants were asked to complete a survey on different energy visualisations and designed a 12-month energy intervention plan for their workplace. Based on an analysis of the participants' responses, the authors identified six design implications, namely incentives, engagement, openness, leadership role, communication, and visualisation.

Given the differences in user motivation between the residential and workplace context and the low adoption rates reported during previous studies that attempted to introduce PLMS in commercial spaces [11], this study addresses a critical research knowledge gap present in the literature by attempting to understand users' perception, concerns, and motivations when adopting such systems in workplaces.

3 METHODOLOGY

3.1 Study Design and Data Collection

We adopted a 2-stage data collection approach consisting of a series of focus group discussions followed by an online survey, which was refined based on the responses obtained during the focus group discussions. Our target audience was office users between the ages of 21 and 65, and they were recruited using a snowball sampling approach. Due to the social distancing measures imposed because of COVID-19, both data collection stages were conducted online. Informed consent was also obtained for all studies in line with our Institutional Review Board (IRB) approved protocol.

3.1.1 Stage 1: Focus group discussions. We conducted multiple focus group discussions with office users to gain a preliminary understanding of their perceptions of adopting PLMS in the workplace. The purpose of commencing the study with a focus group discussion was to facilitate an open discussion and allow participants to freely share their thoughts about different topics related to PLMS without being restricted by the predefined options presented in standard questionnaires.

The focus group discussions were conducted with 15 participants divided into three groups. Each group consisted of five participants from different age groups, genders, and industry sectors to ensure fair representation. The focus group discussion was divided into two main sections, where the participants were asked to share their current plug load management habits and their general thoughts and concerns on adopting PLMS in the workplace. Each focus group discussion took around 1 to 1.5 hours and was audio-recorded and transcribed after each session. The participants were also given the option to opt-out from being audio recorded per IRB guidelines.

3.1.2 Stage 2: Online surveys. The online survey followed a similar structure as the focus group discussion but, at the same time, contained more targetted questions related to the participants' current plug load management habits and general perceptions of PLMS, based on the responses obtained during the focus group discussions. Some examples of these questions includes the participants' demographic information, their switch off habits when leaving their desks during different periods of the day, rating between different motivational strategies when adopting PLMS in the workplace, different attributes and features of an ideal PLMS, and their concerns when assuming such systems. The options listed in each close-ended question are predefined based on the common responses recorded during the focus group discussions and the factors considered in past literature to ensure comprehensiveness. Each close-ended question also came with an "Others" option to allow the survey respondents to provide other responses not listed in the existing set of options. Furthermore, despite almost half of the participants in the focus group discussion having some prior knowledge of SEMS, the research team still observed some unfamiliarity when it comes to the system's specific features. Therefore, by taking note of some of the common questions raised during the focus group discussions, we have included helpful visualisations and detailed explanations in the questionnaire to provide the participants with the necessary information to answer the questionnaire without supervision.

The online survey was distributed via various online channels to reach a larger group of participants and obtain a more accurate representation of the target audience. In the end, we received 86 respondents from different age groups, genders, and industry sectors.

4 RESULTS AND DISCUSSION

In this section, our analysis was based on the qualitative and quantitative responses collected during the focus group discussions and online survey.

The qualitative analysis was conducted in two phases. The first phase involved an open coding process, which required the research team to manually trawl through the participants' responses to obtain a set of conceptual categories that encompassed the common themes found in the responses. These categories were External and Internal Influence, User Control, Ease of Use, Reliability, User Appeal, and Privacy. The second phase of the analysis involved thematic coding, where three researchers, who were not involved in the open coding process, were asked to independently go through the participants' responses and assign a category to each sentence based on the six categories provided [2]. At the end of the thematic coding process, we computed the inter-rater reliability score between the three coders using the Fleiss Kappa statistic to obtain a high agreement score of 0.76.

The following findings are presented based on the six conceptual categories identified during the open coding process. All qualitative responses are tagged with a unique ID that indicates the data collection approach and entry number. For instance, FG-101 refers to the 101st entry obtained during the focus group discussion.

4.1 External and internal influence

External influence refers to extrinsic factors that are not within the user's control but have a discernible impact on his decision to adopt the technology. On the other hand, internal influence refers to intrinsic factors that originate within the user and drives his decision to adopt the technology.

The effect of external influence can be observed when the survey participants are asked to rate the effectiveness of different motivational strategies in adopting PLMS in the workplace (refer to Figure 1). Many participants agreed that external influences, such as complementary company policies would be moderately effective in motivating PLMS adoption in the workplace, with an average rating of 3.95 out of 5. Furthermore, this result is supported by the responses obtained during the focus group discussions where 77% of the participants indicated that they would adopt the technology at their workplace if the initiative was also encouraged by their supervisors and adopted by their colleagues. Therefore, while the technology can be initially introduced as a top-down initiative by the management team, there is a need for appropriate policies and workflows to be in place to encourage the organisation to work collectively to sustain the initiative. This finding aligns with Dearing et al. [6] and Venkatesh et al. [26] in highlighting the positive impact of external influences, with organisational leaders playing a pivotal role in ensuring the successful adoption of sustainable practices [23].

Another common strategy raised during the focus group discussion was introducing competition or games between different individuals or departments to motivate more users to adopt PLMS in the workplace (26%). This finding was also supported by [7], which highlighted the usefulness of using gamification approaches to motivate system adoption.

FG-64: "...some sort of gamification of the system can encourage users to compare their progress with others in the office."

However, a contradictory view was highlighted by a significant group of participants (32%) who indicated that while this approach might reduce energy consumption in the short run, they are concerned that it might have an adverse impact in the long run when users become demoralised or disinterested when the competition becomes too toxic. Furthermore, there were other concerns regarding the fairness of such competitions as some departments may consume more energy than others due to the nature of their operations. The survey results (refer to Figure 1) further supported this view as conducting competitions within the company was the least popular approach, with an average rating of 3.09 out of 5, in motivating users to reduce their energy consumption and adopt PLMS in the workplace.

Instead of competing between different users or departments, many participants, interestingly, expressed a stronger preference for benchmarking their current energy consumption against their historical consumption as a more accurate gauge of their performance. This benchmark can be calculated based on a moving average of their daily or monthly consumption, and users will be informed when they have exceeded this threshold. Some participants (10%) have also stated that it would be helpful if the system could suggest a recommended consumption level based on each user's consumption patterns.

FG-78: "...a moving average based on my daily or monthly consumption would be useful to help benchmark my performance and check my progress." and FG-109: "I would like to see a specification of an ideal consumption compared to actual consumption, and warning me when I exceed the average usage..."

Based on the findings related to the different external and internal influences, the first design implication is for companies to

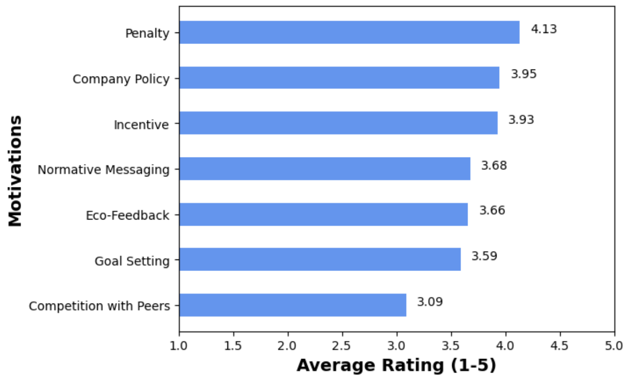

Figure 1: Average ratings that describe the effectiveness of different motivational strategies to encourage PLMS adoption in the workplace. A high score of 5 indicates that the strategy is very effective, and a low score of 1 indicates that it is not effective.

supplement the technology with the appropriate organisational policies and workflows to demonstrate their support for collectively adopting the technology while evaluating users based on their personal progress.

4.2 User control

User control relates to the amount of control that a user would prefer to have when using a system to manage his energy consumption.

The importance of user control was demonstrated when the survey participants are asked to rate a list of attributes that should be included in an ideal PLMS (refer to Figure 2). The participants responded by indicating that the second most important attribute in an ideal PLMS was allowing users to have more control over different plug loads. Moreover, while the survey participants were generally receptive to adopting PLMS in the workplace, most of them (71%) preferred to have a semi-automated system that allowed them to provide their preferred control settings. Only 25% of the participants indicated that they were comfortable with a fully automated system, while the remainder of the participants indicated that they are not comfortable with an automated system.

Moreover, when it comes to the desired level of control they would prefer to have when using the system, interestingly, many participants from the focus group discussions mentioned that the ideal control level would depend on the plug load type. For instance, some participants (31%) would prefer to have more control over plug loads that they deemed more critical such as laptops and desktops, while they are willing to give up control over auxiliary devices such as task lamps and fans since they can be easily switched back on. Furthermore, most participants (86%) preferred to have the ability to adjust the settings of certain control features in the system and even override the system manually as a fail-safe.

FG-88: "If the presence or scheduling-based controls were in place, I would want a system where you can overwrite your existing control settings.", FG-125: "...there should be an option to manually overwrite everything if needed."

Therefore, the second design implication involves including features that empower users to have more control over the system's operation and enable customisation to fit their preferences. The system should also have a fail-safe mechanism so that users can regain full manual controls if desired.

4.3 Reliability

System reliability refers to the system's ability to operate in a stable and predictable manner.

The influence of system reliability was highlighted when the survey participants were asked to rate a list of possible concerns when using an automated PLMS (refer to Figure 2). Interestingly, the participants' top concern was related to the system's reliability, with an average rating of 4.29 out of 5, as they were worried about the system incorrectly switching off their plug loads while they were still in use. These views were also echoed during the focus group discussions, as many study participants (92%) expressed strong concerns that the system would malfunction and unexpectedly switch off their plug loads while still in use.

FG-49: "I am concerned that my devices may get switched off even when I do not want them to be switched off."

Therefore, the third design implication involves prioritising features that recognise critical devices required by the users to operate reliably and initiate a graceful recovery during system failure. One such example is computers running critical programs where the development of shims could help save the programs' state to be continued at a later time.

4.4 Ease of use

Ease of use refers to how easily users can learn to use the technology to manage their energy consumption and adopt it in the workplace with minimal disruption to their current workflow.

Not surprisingly, a system that is intuitive and convenient to use was rated as the most important attribute for an ideal PLMS by the survey participants with an average rating of 4.33 out of 5. The majority of the study participants (91%) from the focus group discussions also indicated that the general design of the PLMS should be simple and intuitive to use so that it can be adopted with minimal guidance, aligning with the findings from Venkatesh et al. [26].

A significant portion of the study participants in the focus group discussions (83%) also indicated convenience as a major contributing factor to system adoption. This preference aligned with the results from Figure 2, where the survey participants' second topmost concern was that the system would be too troublesome or inconvenient to use, with an average rating of 3.83 out of 5. Furthermore, some study participants (37%) also indicated that since they were already actively managing their energy consumption by switching off their devices at the end of the day, they would prefer a system that would make it more convenient for them to continue doing so.

FG-66: "I think convenience and accessibility of the energy management system are the most important factors for me.", S-15: "The convenience and ease of access to the application, on top of simple user interface, is good for the consumers."

Therefore, the fourth design implication involves developing a system with a simple and intuitive design so that it can be adopted

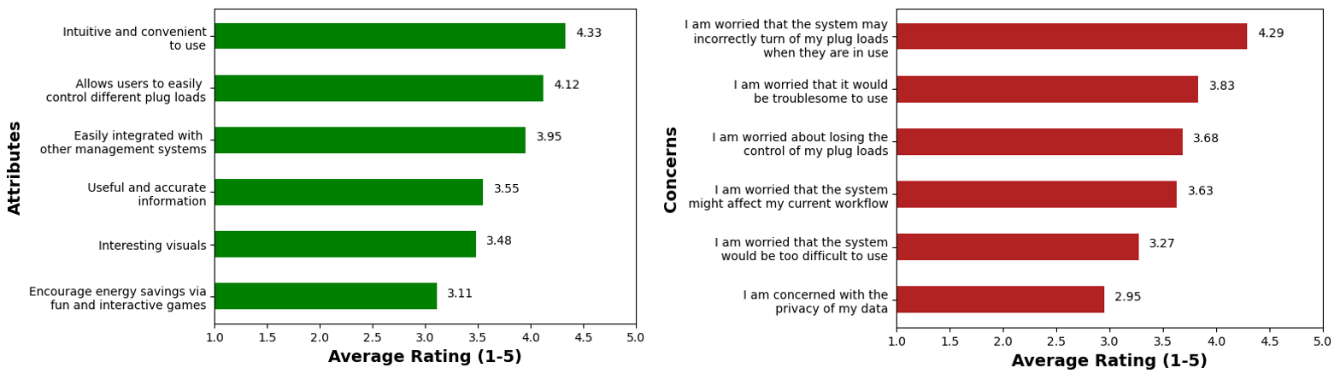

Figure 2: Average ratings that describe the attributes of an ideal PLMS (Left) and concerns when using an automated PLMS (Right). A high score of 5 indicates that the attribute or concern is very important and a low score of 1 indicates that it is not important.

with minimal guidance and does not intrude upon or significantly affect the users' current workflow.

4.5 User Appeal

User appeal refers to the technology's ability to attract user interest and maintain long-term engagement and acceptance from its users.

It was observed from Figure 1 that the inclusion of incentives, with an average rating of 3.93 out of 5, would be effective in motivating users to reduce their energy consumption through PLMS adoption. When the survey participants were further asked to rate the different types of incentives that they would prefer to receive, most respondents preferred financial incentives (76%) over other incentives such as self-accomplishment (6%) and social recognition (18%). This preference was also echoed during the focus group discussions, where a significant portion of the responses were related to providing users with financial incentives based on the amount of energy savings contributed. However, a small group of participants (6%) also questioned the long-term effectiveness of such monetary rewards, especially if the amount awarded is too minuscule.

FG-10: "...office users could be given bonuses depending on the amount of energy saved.", FG-60: "...some sort of reward system that could be redeemable for perks at work such as free snacks or coffee.", FG-93: "If there were vouchers or partnerships with different shops, that would encourage me too."

Apart from introducing incentives to encourage the adoption of PLMS, another potentially controversial but seemingly effective motivational tool was the introduction of penalties with an average rating of 4.13 out of 5, and this involves asking the office users to pay for any excessive energy usage while in the workplace. This approach directly addresses the critical difference between the users' motivations at home and in the workplace as they typically do not pay for their energy usage in the latter scenario. Unfortunately, the real-world effects of this approach are not well investigated and will likely be unpopular within the organisation.

The fifth design implication involves complementing the technology with a suitable incentivisation and penalty system to ensure long-term user engagement and adoption of the system.

4.6 Privacy

Privacy refers to the users' right to control how their personal information will be used and who will have access to it.

It was observed from Figure 1 that the issue of privacy was of low concern to the survey participants when compared to the other concerns listed, with an low average rating of 2.95 out of 5. This result contradicted the findings from [7, 18], which highlighted the importance of maintaining user privacy. Among the participants concerned about their data privacy, they were apprehensive about who will have access to their data and whether it will be misinterpreted. One of the most common examples raised by participants was the fear of being continuously monitored by their supervisors and mistaken as slacking off because they were not at their desks. Other participants were concerned that their energy consumption information will be used as another evaluation metric for their job performance and be passed over for a raise or promotion if they did not conserve enough energy.

FG-47: "I am concerned that my supervisor would be able to find out that I am not at my desk when I am supposed to be.", S-10: "It should have a good security system to ensure that no unauthorized people will have access to the data collected by the sensors."

Therefore, the last design implication on privacy is introducing system features that perform encryption and anonymisation of the users' data during transmission and storage while restricting data access to authorised personnel only. Users should also have full knowledge of the parties who have access to their data and be ensured that their consumption will not be used as an indicator of their job performance.

5 CONCLUSION AND FUTURE WORK

In this study, we attempted to better understand user perception in adopting PLMS in the workplace by following a 2-stage data collection approach involving focus group discussions and an online survey. The qualitative responses were analysed using thematic analysis to identify six conceptual categories, including External and Internal Influence, User Control, Reliability, Ease of Use, User Appeal, and Privacy. By supporting the qualitative analysis with the quantitative results from the online survey, we identified six design implications to guide the design of future PLMS in the workplace. While some of our findings aligned with previous studies conducted in residential homes, there were several interesting findings unique to the workplace context. These include a preference for self-comparison over competing with other users, desiring different user control levels depending on the plug load type, reliability concerns, introducing penalties to discourage excessive energy use, and minor concerns related to data privacy.

Future extensions of this work will include conducting a laboratory study where participants can interact with different system prototypes developed based on the design implications identified in this study. This allows for a more accurate evaluation as it reduces any biases that originate from the participants' prior beliefs and allow them to experience using different control features. An example includes occupancy-based controls, which leverages advanced indoor localisation techniques [22, 24] to automate the users' plug loads based on their presence information. Furthermore, given the users' preference for customising the control settings for different plug load types, different machine learning models [13, 28] can be integrated into the PLMS to enable real-time identification of different plug load based on its energy signature [25].

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