Occupant-Related Energy Use: a Qatar Office Case Study

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ABSTRACT

Accounting for human behaviour while striving to improve energy efficiency has been brought to the fore in recent studies since occupant behaviour impacts energy use in buildings. Maintaining occupant satisfaction with indoor environmental conditions can promote their wellbeing and productivity especially in office buildings. In order to improve efficiency and maintain occupant satisfaction indoors, it is important to capture actual occupant-energy-related behaviour and occupant preferences in buildings. Some of the parameters that influence occupant behaviour indoors are the environmental conditions such as the ambient temperature, lighting levels, and air quality.

Preliminary results obtained from monitoring an office building in Qatar are presented. This study seeks to capture occupants' indoor preferences and behaviours to give an insight into how they impact energy use or may be impacted by the indoor conditions. To achieve this, measurements of energy use (lighting, plug load devices, space conditioning), indoor environmental parameters and occupant feedback (satisfaction, preferences, behaviour) are collected using a combination of approaches including sensors, power meters and surveys. The preliminary findings show that the occupants took action to improve their comfort with the temperature and airflow. The highest energy consumption was when the building was not fully occupied which could provide an opportunity to improve the building operation and achieve energy savings while taking into account occupant needs, preferences and behaviour. Observations made regarding the lighting use pattern are also highlighted. It is intended that this study will provide an important contribution to understanding building occupant behaviour in a hot climate region like Qatar.

Keywords: *indoor environmental conditions, occupant behaviour, building energy monitoring*

1. INTRODUCTION

Sustainable high performance building strategies have been increasingly adopted by various countries as the building sector seeks to improve efficient use of resources. Due to the high environmental impact and the amount of energy consumed by this growing sector, there is an increasing need to ensure the environmental footprint is minimized by ensuring new buildings are energy efficient, improving existing building performance, using renewable energy sources and identifying and cutting down areas of wastage. Statistics from different countries emphasise the need to conserve energy. The US, for instance, is one of the top energy consumers in the world even though it is about one-fourth the population of China, about 40% of US energy is used by the building sector. In Hong Kong, about 90% of the electricity produced is consumed by the building sector (The Energy Efficiency Office, 2016). Qatar is a very small country in the Gulf region and one of the top crude oil producers in the world. It has the highest GDP per capita in the world and one of the top energy consumptions per capita in the world with growing electricity and energy demand (EIA, 2015) as technological advances and population increase. The building sector needs to continuously make efforts to improve its energy conservation efforts.

The main drivers for energy monitoring and energy use measurements are the need to mitigate climate change, to comply with legislation and better understand how energy is used in buildings to improve performance (Ahmad, Mourshed, Mundow, Sisinni, & Rezgui, 2016). While reducing building energy consumption, the industry has begun to recognize the need to ensure occupants have an environment that is conducive and promotes their health and productivity. People could also impact the way energy is used in a building through their behaviour. As various countries strive to meet the energy reduction targets, the needs of the occupants should be taken into consideration. In order to assess and better quantify the impact of people on buildings and be able to provide preferred indoor conditions, their needs and preferences including their actions should be captured. Energy simulation tools oversimplify their representation of occupants and do not properly account for their behaviour.

This study investigates energy consumption, indoor environmental conditions and occupant behaviour in an office building in Qatar. Qatar has a dry subtropical desert climate and also experiences high temperatures in the summer (around 40°C) and cooler winters (around 15-25°C) (WeatherOnline, 2017). There are a number of strategies in place to ensure resource conservation in Qatar buildings such as imposing fines for wasting water, leaving exterior lights on during the day, promoting the culture of energy conservation (Meier, Darwish, & Sabeeh, 2013). In order to capture different occupant-related characteristics, values, preferences and behaviour indoors, experimental approach using sensors, metering devices and a survey application for the occupants to provide their feedback on the indoor conditions and their level of satisfaction with the indoor environment are used. The indoor environmental monitoring includes temperature, relative humidity, air quality, and light intensity measurements, sub metered energy use for the lighting, plug loads and space conditioning, and occupant behaviour and satisfaction tracking through sensors and a Preference Monitoring Application (PMA) survey that was administered to the occupants. The study could provide an insight into occupant-related energy use and occupant preferences in an office. Preliminary results from the study are presented focusing on a few of the parameters.

2. BUILDING ENERGY USE AND OCCUPANT FACTORS

Occupants should be accounted for as energy efficiency strategies are implemented in buildings since people majority of their time indoors. Identifying the needs of the occupants and their energy use habits can help with providing preferred indoor conditions and reducing energy wastage associated with individual efforts to improve their comfort. Studies have suggested that occupant behaviour can significantly increase energy consumption by about 90% (Hong & Lin, Occupant Behavior: Impact on Energy Use of Private Offices, 2012). Investigating energy use behaviour can help with identifying the wasteful habits and possibly encourage a change in behaviour through education or other indirect means such as providing access to energy use information through dashboards.

Data collection techniques for building energy monitoring were explored by (Hong, Taylor-Lange, D'Oca, Yan, & Corginati, 2016). Buildings are different and identical buildings sometimes exhibit different energy consumption patterns, using a context-aware approach enables the actual building characteristics to be captured, though the results may not be generalised or directly applicable to other office buildings but there are lessons that can be learned and applied to a larger number of buildings. There are very limited studies on building energy consumption and occupant-related factors in Qatar. About 80% of the energy use in buildings in Qatar is for air conditioning (Meier, Darwish, & Sabeeh, 2013).

Studies have addressed occupant values (what they consider is of importance) and mentioned their effect on the indoor environment. The values are thermal comfort (temperature and humidity), lighting/ visual comfort (light intensity), indoor air quality (airflow/ ventilation), perceived health and personal productivity. Hong, et al. (2016) mentioned the parameters needed for occupant behaviour studies have been discussed. Human behaviour is dynamic so gaining better understanding could give a better understanding of their preferences and behaviour indoors. Occupants engage in adaptive or non-adaptive behaviour indoors. They could adapt the environment to their needs like adjusting thermostats or adapt to the environment by wearing additional clothing.

Actual occupant-related energy use data is beneficial to improve estimates from building energy simulation tools. Machine learning algorithms could also be used to learn occupant behaviour and predict their needs and provide preferred indoor conditions that minimize energy wastage.

3. METHODOLOGY

An academic office building located in Doha, Qatar was selected for the case study due to its availability and the willingness of the occupants (professors and instructors at the college) to participate in the study.

3.1 Building characteristics

On average the occupants spend about 20 hours in the office since most of their tasks involves teaching. Additional information about the building is presented in Table 1. All the occupants are in private offices and are able to control their thermostats within 6°C (18-24°C). The building has an automation system that controls the whole ventilation and air conditioning system, which is a single variable air volume (VAV) system.

Building Type	Medium-sized office
Year of Construction	2005
Size	680 m^2 (zone monitored)
Number of Floors	2 (ground floor, west zone monitored)
Climate	Subtropical dry hot desert climate
Cooling System	Single variable air volume system
Energy Source	Electricity
Power Distribution	Three-phase
No of Occupants	22 in the zone monitored

Table 10: Case study building characteristics

3.2 Instrumentation

The monitored zone in the office building is presented in

Figure 53. Each room has a temperature and relative humidity sensor. Three air handling units serve the zone and each one has an air quality sensor. Ten illuminance sensors were installed in 10 of the 22 offices in the zone the selected rooms represent different areas of the office namely the interior offices at the core, and a few offices at the perimeter of the building with access to daylighting and some with interior shading devices and others without shading. There is also shading on the exterior of the building (

Figure 53). The sensors were also placed based on whether the occupants were interested in taking part in the study.

Figure 53: Floor plan and exterior of case study building

The set point temperature varies for each office and is between 18 and 26°C. Occupants can control the lights manually to turn them on and off. The sensors were placed close to the occupants' working spaces on their desk

Figure 54. The illuminance sensor measures light intensity as seen by the human eye. The energy use by three major end use categories- lighting, plug loads and space conditioning are considered. The lighting and HVAC energy consumption are measured with power meters while the plug loads are measured virtually. The sensors were tested and calibrated before they were installed.

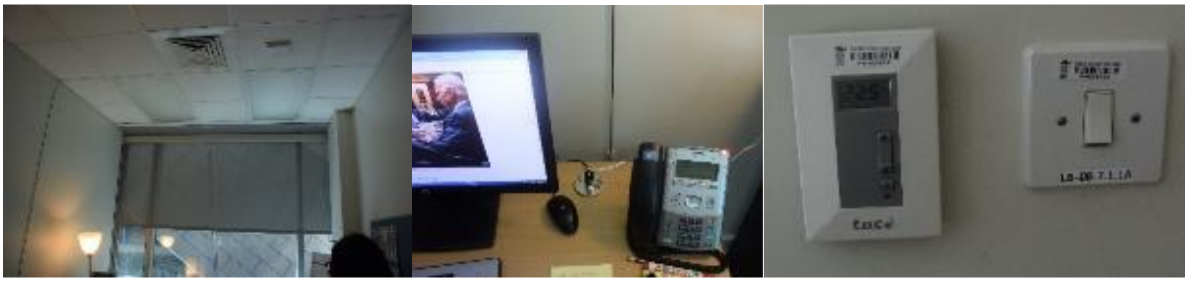

Figure 54: Office interior, illuminance sensor placement and thermostat and lighting controls

Occupant satisfaction with the thermal (temperature and airflow) conditions, lighting and indoor air quality are monitored through the Preference Monitoring Application (PMA) which is a survey provided to them which can be completed daily and is accessible on mobile devices and computers. It is a 3-5 minute survey for occupants to provide feedback on their perception of the indoor environment, their satisfaction and actions related to energy use.

The indoor conditions and energy use measurements are monitored with sensors and stored in the data acquisition system. The data is retrieved from the vista workstation on-site every other week to check the quality of the data and ensure there are no technical problems. Remote access to the workstation was not granted due to security concerns. Information on outdoor weather conditions are collected from local weather stations some of which are available online. Occupant feedback is retrieved online. The study is still ongoing and the total duration is for one year.

4. RESULTS

Preliminary results from the case study are presented in this section. The monthly energy consumption for major end use categories show that the energy use for space conditioning was the highest which is attributed to air conditioning accounting for over 75% of energy consumption monthly (Figure 55).

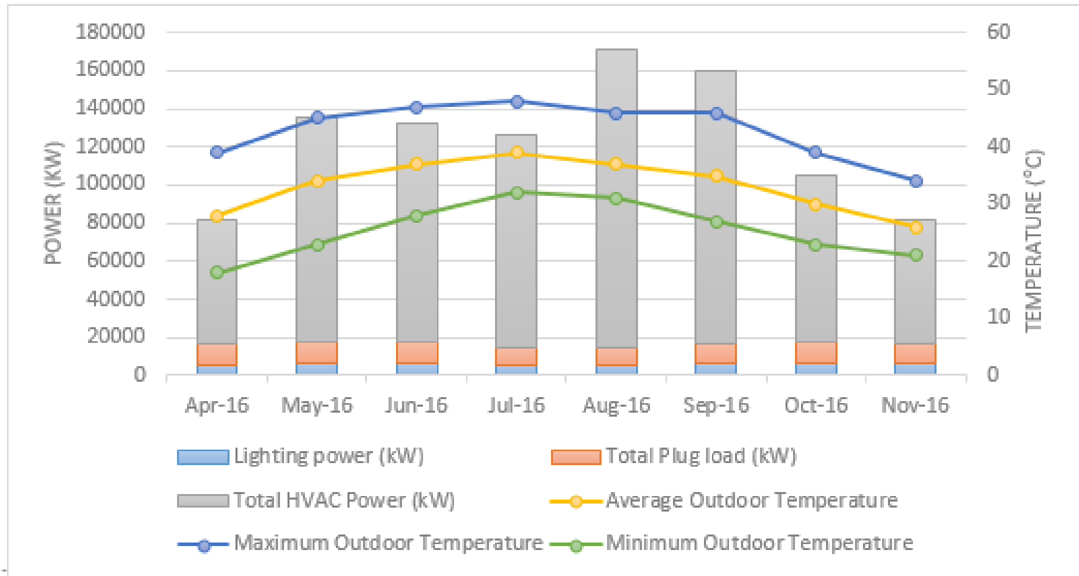

Figure 55: Monthly power demand and average outdoor weather

The peak temperature from April to November 2016 was about 48°C in July. The building was partly occupied in June, unoccupied in July and unoccupied for most of August due to the extremely high temperatures and the college being closed for the summer holidays. The peak average temperature was about 40°C in July while the peak overall power consumed in August (Figure 55). The minimum power measured was in April and November which were not as hot as the average temperature in July.

The response on the PMA surveys from April to October are presented in Figure 56 below, 343 responses were collected from 14 occupants over that period. The feedback rates from the occupants vary from daily to weekly depending on how often they choose to respond.

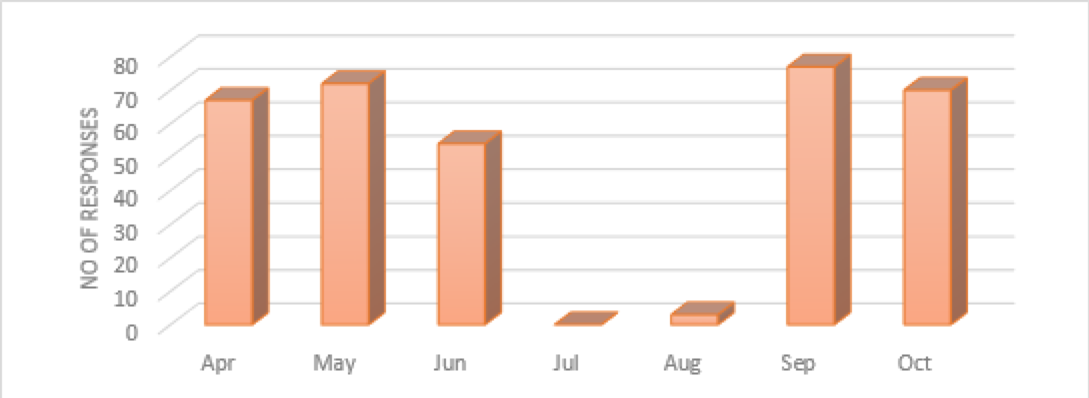

Figure 56: Monthly responses from occupants

A few parameters were considered from the feedback of the occupants. Figure 5 shows that they were mostly satisfied with the lighting, and indoor air quality. They were moderately unsatisfied with the thermal comfort. They took more action on their temperature and airflow than on the lighting levels as seen in Table 2 below.

	Took no action (%)	Took action (%)
Temperature	33.4	66.6
Humidity	100	0
Airflow	42.2	57.8
Lighting	61.1	38.9

Table 11: Response on Actions

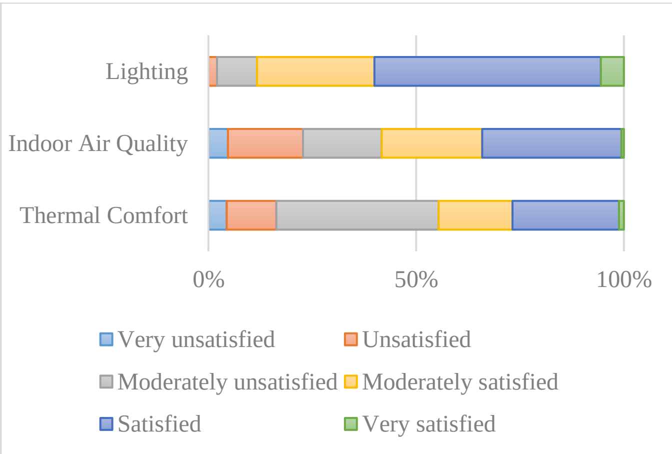

Figure 57: Satisfaction with indoor environmental parameters

Focusing on the occupants' perception of lighting, most of the time, they felt neutral about the lighting but a few other times they felt it was slightly bright (Figure 58).

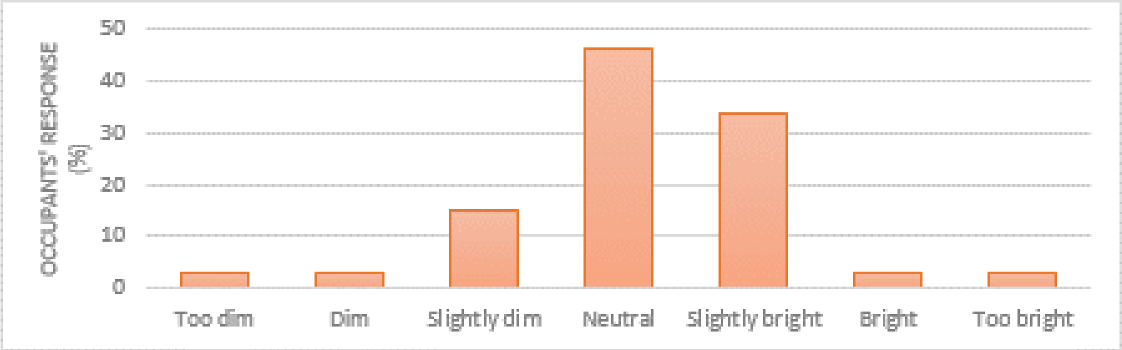

Figure 58: Occupants' response on their perception of lighting indoors

From Figure 8, we observe a strong correlation between the illuminance levels and the lighting energy consumption which is expected. The average illuminance of the 10 rooms was plotted against the overall lighting energy consumption over a working day in April (Figure 7) which also showed a close correlation even though not all the rooms have sensors installed but the rooms selected seem representative of the entire zone.

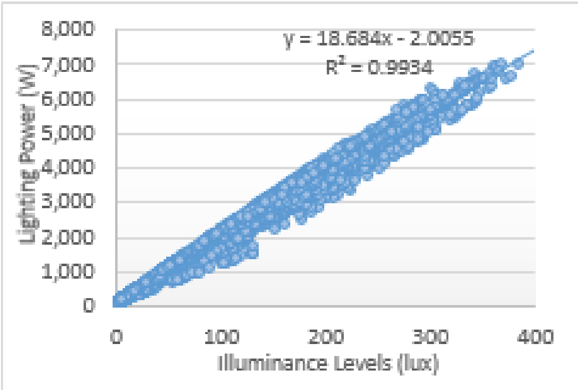

Figure 59: Lighting profile from a working day

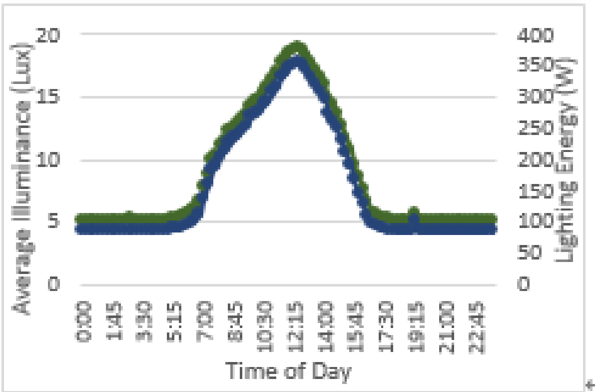

Figure 60: Lighting power vs average illuminance (April- November 2016)

The illuminance by natural daylighting was not separated from that by artificial lighting since the sensors measure how a human perceives light, this might introduce some errors. Overall, the occupants seem more satisfied with the lighting levels than with thermal comfort and indoor air quality.

5. DISCUSSION

July was the hottest month but August had the highest energy consumption overall. Energy consumption was lower in some of the hottest months since the building was unoccupied but it was still cooled for the equipment in the offices. The most obviously fluctuating energy use category is for space conditioning, which was the highest in

August perhaps because people were returning to work in the extremely hot weather and their cooling demand increased.

The strong correlation between the illuminance levels and the lighting energy measurements could indicate that natural lighting has very little contribution to their interior lighting which could be because of the associated heat gain through the large windows. Also since they felt the lighting was too bright at times, it could be reduced to achieve energy savings due to the strong correlation between the illuminance level and lighting energy while also maintaining satisfaction levels. Some offices had additional plug-in lamps without the room lights to dim the environment, these may increase the illuminance but the energy use is measured as plug loads but this does not seem to adversely affect the results since only a few of the offices use the lamps. The illuminance measurements also closely reflect the occupancy patterns and the occupant's lighting use.

6. CONCLUSION

Occupants should be considered in energy efficiency improvements since their behaviour can impact energy consumption. Gaining an insight into not only the energy consumption but also the indoor environment conditions and the occupant behaviour and can bring into focus how occupants impact energy use in buildings and help to identify areas for energy improvements while maintaining occupant satisfaction using actual energy use data. The paper covered some aspects of an ongoing energy monitoring project in an office building in Doha, Qatar. The PMA provides more insight into occupant behaviour, preferences and their satisfaction indoors. The indoor measurements and the energy use measurements also display the building energy use profile. This is still a preliminary analysis of a portion of the results since the study is still ongoing. A more robust analysis will be completed for conclusive findings while translating occupant factors to be included in analysis to predict energy consumption.

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