The Impact of Eco-Feedback on Energy Consumption Behavior: A Cross-Cultural Study

Jing Lin [a], Nan Li [b], Guofeng Ma [a] and Junjie Zhou [a]

[a] Department of Construction Management and Real Estate, Tongji University, Shanghai 200092, China
[b] Department of Construction Management, Tsinghua University, Beijing 100084, China
E-mail: 5_linjing_jocelyn@tongji.edu.cn, nanli@tsinghua.edu.cn, guofengma@tongji.edu.cn, 1432701@tongji.edu.cn

Abstract –

To reduce energy consumption in buildings, researchers have in the recent decade explored the potential of changing occupants' energy consumption behaviors using eco-feedback technologies. Energy consumption behavior is a type of consumer behavior, which has been proven cultural-specific in prior research. This paper aims to examine the impact of cultural differences on the effectiveness of eco-feedback technologies in reshaping building occupants' energy consumption behaviors. Energy consumption monitoring instruments were installed in four student dormitories, three resided by Chinese students and one by international students. The daily energy consumption of every unit in the dormitories was monitored. A web-based eco-feedback system was developed, which was responsible for sending weekly email reminders to students participating in the study and, upon their logins, providing them with their detailed energy consumption data as well as those of their peers. Changes in the students' energy consumption behaviors were analyzed, and correlated with their cultural background, which was assessed using a survey instrument designed based on Hofstede's dimensions of culture. Results proved that cultural background assessed in certain dimensions were significantly correlated with the effectiveness of eco-feedback technologies. The results suggested that eco-feedback technologies should be tailored to specific cultural context to maximize their effectiveness in building energy conservation.

Keywords –

Cross-cultural; Behavior; Eco-feedback; Energy consumption

1 Introduction

Global carbon dioxide (CO_2) emissions have been continuously increasing in the past decades [1], 11% of which was accounted by electricity and heat production consumed in the residential sector [2]. Thus, reducing residential energy consumption can significantly reducing global CO_2 emissions. Many energy saving technologies, such as energy-efficient lighting and thermal insulation materials, have been developed in recent years to improve residential energy efficiency. However, as these technologies are adopted, a "take-back" effect is observed. This effect refers to the phenomenon that effectiveness of the energy-saving technologies decreases due to inefficient energy consumption behaviors by users [3]. Therefore, more recent research has indicated that changing users' energy consumption behaviors is of significant importance in achieving long-term energy conservation [4]. Based on the premise that awareness of actual consumption will motivate energy conservation behavior of occupants [5], many researchers have studied eco-feedback systems which, designed to monitor and present occupants' energy consumption data [6], are believed to have the potential of changing occupant's energy consumption behaviors. The effectiveness of eco-feedback systems has been validated in a number of studies. However, the effectiveness is observed to vary across different settings [7,8], and is reportedly affected by factors such as interface design [9], information representation [7], social influence [10], and so on. One factor that is potentially important but has yet to be examined in the literature is the culture context. Energy consumption behavior by its nature is a type of consumer behavior, which has been proven culture specific in prior research [11]. This paper aims to examine whether the effectiveness of an eco-feedback system is impacted by the cultural background of building occupants whose behaviors the system aims to change. The remainder of this paper is organized as follows: section 2 presents related research, followed by section 3 that introduces the settings of an eco-feedback system developed in this study. Section 4 describes the design and implementation of an eco-feedback experiment. Section 5 then presents findings of this study. Section 6 concludes the paper.

2 Related Research

2.1 Factors Influencing the Effectiveness of Eco-Feedback Systems

The use of eco-feedback system has been reported in prior research to result in reductions in energy consumption that varied between -18% and 55% [7,8]. Such wide range has motivated many researches that focus on identifying and assessing factors that may influence the effectiveness of eco-feedback system, and developing a more effective way of designing and implementing eco-feedback systems. Peschiera et al. [12] reported in their study that weekly email reminders would cause response–relapse behavioral pattern that were impactful on the energy-saving effectiveness. They reported significant energy conservation when test subjects received weekly email reminders. However, their energy consumption quickly relapsed to pre-study levels after they stopped receiving the reminders. The format of information representation could also impact the effectiveness of eco-feedback systems [7]. Another way to improve the effectiveness of eco-feedback is to include users' energy consumption history and their peers' energy consumption data, which could serve to motivate energy-saving behaviors [9,10]. Computerized methods are considered the most effective for delivering eco-feedback information [13]. For instance, interface websites could be used to enable better interactivity of eco-feedback than traditional energy bills, and emails could be used to enable higher frequency of the eco-feedback information being read by energy users. These two methods of delivering eco-feedback information could also be combined to further improve the effectiveness of eco-feedback systems [9].

One factor that has not been thoroughly examined is the characteristics of energy users. When studying the effectiveness of in-home-displays, a typical type of eco-feedback system, Van Dam et al. [14] argued that "a one-size-fits-all approach for in-home-displays cannot be justified", which highlights that the performance of eco-feedback systems is dependent on the characteristics of the users. In fact, it has been reported that not all consumers have the potential of saving energy consumption by using eco-feedback system [15]. Therefore, to make eco-feedback systems work, it is necessary to consider the characteristics of their users, for instance, their cultural background, and to provide a certain level of customization.

2.2 Cross-Cultural Study of Consumer Behaviors

It is a proven theory that culture "is a determinant of certain aspects of consumer behavior " [16]. Culture can impact consumer behaviors through values, heroes, rituals, and symbols [17]. In addition, there are factors that can affect both culture and consumer behavior. Examples include personality, social processes and mental processes [16].

There are two types of approaches to analyzing culture, including etic approaches and emic approaches [18]. Etic approaches define culture as "the collective programming of the mind which distinguishes the members of one group or category of people from another" [19]. This definition emphasizes the comparison among different cultures. Emic approaches, to the contrary, focus on understanding within the culture, where culture is defined as "the 'lens' through which all phenomena are seen". It determines how these phenomena are apprehended and assimilated, and considers values the central views of culture. Hofstede's cultural dimensions model, which adopts the etic approach, is usually used to measure the cultural values for cross-culture comparison purpose [19].

3 Eco-Feedback System

An eco-feedback system was developed for this study. The system consisted of two components, including a data capture component and a data processing and delivery component, as demonstrated in Figure 1. The data capture component included electric meters, concentrators, cables and two servers. Electric meters, each responsible for monitoring one unit in a building, were connected to a concentrator through cables in every building. The concentrators reported to a server to upload the latest readings of energy consumption in a MySQL database, where the data were analyzed and prepared for delivery to the occupants. The delivery component was composed of an interface website that allowed for online checking of current eco-feedback, and an email portal for sending automatic weekly emails to the occupants reminding them of checking eco-feedback information through the website. The following information was presented to the occupants once they logged into the website: (1) an overview of their energy consumption of the previous day, the last seven days and the last thirty days, all measured in kWh; (2) a list of navigation options, including reviewing the charts of daily consumption of the last seven days and thirty days, changing display language, and changing account settings; (3) charts of the users' daily energy consumption of the last seven days and thirty days, as well as of the average of their peers whose rooms were on the same floor and with the same orientation (south or north); (4) contact information of the research team for assistance and feedback.

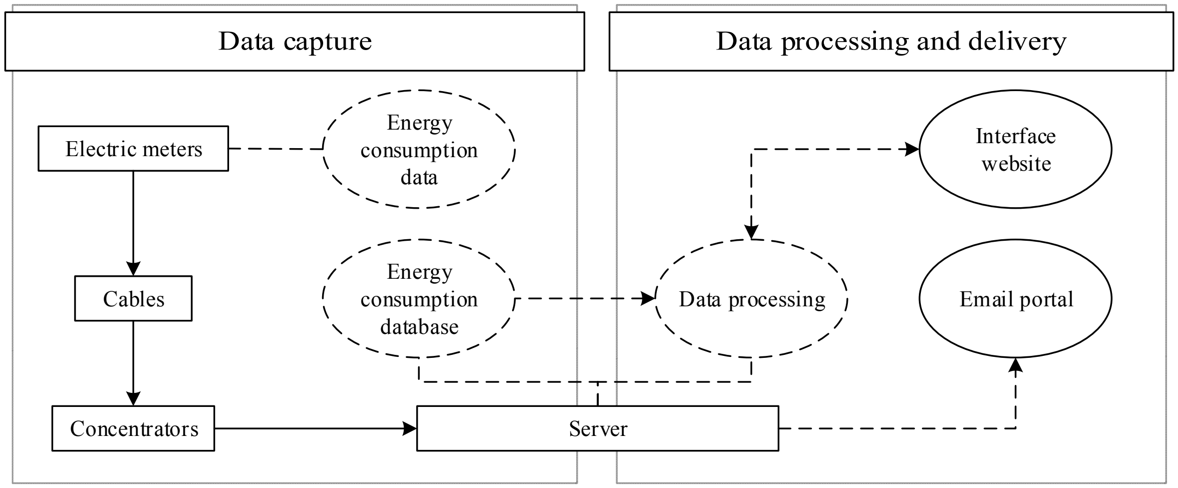

Figure 1. Architecture of the eco-feedback system developed in this study

4 Cross-Cultural Eco-Feedback Experiment

4.1 Test-bed Buildings and Participants

For empirically comparing the effectiveness of eco-feedback system in changing the energy consumption behaviors of occupants having different cultural backgrounds, an experiment was carried out in this study. The test-bed buildings used in the experiment were four six-story dormitories on the campus of Tongji University in Shanghai, as shown in Figure 2. Each unit in the dormitories had an area that varied between 8m^2 and 13.77m^2, included a bathroom, a bedroom and a balcony, and could accommodate one or two students. Chinese students lived in buildings 1, 2 and 3, and international students lived in building 4. All units involved in the study had stand-alone air conditioning units installed during the experiment period.

Figure 2. Test-bed Building

A total of 39 occupants in the test-bed buildings participated in the experiment, including 10 Chinese students and 29 international students who were from Germany (16), Italy (5), France (2), USA (1), Ethiopia

(1), Montenegro (1), Portugal (1), Sweden (1) and Switzerland (1). These participants all lived in single units, so that each electricity meter was associated with one participant. All other single units in the test-bed buildings were also monitored by the eco-feedback system, and their occupants, though not directly invited to participant in the experiment, were considered in control groups. Participants were recruited with face-to-face interviews, during which they were explained the purpose of the study, informed that they would receive weekly emails to remind them of checking the energy consumption information through the website, and provided with an individual login account to the website. Participants filled in a questionnaire about their personal information, such as email address, gender, education, age and so on. Gift cards were given to thank them for participating in the study. All single unit occupants in the test-bed buildings were divided into the following four groups:

- Study Group A (SG A) – Chinese occupants invited to participate in the experiment and provided with online eco-feedback and weekly email reminder.
- Study Group B (SG B) – International occupants invited to participate in the experiment and provided with online eco-feedback and weekly email reminder.
- Control Group A (CG A) – Chinese occupants having no access to eco-feedback.
- Control Group B (CG B) – International occupants having no access to eco-feedback.

The experiment lasted for 13 weeks from October 17 , 2015 to January 15, 2016. It included two periods, a pre-study period and a study period. The pre-study period lasted for 6 weeks from October 17 to November 27, 2015, before the participants were recruited. Daily energy consumption data were collected during this period and used for offsetting the effect of inherent difference between groups. The study period lasted for 7 weeks from November 28, 2015 to January 15, 2016, and daily energy consumption data were collected during this period for analyzing the effectiveness of eco-feedback system upon study groups. During the study period, participants received emails every Monday reminding them of logging into the website to check their the eco-feedback information.

4.2 Six Dimensions of Culture

The Hofstede's cultural dimensions model was applied in this study to compare participants' cultural background. Hofstede defined six dimensions of national culture, including Power Distance Index (PDI), Individualism vs. Collectivism (IDV), Masculinity vs. Femininity (MAS), Uncertainty Avoidance Index (UAI), Long Term Orientation versus Short Term Normative Orientation (LTO), and Indulgence vs. Restraint (IND) [17]. PDI represents the degree to which the less powerful members of a society accept and expect that power is distributed unequally. The fundamental issue here is how a society handles inequalities among people. IDV represents the contrast between individualism, a preference for a loosely-knit social framework in which individuals are expected to take care of only themselves and their immediate families, and collectivism, a preference for a tightly-knit framework in society in which individuals can expect their relatives or members of a particular in-group to look after them in exchange for unquestioning loyalty. MAS represents the contrast between masculinity, a preference in society for achievement, heroism, assertiveness and material rewards for success, and femininity, a preference for cooperation, modesty, caring for the weak and quality of life. UAI represents the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity. Societies exhibiting strong UAI tend to maintain rigid codes of belief and behaviors and are intolerant of unorthodox behavior and ideas. LTO represents the degree of consideration of the future when a society deals with challenges. IND represents the attitude of a society in meeting needs of life, indulgence or restraint.

The VSM 2013 survey instrument was employed in this study to assess the cultural dimensions of the experiment participants [20]. This survey instrument is a 30-item paper-and-pencil questionnaire developed for comparing culturally influenced values and sentiments of similar respondents from two or more countries, or sometimes regions within countries [21]. For each of the six dimensions of culture as defined by Hofstede [17], the survey presents four relevant questions, and provides a technique for computing a score for the dimension based on answers of survey respondents. Six additional questions are about demographic information of the respondents, including their gender, age, education level, kind of job, present nationality, and nationality at birth. All 39 participants were surveyed in this study. Scores of each participant in each cultural dimension were calculated, then averaged per nationality, and related to the participants' behavioral responses to the eco-feedback system, in order to examine the correlation between each cultural dimension and the effectiveness of the eco-feedback system. Details of the analysis and findings are presented in the next section.

5 Findings

A total of 20,304 daily energy usage data points were collected, including 897 data points for SG A, 2,745 data points for SG B, 10,029 data points for CG A, and 6,633 data points for CG B. The statistical method used for measuring the effectiveness of eco-feedback was similar to the one used in prior research [7]. The statistical difference in energy consumption resulting from the eco-feedback information, which was an indicator of the effectiveness of the eco-feedback system, was calculated as follows:

$$\delta_{pre-study} = \frac{\sum_{i=1}^{n}((P-C)/C)}{n} \quad (1)$$

$$\delta_{study} = \frac{P-C}{C} \quad (2)$$

$$\Delta_{consumption}(\%) = \delta_{study} - \delta_{pre-study} \quad (3)$$

where P denotes the energy consumption of a given room on a given day, C denotes the average daily consumption per unit in CG, $\Delta_{consumption}$ denotes the statistical changes of a SG in energy consumption, relative to the corresponding CG, between the pre-study period and the study period, $\delta_{pre-study}$ denotes the average percentage difference between P and C for the pre-study period, δ_{study} denotes the percentage difference between P and C for the study period, and n denotes the number of days of the pre-study period..

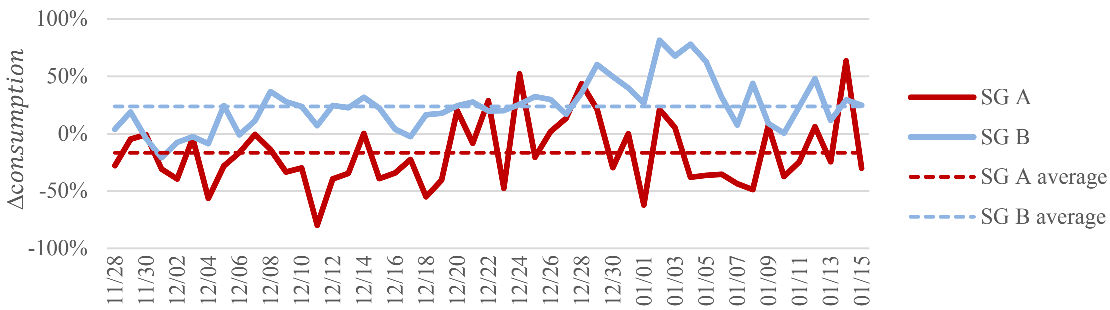

Figure 3. Plot of changes in daily energy consumption between SG A and SG B

The effectiveness of the eco-feedback system was thus calculated for both SG A and SG B, and these two groups were compared. Figure 3 shows the changes in consumption relative to the corresponding control group ($\Delta_{consumption}$) for each day during the study period for both SG A and SG B. As can be seen in Table 1, SG A reduced their energy consumption by 16.7% after using the eco-feedback system, whereas SG B increased their energy consumption by 23.7% during the same period. The results suggested that cultural background significantly influenced the effectiveness of eco-feedback system, which was also supported by a t-test carried out between these two groups, with a p-value of 0.000, rejecting the null hypothesis that SG A and SG B had the same behavioral response to the eco-feedback system. It need to be noted that it was interesting to observe an increase in the average energy consumption of international students after the eco-feedback system was implemented. A possible explanation was that, unlike Chinese students, energy bills of international students were paid by the university, so it was difficult to motivate them to save energy by simply presenting the eco-feedback information.

Table 1 Results of comparison between SG A and SG B

$\Delta_{consumption}$	SG A	SG B
Mean	-16.7%	23.7%
Standard deviation	1.403	0.772
p-value	0.000	

Additional analysis was performed to examine which dimensions of culture had impact on the effectiveness of eco-feedback. All 39 participants were divided into ten groups based on their nationality, and Kendall's tau-b correlation analysis was conducted between the groups' average scores in each cultural dimension and their average $\Delta_{consumption}$ values over the study period. At a 95% confidence level, a p-value less than 0.05 indicates statistically significant correlation. For influential cultural dimensions, correlation coefficient represented the extent of the influence. Table 2 shows the results of correlation analysis between the changes in energy consumption behaviors and six cultural dimensions.

Table 2 Correlation between the changes in energy consumption behaviors and cultural dimensions

Cultural dimension	PDI	IDV	MAS	UAI	LTO	IVR
Correlation coefficient with $\Delta_{consumption}$	-.231	.211	.254	.186	-.063	-.138
Sig.	.000	.000	.000	.000	.054	.000

The results indicated significant correlation between five cultural dimensions (PDI, IDV, MAS, UAI and IVR) and the effectiveness of eco-feedback. Specifically, PDI and IVR had negative correlation, which suggested that occupants in societies exhibiting a large degree of power distance who accept a hierarchical order in which everybody has a place and which needs no further justification would more positively respond to eco-feedback systems. The results also suggested that occupants in societies where people tend to accept a hierarchical order in which everybody has a place and which needs no further justification would more likely reduce energy consumption when provided with eco-feedback information. Furthermore, the results suggested that occupants in societies with low IVR scores, where people are less inclined to satisfy their needs and enjoy life, would behave with more restraints and conserve more energy when interacting with the eco-feedback system. In addition, IDV, MAS and UAI had positive correlation with $\Delta_{consumption}$. Occupants in societies with collectivist culture would respond to eco-feedback information, which contains a comparison with their peers, more positively, as by definition collectivist occupants care about not only themselves but also groups, so they would like to adjust their energy consumption behaviors as a gesture to contribute to the environment shared by others. High scores in MAS represent the society at large is more competitive and preference for success, which may decrease concern of occupants about energy. Conversely, feminine culture making society at large more consensus oriented cares the quality of life and concerns more about energy. Occupants with high scores in UAI would try to control the future and any uncertainty. They feel strongly uncertain about energy consumption without eco-feedback and will take actions to control and save energy consumption. Therefore, when they receive eco-feedback, they lose the incentive to save energy because they are sure about their energy consumption. As there were 6 countries only including one participant in the experiment, the behavior and cultural background may be influenced by individual characteristics. We acknowledge that our study could have benefited from a larger sample size. However, current sample size was adequate to obtain statistically significant results.

6 Conclusion and Implications

This study examines the impact of culture on the effectiveness of eco-feedback systems. An eco-feedback system was developed and implemented in test-bed buildings, and an experiment was conducted among students from ten different countries. By analyzing the energy consumption behavioral changes of the participants and assessing the cultural characteristics, examined in six dimensions, of participants from each country, the correlation between cultural dimensions and the effectiveness of eco-feedback systems was analyzed. The results showed that Chinese students and international students exhibited noticeably different behavioral responses to the eco-feedback system, and that five cultural dimensions, including PDI, IDV, MAS, UAI and IVR, had statistically significant impact on the effectiveness of the eco-feedback system. The results implied that the performance of eco-feedback systems is dependent on the cultural background of the users, and that the systems require a certain degree of adaptation to the cultural context in which they are implemented, in order to improve their effectiveness in building energy conservation.

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