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Users' building optimal performance manual

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ABSTRACT

Occupant behaviour has a significant impact on the overall energy performance of a building. The lack of awareness, misinformation and misunderstanding of the buildings' systems and features are some of the key elements that impact the use of energy in buildings. This paper presents the results of a workshop performed to increase the awareness of the occupants of two university buildings, in Sydney Australia. The occupants were asked to provide their opinions on their interactions with the lighting, cooling, heating, equipment, windows opening and shading. Then, the behaviours collected in the surveys were converted into energy use, through building simulations, and the results presented in a workshop. After presenting the results, a brainstorming was promoted to collect occupants' new perceptions based on the previous results. Occupants highlighted as one of the key impacting factors to high levels of energy use the lack of awareness. To answer to the outcome from the workshop, this paper suggested then the incorporation of a users' building performance (U-BOP) manual as a tool to be used to increase occupant's awareness and increase the overall performance of a building. It was used as an example and baseline for the manual the building user guideline (BUG) from Green Star and BREEAM, as well as exiting O&M reports. The results of this study and workshop should not be extended to other occupant behavioural situations and patterns. The results should be maintained within the present study and context.

1. Introduction

Occupant behaviour (OB) is well known as one of the most contributing factors for poor energy performance in buildings. The unpredictability of occupant's actions and behaviours, the numerous variables impacting their energy and comfort choices and moods, makes the behaviour of occupants one of the most challenging topics within the building sector. OB in the context of energy use has been studied since the early 1950s. One of the first studies related to occupants interactions with the building's systems was performed by Dick and Thomas (1951). They have discussed the relationship between window-opening habits of occupants and the consequent heat losses through air changes rates, in two experimental site houses. The behaviours of occupants were responsible for 87% of the total air change rates (Iwashita and Akasaka, 1997). One of the main characteristics of OB in terms of energy use is its unpredictability (Ashley F. Emery and Gartland, 1991; Weihl and Gladhart, 1990). OB unpredictability impacts in 64% the difference between the actual and predicted energy, followed by 24% discrepancies related to the heating, ventilation, and air conditioning (HVAC) system, and 12% of inefficiencies associated with equipment's conductive heat losses and air rate divergences (Norford et al., 1994). When changes in the OBs are combined with an improvement in building systems, a reduction of 75%–95% in the quality of energy use is predicted (Schweiker and Shukuya, 2010). However, in the past occupants were seen as mere heat generators and the impact of their behaviours were ignored in most energy simulations (A. F. Emery and Kippenhan, 2006; Newsham, 1992). Aspects such as cultural or economic differences (Wilhite et al., 1996), life-style or social moral sense and occupant's location, occupants interactions with shading, windows operation, heating, lighting, fans, etc, were not taken into consideration (Al-Mumin et al., 2003; J. Nicol, 2001; Tanimoto and Hagishima, 2005). The fact that OB was not accounted properly led to the gap between the designed predicted energy and the monitored data during the operation stage, and an over-designing of building's systems and a consequent overestimation of energy use, reflected during the operation stage (Mahdavi et al., 2008; Tanimoto, Hagishima, & Sagara, 2008a, 2008b). Occupants may impact the use of energy in a building either passively or actively. Passively, only due to occupants' presence, movement, and the type of activities they perform. Actively, when occupants interact with switching on and off lights and equipment loads, air conditioning (AC) set-point temperatures, and opening or

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closing blinds, windows, and/or doors (Yan et al., 2017). However, the OB may be impacted by several variables. Fig. 1 represents all the main variables (driving forces) impacting energy-related occupant behaviours, according to the International Energy Agency (IEA) (Yoshino et al., 2017) (see Fig. 2).

In commercial and residential buildings, the energy that is wasted, related to light and equipment, during the after-hours period represents 23% and 29% of all the losses, respectively, due to occupants' lack of awareness, lack of information and misbehaviour in energy use (Al-Mumin et al., 2003; Masoso and Grobler, 2010; Nisiforou et al., 2012). An aware (saving) type of occupant can use less 72% energy when compared to a non-aware (intensive) occupant (Almeida et al., 2020a). The OB is complex and diverges according to occupants' social-psychological contexts, diversity, backgrounds, demography, and motivation; and needs a deeper understanding (T. Hong, Taylor-Lange, D'Oca, Yan and Corgnati, 2016). Occupant's energy-related choices are influenced by subjective aspects associated with their perceptions to what other people expect from their behaviours and/or actions, as well as by descriptive norms where what other people do has an impact on a specific behavioural response. As an example, occupant's saving energy choices are highly impacted by a tendency to feel a moral obligation to a particular behaviour. Therefore, creating campaigns that promote efficient use of energy is extremely important (Al-Mumin et al., 2003; Masoso and Grobler, 2010; Nisiforou et al., 2012). A study conducted in a university where the awareness of occupants was raised by providing information about energy conservation measures, using flyers and/or images or short text blocks, influenced occupants to reduce their computer screen brightness in 50% (Cobben, 2017). Other tools may be used to raise awareness, as interactive and social-media technologies. Social networks and systems may be interesting to influence people's energy choices with the effect of social innovation encouraging the development of new solutions, raising awareness and innovation (Klöckner, 2019). A neighbourhood network may encourage better energy conservative behaviours by comparison, competition and collaboration among community members (Bartram et al., 2010). However, to communicate information that motivates a behaviour change, occupant's values should not be ignored as it affects the way communities and individuals decide and behave (Burrows et al., 2013). Additionally, the use of smart meters as a tool that provides feedback to residential occupants on their use of energy has seen an increasing trend. The feedback provided by the smart meters needs further improvement, as currently lacks in providing information to occupants on "how to act", motivating them to implement practices that save energy and helping occupants to relate and understand properly all the information. Moreover, the improvement of energy efficiency by the effective use of smart meters is subjected to a specific type of consumer. Cost-conscious and non-cost conscious users need to have a different approach (Bent and Kmetty, 2017; Hyysalo, 2013). Furthermore, the significance of the "green" tools and brands are a positive catalyst to increase the awareness of occupants and reduce the use of energy (Darby et al., 2016). Occupants tend to be more tolerant in a green-rated building than in a non-rated one, and even more in small buildings than in larger ones (Leaman and Bordass, 2007). However, a building just by having the "green" brand does not mean that the building is a "green building". The concepts of sustainable design will only have real-time effects when properly used by occupants (Khashe et al., 2015). The carbon emissions related to lighting, heating and equipment are lower in a green-rated building and can be reduced by 50%–70% when compared to a worst-case scenario (Roetzel et al., 2010). Nevertheless, not only the lower carbon emissions are not always associated with a green-rated building but a similar range of reduction is also possible to verify in a non-rated building. A study conducted a green-rated and non-rated buildings showed reductions of 52.5% (761 $tonCO_{2eq/yr}$) and 57.3% (747 $tonCO_{2eq/yr}$), respectively, in both buildings (L. Almeida et al.). The control of energy use may increase occupants' satisfaction but there is no consensus to energy use. Some literature supports that energy use will decrease whenever occupants take control of their usage (Maniccia et al., 1999), however, others state that the more occupants have control over the energy use, the more energy will be used (Azar and Menassa, 2012). This interaction with the energy control systems is aligned with the definition of adaptive

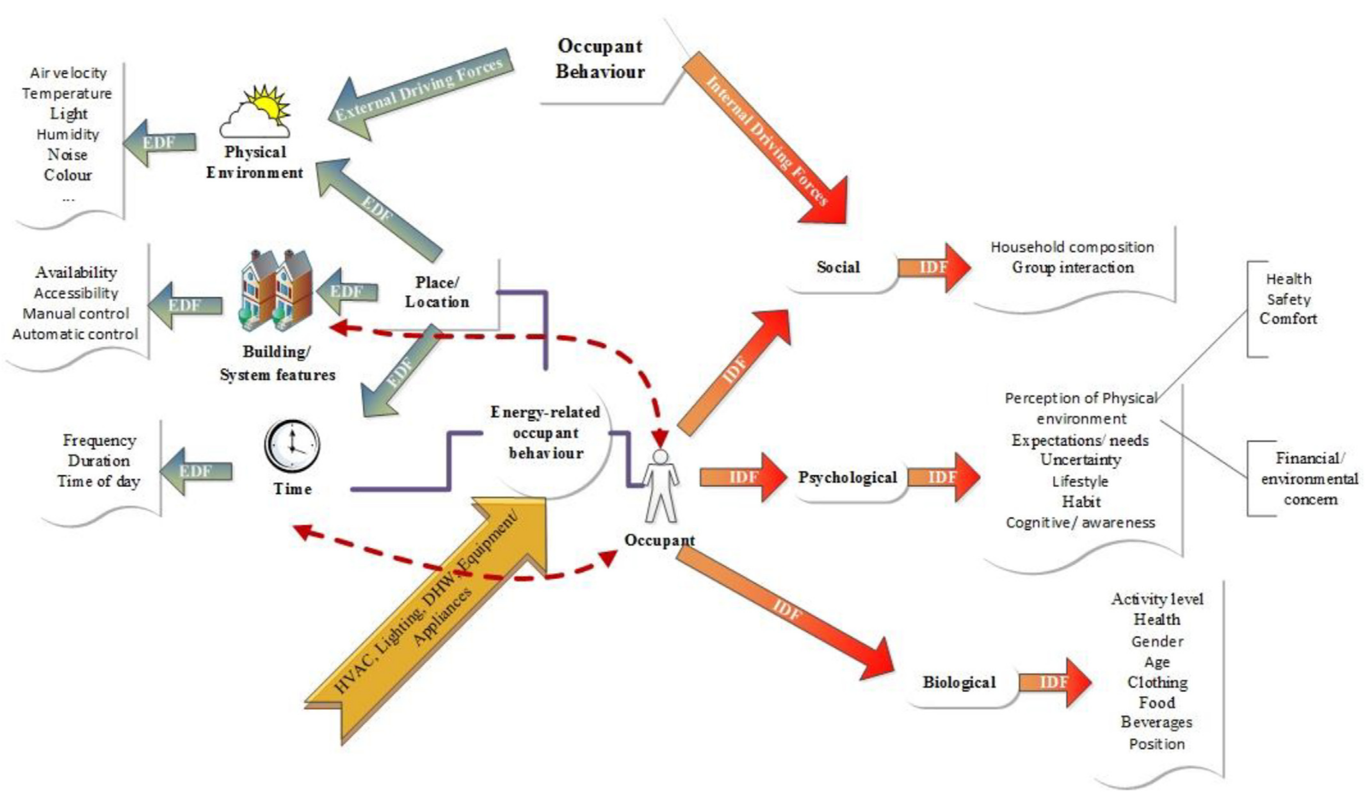


Fig. 1. Driving forces that impact occupant behaviour when interacting with energy (Yoshino et al., 2017).

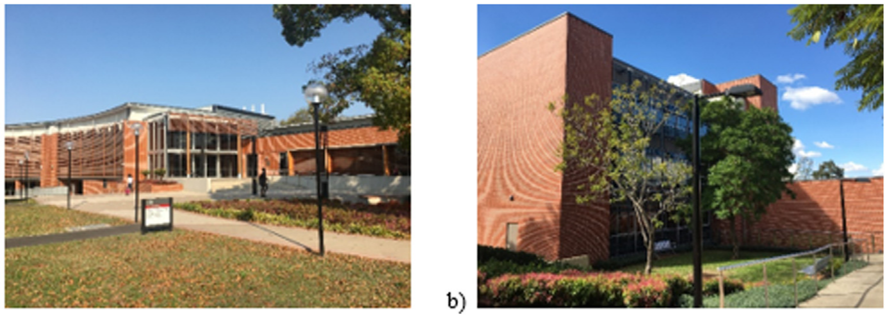


Fig. 2. a) green-rated building and b) non-rated building.

behaviours that, according to J. F. Nicol and Humphreys (2002), 'if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'. To collect occupants' perceptions and opinions associated to different subjects, as noise and light levels, thermal comfort, wellbeing, energy use and indoor air quality (IAQ), surveys have been used as a reliable tool to evaluate these behavioural patterns in buildings (Bluyssen et al., 1996; Crosbie and Baker, 2010; Ek and Söderholm, 2010). Surveys have been used to report physical and social–psychological factors that may impact decision-makers to the implementation of future energy efficiency measures (Tianzhen Hong, Yan, D'Oca and Chen, 2017). However, there are some disadvantages associated to the use of surveys, such as occupant's difficulty in understanding the questions' aim, disinformation to the building systems, psychological and social biases that promote behavioural changes due to the feeling of being observed or 'forced' to choose what is socially acceptable. All these factors may impact the reliability of self-reported behaviours (Yan and Hong, 2018).

This study aims to provide the outcome of a workshop delivered to the occupants of two buildings, a green-rated and a non-rated building after their opinions and perceptions were collected in questionnaire surveys and the impact of their behaviours quantified using building simulation (Almeida et al., 2020b,c). The two buildings chosen for this research are two university buildings from Western Sydney University with similar functions/activities and characteristics detailed on Table 1. The green-rated building (GB) is north oriented, has an area of 5696 m^2, and three levels above the ground. Shading is provided by neighbourhood buildings and architectural features. The GB went through a Green Star certification process and had to comply with requirements in terms of the land use and ecology, transport, energy, emissions, water, indoor environmental quality (IEQ), materials, and management. The building has installed 374 modules of a photovoltaic system that produces 134, 161 kWh/yr and innovative targets as: evaluate the impacts of materials from a lifecycle perspective, reduce the use of potable water by 95%, increase the recycling rates more than 98% and increase the cyclist facilities to cater for 15% of the staff and students. The non-rated building has four levels above the ground and a total area of 5242 m^2. Similar to the GB, it has a west–east orientation and several neighbourhood buildings and architectural features that provide shading during the day.

Taking into consideration the relevance of providing awareness to occupants as stated by Cobben (2017), the workshop intended to create awareness to occupants to their behaviours and the implications on the use of energy, in both buildings, when they were interacting with lighting, air conditioning, equipment, windows, doors and shading systems. OB patterns and how these patterns impact the overall energy performance in the two buildings were studied and presented during the workshop. The results promoted a discussion about the energy-related OB, and occupants were asked for suggestions to improve energy-related OB. Finally, was analysed during the workshop if in a building certified as 'green' occupants were more aware, aligning with what Darby et al. (2016) stated, and what were the main differences between the green-rated and the non-rated buildings in the overall energy performance. The participants from the workshop were asked for suggestions for improvement to be used in the future in the buildings, and based on the main suggestion provided by the participants, this paper intends to find a reliable solution that may be implemented to improve the use of energy in buildings, such as a users' building optimal performance (U-BOP) manual.

Table 1
Building characteristics.

	Green-rated building	Non-rated building
Total floor area (m^2)	5696	5242
Conditioned area (m^2)	5181	4667
Unconditioned area (m^2)	515	576
Annual energy intensity (kWh/m^2)[b]	187.22	190.45
Average occupancy intensity (Occ/m^2)[a]	0.16	0.11
Average plug load intensity (W/m^2)	16.04	23.15
Average light intensity (W/m^2)	6.07	10.85
Main activities	computer-/classrooms, laboratories, offices and corridors	
Occupant type	Academic, students, technical, and administrative	
Primary energy for cooling and DHW	Electricity	
Primary energy for heating	Natural gas	
Latitude and longitude	33°48′41.14′ S 151°01′37.98′ E	33°46′06.14′ S 150°43′44.83′ E
Location	Parramatta, NSW	Kingswood, NSW
Elevation (m)	12	20
Orientation (°)	2	7

[a] Per conditioned area.
[b] Calculated through building simulation.

2. Methodology

2.1. Case study buildings

Two buildings from Western Sydney University, in Sydney Australia, were selected for this study. An existing building from 1989, without any rating, and a green-rated building from 2016, certified according to the Green Star Australian certification system (Dawes, 2013). Both buildings had similar characteristics in terms of the type of construction, floor area, annual intensity rates, primary energy vector, occupancy rates and activity type. and show the main characteristics of the two buildings. The energy performance of these buildings was studied and analysed through building simulations, with the software DesignBuilder and EnergyPlus. Hence, the 3D models from the two buildings were created and calibrated according to actual data, which included energy vectors (electricity and natural gas) and physical characteristics. The models allowed realistic representations of the two buildings and the actual impact in energy use due to the behaviour associated with the respective occupants was possible to be studied (Almeida et al., 2020b).

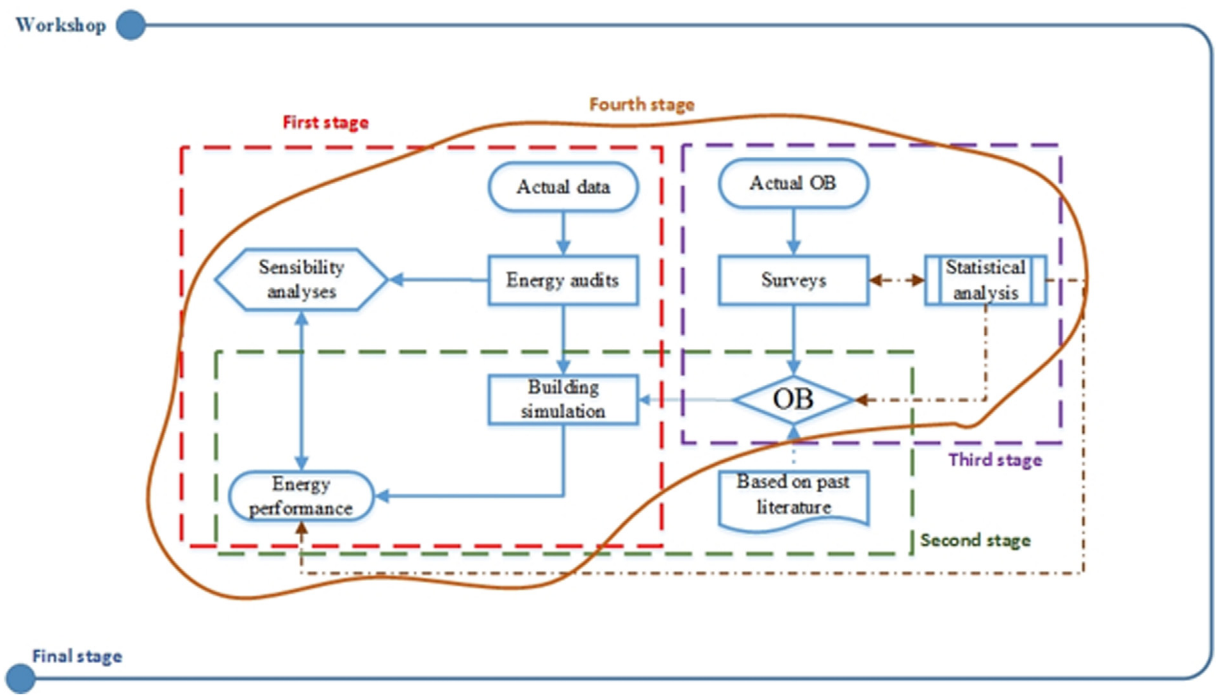


Fig. 3. Correlation between the methods used for this research.

Table 2
Demography of the samples.

		Green-rated building	Non-rated building
Gender	**Female**	68%	27%
	Male	32%	73%
Work role	**Academic**	16%	45%
	Student	52%	41%
	Administration	12%	7%
	Technical	20%	7%
Age	**Average**	30–40	30–40
	Standard Deviation	0.862	1.337
	Maximum	50–60	>60
	Minimum	<30	<30

3. Methods

Fig. 3 represents the main methods used to perform the studies presented in the workshop described in this paper. The methodologies were divided in 5 different stages.[1] The details of each stage were described in papers published previously and referenced through this paper.

The *first stage* represents the case study of a green-rated and a non-rated building. Several visits and energy audits were performed to the buildings to collect actual data related with physical characteristics, energy vectors, existing systems and occupancy. Two 3D models were created to incorporate the actual data from the buildings. Several building simulations were performed to both buildings and through a sensitivity analysis the models were calibrated[2] and validated according to the actual monitored energy data. After the calibration the first simulations with the integration of the OB were performed. The OBs were classified as saving, real and intensive to understand how OB could impact the overall energy performance of the two buildings (Almeida et al., 2020a). To collect the actual energy-related OBs, representing the *third stage*, surveys were delivered to the occupants of the non-rated and the GB. The variables collected under the survey were analysed statistically to understand their correlation and significance with the OBs (Almeida et al., 2020b).

The *fourth stage* represents the quantification of all the behaviours and actions collected in the surveys. The actual OBs were converted statistically and incorporated in the calibrated models (Almeida et al., 2020b). Finally, a *workshop* was performed with the key findings of this research. The main aim was to increase awareness in the use of energy and engage the people who have participated in the surveys, providing them the main conclusions from this research.

To collect the occupant's behaviours in energy use, two representative groups of occupants from the green-rated and non-rated building were selected and studied. Surveys were delivered to 100[3] occupants of the two buildings with questions addressing their awareness in energy use and behaviours when interacting with the buildings systems and features, such as the lighting, heating, cooling, equipment, windows and door opening, and shading (Almeida et al., 2020b). The main characteristics of the two samples are represented in Table 2 and Table 3 shows the probabilities of the interactions of occupants with the buildings' systems and features. Further, Table 4 (Appendix I) shows the main results from the surveys.

After collecting occupants' behaviours in the surveys, these behaviours were introduced as input variables in the building simulations models. The impact on the overall energy use of these behaviours was hence determined and quantified (Almeida et al., 2020b).

3.1. Workshop

After performing the simulations that transcribed the results from the impact of the OB in the overall energy use, a workshop was scheduled to present the results to an audience that included some of the occupants of the two buildings. This workshop intended to promote awareness, to the occupants and technical staff, of their actual impact in the overall energy

[1] Stages 1 and 2 were represented in one paper (Almeida et al., 2020a).

[2] The calibration and validation were performed according to the methodology described on existing literature, using an acceptable deviation range of ±10% (Gucyeter, 2018; Yoon and Lee, 1999).

[3] The sample size was selected based on the methodology described by Belafi et al. (2018) and the reliability of the representativeness of the surveys was based on the ASHRAE Standard 55 (ASHRAE, 2013).

Table 3
Occupants' probability[a] of interaction with the buildings' systems and features.

System	Actions	Green-rated building P(A)$_{GB}$	Non-rated building P(A)$_{NRB}$
HVAC[b]	**Adjust thermostat when cold**	0.11	0.18
	Adjust thermostat when hot	0.09	0.23
Light	**Reduction due to glare and visual discomfort**	0.50	0.38
	Switch off lights at the end of the day	0.50	0.61
	Switch off lights during daytime	0.30	0.43
Plug loads	**Switch off plug loads Offices at end of the day**	0.58	0.78
	Switch off plug loads Labs at end of the day	0.38	0.49
	Switch off plug loads Circulations at end of the day	0.53	0.74
	Switch off plug loads General at end of the day	0.53	0.74
	Switch off plug loads Offices during daytime	0.38	0.48
	Switch off plug loads Labs during daytime[1]	0.20	0.36
Windows	**Open/close windows during daytime when hot/cold**	0.51	0.36
Shading[c]	**Close shading due to glare**	0.31	0.31

[a] The probabilities were calculated with the equation $P(A) = \sum_{i=1}^{n} P(A/E_i)\,P(E_i)$, where 'P(A)' represents the probability of aspecific action to occur, 'P(A/Ei)' is the probability of occupants' interaction at an event i due to action A and 'P(Ei)' refers to the probability of the occurrence of the event i.

[b] The percentage of occupants interacting with the air conditioning system is low due because this system is mainly managed by the management system. Only a few rooms have individual units such as Splits or Multisplits

[c] According to the results from the questionnaire survey, occupants only activated the shading system due to glare in 68% of the rooms with shading in the non-rated building and 61% of the rooms with shading in the green building.

use. The workshop created an atmosphere of discussion surrounding energy use in buildings and energy efficiency. It was promoted by email and comprised of five steps: 1) an introduction to OB, 2) followed by a brainstorming session with four questions where participants were asked to discuss as a group and provide their conclusions, 3) a presentation with the main findings from the study described in the four stages from section 2.2, 4) a new brainstorming session where participants were asked to provide their opinions and feedback related to energy conservative measures that would be applicable in the future, in the two buildings, and finally 5) the most relevant energy conservative measure was selected and discussed.

4. Main results

The results from the buildings presented in and that correspond to the first and second stages on section 2.2 show that the main indicators in terms of energy, greenhouse gas emissions and costs, for the green-rated and non-rated buildings, are; 190 kWh/m^2, 194 kgCO$_{2\text{-eq}}$/m^2 and 10 AUD/m^2, and 187 kWh/m^2, 192 kgCO$_{2\text{-eq}}$/m^2 and 11 AUD/m^2, respectively. The energy use due to the actual OBs and actions associated with Table 3, that correspond to the fourth stage on section 2.2 and researched by Almeida et al. (2020b), represents 25% (47 kWh/m^2 pa) and 19% (35 kWh/m^2 pa) of the total energy use in the non-rated (190 kWh/m^2 pa) and GB (187 kWh/m^2 pa), respectively. Plug loads have the highest potential for the reduction of energy use, and the heating is impacted the most by the OB. Heating (81%), lighting (66%), and plug loads (46%) represent the end uses that are impacted the most the energy performance in the non-rated building, and lighting (43%), heating (28%), and cooling (24%) represent the end uses that are impacted the most in the GB. An intensive energy user increases the use of energy by 29%, and a saving type of energy user decreases the energy use by 43%. Moreover, the results show that the GB is operating as a non-rated building due to occupants' interactions with set-point temperatures and, therefore, the Green rating has no impact on the overall energy use or on the way occupants perceive the energy use. The GHG emissions and costs are higher in the GB when compared to the non-rated building. The occupants in the non-rated building use 25% less energy than the occupants of the GB.

The third stage on section 2.2 researched in detail on the authors' paper Almeida et al., 2020c show that the green rating impacts the overall satisfaction. Occupants are more satisfied and therefore, more tolerant when working in a green building. The occupant interactions with shading are directly related to visual discomfort and not to the increasing natural light levels. The age, gender, workplace location, and size, as well as the working role, have an impact on the energy-related behavioural patterns of occupants. Older generations are more energy-efficient than younger generations and women are more energy-efficient than men in the GB; yet, the opposite was noticed in the existing building. Men interact more often with building features, and women interact more often with the building systems (e.g. lighting). The workplace size/built environment promotes the interaction of occupants with the lighting system. Changes in the OB will strongly impact the overall energy performance of a building. The OB impact is more significant in the non-rated building than in the GB because a GB is already an optimised building version. Therefore, changes in climate affect the energy-related occupant behaviour in the non-rated building but not in the GB. Finally, the study shows that occupant behaviours and actions are affected by parameters other than climate and that the energy use based on the OB is higher in warmer climates than in cooler climates, in both buildings.

5. Workshop

After finding the previous results a workshop was scheduled. The main objectives of the workshop were to present the results and main conclusions of the research addressed previously, and bring together several professionals/experts[4] with different professional backgrounds to:

- Promote a discussion based on the main conclusions from the previous research and create a brainstorm session related to OB and the efficient use of energy in buildings;
- Point out the relevance of the occupant behaviours and actions when interacting with systems and/or features in buildings;
- Share good practices and develop knowledge about energy-related occupant behaviours and actions;
- Provide an overview of the main end-uses impacted by the OB;
- Provoke the reflection and critical evaluation of the key systems and/or features impacted by the occupant behaviour and follow-up discussions;
- Inspire and motivate participants to share knowledge, collaborate, and suggest future research topics and/or improvement measures addressing the energy-related OB, having as background the information and the results provided and discussed under this workshop.

Fig. 4 was shown to the participants of the workshop. The figure highlights key concepts associated with OB and intended to serve as a subliminal message provided at the beginning of the workshop to capture participants attention. These key concepts were clarified throughout the workshop and in the main presentation.

[4] Some of these professionals have participated in this research by providing their feedback to the questionnaire surveys, mentioned previously. Therefore, this workshop intended to provide them with the outcomes of their own impact in the studied buildings.

Fig. 4. Occupant behaviour.

5.1. Participants

The workshop was performed to participants with different skill sets, expertise, and professions, such as academics, students and technical staff. The workshop welcomed the participation of individuals with experience and/or interest in the OB, GBs, and energy efficiency. As mentioned previously, the workshop aimed to present the main findings of the results presented in section 3 in the field of energy-related OB. The workshop consisted of a presentation of the major findings, discussions, exercises, and the sharing of knowledge and results provided information for the participants, leading to the brainstorming of recommendations for future research and improvement. Fig. 5 shows some of the participants of the workshop (see Fig. 6).

5.2. Initial questions for the participants

After a small introduction to the main subject of this workshop, to test participants' knowledge in energy-related occupant behaviour, energy efficiency and green buildings, four initial questions were directed to the audience.

Q1 – Do you believe that occupants have a significant impact on the energy use? Why?

Q2 – Has the green rating an impact on the OB? How?

Q3 – Is a green-rated building more energy-efficient than a non-rated building? Why?

Q4 – Does the climate impact the occupant behaviour? How?

The participants were divided in four different groups and each group was asked to answer one of the questions.

For Q1 (question 1) the group of participants selected to provide their opinion, agreed that occupants have a significant impact on the overall energy use in a building, and this impact is related to:

- Thermal comfort, which leads to variable individual variations and tolerances;
- Choice consciousness in terms of their interactions with clothing, HVAC, equipment types, fresh air, cost and energy use;
- The design of the buildings, namely the orientation, passive design, insulation, building materials;
- Occupants availability to control building systems (switch on–off lighting, cooling, heating), features (open/close doors and windows) and equipment/appliances (computers and other electrical devices);
- Determine the usage and dimension.

For Q2 (question 2), similar to the previous question, the group of participants selected to provide their opinion, agreed that the green rating impacts the OB, and this impact is related to:

- If the green rating accurately reflects the building comfort levels, the occupants should not need to use excessive energy for lighting, heating, and cooling;
- The rating probably does not change the occupants' thoughts but may have affect human action;

Fig. 5. Workshop participants.

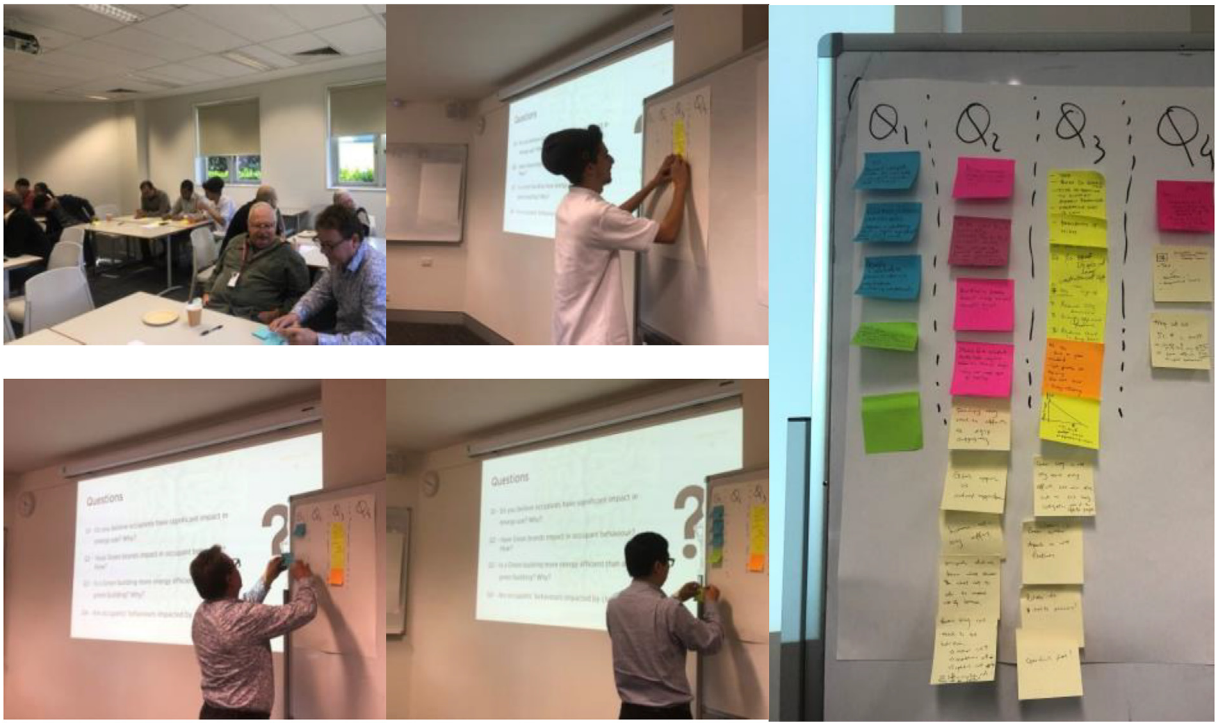


Fig. 6. Questions for the audience.

- Occupants should be forced to stop negative behaviours through design (e.g. not requiring lights or heating);
- Occupants do not know what or what not to do to comply with the requirements of a green rating in terms of energy use;
- Motion sensors scale up the ratings and technology may bring about the need to afford appropriate equipment;
- The cost related to a 'green' approach tends to imply the implementation of advanced technologies:

o The green-rated building process has higher initial costs, but lower maintenance costs and operation costs;

o However, life cycle costs may not have a positive impact in the implementation of a 'green' approach in buildings.

The group of participants selected to provide their opinion for Q3 (question 3), answered affirmatively when stating that a green building is more energy-efficient than a non-green building, which is due to:

- The green-rated building is built to comply with a specific standard;
- The type of features installed in a green-rated building, to support the green features, such as energy-efficient features which allow a reduction in CO_2 emissions;
- The operating costs are lower when compared to a non-rated building and therefore the overall efficiency is higher;
- Life cycle costs are lower but the construction costs are higher;
- Green rating is not only about energy efficiency but also about other issues such as the sick building syndrome, indoor environmental quality and the need to build for a purpose;
- Green 'brainwash' depends on what features?

Finally, the last group of participants designated to provide their opinion for Q4 (question 4), similar to the previous groups, replied that the climate has impact on OBs, because:

- Depending on the temperature levels, occupants decide about using heating or not;
- Depending on the weather, if it is rainy and/or cold occupants tend to stay indoors;
- According to research from the council of Sydney, the temperature will be 5 °C higher in 2050. The number of days with 35 °C will increase, and higher temperatures have affected the OB;
- OB is impacted by climate change.

5.3. Workshop conclusion/recommendations for future studies and improvement[5]

After the participants express their opinions to the previous questions, the main results expressed under section 3 were presented in the workshop. At the end of the presentation, based on the main findings from this research (Almeida et al., 2020a–c), a discussion was created among all participants to collect their suggestions for future areas of research and improvement measures to be implemented in the two buildings, according to the perceptions created after the presentation and the feedback from the previous four questions. The prominent areas for improving OB according to the participants are: 1) occupant awareness, 2) new technologies and 3) maintenance/building management systems (BMS).

Under the new technologies topic, the participants focused on the importance of using the artificial intelligence (AI), machine learning and data mining to improve the understanding of occupant's behaviours when facing with options and controls, as well as mixed-mode operations and seasonal set point. The increase in occupant's awareness, which was the second topic suggested by the workshop's participants, can be achieved by clearly communicate the implications and leverage of OB. This may be achieved by providing users' guidelines, implement frequent workshops to educate occupants who are not familiar with engagement in the buildings' technical features, allow occupants to make suggestions for improvement within specific general and individual recommendations on the energy use (e.g. turning off computers at night, raising/lowering AC temperatures, usage of blinds) and promote the green-rating building concept. Finally, proper maintenance and building management

[5] The conclusion/recommendations provided under this chapter correspond only to the recommendations collected as an outcome to this workshop.

systems (BMS) control is extremely important. The commissioning and maintenance of smart energy systems, improving the BMS and energy monitoring, and implement a strategy for engineering assessment, were the final suggestions made in the workshop.

A final discussion was then promoted and participants were asked to vote, what according to their opinion was the most relevant topic of the three mentioned previously. Most of the participants chose that the main relevant research topic of future studies related to the occupants' energy use, with a total of 54% of votes, was the 'Occupant awareness'. Participants highlighted the relevance of communication and providing guidance to occupants in buildings, in an open environment in which occupants will be able to provide their feedback and suggestions to improve the energy performance of the building. The second most relevant future research topic regarding the energy-related OB, with 38% of the votes, was 'New technologies'. Participants suggested new options and forms of control regarding energy use and the implementation of other technologies such as artificial intelligence and machine learning, as mentioned previously. Finally, the last relevant area of future research and/or improvement regarding the energy-related OB, with 8% of the votes, was 'Maintenance/BMS'. Participants suggested more frequent commissioning and maintenance of smart energy solutions as well as BMS and energy monitoring.

6. Discussions

6.1. Users' building optimal performance (U-BOP) manual

One of the questions asked in the questionnaire surveys, mentioned under section 2, was if the occupants were educated in terms of the building operation. 25% of the occupants in the GB answered that they have been educated in how the building operates. However, in the non-rated building, only 15% of the occupants replied affirmatively to this question. From the combination of the two buildings, only 19% of the occupants have some sort of education on the buildings' operation, leaving 81% of occupants without any knowledge on the mater. The lack of information on how to operate efficiently the building systems and features and the urgency for occupant awareness aligns with the main topic selected by the majority of the workshop participants and is supported by literature, leading to significant losses due to the misuse of energy (Al-Mumin et al., 2003; Masoso and Grobler, 2010; Nisiforou et al., 2012).

Therefore, according to the main outcomes of the workshop, the most relevant impacting topic is improving "occupant's awareness" use of energy in buildings. As mentioned previously in the introduction section, several solutions were tested and suggested by past researchers as possible tools to be implemented in buildings to increase occupants' awareness on energy use. Solutions such as campaigns to promote energy efficiency (Al-Mumin et al., 2003; Masoso and Grobler, 2010; Nisiforou et al., 2012), use of flyers and/or images or short text blocks (Cobben, 2017), interactive networks and social-media technologies (Klöckner, 2019), use of smart meters with feedback to the occupants on their uses and preferences, and the green brand and tools significance (Darby et al., 2016) were referred as having an impact on OB. However, these solutions are punctual and do not provide extensive information on the building's characteristics and the best practices, as a whole, to adopt to drive the building towards an effective and sustainable system.

According to Yan and Hong (2018), there is a need for guidelines on occupant behaviour in buildings, during the design stage. The development of a guidebook with information related to occupant behaviour to aid simulation users during the design stage, detailing suitable situations for each new model, with the integration of occupant behaviour in each one of the different stages of the lifecycle of a building (from planning and design to operations and retrofit) that allows the understanding of the variation of performance and the risk of implementing new technologies.

Moreover, the construction sector world widely is responsible for USD 1.39 trillion, representing China 41%, Europe 26%, Japan 13%, the United States 9% and South Korea 7% of all the largest companies in the world (Parada, 2019). As an example, the construction sector in the UK represented in 2018 6.1% (£116.3 billion) of the total gross domestic product. With a total of 28 Million homes and 2.4 Million other types of buildings, like hospitals, offices, schools and shops (Green, 2020), and representing buildings one of the main assets to people, almost none of these buildings have a building manual that provides information to users on how to use them efficiently and appropriately. When an appliance is bought normally comes with a user manual that provides, not only technical information and characteristics but also specific guidelines to promote an appropriate usage of the appliance. However, when a building or dwelling is sold, there are no guidelines on which best practices should be implemented to ensure efficient use of that asset.

Currently, there are already some building guideline manuals for operation and maintenance, mostly addressing technical aspects of the building and directed to the owner, but not as much to the user. The Green Star and BREEAM certification tools have developed the building user guide (BUG) with the intent to provide information to project teams, in the first case, and to provide information on how the building works in terms of use and layout, covering aspects such as user's interactions with energy, water and waste systems, in the case of BREEAM, under the category of commissioning and handover (BRE, 2018). The latest one is closest to what is intended to be discussed under this section of the paper. However, the building user guide is only applicable to non-residential buildings, and to the ones that are certified according to the BREEAM certification tool, leaving a vast section of the built environment without any information on how to be used to optimal standards. It is the opinion of the authors of this paper that all buildings must have a guideline that addresses the needs of the occupants and increase their understanding of the building function, provide information on how to improve the building's performance and maintain it up to optimum levels, ensuring that all systems are adequately used and maintained by all occupants and/or technical staff during the building lifecycle, reduce the main gap found in literature which is the difference between the predicted energy during the design stage and the actual operation stage (Mahdavi et al., 2008), and reduce operational and maintenance costs because all users know and understand properly how the building works and act to keep it working to optimal levels of performance. Improving occupants' awareness and meet the users' requirements will enhance overall productivity and satisfaction. Fig. 7 represents what is intended to be achieved with the introduction of a users' building optimal performance (U-BOP). Optimal performance may be achieved with an improvement on occupant's energy-related behaviours, increase the performance of systems and features, and reduce the inefficiencies. Proper maintenance and higher user's awareness are, therefore, crucial.

As a suggestion for a template to the users' building optimal performance manual the authors of this paper suggest the template provided by BREEAM for the building user guide, as a baseline (BRE, 2018). The manual should be clear, and perfectly understood by any building user, and the manual must be accessible to all occupants/users. In terms of the main contents, the manual should begin with a clear identification of the building and its main functions, provide clear instructions on how to use the manual, describe the main systems, equipment/appliances and features in the building, and provide clear guidelines on how to use them efficiently. Appendix II intends to provide a guideline for a table of contents that may be used for the U-BOP manual. The table of contents was based on the suggested template for a BUG from Green Star and BREEAM, as well as from O&M reports. The U-BOP manual should be clear and user friendly and updated whenever necessary.

Finally, there are already several reliable guidelines that may be used as a complement to the manual. The energy rating website in Australia (EnergyRating, 2016), provides several user guidelines that may be incorporated in a residential manual to aid occupants with optimizing their usages of energy. However, is recommended that the comments are personalized for each building and each particular system. Fig. 8 provides

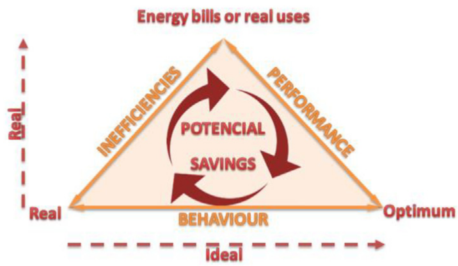


Fig. 7. Variables impacting the overall energy performance in buildings.

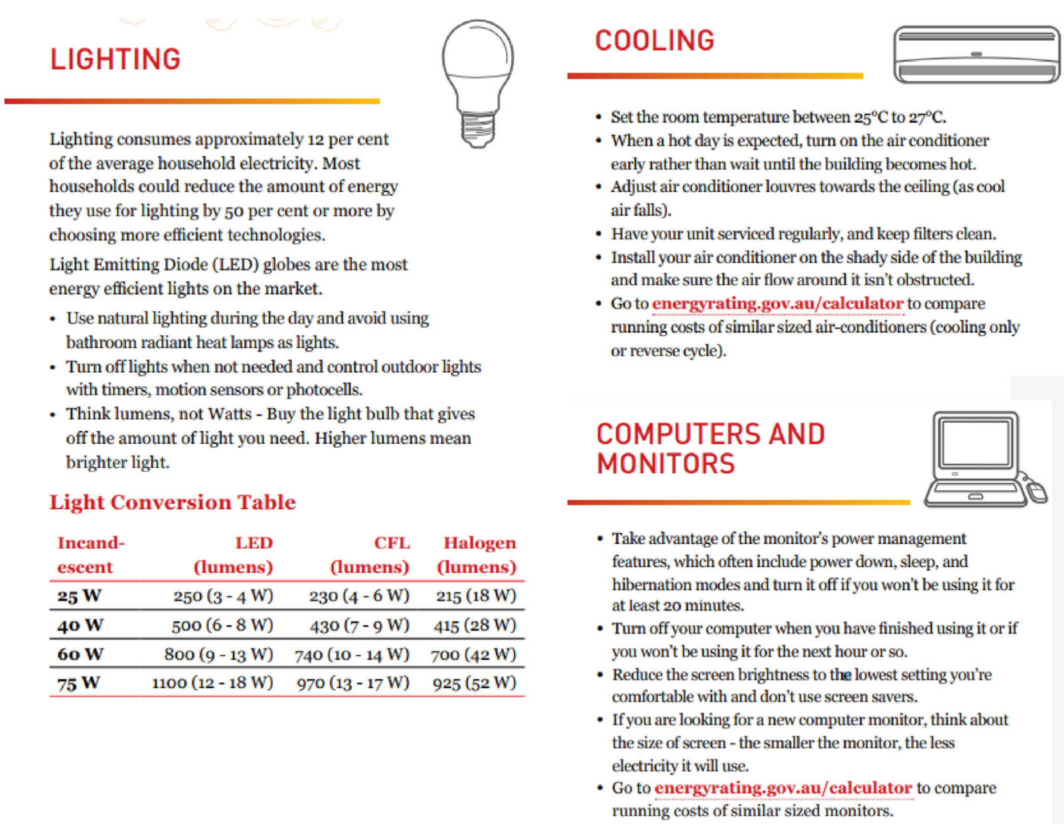
an example of tips that may be included in the U-BOP.

6.2. Limitations of this paper

This paper should be analysed in the context that is described and not extrapolated to other situations or occupant's behavioural patterns. It provides an overview of the opinions of occupants that were subjected to questionnaire surveys and presented to the outcomes of their impacts in the use of energy of two university buildings. After being presented with the impacts on energy use, their opinions were collected under a workshop. Therefore, one of the limitations of this paper is the subjectivity of the outcomes of the workshop. These outcomes are based on occupants own perceptions and levels of knowledge on energy use. However, the authors believe that occupants' perceptions and feedback are extremely important to improve energy-related OB. Occupants tend to feel more satisfied in buildings when considered as active actors and their opinions are heard (Burrows et al., 2013; Maniccia et al., 1999). Another limitation from this study is that the psychological aspects that lead occupants to behave within the patterns presented in this study, or even related to the opinions provided under the workshop, were not accounted for. Moreover, the users' building optimal performance manual was presented in this paper as a suggestion to increase the awareness of energy-related OB. It is the opinion of the authors that any building should have a manual that provides technical information on the building and guidelines on how to use the building to optimal performance. However, the impact of the use of this manual was not studied. This should be addressed in a future study.

7. Conclusion

This paper provided the outcomes from a workshop presented to the occupants of two university buildings, in Sydney Australia. Occupants' opinions and behaviours in energy use were collected under questionnaire surveys, in both buildings, and their behaviours were quantified and analysed using building simulations. One of the main key results from the surveys addressed that the GHG emissions and costs are higher in the green-rated building, when compared to the non-rated building and the occupants in the non-rated building use 25% less energy than the occupants of the green-rated building. The surveys have also shown that 81% of the occupants from the two buildings do not receive any information on how the buildings operate. After the results were presented in the workshop and, through a brainstorming discussion, occupants stated that one of the key factors that may improve their rational use of energy is 'occupants' awareness'. Other factors such as the implementation of 'new technologies' and a proper 'maintenance/building management systems' were referred to as important factors that need to be taken into account when addressing energy use. Based on the results from the workshop, and to increase occupant's awareness and address the negative impacts on energy use due to occupant behaviour, this paper suggested the implementation of a users' building optimal performance (U-BOP) manual as a tool to be used to increase occupants' awareness in energy use in buildings. The manual should provide guidelines to users to drive the building towards optimal performance. It is the opinion of the authors that manuals directed to building users should be an



LIGHTING

Lighting consumes approximately 12 per cent of the average household electricity. Most households could reduce the amount of energy they use for lighting by 50 per cent or more by choosing more efficient technologies.

Light Emitting Diode (LED) globes are the most energy efficient lights on the market.

- Use natural lighting during the day and avoid using bathroom radiant heat lamps as lights.
- Turn off lights when not needed and control outdoor lights with timers, motion sensors or photocells.
- Think lumens, not Watts - Buy the light bulb that gives off the amount of light you need. Higher lumens mean brighter light.

Light Conversion Table

Incandescent	LED (lumens)	CFL (lumens)	Halogen (lumens)
25 W	250 (3 - 4 W)	230 (4 - 6 W)	215 (18 W)
40 W	500 (6 - 8 W)	430 (7 - 9 W)	415 (28 W)
60 W	800 (9 - 13 W)	740 (10 - 14 W)	700 (42 W)
75 W	1100 (12 - 18 W)	970 (13 - 17 W)	925 (52 W)

COOLING

- Set the room temperature between 25°C to 27°C.
- When a hot day is expected, turn on the air conditioner early rather than wait until the building becomes hot.
- Adjust air conditioner louvres towards the ceiling (as cool air falls).
- Have your unit serviced regularly, and keep filters clean.
- Install your air conditioner on the shady side of the building and make sure the air flow around it isn't obstructed.
- Go to energyrating.gov.au/calculator to compare running costs of similar sized air-conditioners (cooling only or reverse cycle).

COMPUTERS AND MONITORS

- Take advantage of the monitor's power management features, which often include power down, sleep, and hibernation modes and turn it off if you won't be using it for at least 20 minutes.
- Turn off your computer when you have finished using it or if you won't be using it for the next hour or so.
- Reduce the screen brightness to the lowest setting you're comfortable with and don't use screen savers.
- If you are looking for a new computer monitor, think about the size of screen - the smaller the monitor, the less electricity it will use.
- Go to energyrating.gov.au/calculator to compare running costs of similar sized monitors.

Fig. 8. Variables impacting the overall energy performance in buildings (EnergyRating, 2016).

indispensable component for all buildings and not just a document from a green certification process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix I

Surveys results

Table 4
Interaction of occupants with building systems according to gender.

		Non-rated Building			Green Building		
		Female	Male	Total (/100%)	Female	Male	Total (/100%)
Periodicity that appliances are switched off	Never	16.7%	6.3%	9.1%	29.4%	25.0%	28.0%
	Sometimes	41.7%	53.1%	50.0%	58.8%	50.0%	56.0%
	Always	41.7%	40.6%	40.9%	11.8%	25.0%	16.0%
Periodicity that portable electronic devices are charged	Never	0.0%	12.9%	9.3%	11.8%	0.0%	8.0%
	Sometimes	16.7%	25.8%	23.3%	41.2%	12.5%	32.0%
	Regularly	58.3%	45.2%	48.8%	41.2%	62.5%	48.0%
	Always	25.0%	16.1%	18.6%	5.9%	25.0%	12.0%
Light switch (Overhead)	Unable	8.3%	3.1%	4.5%	6.3%	0.0%	4.3%
	Never	8.3%	15.6%	13.6%	50.0%	42.9%	47.8%
	Sometimes	16.7%	18.8%	18.2%	12.5%	28.6%	17.4%
	Regularly	25.0%	31.3%	29.5%	6.3%	14.3%	8.7%
	Always	41.7%	31.3%	34.1%	25.0%	14.3%	21.7%
Light dimmer (Overhead)	Unable	70.0%	52.2%	57.6%	13.3%	0.0%	8.7%
	Never	30.0%	21.7%	24.2%	46.7%	37.5%	43.5%
	Sometimes	0.0%	4.3%	3.0%	20.0%	62.5%	34.8%
	Regularly	0.0%	21.7%	15.2%	13.3%	0.0%	8.7%
	Always	0.0%	0.0%	0.0%	6.7%	0.0%	4.3%
Task light (Desk lamp)	Unable	70.0%	47.8%	54.5%	42.9%	28.6%	38.1%
	Never	30.0%	21.7%	24.2%	35.7%	71.4%	47.6%
	Sometimes	0.0%	13.0%	9.1%	14.3%	0.0%	9.5%
	Regularly	0.0%	13.0%	9.1%	7.1%	0.0%	4.8%
	Always	0.0%	4.3%	3.0%	0.0%	0.0%	0.0%
Ceiling fan	Unable	70.0%	50.0%	56.3%	64.3%	57.1%	61.9%
	Never	30.0%	27.3%	28.1%	28.6%	28.6%	28.6%
	Sometimes	0.0%	13.6%	9.4%	7.1%	14.3%	9.5%
	Regularly	0.0%	9.1%	6.3%	0.0%	0.0%	0.0%
Portable fan/heater	Unable	60.0%	52.4%	54.8%	66.7%	50.0%	60.0%
	Never	40.0%	28.6%	32.3%	25.0%	25.0%	25.0%
	Sometimes	0.0%	9.5%	6.5%	8.3%	25.0%	15.0%
	Regularly	0.0%	9.5%	6.5%	0.0%	0.0%	0.0%
Ducted air-conditioning/Thermostat	Unable	54.5%	45.5%	48.5%	50.0%	37.5%	45.8%
	Never	36.4%	22.7%	27.3%	25.0%	37.5%	29.2%
	Sometimes	0.0%	18.2%	12.1%	12.5%	0.0%	8.3%
	Regularly	0.0%	13.6%	9.1%	12.5%	12.5%	12.5%
	Always	9.1%	0.0%	3.0%	0.0%	12.5%	4.2%
Blinds / shutters / shades	Unable	0.0%	14.8%	10.3%	31.3%	12.5%	25.0%
	Never	41.7%	11.1%	20.5%	18.8%	37.5%	25.0%
	Sometimes	41.7%	55.6%	51.3%	25.0%	12.5%	20.8%
	Regularly	0.0%	14.8%	10.3%	18.8%	37.5%	25.0%
	Always	16.7%	3.7%	7.7%	6.3%	0.0%	4.2%
Operable window	Unable	18.2%	28.6%	25.6%	52.9%	50.0%	52.0%
	Never	36.4%	21.4%	25.6%	11.8%	25.0%	16.0%
	Sometimes	36.4%	32.1%	33.3%	23.5%	0.0%	16.0%
	Regularly	9.1%	14.3%	12.8%	5.9%	25.0%	12.0%
	Always	0.0%	3.6%	2.6%	5.9%	0.0%	4.0%

Appendix II

Suggested table of contents for the U-BOP[1]

1	Introduction - provide general identification of the building and the purpose of the manual
2	***Building Information*** *- all information related to the building and its systems*
2.1	

(continued on next column)

(*continued*)

1		Introduction - provide general identification of the building and the purpose of the manual
		General Building Information - building description and activities, floor areas, access and egress, location, plans …
	2.2	***Building envelope*** - external and internal fabric, glazing, shades, thermal properties, strategies …
	2.3	***Building systems and features*** - building systems and features: HVAC, lighting, hot water, lifts, shading, system failure …
	2.4	***Safety and public health*** - safety features, fire safety and evacuation procedures, emergency, first aid …
3		***Building Utility and Environmental Information*** - detailed information on sustainable considerations and utilities
	3.1	***Environmental Policy and Practices*** - sustainability strategies and policies
	3.2	***Energy & Environmental Management: Technical Information*** - energy sources and renewable systems
	3.3	***Mechanical systems*** - heating, cooling and ventilation
	3.4	***Electrical systems*** - lighting, plug loads …
	3.5	***Hydraulic systems*** - pumps, valves, piping …
	3.6	***Building management and control system*** - BMS, metering and monitoring
	3.7	***Communications and networking***
	3.8	***Security systems*** - access, intruder alarms, closed-circuit television and intruder alarms
	3.9	***Maintenance and inspections***
4		***Water Management*** - water supply, recycling, water reduction, leakage
5		***Indoor environment quality*** - air quality, pollutants, light levels, daylighting …
6		***Materials & Waste Management*** - recyclables, reusables, recoverables, location, toxic waste …
7		***Transport Facilities*** - cycling and changing facilities, public transport, car park and accessibility, alternative transport
8		***Do's and don'ts*** - specific do's and don'ts directed to the users (this point should be addressed in a simple and clear form, and may be added under each one of the previous sections with specific guidelines to the users)
9		***Refit and Rearrangement Considerations*** - design information, O&M, health and safety …
10		***Reporting Provision*** - relevant contacts, operation times …
11		***Training and occupant awareness discussions*** - training and occupant awareness discussion sessions where occupants are asked for their feedback and opinions on the performance of the building. From these sessions, future improvement measures may be discussed and applied immediately in the buildings
12		***Referencing***

[1] All the following sections may or may not be applicable, depending on the type of building. The level of detail depends on the complexity of the buildings and their systems.

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