The home as a system of practice and its implications for energy and water metabolism

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Abstract

Policy and regulations for residential houses often consider the physical system alone and tend to focus on the energy performance of the building. This ignores the effect of occupants' everyday practices and their interaction with the building technologies. This research applies practice theory and the concept of system of practice to eight Australian homes with the objectives of providing a deeper understanding of the complexities of the home system as well as providing approaches to enable (rather than persuade) resource reduction. The homes were investigated through explanatory design mixed methods which combined results of one year of longitudinal quantitative data collection and home occupant interviews. The results revealed that practices are performed in a sequential temporal spectrum as part of a routine and are influenced by interlocked practices as well as interlocking routines from other home occupants. Practices also follow established daily patterns reflected by a frequency distribution curve where the standard deviation reflects the degree of habituality of the practice. Highly interlocked practices with a high degree of habituality are challenging to affect. However, automation could enable resource intensive activities to be dis-interlocked from an established routine and make change within the home system of practice easier and more flexible.

Keywords: home system; everyday practice; energy; water; automation; routines.

1. Introduction

The home can be considered a juxtaposition of the physical system including associated energy, water and resource metabolic flows (Harder et al., 2014) with the occupied social system of everyday practice (Guy and Shove, 2000) (Figure 1). The concept of metabolism is used to describe the flow of materials and energy through an urban system, which similarly to living beings, consumes resources, transforms them internally and generates waste (Girardet, 2010).

The implementation of technologies which lead to more efficient buildings, including energy and water efficient appliances, renewable energy and sealed building envelopes, has been a significant focus for research (Moore, 2012). In contrast, the home itself is not well understood and a theoretical and practical understanding of the complexities of occupant behaviour and their interaction with the physical system of the building is an emerging area of investigation (Keyson et al., 2017). Attempts at reducing home resource use through changing attitudes and values and intelligent design features, may be confounded when users resist external control or refuse to change their behaviour (Scott et al., 2012). Another approach has been to classify homes into simple typologies with targeted policy or resource criteria but these encounter similar issues of push back from the home residents (Ashton et al., 2016).

Proponents of practice theory argue that innovative user technology cannot be adopted without innovation in practice (Shove et al., 2012; Strengers and Maller, 2014). Smart meters, feedback displays and automation technologies are increasingly deployed to reduce energy and water consumption in residential homes (Faruqui et al., 2010; Fischer, 2008; Jain et al., 2012; Yew et al., 2012). However, these technologies do not necessarily fulfil their objectives if they fail to become embedded in the habits and routines that compose the practices of daily life (Brynjarsdóttir et al., 2012; Strengers, 2011). As a consequence, reducing energy, water and resource use in homes depends on the available infrastructure and technology, but also on occupant's everyday practices (Shove et al., 2007).

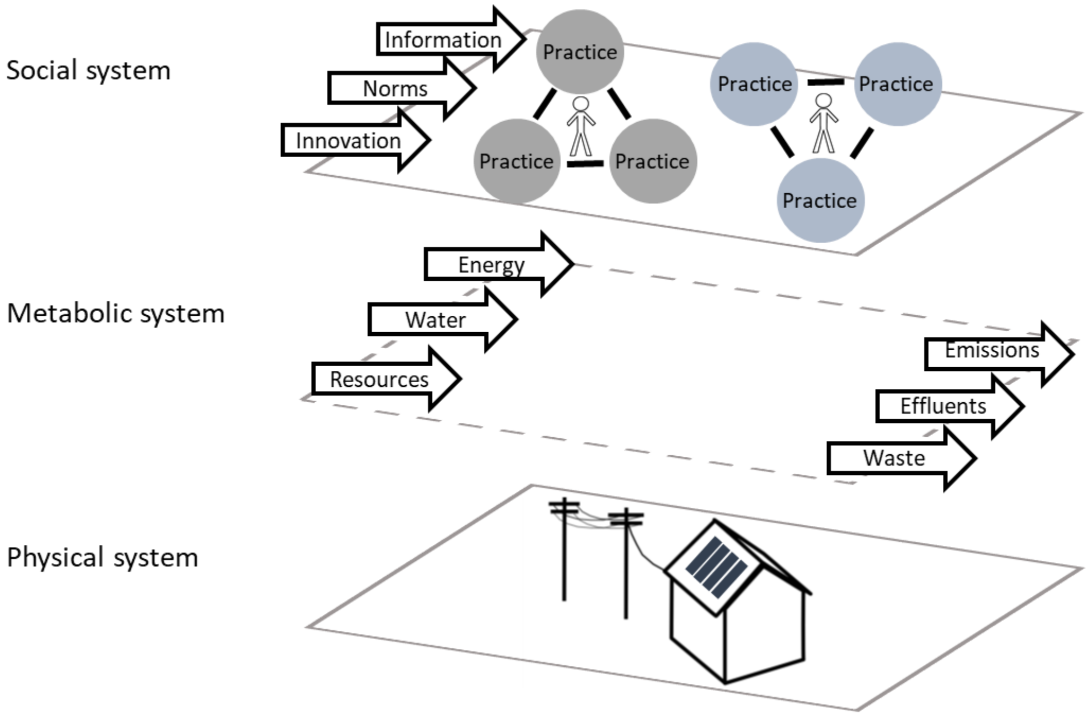

Figure 1. The home system, which includes the physical building system, metabolic flows and occupant practices, which are connected in a system of practice (SOP).

Practice theory (Shove et al., 2007), also termed social practice theory (Schatzki, 1996), identifies practice as the preferred unit of analysis rather than the individual (Reckwitz, 2002; Røpke, 2009, 2001; Schatzki, 2002; Schatzki et al., 2001; Shove et al., 2012, 2010, 2009, 2007; Warde, 2005). The advantage is that this approach provides a holistic view to understanding occupant behaviour as it recognizes that elements of place and broader societal aspects affect the way practices are carried out in addition to individual values and attitudes (Hargreaves, 2011). Moreover, practice theory posits that individuals do not use resources for the sake of it, but rather as a means to achieve an objective. Therefore, comprehending the external context and occupant needs is crucial to understanding home resource use.

A practice is characterised as a routine behaviour composed of several elements which are interconnected (Reckwitz, 2002). As practice theory is still emerging, there is a lack of a unifying model of assessment, however most models feature a number of elements (McMeekin and Southerton, 2012; Schatzki, 1996), the doings and sayings which collectively form the entity of a practice. These previous models can be collated into the three elements of practice defined here as meaning, skill and technology (Figure 1). Meaning is the aspirations, emotions, ideas, perceptions, symbolic meanings and values associated with the practice (Shove et al., 2012). Skill refers to the know-how, technique, and understandings for accomplishing a practice (Scott et al., 2012), although an important distinction of skill exists between implicit know-how and explicit rule-based or theoretical knowledge (Gram-Hanssen, 2010a). Technology is referred to as the devices used to perform a practice which are the infrastructure, materials and objects (Gram-Hanssen, 2010b). Practice theory should not be confused with the study of cultural practices that is currently being undertaken by cross-cultural psychologists (Kashima, 2014; Kashima et al., 2015; Kashima and Gelfand, 2012).

The implication of applying practice theory to the study of household resource use is that the sources of changed behaviour lie in the development of practices (Warde, 2005). The quantitative monitoring of technologies utilised in a home reveals the performance of the products (Foulds et al., 2013), but not necessarily how the resource use fits into the broader systems of the home. Habits and routines co-evolve with practices (Shove, 2004) and the practices relating to the use of resources in the home are manifested in their daily performance (Chappells et al., 2011). Practices exist both in the historical collective reproduction of them as practice-as-entities and in their performance by individuals (Schatzki, 2002), the former being the storage of knowledge and learnings of the elements of the practice (meaning, skills and technology) within a practitioner's mind. Some household members have similar practice-as-entities in that everyone understands practices the same way and thus perform them similarly, resulting in resource use patterns, such as similar shower times. When practice-as-entities vary, we see intra-home and interpersonal variances in resource use and the performance of practices that are related to household habits and routines (Røpke, 2009). Section 3.1.1 outlines in more detail how a change in one part of the practice entity can influence the performance, and as such resource use, of the practice.

This paper builds on the approach that the continual reproduction of habits and routines that compose practices within a home are connected in a system of practice (SOP) (Watson, 2012). The interconnectedness between practices is referred to as interlocking (Figure 1) (Macrorie et al., 2014; Spurling et al., 2013; Spurling and McMeekin, 2014) which emphasises that individual practices are inseparably bound up in the spectrum of everyday practices that are combined in bundles across space and time (Macrorie et al., 2014).

The objective of this research is twofold; firstly, it aims to understand how practices are bound up in the home SOP, especially in a context where houses are becoming more energy efficient; and secondly, it aims at understanding how these practices can be changed to promote resource savings given their layers of complexity. Previous studies of SOPs in the resource use literature have focused on broader societal systems, investigating how these systems influence everyday practices (Macrorie et al., 2014; Watson, 2012). Our research scales down to, and provides interpersonal detail on, the home as a SOP and concentrates on the influence that everyday practices have on energy and water use. This research contributes to understanding how resource reduction can be enabled in the multifaceted system of the home.

This research is based on the longitudinal monitoring of eight Australian energy efficient homes. The analysis of selected practices in the homes was carried out through a mixed methods approach, which combined quantitative and qualitative methods to provide holistic insights into the home SOP and better understand the interaction between occupants and the building technologies. The analysis started with a discussion of the targeted practices in isolation, describing through statistics how they are influenced by meaning, skill and technology. The analysis then focused on the integration of these practices in the home SOP, discussing the influences of interlocked practices and other home occupants. The last section of the analysis discusses automated practices, which unlike other everyday practices, are dis-interlocked (i.e. disconnected or isolated) from the SOP and may provide an opportunity to enable resource use change.

2. Materials and Methods

Eight homes were established as Living Laboratories (Burbridge et al., 2017; Leminen et al., 2015; Leminen and Westerlund, 2012; Liedtke et al., 2015) to investigate the effect of everyday practices on energy and water use in the home system (Herrena, 2017). The two most water intensive practices in Australian homes are garden irrigation and personal showering, representing 39% and 25% respectively of the total water use in the home (Water Corporation, 2010). The highest energy related practices consist of cooling and heating, using approximately 40% of the total energy use in the house (DEWHA, 2008) and generating 16% of operational greenhouse gas emissions (Lawania and Biswas, 2017). Accordingly, this research is scoped to concentrate mainly on the practices of personal showering, garden irrigation and home heating to represent some of the key practices in the home SOP. The practices of reticulated irrigation, dishwasher use and pool cleaning are also introduced to discuss automated practices.

The homes are located in Fremantle, Western Australia (WA), and possess characteristics that make them more energy efficient than the average WA dwelling. For instance, they all have passive solar design characteristics; that is, they take advantage of afternoon breezes to cool the house in summer as well as direct sunlight and thermal mass to increase thermal comfort in winter. Moreover, seven of the houses possess solar photovoltaic (PV) panels on their roofs (Table 1). Minimum house energy efficiency standards are currently mandated in Australia and internationally and PV panels are increasingly adopted in suburban homes (ABS, 2016; Green and Newman, 2017). The understanding of the home SOP in the context of energy efficient homes is important to ensure that they perform to their full potential.

The eight homes were selected through two distinct methods; response to a media advertisement and contact through a mail drop. Households that submitted an expression of interest were further selected to provide a cross-section of demographic profiles (Table 1).

Empirical analysis was conducted through an explanatory design mixed methods approach (Creswell et al., 2003; Creswell and Plano Clark, 2007). Quantitative data was continuously collected through sensors and convergent qualitative data was collated through semi-structured interviews that focused on the habits and routines of the occupants. This builds on previous research concerning the analysis of daily energy practices through the integration of monitoring data with qualitative interviews to provide insights beyond those of non-integrated approaches (Foulds et al., 2013).

Table 1. House characteristics and occupancies

Home	No. occupants	Occupation	Efficient technologies
1	2 adults 1 young adult	Retired Full-time worker	Solar hot water
2	2 adults 2 children	Full-time worker / stay-at-home parent Student / preschool toddler	PV, solar hot water
3	1 adult 2 teenagers 1 young adult	Full-time worker Students Unemployed	PV, solar hot water
4	2 adults	Full-time workers	PV, solar hot water
5	2 adults 3 children	Full-time worker / stay-at-home parent Students	PV
6	2 adults	Full-time workers	PV, solar hot water
7	2 adults 1 young adult	Full-time workers Full-time worker	PV
8	2 adults 2 children	Full-time worker / part-time worker Student / preschool child	PV, solar hot water

2.1.Quantitative data collection

The eight homes had their gas, grid electricity, internal temperature and water use monitored for the full year of 2015. Sensors were connected to existing meters, sending pulses to a data logger (Schneider Electric COM'X 200), which then transmitted the data in csv format to a cloud via a 2G wireless internet connection. Data was collected at 15 minute intervals, resulting in a total of 35,040 data points per meter or sensor at the end of the year. The following meters and sensors were employed to gather gas, grid electricity, temperature and water data respectively: Ampy 750 gas meter and pulse counter Elster IN-Z6; Schneider Electric iEM3110; Kimo TM110; Actaris TD8 and Cyble sensor 2W K=1. Home 3 has a rainwater tank designed for use in the outdoor area and a separate water meter was installed in the rainwater tank outlet to measure hand watering of the garden.

2.2.Data analysis

The first stage of the data analysis involved the graphic identification of patterns of energy and water use associated with the defined everyday practices. An algorithm was developed to process all the data and identify daily resource use related to ambient heating, garden irrigation and personal showering. The highest summer water peaks (higher than 120 L/interval) were attributed to garden irrigation. Water use for personal showering represents the second highest water peaks of the data. Water volumes used for personal showering were identified in the winter months by an increase in water use concurrently with an increase in gas or electricity use for water heating. The water volume range for personal showering as identified for the winter months was extrapolated to the rest of the year as some of the houses possess solar hot water systems which limit water heating in summer. Previous Australian research has shown that showering volumes between winter and summer can differ by around 8L/person (Rathnayaka et al., 2015), which corresponds to a shower length difference of less than one minute. These seasonal differences could have impacted on the results; however, it is assumed that the variation is captured by the wide shower volume range of 50L to 120L per interval that was detected by the algorithm. This attribution correctly excludes the use of the water in the dishwasher (6.15L to 6.85L per filling cycle) and washing machine (28.5L to 43L per filling cycle) for each home. A similar algorithm was used to identify energy used for ambient heating. A significant increase in energy (electricity or gas according to the heating system of the house) followed by a concomitant increase in the internal temperature during winter was attributed to the practice of manually regulating the heating system. The temperature sensor was placed in the living area to ensure that temperature increase from kitchen practices were not mistaken for ambient heating practice.

Personal shower practice was analysed separately for weekdays and weekends due to an identified difference in routines. Shower lengths were determined by dividing the volume of water used by the volumetric flow rate of the shower head. This method does not specifically differentiate between water used for showers or baths, the latter being undertaken exclusively by only 5% of the Australian population (Water Corporation, 2010).

Statistical analysis was undertaken through the graphic software OriginLab 2017 which provided a systematic analysis of the data set for the eight houses with a total of 35,040 data points per meter (gas, grid electricity and water) or sensor (temperature) in each home over the year. Distributions of personal shower and irrigation lengths and times were plotted as histograms; those depicting lengths had a specified bin size of 1 minute and those depicting time of day had 48 bins (30-minute resolution). Peak analyses generated fitted curves providing coefficient of determination (R^2), coefficient of variation (CV), mean (μ), mode (Mo) and standard deviation (σ). These parameters were used to interpret the elements and interlocking of practices as well as patterns of intra-home practices.

The non-parametric Mann-Whitney *U*-test (Rosner and Grove, 1999) was conducted to identify statistical differences related to the showering practice during the week and weekend as well as mornings and afternoons over one year. We understand that this test is for unpaired data and was used correctly in this study. Morning and afternoon showers as well as week and weekend showers are independent variables and the samples are not paired, which excluded the use of a non-parametric paired t-test. The reasons that the samples are treated as independent populations are the following:

- The morning and afternoon showers as well as week and weekend showers may be taken by different (or a different number of) occupants of the same house;
- The showering practices may be different in the morning and afternoons as well as during the week and weekend;
- The number of showers (N) in the morning and afternoon differ (as shown in Table 3);
- The population of showers taken during the week over the course of one year is significantly larger than the population of showers taken during the weekend for the same period.

The analysis relating to diurnal energy use in the homes was through line graphs and contour plots.

2.3.Qualitative data collection

Semi-structured interviews (Kallio et al., 2016) with household members were conducted at the end of the quantitative data collection period in two stages. Initially the occupants were shown a summary of their monthly energy and water use and asked to identify reasons for any significant change in use between months (Foulds et al., 2013). The second stage of the interview targeted everyday practices in terms of meaning, skill and technology as well as household configuration and lifestyles. This second stage included participant articulation through a home survey with considerations of garden watering, thermal conditioning and washing practices as well as home technology. During this stage occupant routines and possible barriers to changing practices were revealed (Foulds et al., 2013). The explanatory design mixed method approach (Lave and Wenger, 1991) uses qualitative data to provide an in-depth explanation of the measured quantitative data and data from interviews to interpret everyday practices in the home (Foulds et al., 2013).

Care was taken to minimize influence on home occupants as a result of this research as this might lead to practice and behavior modifications. For instance, the researchers did not maintain contact with participants after equipment installation and until the end of the monitoring period. While the participants were aware of the overall research intentions, the behavioural and practice aspects of the project were not emphasized. The longitudinal nature of this experimental design also reduces the chances of everyday practices being affected in the long term by occupant knowledge of the presence of monitoring equipment (Keyson et al., 2017). While there is still a possibility that practices might have been initially affected despite the measures listed above, the large number of data points (35,040) collected over the year reduces the likelihood of the results being significantly impacted.

3. Results and discussion

Patterns of energy and water use in the home were considered in terms of each individual everyday practice (section 3.1); interlocking practices and other elements that compose the home SOP (section 3.2); and automated practices acting independently of the home SOP (section 3.3). Information and insights gathered from the interviews were used to support the quantitative results (Creswell and Plano Clark, 2011), relating them to other interlocked practices and wider influencing factors outside the home.

3.1.Everyday practice

The practices of personal showering, garden hand watering and home heating were chosen for analysis through contemporary practice theory (Macrorie et al., 2014). The selected practices were discussed in terms of the three influential practice entity elements, which are defined as meaning, skill and technology.

3.1.1. Personal showering

Personal showering is the predominant form of bathing for cleanliness, warmth and feeling fresh in many (although by no means all) cultures, and is an established practice that has been performed daily by most home occupants, although not necessarily with the same meaning (Shove, 2003). The length of a shower is a key component of the water metabolism of the house as a system (Kenway et al., 2014).

The histograms representing the frequency distribution of the length of showers (151< n <939, where n is the number of identified showers in a home) in each home over one year had one or more modes which generally followed a lognormal distribution curve (Figure 2 and Table 2). It is posited that the lognormal curve reflects the practice elements affecting shower length (e.g. meaning, skill and technology). The implicit know-how skills and showerhead technology should not fluctuate over time, unlike the meaning for personal showering, which can frequently change and be the influential element for the practice (Shove et al., 2010). Consequently, the distribution curves represent variations in shower length driven by variations in meaning; the mode being the most frequent length and meaning for the showers. The interquartile range of the lognormal distribution (i.e. higher number of showers) represents the main routine for the showering practice, while the upper quartile (i.e. less frequent and longer showers) could indicate alternative meanings for the practice (Figure 2). Where technology and skills are constant, the meaning of practices can be determined and described by the coefficient of variation (CV) and the standard deviation (σ) of the frequency curve; with a lower CV or σ value indicating a higher degree of habituality (Table 2). Showering length frequency distributions presenting more than one mode could represent the routine of distinct inhabitants with different showering practice-as-entities or different showering meanings for the same occupant.

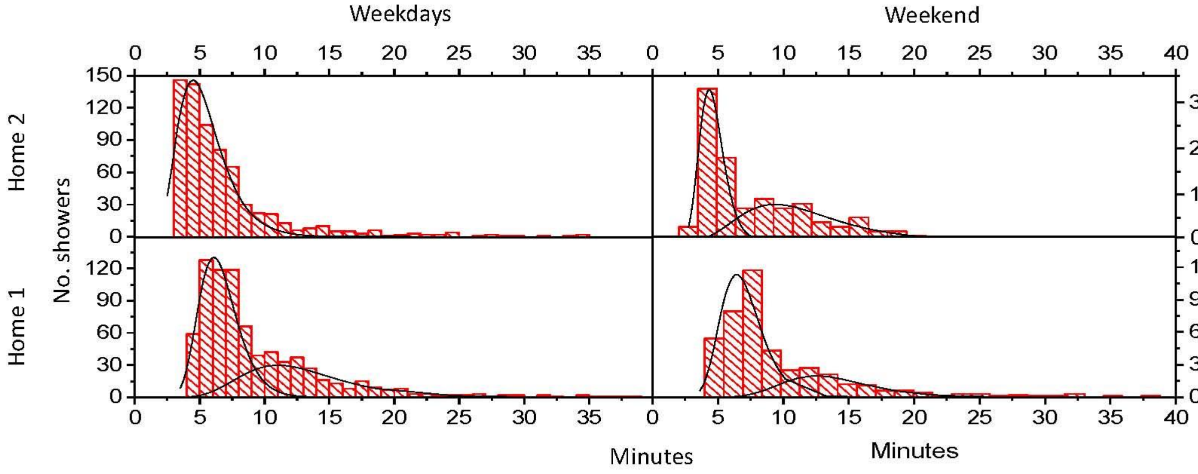

Figure 2. Shower length histograms and corresponding fitted (frequency) curves for two homes. During the week the occupants of home 1 have different intra-home showering practices while the occupants of home 2 follow the same practice. The weekend frequency distributions reveal a mix of showers with dispersed meanings. The statistics of the aggregate data for all homes are presented in Table 1.

For instance, during weekdays, in home 1 (a home with three occupants comprising a retired couple and their working granddaughter) the showering length histogram of the household contains two peaks (i.e. two modes) (Figure 2); the first has a frequency curve with an associated Mo value of 6.1 minutes (σ value 1.6 minutes, μ value 6.6 minutes) and the second has a Mo value of 11 minutes (σ value 4.3 minutes, μ value 12.9 minutes). Interviews with this home revealed that the retired couple share a similar practice-as-entity that differs from their granddaughter. The granddaughter enjoys long showers and weekly baths, articulating a different meaning to showering and bathing than her grandparents. The second curve with associated Mo value of 11 minutes could therefore be attributed to the granddaughter. Her showering practice (σ value 4.3 minutes, CV value 0.4) is also less habitual and routine based than her grandparents (σ value 1.6 minutes, CV value 0.2), which is reflected in the larger standard deviation and coefficient of variation (Table 2).

Table 2. Description of the showering length distribution for the eight homes. Statistically valid Gaussian (G) and Lognormal (LN) distributions are identified and numbered in a daily time sequence.

Home	Weekdays				Weekend			
	Shower, n	Mo (min)	σ (min)	R^2	Shower, n	Mo (min)	σ (min)	R^2
1	1 (LN)	6.1	1.6	0.98	1 (LN)	6.4	1.6	0.99
	2 (LN)	11.0	4.3		2 (LN)	12.5	3.5	
2	1 (LN)	4.5	2.0	0.94	1 (LN)	4.3	0.9	0.98
					2 (LN)	9.3	4.5	
3	1 (LN)	4.1	0.8	0.99	1 (LN)	4.0	0.6	0.96
	2 (LN)	8.0	5.0		2 (LN)	6.6	4.5	
4	1 (LN)	4.9	2.9	0.84	1 (LN)	4.4	1.4	0.84
5	1 (LN)	4.4	1.5	0.97	1 (LN)	4.3	0.9	0.95
	2 (LN)	13.9	10.1		2 (LN)	12.5	9.5	
6	1 (LN)	7.0	4.8	0.95	1 (LN)	4.3	5.4	0.93
7	1 (LN)	5.3	2.3	0.97	1 (LN)	4.9	2.2	0.87
8	1 (G)	7.1	1.1	0.97	1 (LN)	6.9	0.9	0.98
	2 (LN)	11.2	1.6		2 (LN)	10.6	3.2	

Mo - Mode; σ - standard deviation; R^2 – coefficient of determination

The occupants of home 2 (one working adult, one stay-at-home parent and two preschool children), on the other hand, all possess the same weekday showering practice with the personal showers following only one single-modal lognormal frequency distribution (Mo value 4.5) (Figure 2 and Table 2). This indicates that there is a similar meaning or meanings for personal showering between all the occupants.

The local water authority in Perth, Australia, faces serious water shortages for the city and widely promotes for personal showers under 4 minutes (Water Corporation, 2010), attempting to introduce explicit rule-based knowledge (McMeekin and Southerton, 2012) into the skill of personal showering practice. The Mo values in Table 2 reveal that this is not met for any home. The closest Mo values to 4 minutes usually occur for the first early morning shower where the meaning is to freshen up before work (weekday) or the day ahead (weekend) (Table 3). This explicit knowledge may not affect the longer showers due to the heterogeneity of meanings associated with the upper quartile of the frequency distribution curve. The later showers are generally longer (Table 3) than the morning showers as they are situated between different routines. They are likely to be more flexible than the morning showers, since they are less constrained by scheduled activities such as work and school. Later showers may also hold meanings other than cleanliness which might include relaxation at the end of a busy day or warmth on a cold winter day, hence the extended length of showering time (Shove, 2003).

Table 3. Comparison between morning and afternoon shower lengths (minutes) in homes with more than one showering practice (multiple modes). The statistical significance (Sig) of the Mann-Whitney *U*-test results are evaluated at a 99% confidence level. For s the difference between the two populations is statistically significantly different and for ns the difference between the two populations is not statistically significantly different. N is the total number of morning or afternoon showers in the year.

Home	N morning	N afternoon	Median (min)		*P*-value	Sig
			Morning	Afternoon		
1	256	175	6.89	8.55	.000	s
3	415	231	7.11	6.44	.703	ns
5	253	99	6.67	12.56	.000	s
8	168	94	9.11	9.28	.368	ns

The semi-structured interviews confirmed that occupants of the same home can have different meanings for personal showering, affecting the length of shower. Motivations mentioned by the households included showering for relaxation (teenagers in house 3, granddaughter in house 1), showering for the purpose of health (husband in house 4), showering for cleanliness alone (preschool children and stay-at-home mother in house 5) and the social expectation of everyday showering by colleagues in a work place culture (husband in house 5). Those who attribute health or relaxation to their showering practice mentioned enjoying long showers. One of the participants having showers for cleanliness purposes (house 5) also revealed not showering on a daily basis but compensating instead, with long showers when doing so (Mo value 13.9 minutes, σ value 10 minutes, Table 2).

Shower lengths between weekdays and weekends were not statistically significantly different for six of the homes at a 99% confidence level (Table 4). The similarity in shower lengths as well as the positive skewness of the length distribution curve shows that a personal shower routine of a regular length of time is followed each day to achieve a specific meaning and that shorter showers are unlikely to occur, unless the skill or technology elements of the practice are altered (Shove, 2003). The reduction of personal shower length may be particularly challenging for occupants whose degree of habituality for showers is high.

Table 4. Comparison between weekday and weekend showers. The statistical significance (Sig) of the Mann-Whitney *U*-test results are evaluated at a 99% confidence level. For s the difference between the two populations is statistically significantly different and for ns the difference between the two populations is not statistically significantly different. N is the total number of weekdays or weekend showers in the year.

Home	N weekdays	N weekend	Time		Length	
			P-value	Sig	*P*-value	Sig
1	778	423	.002	s	.310	ns
2	697	102	.286	ns	.044	ns
3	939	377	.001	s	.110	ns
4	413	288	.000	s	.124	ns
5	416	155	.000	s	.749	ns
6	479	165	.947	ns	.000	s
7	543	212	.000	s	.709	ns
8	376	167	.751	ns	.285	ns

3.1.2. Garden hand watering

The other water intensive practice in households is outdoor use (Ashton et al., 2016). The same pattern of habits and routines identified for showering was also found for the practice of hand watering the garden (Table 5), which uses similar volumes of water on each occasion. Hand watering practices depend mostly on technology (garden size) and user skill. A household will not use water for irrigation unless there is a garden, which may be reliant on a household member having the meaning, skill and technology for undertaking the practice of gardening. The volume of water applied to the garden follows a lognormal distribution (Table 5) which indicates that households follow a similar irrigation pattern each time. Homes 1 and 4 both possess gardens (approximately 85 m^2 and 220 m^2 respectively) with lawns as well as decorative and edible plants, requiring larger volumes of water compared to home 3, who only plant in pots located in a paved courtyard. Larger watering volumes (reflected in a greater σ value) especially for homes 1 and 4 could represent meanings other than maintaining plant health. For instance, home 1 occupants revealed that the practice of hand watering is sometimes undertaken twice daily and consists of a pleasurable activity. This is consistent with previous research which identified other meanings for irrigation, including enjoyment (Syme et al., 2004). The σ value for home 3, on the other hand, is only 8 litres, indicating that the occupants of this home may only have the one meaning of maintaining plant vitality for garden watering.

Table 5. Hand watering irrigation practice in the three homes that practice hand watering; the other five homes possess reticulation systems set on a timer. Modes of time are expressed as times (t) and volumes are expressed in litres (L). Statistically valid Gaussian (G) and lognormal (LN) distributions are identified.

Home		Hand watering, n	Mo (t, L)	σ (min, L)	R^2
1	Time	1 (G)	8.57	49	0.90
		2 - 5 (G)	11.47 - 20.57	22.3 - 46.6	
	Volume	1 (LN)	125.9	21.2	0.97
3	Time	1 (LN)	6.6	33.0	0.78
	Volume	1 (LN)	21.5	8	0.98
4	Time	1 (LN)	6.45	30.0	0.82
		2 - 3 (G)	10.31 - 18.44	30.0 – 102.0	
	Volume	1 (LN)	149.2	92.5	0.85

Mo - Mode; σ - standard deviation; R^2 – coefficient of determination

3.1.3. Ambient heating

Practices to regulate indoor comfort based on temperature have also been performed by people over their lives using various technologies with different meanings and skills. This practice has become increasingly resource intensive with the broad uptake of reverse cycle air-conditioning and heating units in homes in Perth (Strengers, 2010) and in the studied homes. It was observed that households follow different heating practices. Home residents were not strictly motivated by thermal needs when they operated the heating system. Some turn on the heater as part of a routine for the colder months, when arriving home from work, whereas others seek a hedonic experience instead of wearing warmer clothes when the temperature falls (Eon et al., 2017; Shove, 2003).

Figure 3 provides the example of three homes that operated the heater during weekdays in July 2015, the middle of the Australian winter. In home 1 the heater was switched on for two hours in the morning (07.30 to 09.30) when the internal temperature was on average 18°C. This occurred when the occupants woke up and was based on their morning routines as well as the experience of feeling cold. As they left the home for their daily activities, the heater was switched off, and this routine was repeated through the winter months. The heater was then switched on again for the rest of the evening, between 17.30 and 23.00, when the occupants were home and the external temperature had dropped. According to home 1 occupants, they turn the heater on while watching television in the evenings. The occupants of home 5 only switched the heater on during the late morning, at around 10.00, even though their house was on average 2 degrees colder than the other two homes and the heater in this home was not usually used in the evenings. This indicates that the occupant’s practice-as-entity could be influenced more by the meaning or the technologies they associate with heating than the internal temperature itself (Shove et al., 2010). Home 5 possesses PV rooftop panels, which according to the occupants, are the main driver for the time when the heater is switched on. Their preference in the evenings and early mornings is to wear warm clothes rather than use the heater. A different heating practice was encountered in home 7, which only uses the heater in the evenings, from around 17.30 to 22.00, after arriving home from work. According to these participants, comfort and convenience are the main reason to use the heater. Our results indicate that regardless of the thermal temperature in the household, the occupants use the heating technology with various meanings and interlocked with their daily routines.

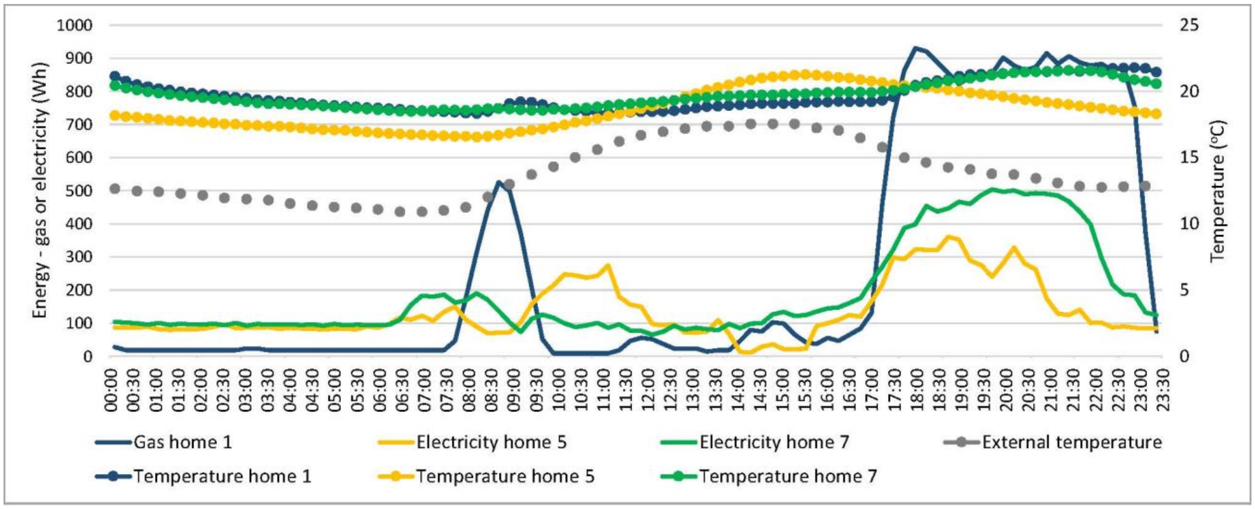

Figure 3. Average use of the heating system on weekdays in homes 1, 5 and 7 in July 2015, in the middle of the Australian winter. An increase in internal temperature alongside an increase in energy (gas or electricity depending to the heating system of the home) use is attributed to the practice of heating.

3.2.Interlocking practices

While individual practices are influenced by meaning, skill and technology, they are also constrained by other home occupants and interlocked practices inside and outside the home system. The term interlocking refers to the interconnectedness and interdependence of practices in a routine. For instance, the practice of composting relies on the practice of gardening and/or the practice of cooking and cannot exist without one or the other. These practices are all connected in the home SOP.

Previous research has related the time of practices to occupant lifestyles and socio-economic status (Ashton et al., 2016). For instance, peak water use occurs earlier in houses occupied by early risers who are economically active and therefore bound by the practices of breakfast, transport and work. Late risers, on the other hand, do not have a specific water use pattern (Keyson et al., 2017) and are not interlocked in binding activities constraining the hour of water use. Similar results were observed in this research.

This section will explore interlocking practices in the SOP by discussing the practices of personal showering and garden hand watering.

3.2.1. Personal showering

The time of shower and the habituality and routine nature of the practice (reflected in the σ values in Table 6), are influenced by other interlocked practices in the system. Home 3, for instance, comprises a mother and her three teenage sons. The mother works in a full-time job and therefore her time of taking a personal shower is constrained by the practice of work as well as other interlocked practices that form her daily routine, such as waking up in the morning, eating breakfast and transport to work. Her sons, on the other hand, have a flexible schedule and are often at home during the day. The showering time histogram for home 3 (Figure 4) reveals two weekday peaks, one in the morning (Mo and μ at 07.22), which has a σ value of 55.8 minutes, and one in the evening (Mo and μ at 17.19), which has a σ value of 225 minutes (Table 6). The morning shower, which is taken over a shorter time-period may be attributed to the mother, while the afternoon showers, spread over a longer time period (therefore less habitual and routine based), may be attributed to the sons, who are likely to have showers when convenient rather than as part of an interlocked routine.

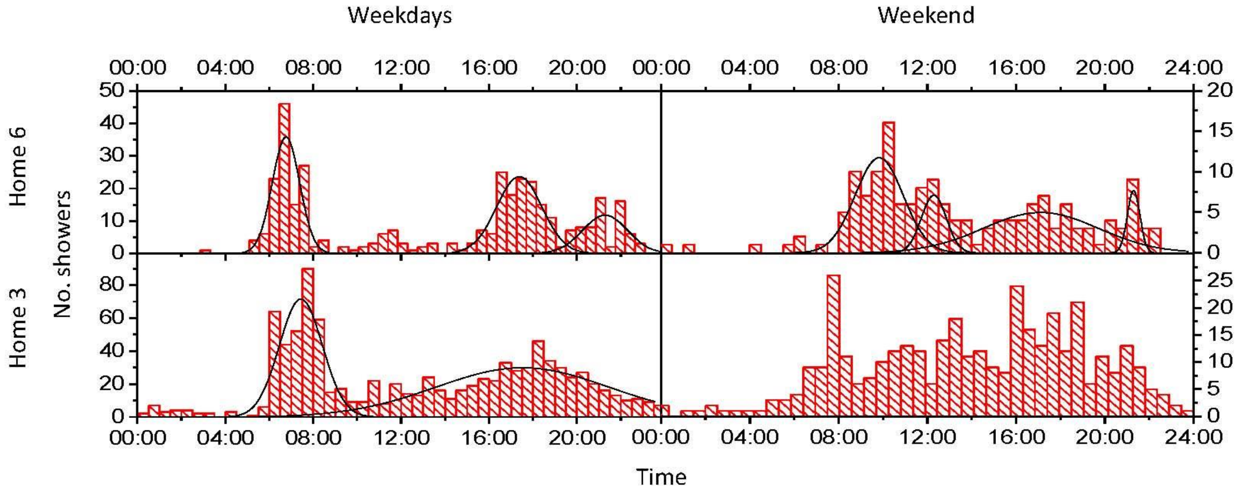

Figure 4. Personal showering time histograms and corresponding distribution curves for two homes. Shower times generally follow a Gaussian distribution curve (Table 6).

Home 6 consists of a working couple whose weekday shower times follow the same patterns as the mother of home 3 (Figure 4). Morning showers have a small σ value (33.6 minutes), as they are constrained by the interlocked practice of work (Table 6). Evening showers, on the other hand, have higher σ values (56.4 and 63.6 minutes) as evening routines are more flexible and less interlocked (Table 6).

Showering times were statistically significantly different during weekdays compared to weekends for five of the homes at a 99% confidence level (Table 4). There is also a higher σ value during the weekend for the time that showers are taken than for weekday showering (Table 6 and Figure 4). Weekend showers are usually taken later in the day and show a greater time distribution for most households compared to weekdays. The weekend shower distributions of homes 2, 3, 5 and 8 are multimodal and cannot be attributed to a specific routine. This demonstrated that although personal shower time is generally tightly interlocked with other practices this may realign in a different context when new home dynamics emerge (e.g. during weekends).

Table 6. Description of the showering time distribution for the eight homes during weekdays and the weekend. Statistically valid Gaussian (G) distributions are identified and numbered in a daily time sequence. Showers that do not have a clear distribution shape were not evaluated.

Home	Weekdays				Weekend			
	Shower, n	Mo (time)	σ (min)	R^2	Shower, n	Mo (time)	σ (min)	R^2
1	1 (G)	8.06	8.60	0.96	1 (G)	9.22	53.8	0.93
	2 - 6 (G)	8.43 - 21.32	26.4 - 95.2		2 - 5 (G)	11.48 - 21.13	19.4 - 89.5	
2	1 (G)	6.29	19.20	0.92	NA	-	-	
	2 - 3 (G)	9.12 - 18.37	92.2 - 147					
3	1 (G)	7.22	55.8	0.85	NA	-	-	
	2 (G)	17.19	225.0					
4	1 (G)	6.49	25.8	0.91	1 (G)	7.50	34.6	0.93
	2 (G)	16.11	145.2		2 - 3 (G)	9.31 - 17.38	103.5 - 136.0	
5	1 (G)	7.53	25.8	0.94	NA	-	-	
	2 (G)	18.36	61.8					
6	1 (G)	6.53	33.6	0.89	1 (G)	9.50	64.9	0.85
	2 - 3 (G)	17.14 - 21.15	56.4 – 63.6		2 - 4 (G)	12.17 - 21.17	33.9 - 156.4	
7	1 (G)	6.47	14.6	0.98	1 (G)	10.17	73.6	0.88
	2 - 4 (G)	8.50 - 17.32	29.6 - 62.3		2 (G)	17.07	25.6	
8	1 (G)	7.22	12.6	0.75	NA	-	-	
	2 (G)	19.23	13.3					

Mo - Mode; σ - standard deviation; R^2 - coefficient of determination

Shower time histograms follow a Gaussian distribution curve (Figure 4 and Table 6). This could be explained by personal showers occurring at certain times of the day based on routines and interlocked practices. However, once in the shower, meaning and skill combined with the available technology take over and showering practitioners tend to follow certain procedures for achieving cleanliness or comfort. This is demonstrated in Figure 3 by the length of the shower during the weekend being similar to that of the shower during the weekday. While the shower time varies based on the interlocking practices and routines to be followed that day, the actual process of showering remains the same for these occupants.

3.2.2. Garden hand watering

As with personal showering, hand watering takes place during defined periods of the day, when occupants are at home before or after going to work and becomes part of an interlocked daily routine (Table 5). Interviews revealed that garden watering practices are also variable over time and are dependent on skills as well as on the practices of other home occupants. For instance, home 6 revealed that while they did not irrigate their garden in the past, they decided to establish a new lawn, creating the need for a new watering practice to be interlocked into their daily routines. On the other hand, home 2 revealed that they had been trying to grow vegetables but did not have the skill required and decided therefore to cease the watering of their vegetable beds. Home 1 explained that they need to water the lawn daily due to their dog's waste. The local water company also promotes for conservation of water use in the garden (Water Corporation, 2017). However, requesting the occupants of home 1 to reduce external water use may never work simply because their watering practice is interlocked with the practice of the dog relieving itself. Replacing the existing garden water hose for a more efficient fitting or training the dog to go elsewhere would be a more effective solution to influence the water metabolism of the home.

While other research has posited that practices are bound in complex spatial and temporal bundles (Macrorie et al., 2014), we demonstrate here that distributed, interlocked home practices are reproduced in a sequential temporal spectrum. This sequential spectrum can re-align when social conditions change, as is evidenced through the difference in interlocked practice times between weekdays and weekends (Table 6, Figure 4).

3.3.Automated systems

Given the complexity of everyday practices and their interconnectivity in the home system, affecting them is challenging and unlikely to occur without taking a holistic perspective (Brynjarsdóttir et al., 2012). Traditional behaviour change approaches that attempt to persuade change through the provision of information and feedback displays assume that individuals are driven mostly by reason (Steg and Vlek, 2009). This often ignores that practices are bound in space and time and reproduced sequentially as part of an established routine (as discussed in section 3.2). Modifying them requires therefore either a change in the practice elements, including meaning, or a complete re-alignment of the home SOP. Another solution is to separate, or dis-interlock, practices from the home SOP, for instance, through their automation.

Four of the homes in this research use automatic irrigation to water the garden. The quantitative monitoring data showed that the irrigation volumes were frequently readjusted through the year. According to the research participants, these readjustments were the consequence of other interlocked practices, for instance, the establishment of a new lawn. Local regulations require that reticulated irrigation is only used on allocated days, times and months of the year. However, results revealed that three of the homes programmed the irrigation system incorrectly, watering on the wrong days or times. The innate flexibility of the automated irrigation promptly enables practice modifications. However, skills are still needed to operate the system. This is especially true for new homes that come with pre-installed and pre-programmed automated garden systems, as was the case for home 7. Interviews revealed that the occupants were not able to detect when the irrigation was on due to the underground drip irrigation pipes and their poor understanding of the reticulation settings. In this case automation also gave a sense of disconnection from the practice and the occupants were therefore less engaged in its performance.

If used and programmed correctly, automation can positively influence the use of resources in the home system without it becoming directly interlocked with other practices. The semi-structured interviews with occupants of homes 3, 6 and 7 revealed that since moving into a home fitted with PV panels, they have modified their dishwashing practices, programming the dishwasher to run during daylight hours. In this case, the practice of washing the dishes was dis-interlocked from the practices of cooking, eating or working. On the other hand, dishwashing became interlocked with the skill and technology related to both the operation of the dishwasher and the understanding of the solar technology.

A third example of automation was the use of an automatic pump to conduct the practice of pool cleaning. Home 6 has a pool pump on a timer, functioning twice per day, once in the morning (8.00 to 10.30) and once in the evening (16.30 to 18.45). Whilst the practice of pool cleaning is interlocked with the practice of swimming, it does not depend on any other practice, and functions independently of the home SOP. This practice, however, is also dis-interlocked from the solar system which could power the pool pump thereby avoiding the use of grid electricity. The occupants of home 6 were not aware of this advantage, lacking the skills to reduce the energy related to the practice of pool cleaning.

4. Conclusion

Policy and regulations for residential houses often consider the physical infrastructure alone and tend to focus on the energy or water performance of the building. However, they fail to include users as an integral part of the system. Behaviour change programs that are based on socio-psychology theories (Ajzen, 1991; Cialdini et al., 1991; Festinger, 1957; McKenzie-Mohr, 2011) attempt to influence consumers through information campaigns or feedback technology. However, this approach also ignores the fact that homes are complex systems made of people, technologies and practices that are reproduced in bundles across space and time. This research applies the concept of SOP to homes and uses practice theory to provide an understanding of occupants' everyday practices and the intricacy of the interactions between home occupants, the building infrastructure and natural resources.

Detailed quantitative and qualitative data collected over one year were used to analyse resource intensive practices in eight Australian homes in order to provide a holistic insight into the home SOP and understand what is required to enable effective resource savings. Results revealed that practices are performed in a sequential temporal spectrum as part of a routine and are influenced by interlocked practices as well as the routine of other home occupants. Moreover, the manner by which practices are performed are dependent on intrinsic human needs which may be challenging to influence through behaviour change programs alone.

Rigid and habitual routines that are highly interlocked have smaller standard deviations related to the time that practices are performed in comparison to more flexible routines. These rigid routines may prove harder to influence. Routines, however, are re-aligned when there is a change in context (e.g. at the weekend). Personal showers and hand irrigation lengths follow a similar pattern every time they are accomplished. For instance, individuals tend to have personal showers of the same length every day but longer showers that have meanings other than getting clean also occur. The lognormal distribution shape of personal showers indicates that shorter showers are unlikely to happen. Similarly, the use of the heating system is not only directly related to the temperature, but also to other interlocked practices and personal expectations.

Information campaigns that do not address users' needs and fail to understand the intricacies and interlocking of the home SOP are unlikely to have significant impact on energy and water use.

Automation, on the other hand, can enable resource intensive activities to be dis-interlocked from an established routine and make change within the SOP easier and more flexible.

This paper has demonstrated through a rich data set how practices are shaped by the routines that they are part of and how a SOP perspective providing a holistic insight into the home could be beneficial to influencing household metabolism and technology into the future.

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