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IMPLEMENTATION OF A PREFERENCE MONITORING APPLICATION FOR OFFICE BUILDING OCCUPANTS

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Abstract: Buildings should provide a level of comfort that is acceptable to majority of the occupants and enhance their health and productivity. When indoor environmental conditions are not as good as expected, occupants sometimes make adjustments. In order to capture and monitor occupant preferences and occupant behavior indoors, a feedback system- Preference Monitoring Application (PMA) was created. With the PMA, energy use behavior and occupant preference data are collected on a continuous basis while energy consumption and indoor environmental parameters are being monitored separately in a building.

The PMA was developed by identifying the values that are important to building occupants and following recommendations from other indoor environmental quality surveys. It is a simple application that captures satisfaction with temperature, lighting, indoor air quality and other parameters that influence occupant comfort and behavior on a continuous basis by using human input. A comparison of the feedback from 10 occupants in an office building in Pennsylvania, USA and 14 occupants in an office building in Doha, Qatar over 7 months are presented in this paper. This can enable the use of actual data to develop occupant profiles to improve occupant satisfaction.

Keywords: Occupant feedback, occupant behavior, satisfaction, values.

1 Introduction

Office buildings comprise the largest proportion of the commercial building stock in the US and consume about 18% of commercial building energy (EIA 2016). Qatar has one of the highest energy consumption and greenhouse gas emissions per capita in the world and a large proportion is used by buildings (Meltzer et al. 2014). Several factors contribute to building energy consumption such as weather, building function, and occupant-energy-related activities. Occupant behavior impacts energy consumption and can increase energy use by almost 150% in commercial buildings (Yu et al. 2011). The use of portable electrical devices, such as heaters and fans and increasing use of other plug load devices contribute to high energy use in buildings.

The Preference Monitoring Application (PMA) allows building occupants to enter their perception of comfort indoors and report on their actions. The tool is intended to provide insight into human behavior indoors, capture seasonal changes in energy use patterns and identify other factors that influence energy consumption. As part of a wider study, the energy use for lighting, space conditioning, and plug loads are measured along with indoor

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environment monitoring of temperature, relative humidity, carbon dioxide (CO2), and light intensity. Data on outdoor weather conditions are also collected. This study employs an interactive sensing approach where humans are active participants and their feedback enables the continuous monitoring of satisfaction and energy use behavior.

The goals of the PMA are (1) to serve as a platform for collecting occupant feedback on comfort (thermal, visual and air quality), clothing and activity levels; (2) capture occupant actions and behavior in a space in relation to comfort; (3) use collected data to create profiles for building occupants and develop machine learning algorithms that can improve how occupant preferences are accounted for indoors. Preliminary results of the occupant feedback collected using the PMA in an office in Pennsylvania, USA, and one in Doha, Qatar are presented in this paper.

2 BACKGROUND

Occupant values, in this context, are defined as those things of importance or worth to building occupants (Amasyali and El-Gohary 2016). Five values are considered in this study for continuous monitoring namely thermal comfort, visual comfort, indoor air quality (IAQ), health and personal productivity (Abraham et al. 2015). The latter two can be impacted by the indoor environmental quality (IEQ). Amasyali and El-Gohary (2016) surveyed about 200 office building occupants in Pennsylvania and Doha to identify values that are important to them, they ranked health as the most important followed by personal productivity. Preferences focus on what people desire in relation to their values.

Unfavorable IEQ is mostly thermal comfort-related (Federspiel 1998) and it could also result in unpleasant effects such as sick building syndrome (SBS) where people suffer from headaches and other illnesses due to inadequate ventilation, poor lighting, or thermal discomfort resulting in decreased productivity (Bluyssen 2006). American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) Thermal Comfort Standard 55 identifies air temperature, ambient water vapor pressure, relative air velocity, mean radiant temperature, clothing and activity levels as factors that affect the thermal comfort of building occupants (ASHRAE 2013). IAQ, lighting, ventilation and noise also affect occupant comfort (Bluyssen 2006) (Clements-Croome and Li 2000). IAQ can be evaluated by the amount of CO2 in the space and is influenced by occupant density, ventilation and the particulates in the air (ASHRAE 2009). Visual comfort relates to the 'quantity, distribution and quality of light' (Cauwerts 2016) and comprises illumination, luminance and brightness, luminous spectrum, and risk of glare. Rather than providing occupants with comfort settings that do not adequately reflect their preferences, there is an emphasized need for a broader experience of comfort that takes into account the dynamic and participatory aspects of occupants (Cole et al. 2010; Hong and Lin 2012). Encouraging occupants to provide feedback on their perception of comfort indoors can help identify the energy wasteful behaviors and provide energy efficient means to meet their comfort needs.

Azar and Menassa (2016) proposed a framework for occupancy-focused data collection and analysis and highlighted the need for further investigation of occupant behavior in relation to energy use through interviews or questionnaires. Peretti and Schiavon (2011) reviewed ten IEQ surveys that focused on occupant satisfaction with different parameters in buildings using one-time surveys. Feedback applications such as Building Agent (Schott et al. 2012) and Ambient Factors (Jazizadeh et al. 2013) have been used to report on indoor conditions. They are both standalone applications that demonstrate the potential use of occupant feedback in building operation. Some of the existing tools could be leveraged but may be difficult to customize for the purpose of this study while providing flexibility for modifications and accessibility on different platforms. The use of actual occupant feedback for improving building energy performance beyond relying on schedules based on occupancy levels could improve satisfaction. It also provides a clearer picture of what occupants want and the actions they take to improve their comfort indoors as they self-report their perception, satisfaction and their activities. This is a highly researched field but not a lot of studies cover hot desert climate regions and there is a need to continuously assess a variety of indoor environmental parameters.

3 System Development Methodology

The PMA is one of the components of an interactive data sensing system which includes sensors (temperature, relative humidity, CO2, and illuminance), and sub-metering devices to measure energy use by different end-use categories (lighting, HVAC and plug loads). Details of the data sensing system will not be discussed in this paper.

3.1 Description of the PMA

The PMA is a 3-5 minute Web-based survey that collects time-stamped occupant responses and contains 20 questions with the opportunity to provide open-ended comments. It was created using Qualtrics survey development software accessible on smartphones (Fig. 1) and computers (Qualtrics 2016). It is currently being administered to occupants in an office building in Pennsylvania, USA with a humid subtropical climate and in Doha, Qatar with a hot desert climate. Although the two locations have different climates, it was beneficial to study the differences in occupant preferences and behavior. The monitored zone in each building has instrumentation for energy use and indoor environmental parameter measurements. Occupants can respond as often as they want through their unique Web link. The questions were checked for clarity, and understanding and were refined based on feedback from the Survey Research Center at the Pennsylvania State University, pilot testing with the research team, and initial feedback from the occupants. Questions on activities, clothing, and equipment being used were included to give more context (ASHRAE 2013).

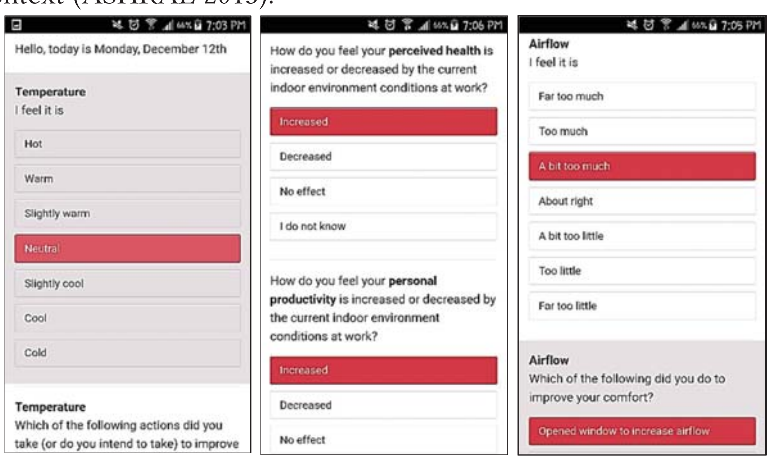

Figure 1: Screenshots of the PMA on a Smartphone

Energy use data are collected at 15-minute intervals for the Qatar building and can be as low as 1-minute intervals for the US building for the duration of the study (12 months).

Weather data was also collected for the two locations. Occupant behavior, such as window opening, are monitored through sensors in addition to occupant feedback.

3.2 Survey Development

In developing the questions, a variety of sources were used including the ASHRAE Thermal Comfort Standard 55 (ASHRAE 2013) and the Center for the Built Environment (CBE) survey at the University of California, Berkeley (CBE 2015). Prior to completing the PMA, occupants completed a background questionnaire to elicit their values and overall satisfaction with the values. They provided background information on their age, gender, and other factors that could influence their energy use habits. The application contains questions on occupant perceptions of comfort (thermal, lighting and airflow) and actions they took to improve their comfort (adjusting thermostats, wearing additional layers of clothing, etc.). Responses to each question were numerically coded for analysis and each participant was assigned a unique ID. The parameters that were measured with the PMA along with the rating scales are presented in Table 1.

Table 1: Parameters Measured and Rating Scales

Parameter	Quantified by
Thermal comfort	7-point scale- Temperature (hot to cold) humidity (too humid to too dry)
Thermal comfort satisfaction	6-point scale (very unsatisfied to very satisfied)
Lighting/visual comfort	7-point scale- Lighting (too dim to too bright)
Lighting level satisfaction	6-point scale (very unsatisfied to very satisfied)
Indoor air quality	7-point scale- Airflow (far too much to far too little)
Indoor air quality satisfaction	6-point scale (very unsatisfied to very satisfied)
Perceived health	Impact on health (increased, decreased, no effect, do not know)
Personal productivity	Impact on productivity (increased, decreased, no effect, do not know)

3.3 Data Analysis

The data was analyzed using statistical techniques for the overall responses from each case study building. Each category of response was collated, the occupants answered all the questions with only one incomplete response but this was not excluded from the analysis since the key questions were answered. The data management capability and interoperability of Qualtrics with other statistics tools and spreadsheets was beneficial for the analysis of the data (Qualtrics 2016). Current analysis is limited to the preliminary data. In the future, further analysis of a larger dataset will be completed to determine relationships that might exist between occupant perception and the indoor environmental conditions. Profiles that typify energy use behavior and preferences of occupants over a period of time will be developed.

4 RESULTS

From the PMA, a total of 254 responses have been collected from 10 occupants and 343 responses from 14 occupants in the US and Qatar offices respectively over 7 months. Figure 2 shows the responses on the PMA from April 2016 to October 2016. In July and August, the Qatar office building was closed for holidays so there were only a few responses during this time. All the Qatar occupants are in private offices while five of the occupants in the US office share with one other person, other participants are in private offices.

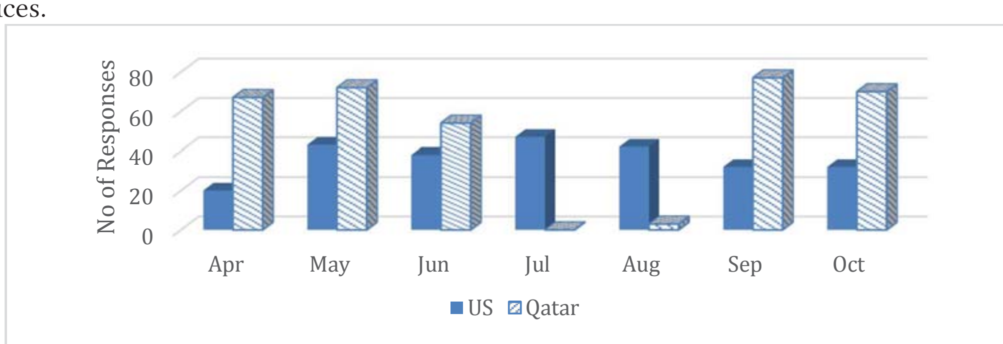

Figure 2: Survey Responses

The response on the temperature, humidity, airflow and lighting levels indoors are presented in Table 2. Most of the time US occupants felt the temperature was neutral while Qatar occupants felt it was slightly warm. Qatar occupants had more complaints about their offices being 'slightly cool', 'cool' or 'cold'. The satisfaction with the humidity levels was almost the same in both locations. Most of the time, the occupants thought it was 'about right' but 'slightly dry' at times. The comparison of the feedback from the US and Qatar for airflow shows that most of the time the occupants felt they had more airflow in the Qatar office. With the indoor lighting levels, most responses showed the lighting levels were 'neutral' or 'slightly bright' in Qatar but most times they thought it was 'slightly dim' in the US office.

Table 2: Occupant Perception of Values

Temperature	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
US (%)	2.8	5.5	22.0	43.3	16.9	7.1	2.4
Qatar (%)	0.9	7.0	29.2	24.5	21.9	9.6	7.0
Humidity	**Too humid**	**Humid**	**Slightly humid**	**About right**	**Slightly dry**	**Dry**	**Too dry**
US (%)	0.0	1.6	2.4	63.4	23.6	6.7	2.4
Qatar (%)	0.3	0.9	5.8	64.1	19.2	6.1	3.5
Airflow	**Far too much**	**Too much**	**A bit too much**	**About right**	**A bit too little**	**Too little**	**Far too little**
US (%)	1.2	3.9	11.0	63.0	16.9	3.5	0.4
Qatar (%)	3.2	15.2	30.3	39.7	11.1	0.6	0.0
Lighting	**Too dim**	**Dim**	**Slightly dim**	**Neutral**	**Slightly bright**	**Bright**	**Too bright**
US (%)	1.6	11.1	40.3	36.4	9.5	1.2	0.0
Qatar (%)	0.9	2.0	15.2	46.4	33.8	0.9	0.9

Figure 3 shows the percentage satisfaction with lighting, IAQ, and thermal comfort. Occupants in the US office were more satisfied with thermal comfort and IAQ than those in the Qatar office but were less satisfied with the lighting comfort than those in the Qatar office. IAQ perception in Qatar could be as a result of particulates in the air.

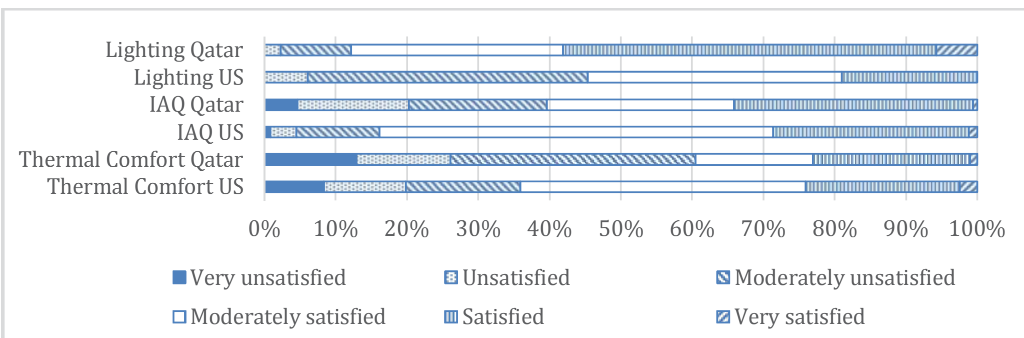

Figure 3: Percentage Satisfaction with Values

Looking at the occupants' actions in Table 3, 72.7% of the time US office occupants took no action to improve their comfort with the indoor temperature while 33.4% of the time they took no action in Qatar. There was a negative correlation between thermal comfort satisfaction and taking action to improve temperature in the US (-0.43) and Qatar (-0.52). In both locations, they sometimes took action when they were satisfied with the thermal conditions.

Table 3: Occupant Behavior in Relation to Indoor Environmental Parameters

	US		Qatar	
	Took no action (%)	Took action (%)	Took no action (%)	Took action (%)
Temperature	72.7	27.3	33.4	66.6
Humidity	98.8	1.2	100.0	0
Airflow	56.0	44.0	42.2	57.8
Lighting	50.8	49.2	61.1	38.9

On the question about the impact of the indoor environment on their perceived health and personal productivity, majority of the time the occupants in the US office thought the indoor environment had no effect on both (Fig. 4). In Qatar, they mostly felt that it had no effect on their perceived health but it decreased their personal productivity.

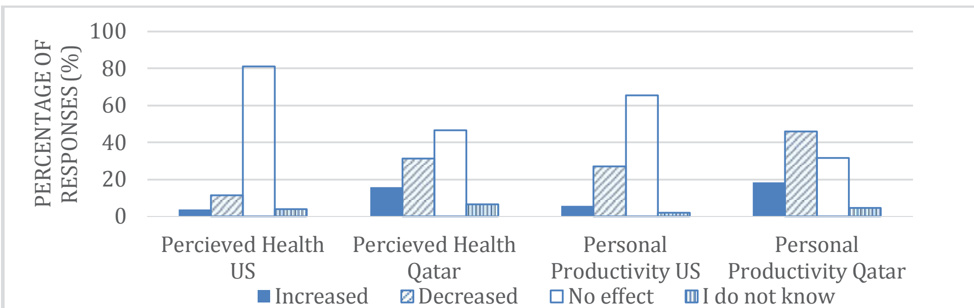

Figure 4: Impact on Perceived Health and Personal Productivity

5 Discussion

The hottest season in Qatar is between May and September, where temperatures could be as high as 40°C. The building was unoccupied during the hottest months (July and August). It would have been interesting to capture occupant responses during that period to determine if the HVAC systems are still able to meet their cooling needs. Occupants in both locations mostly felt the humidity was 'about right,' people might not be very sensitive to humidity issues indoors except in severe cases where there is mold and damp or people experience dryness. US occupants did not seem to take lots of action on their thermal comfort, probably because they are unable to control the thermostats although it was observed that they sometimes used portable heaters. In both case study buildings the occupants sometimes took action when they were satisfied, it indicates that they are active participants in the buildings. The main limitations are the small sample size, even though the results are not intended to be generalizable. Also, some information can be missed from occupants that are not providing feedback. A number of other factors could impact the results collected, analyzing these with the indoor environmental parameters and energy use measurements can provide a better understanding of how occupants perceive indoor conditions in different contexts.

The response rate can be affected by a number of factors including non-response and fatigue. Maintaining regular contact with the occupants improved response rate. Intervention methods such as adjusting the temperature settings in order to prompt some feedback were also explored. Incentives are provided monthly to encourage continuous feedback since incentives have been proven to increase response rates (Perkins 2011).

6 Conclusions and Future Work

This paper has looked into the implementation of the PMA for two office buildings in the US and Qatar and presented occupant feedback. There is only a limited amount of data that can be captured on occupant characteristics in a cost-effective way using sensors but the PMA allows for continuous assessment of occupant values and the extent to which these values are met. There is scope to make the PMA available on a wider range of platforms and to improve its aesthetics and usability. The feedback obtained could also help facility managers determine if current building operation is satisfactory to the occupants and what their preferred indoor conditions are. Overall, the results obtained from the PMA will be an important contribution to understanding occupant satisfaction over a period of time in two different climates especially for Qatar.

Future work involves identifying the relationships that exist between the occupant feedback, the indoor environment, and energy use. Another area for further studies is to identify how preferences change over different seasons and explore how individual profiles can inform the design of building systems that adapt to occupants based on their preferences. Providing a working environment that is perceptive to the needs of the occupants can improve personal productivity and wellbeing whilst also reducing energy consumption.

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