Analysing Meteorological Variables, Energy Consumption and Occupant Behaviour in an Office Building in Hot-Humid Climate Zone

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Abstract: ***In the last decade, new designs target green buildings, which emphasised the prominence of energy conservation and efficiency. Designing a green building in a sustainable way does not promise it will be energy efficient, as consumption is heavily relied on occupant behaviour. Besides, the variation of energy consumption is also associated with meteorological variables, which are highly significant in the building sector. Thus, it is vital to understand the influence of these factors on energy consumption in which a better understanding of it can contribute to a more effective strategy in meeting energy conservation goal. This paper presents analyses of meteorological variables, occupant behaviour and energy consumption in terms of electricity consumption based on field data collection conducted in August 2012- August 2013 in an office building located in Northern Peninsular of Malaysia. Meteorological data were recorded and monitored using a weather station system, and monthly energy consumption data were recorded based on meter readings. Analysis of occupant behaviour was carried out through a questionnaire survey (r=0.825) to 40 occupants of the building. The questionnaire was divided into four sections: i) demographic data; ii) knowledge and awareness about energy; iii) perception and view of energy consumption and efficiency and; iv) energy practices. From the study it was found that the meteorological variables in terms of outdoor mean temperature, outdoor relative humidity and wind speed ranged from 27.4 to 29.3°C, 77.4 to 81.3% and 1.6 to 2.3 m/s. Most of the occupants in this study had high knowledge and awareness about energy, and they gave a positive feedback on view of energy consumption and energy efficiency. In contrast, these behaviours did not translate to good energy practices among the occupants as low energy efficiency practices were observed in this study. In conclusion, meteorological variables and occupant behaviour had an influence on energy consumption in the case study building. However, a more detailed investigation should be carried out concerning this area in the future.***

Keywords: energy consumption; occupant behaviour; meteorological variables; office building

1. Introduction

Energy consumption and efficiency have earned significant attention in recent years, particularly with respect to the building sector, as it contributes around 20 to 40% of total energy consumption in developed and developing countries [1, 2]. It is expected that energy consumption in buildings will continuously take a larger portion of total energy consumption in the future [3, 4]. Since the building sector has been identified as one of the major factors to in climate change, numerous efforts have been taken across the world to improve building design by adopting low-carbon energy technologies and by promoting awards and policies in this regard. In response to this, green or low-carbon building is introduced as one of the important design elements toward energy-efficient buildings all over the world [5-8]. Green building or low-carbon building is defined as a design that has superior environmental performance by using sustainable energy resources and materials [9]. However, designing a green building in a sustainable way does not promise it will be energy efficient, as energy consumption is heavily dependent on the building's occupant behaviours [9]. From literature, it has been found that poor occupant behaviour can significantly contribute to lower building energy performances [10, 11]. Occupants' comfort is also a critical part to green building design, which could lead to a large portion of energy consumption of indoor spaces [12]. Thus, a study on occupant behaviour should be emphasised in ensuring objectives of low energy consumption in buildings to be achieved in the future. This would help to prioritise action and management plans towards an energy-efficiency management system.

On the other hand, variation of energy consumption is also associated with meteorological variables, which are highly significant in the building sector [13]. Fung et al. [14] stated that 1°C rise in monthly outdoor temperature would increase annual electricity consumption by 3% in buildings, especially in hot-humid zones. For instance, in the hot-humid zone of Malaysia, daily outdoor air temperature normally varies from 24 to 38°C with mean monthly relative humidity ranging from 70 to 90% throughout the year that vary depending on locations and months [15, 16]. This hot and humid weather throughout the year causes the building occupants to heavily rely on cooling, ventilation or air-conditioning systems. In this regard, as stated in [4] and [16], the cooling or air-conditioning systems consumed more than 60% of the total electricity consumption in buildings.

Keeping the above facts in mind, it is vital to understand meteorological variables, energy consumption and occupant behaviour and their associations in which a better understanding of these factors can contribute to a more effective strategy in meeting energy conservation goals of a building towards an energy-efficiency management system. This paper presents an analysis of these factors based on a case study of an office building in a hot humid climate zone.

2. Methodology

2.1 Building description

A building with 30 various sizes of office rooms located in a tertiary educational institution in Northern Peninsular Malaysia was selected in this study, which contains assignable 3,000 square meter of instructional space. The geographical coordinates of the building lies at 05° 21' 20" North Latitude and 100° 17' 49" East Longitude with average outdoor temperature of 28°C and outdoor average relative humidity of 80%. This particular building was chosen based on the fact of design and operation principles, including the orientation of form, ventilation and management practices. This building was constructed in 1983 consisting of two floors (upper and ground levels) using material composition of walls, windows and other elements of building fabric as shown in Table 1. The structure and material of this building are not different from most office buildings situated in the area and therefore, lessons drawn could be applied to office buildings in general. Furthermore, layer properties, which include solar transmittance, absorbance and reflectance characteristics, were also constructed for building glazing. The building is denoted as A in Figure 1.

Table 1: Material properties of building fabric

Envelope components	Material
External wall	Brick plaster
Internal ceiling	Plasterboard ceiling tile
Internal floor	Tile, woven carpet
Window glass	Casement metal frame

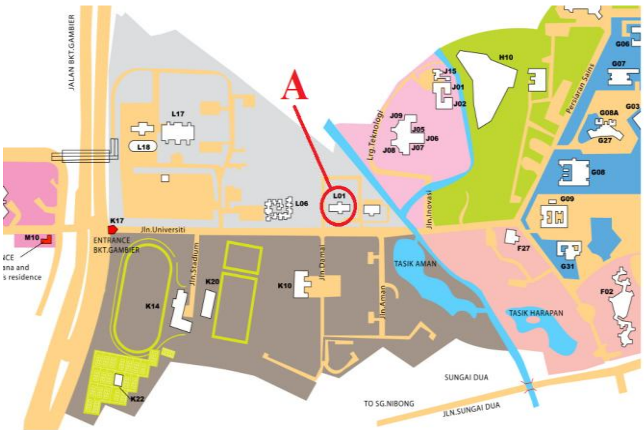

Figure 1: Location of the case study building

2.2 Field Measurements

Measurements of meteorological variables in terms of temperature, relative humidity and wind speed were collected using HOBO® micro station data logger H21-002 connected to 12-Bit temp/RH smart Sensor S-THB-M002 (temperature: ±0.21°C from 0° to 50°C; RH: ±2.5% from 10 to 90%; wind speed: ±1.1 m/s). An 8-hour continuous measurement was performed during working hours following methods and procedures in [17] for 12 months (from August 2012 to August 2013). In parallel to this, monthly energy consumption data were recorded based on meter readings for 12 months.

2.3 Questionnaire Survey

Questionnaire survey (r = 0.825), with Likert Scale in five ordered response options was conducted in order to assess occupant behaviour to 40 occupants of the selected office rooms. An ethical approval to this study was given by Human Research Ethics Committee USM [Ref: USM/JEPeM/281.4.(1.1)]. The questionnaire survey adopted form was divided into four sections: A) demographic data; B) knowledge and awareness about energy; C) perception and view of energy consumption and efficiency and; D) energy practices. Section A was done to collect demographic data of the occupants such as gender, age, educational background, working position, working hours and working experiences. Section B, C and D emphasised on understanding and general knowledge of energy, view of energy consumption and practices of energy among occupants in the office rooms. The survey was carried out to the occupants during the collection data of field measurement in each office room.

2.4 Data Analyses

Two sets of parameters in terms of physical (meteorological variables and energy consumption data) and subjective (the questionnaire survey) were investigated and analysed with the aid of Microsoft Excel and statistical analyses tools.

3. Results and Discussion

3.1 Analysis of Meteorological Variables

The outdoor air temperatures during the field measurements were between 27.4°C and 29.2°C with outdoor relative humidity between 77.4% and 81.3% and wind speed between 1.6 m/s and 2.3 m/s. The descriptive statistics of the environmental parameters data is shown in Table 2.

Table 2: Descriptive statistics of the meteorological variables

Outdoor Atmospheric Data			
	Air temperature (°C)	*Relative humidity (%)*	*Wind speed (m/s)*
Mean	28.10	79.00	1.90
Standard deviation	0.67	1.48	0.25
Minimum	27.40	77.40	1.60
Maximum	29.30	81.30	2.30

3.2 Energy Consumption Data

The monthly electricity consumption for the building for 12 months is shown in Figure 2 with the average electricity consumption of 24,425.54 kWh and the annual working day was 264 days. From the figure, it can be seen the monthly electricity consumption of the building was directly associated to the number of working days. Of the total building electricity consumption as stated by the building top management, 45 % were from air conditioning systems such as cooling and ventilation, followed by lighting (25 %), office equipment and others, 20% and 10% respectively as can be seen in Figure 3. In order to convert electricity consumed in kWh to kg of carbon dioxide (CO_2) emissions, the energy consumption was multiplied by a conversion factor of 0.523 $kgCO_2/kWh$ (Defra/DECC, 2012). Carbon dioxide emissions from electricity produced in the building are shown in Figure 4. From this figure it can be seen that the highest value of 15,317.1 kgCO2 was recorded corresponding to 29,287 kWh in March 2013. As stated in The 4th Assessment Report of the Intergovernmental Panel on Climate Change, electricity consumption in building sector contributed 30 to 40% of total green gas emission in terms of carbon dioxide [4]. However, the association between electricity consumption and carbon dioxide emissions can fluctuate significantly depending on building type services [18].

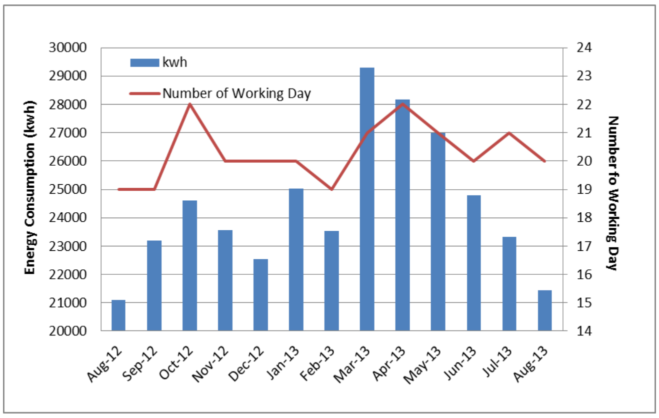

Figure 2: Electricity consumption and number of working day from August 2012 to August 2013

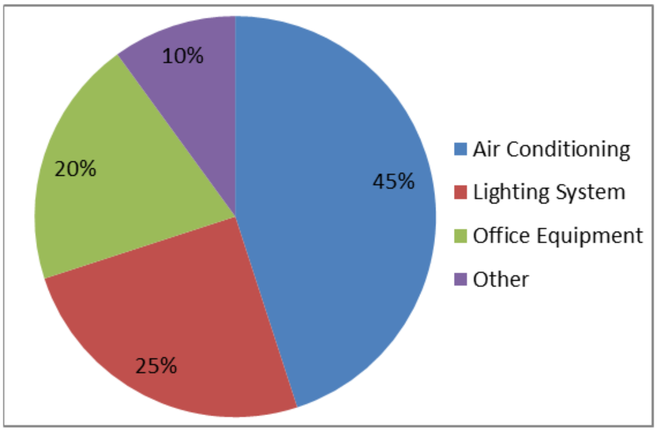

Figure 3: Breakdown of total electricity consumption in case study building

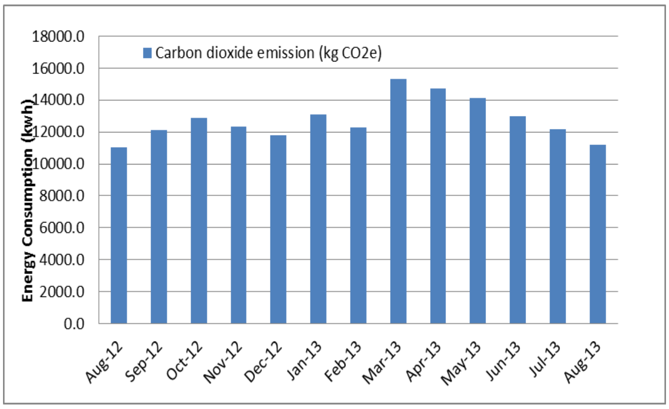

Figure 4: Carbon emission data from August 2012 to August 2013

3.3 Analysis of Occupant Behaviour

A total of 40 occupants participated in the survey in which 75% of them were male and 25% were female. Demographic data is shown in Figure 5. Most of them were aged between 31 to 40 and 51 to 60 years and their educational level were relatively average, with SPM/STPM/Matriculation graduates. In term of working position, 35% of the occupants work as technician and 27.5% of occupants involved in professional fields. With regard to working hours and experience, 87.5% of occupants work at least 8 hours and 62.5% of the occupants have worked in the building for seven years and above.

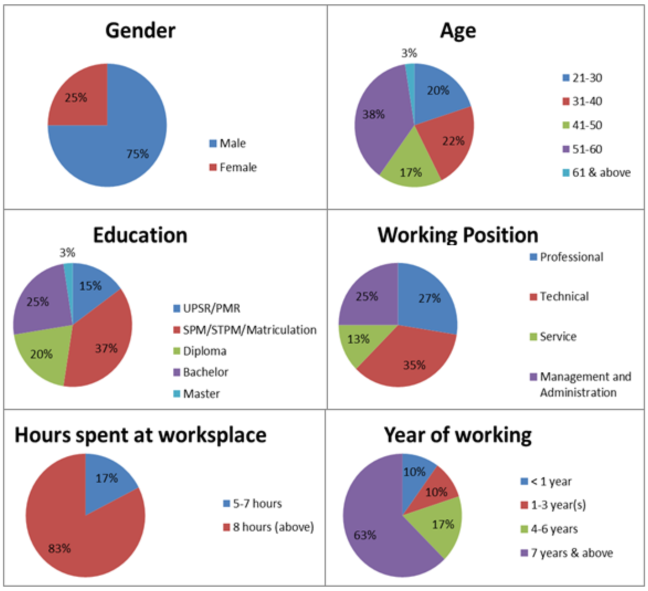

Figure 5: Demographic data of occupants in the building

Section B of the questionnaire aimed to obtain knowledge and awareness about energy from the occupants. Analysis of the occupants' knowledge and awareness about energy is illustrated in Figure 6 in which mean value is presented. For instance, it was found that limited number of occupants (mean value: 3.725) had knowledge about 5-Star rated (Energy Star) of energy-efficient electrical products. The U.S. Environmental Protection Agency (EPA), to promote the use of energy-efficient products and to reduce the emission of greenhouse gases by reducing energy consumption, introduced the "Energy Star" programme in 1992 [19, 20]. However, there was a conflict in occupants' answers in relation to Energy Star and saving energy tips questions. Most of the occupants claimed that they were aware of energy saving and had knowledge about energy consumption (mean value: 4.45) but in contrast they had less understanding about Energy Star products. In this case, more campaign and awareness programmes should be carried out in the future to publicly disseminate knowledge about Energy Star Programme in ensuring the public and consumers so they can easily identify energy-efficient products and their benefits.

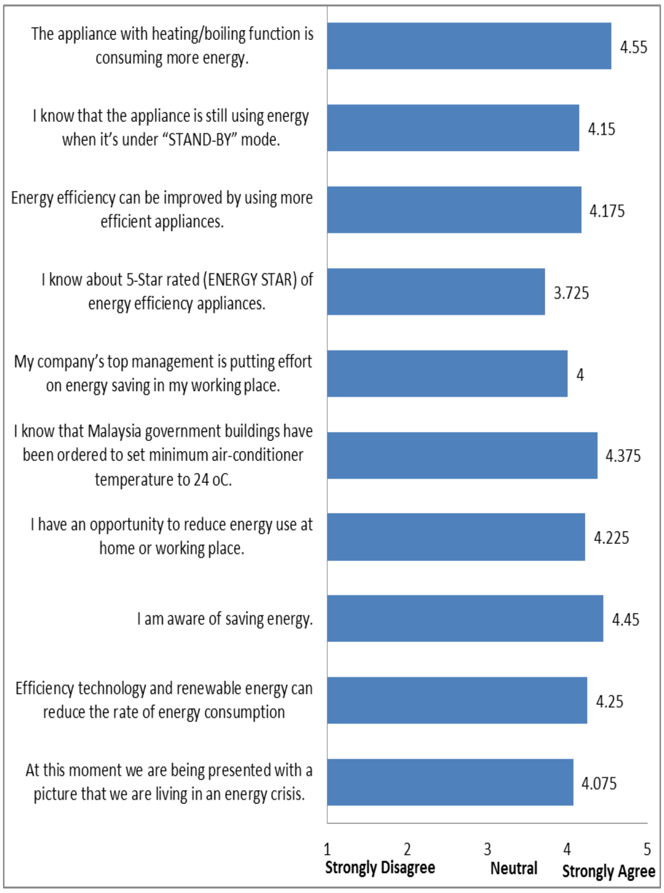

Figure 6: Analysis of occupants' knowledge and awareness about energy (based on 1-5 Likert Scale)

Section C of the questionnaire explored views of energy consumption and energy efficiency among occupants. Figure 7 summarises mean value of the analysis of views of energy consumption and energy efficiency among the occupants. It was found that the occupants agreed (mean value: 4.275) that top management should appoint a responsible team to coordinate energy management activities. As the responsible team for energy management, the team should provide informative material and organise periodic internal training such as workshop about energy efficiency to the employees [21]. In addition, they should ensure that the energy management programme is properly executed and monitored, and the employees should report any energy failure or energy wastage to the top management. Besides, the occupants preferred to see more visible reminders of energy consumption warning or indication (mean value of 4.250) as this could help them to be more aware about the importance of energy saving.

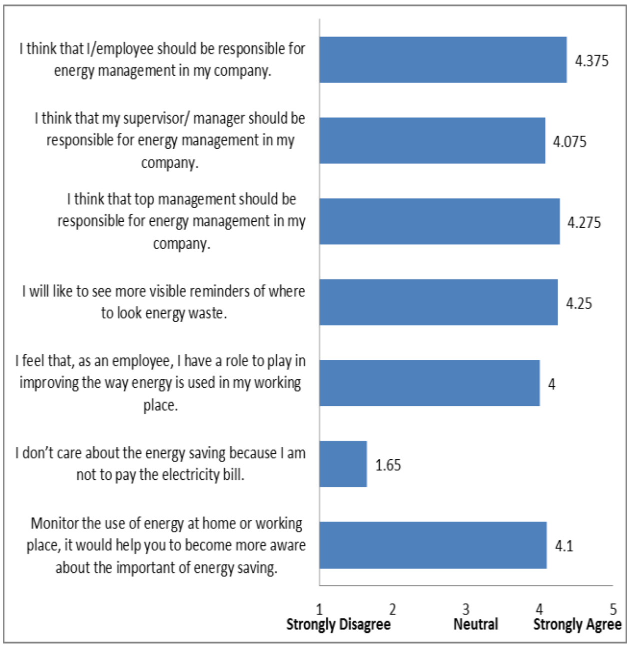

Figure 7: Analysis of occupants' view of energy consumption and energy efficiency (based on 1-5 Likert Scale)

Section D of the questionnaire investigated the occupants' energy practices. In this section, the occupants were asked about frequency of their behaviour that could lead to energy wastage as can be seen in Figure 8. From this analysis, it can be seen that, the occupants had the tendency to turn on the light even when there is enough light in the room with a mean value of 2.925, and they chose to leave the light on even when the room is vacant (mean value: 3.425). Ouyang and Hokao [22] reported that this kind of behaviour could lead to energy wastage and improvement of occupant behaviour on energy practices can save more than 10% of building electricity consumption.

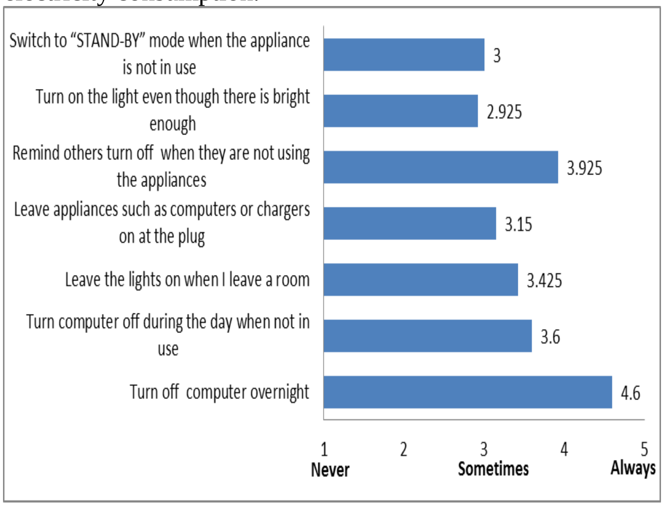

Figure 8: Analysis of occupants' energy practices (based on 1-5 Likert Scale)

3.4 Meteorological Variables Versus Energy Consumption

Impact of meteorological variables on electricity consumption cannot be disregarded as many studies have been carried out around the world pertaining to this matter

[23, 24] As stated by [24], high outdoor temperature will heat up a building and as the consequence, the occupants of that particular building feel uncomfortable with indoor environmental condition thus, they have the tendency to depend on cooling or air-conditioning system to comfort their zone. Figure 9 shows variation of electricity consumption of the case study building with outdoor mean temperature. The highest outdoor temperature of 29.3°C was recorded with 29,287 kWh in month of March 2013 and the lowest outdoor temperature of 27.4 °C was recorded with 23,193 kWh in month of September 2012. It can be seen that a sudden boost of electricity consumption occurred in March 2013, approximately 24.5% higher than electricity consumption as compared to February 2013 energy consumption, and a difference of 1.6°C of outdoor mean temperature between these months. The electricity consumption started to fall from March to August 2013 as the outdoor mean temperature dropped. On the other hand, analyses of electricity consumption of the case study building with outdoor relative humidity and wind speed are shown in Figure 10 and Figure 11, respectively. From the figures, the highest outdoor relative humidity of 81.3 % was recorded with 24,603 kWh in month of October 2012 and the highest outdoor wind speed of 2.3 m/s was recorded with 23,526 kWh in month of February 2013. A detailed study should be carried out in this area to further investigate the association between outdoor conditions and indoor conditions as these factors will directly impact energy consumption in buildings, especially for heating, ventilation and air-conditioning systems as stated in [23, 24]

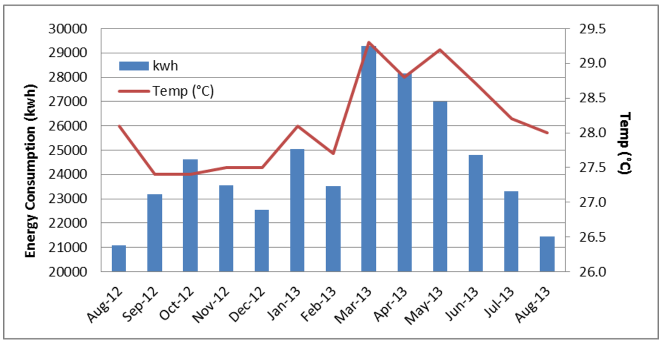

Figure 9: Electricity consumption versus outdoor mean temperature

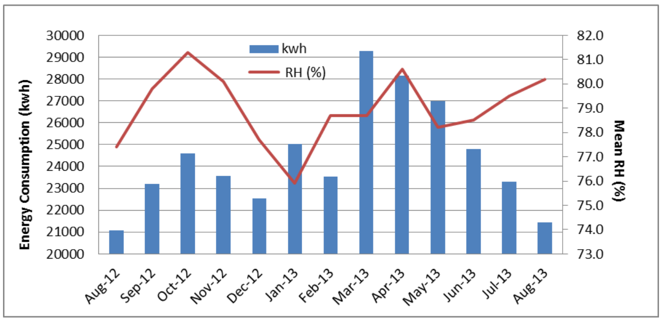

Figure 10: Electricity consumption versus outdoor mean relative humidity

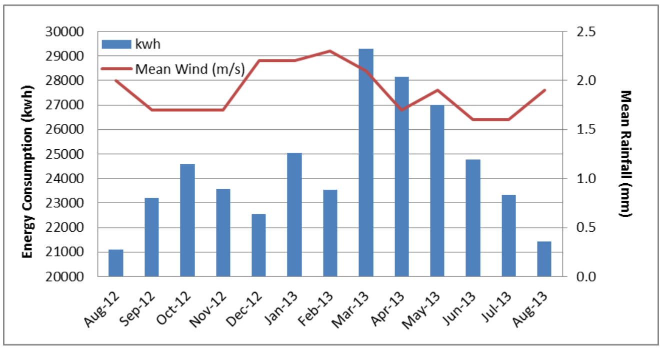

Figure 11: Electricity consumption versus outdoor mean wind speed

4. Conclusion

This paper analysed meteorological variables, energy consumption and occupant behaviour in a selected office building in a hot-humid climate zone. This study was carried out based on: i) field measurements in relation to energy consumption data and meteorological variables; ii) preliminary data on occupants' knowledge, view and practices about energy in relation to occupant behaviour and; iii) relationship between energy consumption and meteorological variables. In conclusion, meteorological variables and occupant behaviour had an influence on energy consumption in the case study building. However, a more detailed investigation should be carried out in the future about the relationship between meteorological variables and building energy consumption. It is hoped that this study could provide baseline data in prioritising efforts of evaluation and modification of occupant behaviour for energy conservation and energy saving in office buildings towards energy-efficiency management system in hot-humid zones.

5. Acknowledgments

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