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Unraveling everyday heating practices in residential homes

Christine Eon[a,*], Gregory M. Morrison[a], Joshua Byrne[a]

[a] Curtin University Sustainability Policy Institute, Perth, Western Australia, 6102, Australia

Abstract

Recent research has found that low-emission buildings do not necessarily meet their full theoretical energy saving potential and one of the reasons for this discrepancy is related to occupancy. Inside the building, users interact with technologies and are influenced by everyday practice and subsequent behaviour. This research aims to unravel the layers of complexity in everyday practice with regards to heating and the use of renewable energy. For this purpose, ten Australian houses were established as embedded Living Labs and monitored for over a year. Results show that the studied households use climate control at different times of the day depending on lifestyle. However, individuals in the same household may have different heating practices according to motivations, attitudes and subjective norms. The combination of quantitative monitoring and qualitative assessments revealed that lifestyle, family structure, habits, comfort and the presence of renewable energy all impact on the frequency, timing and intensity of heating and cooling practice. This research provides a better understanding of intra-home and everyday practices, helping to inform the transition from energy efficient houses to energy efficient home systems.

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Keywords: Living Labs; Everyday Practice; Behaviour; House; Home; Heating Systems; Thermal Comfort, Renewable Energy

1. Introduction

Recent research has found that low-emission buildings do not necessarily meet their full theoretical energy saving potential and one of the reasons for this discrepancy is related to the effect of occupant behaviour [1-3]. Whilst energy efficient technology and house design exert an impact on domestic energy consumption, occupants can negate energy efficiency measures through rebound effects [4].

* Corresponding author. Tel.: +61 466-447-551.
E-mail address: christine.eon@curtin.edu.au

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The understanding of behaviour change in households has traditionally been informed by socio-psychology theories, such as the theory of planned behaviour [5], social norms [6] and the theory of cognitive dissonance [7]. These theories consider humans as rational beings, making decisions based on their attitudes, values, norms, knowledge and intentions. Accordingly, socio-psychology practitioners have attempted to influence behaviour through persuasive methods, such as feedback delivery, information provision and social norms [8]. The emerging field of practice theory has challenged the traditional persuasive approaches, arguing that the effects of persuasion are short-lived and do not become part of users' routines [9]. Practice theory advocates that everyday practices are directly influenced by technology, knowledge, motivations and habits [10, 11]. Practices are also fluid, changing over time and in accordance to the context [12], the evolution of infrastructure and social networks [13]. For instance, the practice of maintaining warmth is not only dependent on attitudes but also on available equipment (e.g. fire place, warm clothes or mechanical heating). Practice theory aims to enable change rather than persuade change and develop technology that meets user needs while promoting sustainable behaviours, rather than expecting change to occur without a change in context [9].

While the two schools of thought discussed above have been viewed as misaligned, they are now converging in Living Laboratories (Living Labs) [14] as researchers attempt to obtain a deeper understanding of the layers affecting occupant everyday practices and behaviour at a home level. Living Labs are real-life places (e.g. homes or workplaces) that support the co-creation and testing of technical and social innovations while also providing insights into user behaviour and daily practices [15-17]. Living Labs enable the observation of users in their own environment, interacting with other household members and familiar objects in an everyday situation.

The 10 House Living Labs project, consisting of ten Australian embedded Living Labs [18], uses mixed methods to understand intra-home dynamics, practices and behaviours and how these affect total energy use. A better understanding of the home system might accelerate the implementation of social innovation and technology to help close the gap between theoretical and actual energy use in low-carbon houses. This research focuses on heating practices and the use of rooftop photovoltaic (PV) panels.

2. Methods

2.1. 10 House Living Labs

The ten Australian Living Labs are located in the City of Fremantle, Western Australia, within close proximity to each other and therefore in the same microclimate. They consist of single detached dwellings, which are the predominant residential typology in Australia, and have mixed occupancies and designs (Table 1). The mix of houses include older houses that have been retrofitted to become more energy efficient through the installation of insulation and renewable energy; modern houses that were built to meet the minimum current Australian building standard of 6-Star or deemed-to-satisfy; and high performance houses, which are rated 7 or more stars. The higher the star rating, the lower the need for artificial heating or cooling per square meter to keep houses thermally comfortable, that is, in the range between 20 and 25^{o}C [19].

Nine of the selected houses possess solar panels and eight houses possess a solar hot water system, enabling us to study user practices and behaviours under the influence of home energy systems with a significant renewable contribution.

2.2. Mixed methods

Several techniques with varying levels of user engagement can be employed in Living Labs depending on purpose. These can vary from the observation and understanding of daily practices to the co-creation and testing of new technologies and solutions where the user is central to the process [20]. The first level of integration involves sporadic user engagement and is mostly descriptive as it aims to generate knowledge about baseline practices [20]. The 10 House Living Labs are positioned at this first level of integration and a merging mixed method approach was adopted for data analysis, where quantitative and qualitative data were the basis for interpreting results [21].

Table 1. Household characteristics. NatHERS rates houses between 0 and 10 stars according to the predicted heating and cooling load required to keep houses within a comfortable temperature range year round. The alternative to the minimum requirement of 6-Star is the rating 'deemed-to-satisfy' (DTS), which means that houses follow certain prescribed design principles but their heating and cooling loads have not been determined.

House	Year built	Occupancy	Renewable energy	NatHERS code/description
A	2009	4 young adults	1.2kW PV and solar hot water	8.5 Star
B	1950 (renovations in 2011)	2 adults and 2 children	1.5kW PV and solar hot water	Retrofitted
C	1899 (renovations in 2001)	2 adults	1.68kW PV and solar hot water	Retrofitted
D	1920 (renovations in 2014)	2 adults and 2 children	1.1kW PV and solar hot water	DTS
E	2011	2 adults and 1 young adult	2kW PV	7 Star
F	2011	2 adults and 2 children	2.28kW PV system and solar hot water	8 Star
G	2013	2 retired and 1 young adult	Solar hot water	6 Star
H	2013	1 adult, 2 teenagers and 1 young adult	2.66kW PV system and solar hot water	6 Star
I	2013	2 adults	1.8kW PV system and solar hot water	6 Star
J	1901 (renovations in 2014)	2 adults and 3 children	3.5kW PV system	6 Star

2.2.1. Quantitative data collection

Monitoring equipment (Table 2) was installed in the ten participant houses for the measurement of temperature in the living area, grid electricity, gas consumption and photovoltaic electricity generation in the nine houses that possess solar panels. Photovoltaic electricity exports were not measured, but this information was obtained through electricity bills, requested from the households at the end of each calendar year.

Table 2. Monitoring equipment specification. The monitoring equipment consists of multiple sensors that are coupled to existing meters and transmit electric pulses to a data logger. The data logger collects the data at 15 minute intervals and transmits csv files to the researchers remotely through a 2G wireless connection.

Parameters monitored	Meters & Sensors	Data logger
Gas	Ampy 750 gas meter & pulse counter Elster IN-Z61	Schneider Electric COM'X 200
Grid electricity	Schneider Electric iEM3110	
Photovoltaic electricity generation	Latronics kWh	
Internal temperature	Kimo TM110	

2.2.2. Qualitative data collection

Insights into individual behaviours and practices were obtained through semi-structured interviews [22] involving all members of each household whenever possible. The interviews were conducted at the participants' homes and consisted of two stages. The first stage of the interview addressed behavioural elements and included questions about individual attitudes concerning energy consumption and greenhouse gas emissions; perceptions of other people's attitudes (in the community); barriers and opportunities to reduce energy consumption in the house; and support amongst individuals in the household with regards to saving energy. The second stage of the semi-structured interview targeted everyday practices. At this stage, participants were shown a summary of their historical energy use data for the previous 12 months and asked to comment about any particular reasons for having consumed more energy in one month in comparison to another. This was followed by a house audit, which was an informal conversation, whereby participants were asked about their energy related practices, such as operating the heating systems. The answers obtained from the semi-structured interviews and researchers observations were used to support and evaluate the quantitative data obtained through the house monitoring system.

3. Results and discussion

This section analyses household dynamics, lifestyles and intra-home practices related to the use of heating systems in winter.

3.1. Heating practices

What happens inside dwellings, at a home level, is dynamic and a factor of multiple influences, including lifestyle, interaction between family members, social norms, habits, knowledge, as well as the need for comfort and everyday practices [13, 25, 26]. This section analyses differences in practices related to the use of mechanical heating during the month of July 2015, which corresponds to the Australian winter.

3.1.1. Influences of lifestyle and family composition in heating practices

Eight of the ten houses in this study possess mechanical heating to maintain a comfortable environment in winter, with increased electricity and gas use occurring in these houses during that season. However, the home practice for energy use differs significantly between households. The coldest day of 2015 was on the 9th (Thursday) of July, with external temperatures reaching a minimum of 1.5^{o}C at 07.00. On this day, the occupants of Houses E (7 Star), H (6 Star) and I (6 Star), who are not usually at home during the day, only used their heating system during the morning and evening. In House C (retrofitted), a household of working adults, the heater was only turned on in the evening. Houses B (retrofitted) and G (6 Star), which are usually occupied during the day, used the heater during periods of the morning, afternoon and evening. Finally, House J (6 Star), which consists of a family of young children and a stay-at-home mother, only used the heater during the day clearly disregarding the experience of the lowest internal temperature of all houses in this study (Table 3).

Table 3. Maximum and minimum winter internal temperatures in houses that used mechanical heating systems during the coldest day of 2015.

House	Minimum temperature (^{o}C)	Maximum temperature (heater was on) (^{o}C)	Heater on	Family composition and occupant lifestyle
B	15.3	19.1	Morning, afternoon, evening	Stay-at-home mother and children. At home during the day
C	15.5	16.9	Evening	Working adults. Work full time
E	16.4	20.3	Morning, evening	Working adults. Work full time
G	16.4	20.8	Morning, afternoon, evening	Retired adults. At home during the day
H	13.8	18.9	Morning, evening	One working adult and teenagers. Some household members are at home during the day.
I	16.4	20	Morning, evening	Working adults. Work full time
J	12.4	20.7	Afternoon	Stay-at-home mother and children. At home during the day

3.1.2. Heating practices at the home level

The feeling of warmth is often considered to be the most important aspect of comfort [27], however, how different individuals seek and experience warmth can vary significantly. Research has shown that when cold is experienced the most common actions taken by individuals include changing clothing, changing posture, opening or closing windows, making a warm drink, showering and adjusting the building thermal control [28]. Heating practices can be related to hedonic experiences, such as showering [28] and are not necessarily conscious or effective solutions. This research demonstrated that heating practices varied significantly not only between houses but also within houses. It was found that the inhabitants of dwellings possessing mechanical heating systems fit into three main groups according to their intra-home practices and behaviours (Table 4).

Table 4. Three dwelling groups according to intra-home practices and behaviours.

Dwelling groups	Description
Group I	Occupants with heterogeneous behaviours resulting in multiple practices
Group II	Occupants with heterogeneous behaviours resulting in one predominant practice
Group III	Occupants with homogeneous bahaviours resulting in one predominant practice

The first group consists of dwellings whose occupants have heterogeneous behaviours; that is, occupants do not share the same attitudes, subjective norms, knowledge or motivations in regards to energy savings and comfort. As a result, the use of energy, in particular for the use of the heating system is also inconsistent and more unpredictable. House H, for example, fits in this first group. The household comprises of a mother who works full time and her three teenage children who are often at home during weekdays afternoons (Table 1). As noted during the interview with the mother (Table 5), she has very different behaviours compared to her children. For instance, she appears to understand the implications of carbon emissions and is motivated to saving energy and money by using appliances while the PV system is generating electricity. The teenagers, on the other hand do not have the same motivations, enjoy using the heating system and are mostly driven by comfort.

Table 5. Behaviours and self-reported practices in House H.

Behaviours/Practices	Mother	Teenagers
Attitudes	Committed to saving carbon emissions and energy	Not aware of the importance of saving carbon emissions
Subjective norms	People do not know enough but the local community is very green and want to make a difference	
Perceived behavioural control	Believes she can make a difference at a small scale	
Motivations	Economic savings and comfort	Comfort
Understanding of PV technology	Good understanding	
Self-reported practices	Since moving to this house she has tried to use appliances during the day, such as dishwasher, taking advantage of the PV system. Does not require much climate control	Forget to turn lights off, have long showers. Enjoy using thermal control

Figure 1 reveals that in winter the heater in this house is turned on daily (some mornings, some afternoons and evenings), however the time and duration of its use is inconsistent. Occasionally, the heater is on for brief periods, and on other days it stays on for several hours, such as on the 10th and 11th of July (Fig. 1). An assumption is that the mother is the one turning the heater on for brief amounts of time in order to achieve thermal comfort. The teenagers in contrast are presumed to turn the heater on for extended periods including on week day afternoons, either as a hedonic experience or due to forgetfulness. In this house the heater is usually turned on when the internal temperature averages 18.69^{o}C. It was also observed that the internal temperature varies between 21 and 25^{o}C when the heater is on, indicating that different occupants feel thermally comfortable at different set temperatures.

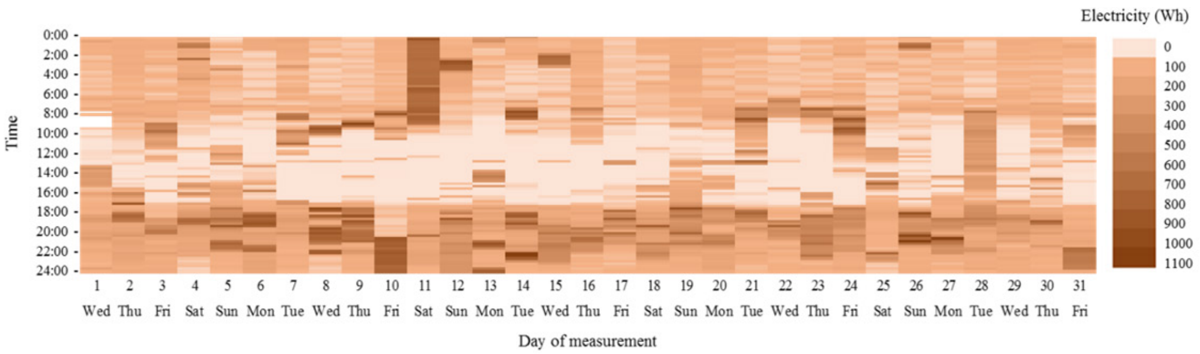

Fig. 1. Electricity heat map of House H in July 2015 at 15 minute intervals. Dark shades representing an electricity usage of 500Wh or higher can be associated with times when the heater was on. The lighter band during day hours reveals the impact of the PV panels on grid electricity consumption. The PV system covers small electricity needs, but higher loads such as ambient heating requires additional grid electricity.

The second group consists of households whose house members have heterogeneous behaviours, however, only one heating practice dominates. House E, a family of three working adults fits in this group (Table 1). The interview with the family members (Table 6) revealed that while the mother and father mostly differ in opinions and motivations to save energy, they both perceive themselves as using less energy than others due to living in a low-carbon house. In addition, they do not believe that further energy savings are feasible. The perception of doing enough and lack of perceived control is reflected on the house energy use, as anticipated by the theory of predicted behaviour [5, 29]. Figure 2 shows that this household uses the heater in winter on a daily basis and for extended periods of time, usually between 17.00 and 23.00 and sometimes during mornings and afternoons. The fact that the heater is turned on every day at approximately the same time could indicate that the individuals in this family have developed a habitual behaviour of turning the heater on when at home in spite of their divergent attitudes toward energy savings. This behaviour could also be caused by rebound effects due to a limited understanding of the technical system of the house and in particular the use of the PV system (Table 6) [4]. Just before the heater is turned on the internal temperature in the house is on average 19.33°C.

Table 6. Behaviours and self-reported practices in House E. GHG means greenhouse gas.

	Mother	Father	Son
Attitudes	Committed to saving carbon and would make an effort to saving energy	Does not care.	Does not have an opinion about saving GHG emissions
Subjective norms	Friends are not conscious about GHG emissions and energy saving but the community is	Friends and wider society are not aware of the need to reduce GHG emissions	Friends do not have any awareness
Perceived behavioural control	Believes that the house design and energy efficient technology are enough in terms of energy savings.	Believes that emissions are insignificant at a home level.	
Motivations	Comfort and convenience	Economic savings and comfort	Comfort
Perception of self	Lives a simple life and uses less energy than others.	Does not actively pollute.	
Understanding of PV technology	Limited	Good understanding but is not at home to benefit from it	
Self-reported practices	Makes an effort to turn on dishwasher during the day	Has long showers, changed lamps for more efficient ones	

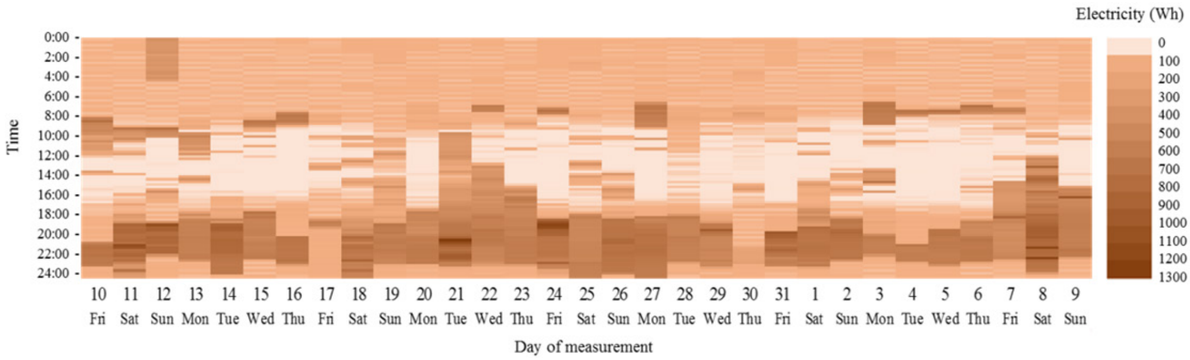

Fig. 2. Electricity heat map of House E from the 10th of July to the 9th of August 2015 at 15 minute intervals. Dark shades representing an electricity use of 500W or higher can be associated with times when the heater was on. The lighter band during day hours shows the impact of the PV panels on grid electricity consumption. The PV system covers small electricity needs, but higher loads such as ambient heating requires additional grid electricity.

Finally, the third group consists of households whose occupants have homogeneous behaviours, reflected in their everyday practices. House J fits this description. This house consists of a family of five, including one adult working full time, one stay-at-home parent and three children (Table 1). Interviews with the adults revealed that their main motivation is to save on energy bills, but they are also mindful of greenhouse gas emissions and perceive their community and friends as environmentally aware and anti-consumerism. This household is familiar with the PV system technology and they try to warm up the house during the day so as to make the most of the renewable energy. As noted during the interview, the occupants' first reaction to the feeling of cold involves putting on warmer clothes rather than turning on the mechanical heater. As such, they can also withstand colder temperatures compared to other participant houses and only feel the need to turn on the heater when the internal temperature reaches on average 18.15°C. These behaviours are reflected in the household heating practices, as the heater is mostly turned on during solar generation hours and occasionally in the evenings during very cold days such as the 10th of July (Fig. 3). The duration of time during which the heater is on is also very short, varying between 2 to 4 hours. The use of the mechanical heater in this house appears to be driven by a very conscious decision making process, involving considerations about the PV system, alternative heating practices and the feeling of cold.

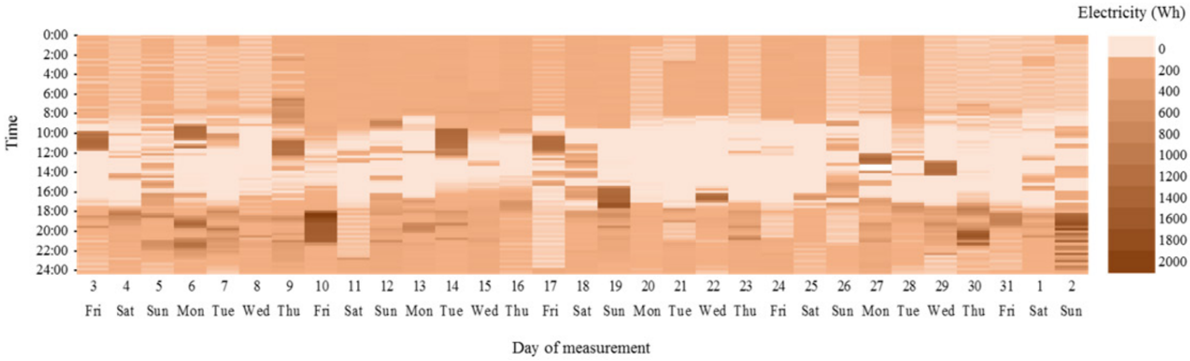

Fig. 3. Grid electricity heat map of House J from the 3rd of July to the 2nd of August 2015 at 15 minute intervals. Dark shades representing an electricity use of 800W or higher can be associated with times when the heater was on. The lighter band during day hours shows the impact of the PV panels on grid electricity use. The PV system covers small electricity needs but higher loads such as ambient heating requires additional grid electricity.

4. Conclusions

This research revealed that behaviours and winter heating practices vary considerably not only between houses due to differences in lifestyle and family structure, but also within houses. Intra-home practices are affected by elements of personal behaviour such as attitudes, motivation, values, social norms and perceived behavioural control; but also by technology, interaction between family members, habits and knowledge. Awareness or motivation to save energy may change people's priorities, that is, individuals can choose to put on warmer clothes before turning on their heating system. As such, one can also adapt to colder temperatures. However, individuals of the same household may experience thermal comfort in different ways and use the heater for different purposes, such as to achieve a hedonic experience, as a habit or consciously to feel warm.

This research also demonstrates that the presence of solar panels can have a double effect. On the one hand, it can act as a trigger for practice change as some households have become more aware of energy use and try to maximize the use of appliances during daylight hours to take advantage of the solar panels. However, on the other hand, it might also have caused rebound effects. Not all individuals that possess a PV system are familiar with its use and might be using electricity indiscriminately.

When targeting occupant behaviour to achieve energy saving in households, it is therefore important to understand the whole system of the home, which consists of people, interactions, external influences and technology innovation.

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