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Modelling and analysis of post-occupancy behaviour in residential buildings to inform BASIX sustainability assessments in NSW

Marini Samaratunga[a,]*, Lan Ding[a], Kate Bishop[a], Deo Prasad[a], Kevin W.K. Yee[b]

[a] *Faculty of Built Environment, University of New South Wales, Sydney, Australia*
[b] *New South Wales Department of Planning and Environment, 23 – 33 Bridge Street, Sydney NSW 2000, Australia*

Abstract

Sustainability assessment tools aim to promote high sustainability outcomes in residential buildings, ensuring less consumption of water, energy and less emission of greenhouse gases. However, existing literature often presents variations between the estimated outcomes from the assessment tools and actual outcomes after building occupation. Research suggests that actual energy consumption could be significantly influenced by resident behaviour in addition to the dwelling conditions and the energy efficiency of appliances. This qualitative study explores the nature of resident behaviour in achieving thermal comfort and how these influence the actual energy performance of BASIX-affected dwellings in NSW. A preliminary evidence-based behaviour model is developed to support the behavioural analysis. The model positions the heating and cooling effects of the dwellings' design, the behaviour of residents in space heating and cooling, hot water consumption, etc. as well as multiple influential attributes such as resident's perceptions, preferences, attitudes and knowledge towards energy efficiency in relationship to energy efficiency outcomes. The model not only identifies the key drivers that trigger energy consumption behaviour, but also investigates the potential inter-relationships among all the key influential attributes. The findings of this research will inform the BASIX assessment tool, sustainability policy, building designs and government educational programs on sustainability.

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Keywords: Building Sustainability Index (BASIX), Energy consumption behaviour in Dwellings, Evidence-based Behaviour Modelling

* Corresponding author. Tel.: +61-0424633113
E-mail address: m.samaratunga@student.unsw.edu.au

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1. Introduction

Building sustainability assessment tools play an important role to maintain sustainability standards in the residential building sector. Building Sustainability Index (BASIX) is one of the sustainability assessment tools developed by the New South Wales (NSW) Government. BASIX estimates water consumption, energy consumption and greenhouse gas emissions from new residential developments and it is based on information available at the design stage. BASIX is also a planning assessment policy that requires all new residential developments to achieve certain mandatory reduction targets in potable water consumption and greenhouse gas emissions before their development can be approved. More than 140,000 dwellings have been built in NSW since BASIX was introduced in 2004.

However, studies conducted recently [1] reveal that there is a significant variation between the energy performance estimated by BASIX and the actual performance from BASIX-affected dwellings after occupation. A better understanding of the actual energy performance of BASIX-affected dwellings after occupation is essential to evaluate the effectiveness of BASIX to reduce greenhouse gas emissions from the residential building sector. A project funded by the Cooperative Research Centre for Low Carbon Living (CRCLCL) is therefore aimed at providing a better understanding of actual energy performance of BASIX-affected dwellings. The project is led by the University of New South Wales in collaboration with the Commonwealth Department of Industry, Innovation and Science, the NSW Department of Planning and Environment, NSW Office of Environment and Heritage and the City of Sydney council.

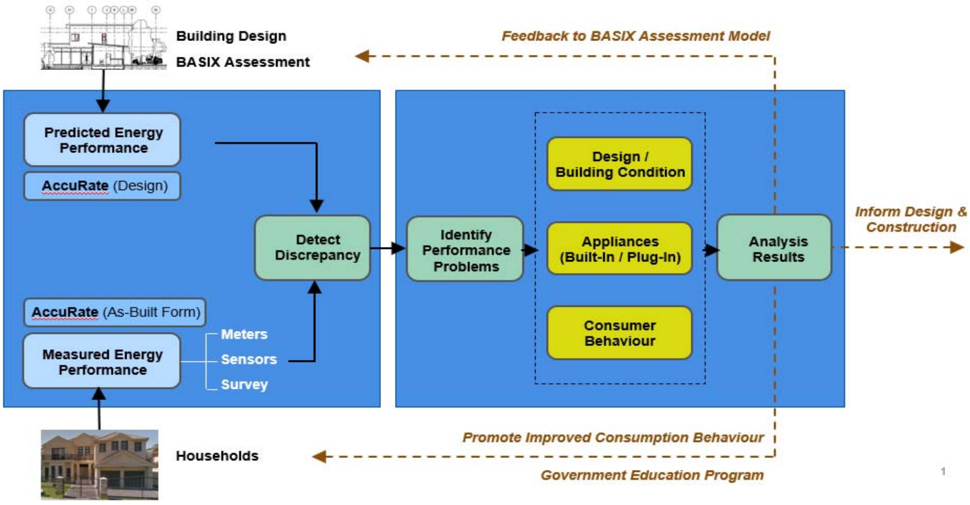

Fig. 1. Overview of the larger project titled; "Validating and improving the energy performance of BASIX-affected dwellings" funded by Cooperative Research Centre for Low Carbon Living (CRCLCL) (RP1017 CRCLCL BASIX project interim report #1)

The CRCLCL project illustrated in Figure 1 identifies and evaluates the significance of three major components that may cause the discrepancies between the energy performance of buildings estimated by BASIX and their actual performance. These three major components are: dwelling conditions (such as dwelling design, construction quality, air leakage and insulation), efficiency of appliances and the post-occupancy behaviour in energy consumption.

This study focuses on the post- occupancy behaviour of BASIX- affected dwellings and how it influences the actual energy performance. This is a significant component of the CRCLCL project shown in Figure 1. Recent studies reveal that the energy performance of buildings is affected by not just how buildings are designed, but also how they are built, commissioned and used [2]. The role of building users on energy consumption from the built environment is critical, but it is poorly understood and often overlooked [2]. Therefore the research in the sustainable built environment field today needs to focus on not only technical and design strategies to improve buildings but also on seeking ways of integrating user behaviour in building performance measures. This research presents findings that would provide a better understanding of the contribution of post-occupancy behaviour to the discrepancy between energy performance estimated by BASIX and actual building performance, and the interaction between post-occupancy behaviour with dwelling design and appliances. An evidence based model is being developed to identify what behaviour contributes to energy consumption and why and how these behaviours transpire.

In particular, this paper aims to develop a framework for this evidence based behaviour model of energy consumption. Preliminary data collected in response to the literature based conceptual framework are analysed to confirm the relevance of these data as evidence in developing the behaviour model of energy consumption.

The scope of this paper is limited to certain aspects, as it is an initial section of a larger project. Although the actual energy consumption in dwellings are for many activities such as cooking, lighting, etc., this paper focuses on how people behave to achieve thermal comfort in their homes during the cool season in which active heating may be required. The cool season considered in this study is the time period in the year where most days are below eighteen degrees Celsius. In New South Wales, this is the time period between autumn and spring (May-September). Previous research has identified that a significant portion of energy is used to achieve thermal comfort through heating and cooling in dwellings [3]. Therefore understanding resident's perspectives towards thermal comfort and what they do in achieving thermal comfort is vital to understand energy consumption in dwellings. The literature based conceptual framework in this study identifies behaviour related to achieving thermal comfort and their influential attributes. This paper focuses on energy use behaviour and adaptive behaviour to achieve thermal comfort, and in particularly the perception of thermal comfort. These are explored to identify what types of behaviour may contribute to the difference between predicted and actual energy consumption in dwellings together with the attributes that may influence resident's post-occupancy behaviour.

This paper starts with an introduction to the theories and models of behavioural analysis followed by the development of the framework for the evidence based behaviour model. The methodology and methods of data collection is then explained and the paper will conclude with an initial analysis and discussion of the preliminary findings.

2. Theories and models of behaviour

There are two principal bodies of theories that provide the overarching framework of the behaviour analysis of energy consumption in the residential sector, namely the theories of human behaviour and the theories of energy consumption behaviour [4]. Specific theories and models relevant to the development of the proposed evidence based behaviour model are discussed below.

2.1. Theories of human behaviour

2.1.1. Theory of Planned Behaviour

This theory conceptualised by Ajzen placed significant emphasis on individual agency as the major influence on individual behaviour [4]. This theory is appropriate to this study because dwelling energy consumption to achieve thermal comfort starts with individual agency. Therefore understanding individual's behaviour and influential attributes on this behaviour are significant in this study. Similar to the theory of planned behaviour, energy consumption behaviour too depends on both motivation (intention) and ability (behavioural control) [5]. Motivations for individuals such as rewards, tariffs, enforcements, etc. and behavioural abilities of individuals such as environmental attitudes, perception of comfort, preferences, personal skills, etc. are identified as influential attributes on an individual's behaviour in achieving thermal comfort in dwellings [4]. These attributes from the Theory of Planned Behaviour, inspire the development of the proposed framework for the evidence based behaviour model of dwelling energy consumption.

2.1.2. Social Practice Theory

This is a social theory pioneered by Giddens and Bourdieu, where behaviour is discussed as a product of relationships between people, their environment, and the technology that surrounds them [6]. In this sense, objects and environments become active in the production of behaviour [4]. This theory is appropriate in this study as dwelling energy consumption that results from achieving thermal comfort is essentially an outcome of the inter-relationships between members of the family, neighbours, institutional systems, features of the physical environment, appliances and technology. Therefore, Social Practice Theory inspired the development of the proposed framework for the evidence based behaviour model of dwelling energy consumption, not only in terms of identifying influential attributes such as situational contributors but also inter-relationships among the influential attributes.

2.2. Theories of energy consumption behaviour

While a number of theoretical perspectives have emerged in the literature, there is no single universally accepted framework or model that provides an all-inclusive explanation of energy consumption or conservation. There is also no single approach that precisely predicts individual differences in energy consumption. It is so complex that it is difficult to capture in a single framework [7]. Due to the complex and dynamic nature of energy consumption behaviour, researchers have increasingly favoured integrative approaches which view energy consumption and conservation as arising from an ongoing interaction of multiple attributes [8, 9]. An integrative approach incorporating the 4E's model [10, 11] and the energy culture framework [12] is adopted in this study (Figure 2).

The 4E'model for behavioural changes in energy consumption is discussed by several UK government reports related to sustainable development programmes [10, 11]. In this model the four E's represent; Educate, Encourage, Empower, Enforce. It has an integrative approach where multiple attributes that go beyond personal and social attributes are incorporated. This model is appropriate for this study as the proposed dwelling energy consumption behaviour model is complex and comprehensive with a variety of influential attributes on consumer behaviour. Most of the parameters identified under the four strategies proposed for consumption behaviour changes could also be considered as influential attributes of dwelling energy consumption (Figure 2).

The energy cultures framework developed by Stephenson is appropriate for this study as it identifies influential attributes on energy consumption and their inter-relationships which underpin the development of dwelling energy consumption behaviour model. Some of the influential attributes of this framework identified as appropriate for this study are beliefs, education, demographics, tradition, building characteristics, regulations, income and technologies [12]. Furthermore, the interactions among the influential attributes also provide inspirations relevant to this study. Thus the energy cultures framework, similar to the 4E's model, consider multiple attributes on energy consumption with an integrative approach.

Therefore, the dwelling energy consumption behaviour model of this research is developed based on the theoretical models discussed above. Figure 2 offers a representation of the relevant theoretical components that support the conceptual framework for the proposed behaviour model of energy consumption.

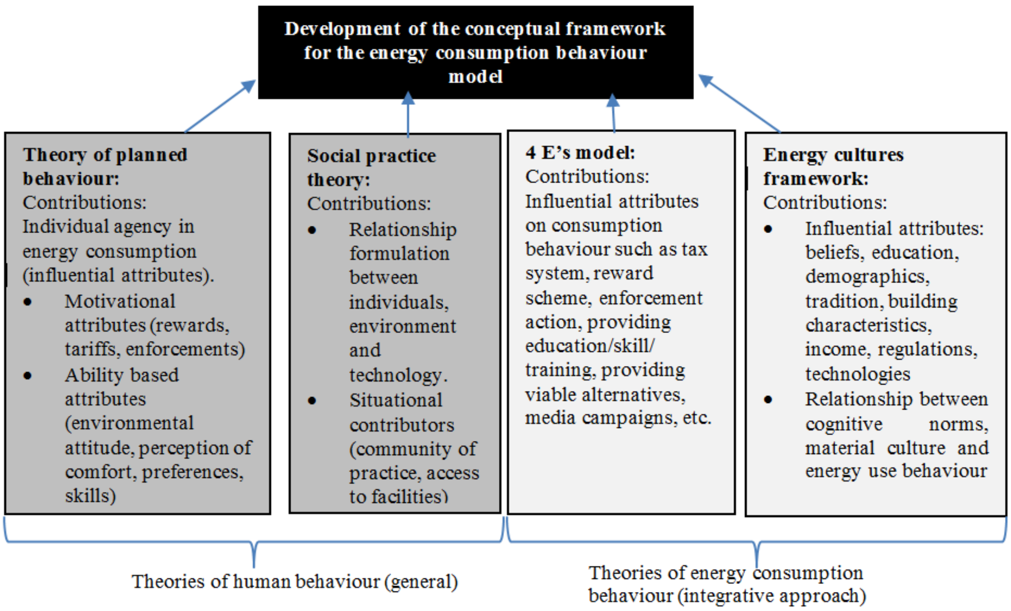

Fig. 2. Diagram depicting selected major theoretical areas and their contributions to developing the framework for the evidence based behaviour model

3. Conceptual framework for an evidence based behaviour model of dwelling energy consumption

A conceptual framework for the proposed behavior model is illustrated in Figure 3. It consists of three categories of energy consumption behaviour that could potentially lead to the actual energy consumption during dwelling's post occupancy period and the reasons that cause such behaviour.

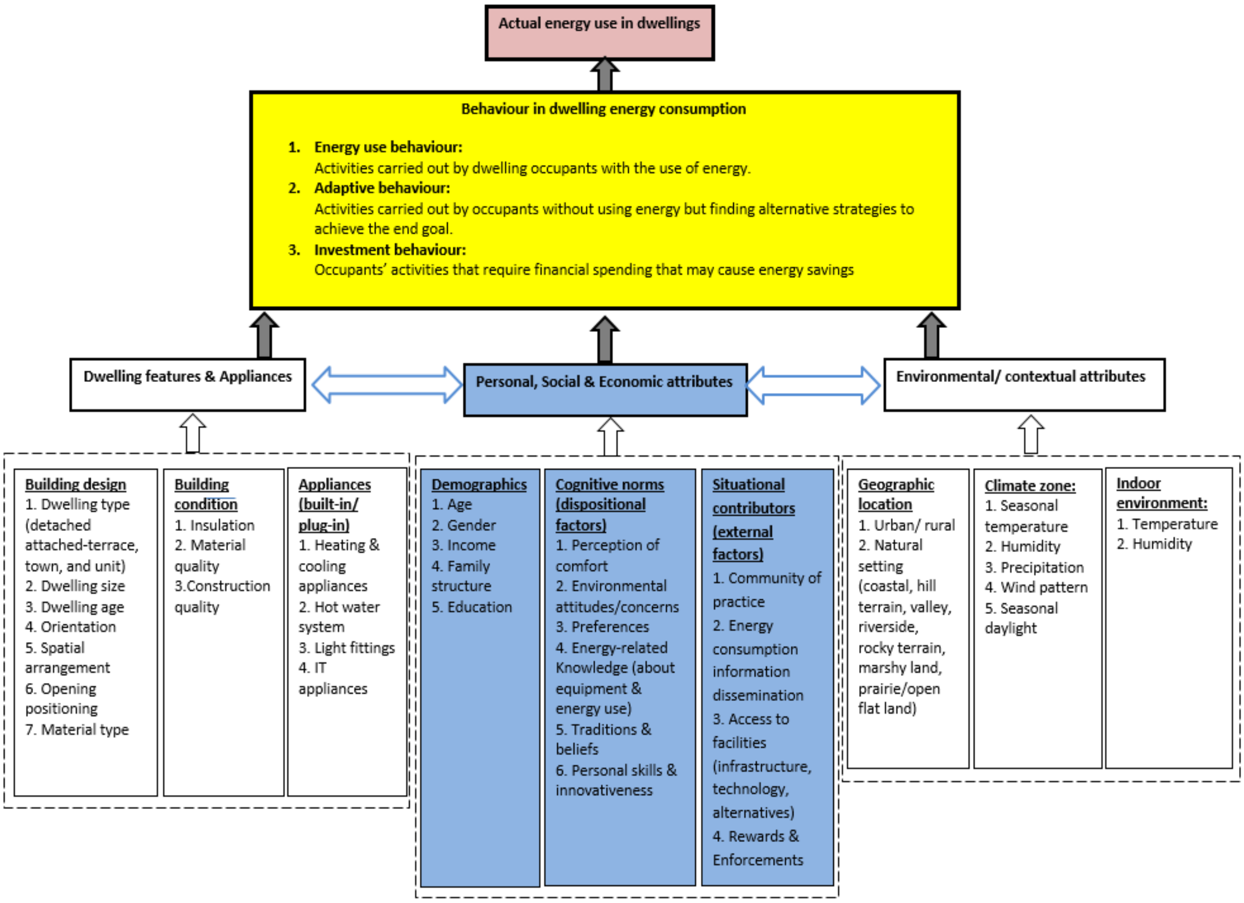

Fig. 3. Proposed conceptual framework for behaviour model of dwelling energy consumption

The main facets of exploration which are reflected on the proposed conceptual framework are briefly described below.

1. Behaviour in dwelling energy consumption: Residents' potential behaviour in relation to dwelling energy consumption could be divided into three categories including, energy use behaviour, adaptive and investment behaviour [11, 14, 15, 16]. Energy use behaviour involves activities carried out by residents with the use of energy. Adaptive behaviour [14, 15] involves activities carried out by residents without using energy but finding alternative strategies to achieve the end goal. For example, wearing multiple layers of clothing without turning on the heater is an adaptive behaviour. Investment behaviour involves resident's activities that require financial spending that may cause energy savings [11, 16]. For example if a resident upgrades the heating system and retrofit his dwelling, it is an investment behaviour that leads to energy savings.

2. Influential attributes on resident's energy consumption behaviour: Based on literature sources, three main potential influential attributes are identified. One attribute identified is the personal, social & economic

attributes [17]. Another attribute identified is the environmental/contextual attribute and the third attribute identified is the dwelling features & appliances [18, 19, 20, 21]. Key social, personal & economic attributes that influence the dwelling energy consumption behaviour of residents are shortlisted to family demographics (age, gender, income, family structure, education), personal cognitive norms (perception of comfort, environmental attitude, preferences, energy related knowledge, traditions and beliefs, personal skills and innovation)[22] and external situational contributors (community of practice, energy consumption information dissemination, access to facilities, rewards) [19]. Selected environmental attributes that influence dwelling energy consumption behaviour of residents are geographic location (urban/rural, natural setting), climate zone (seasonal temperature, humidity, precipitation, wind pattern, seasonal day light) and indoor environment (indoor temperature, indoor humidity) [19]. Dwelling features & appliances related attributes that influence dwelling energy consumption behaviour of residents are categorised as building design, building conditions and built-in/plug-in appliances [23, 24].

3. Interactions among the influential attributes: The double directed arrow heads on Figure 3 and 4 depict the potential interactions between resident's personal, social & economic attributes, environmental attributes and the dwelling features & appliances within the dwelling which would form a close interaction loop.

Three research questions are derived for this study related to BASIX sustainability assessment, which align with the above identified three main facets of the conceptual framework (Figure 3). They are:

1. What are the behaviours that may cause the difference between the estimated and the actual energy consumption of dwellings in the context of BASIX?
2. How and why do those kinds of energy consumption behaviours occur? (Influential attributes)
3. What are the interactions between the influential attributes?

Exploration of these three research questions are discussed in the following section.

3.1. Framework of behavior analysis to inform BASIX sustainability assessment

In response to the research questions identified in this study, an analysis framework is developed as shown in Figure 4. It depicts the hierarchy of the process where the identified potential behaviour categories and influential attributes are explored to inform reasons for the difference in energy use between actual and estimated energy consumption in BASIX-affected dwellings. As shown in the Figure 4, data collected would be analysed to inform the proposed behaviour model.

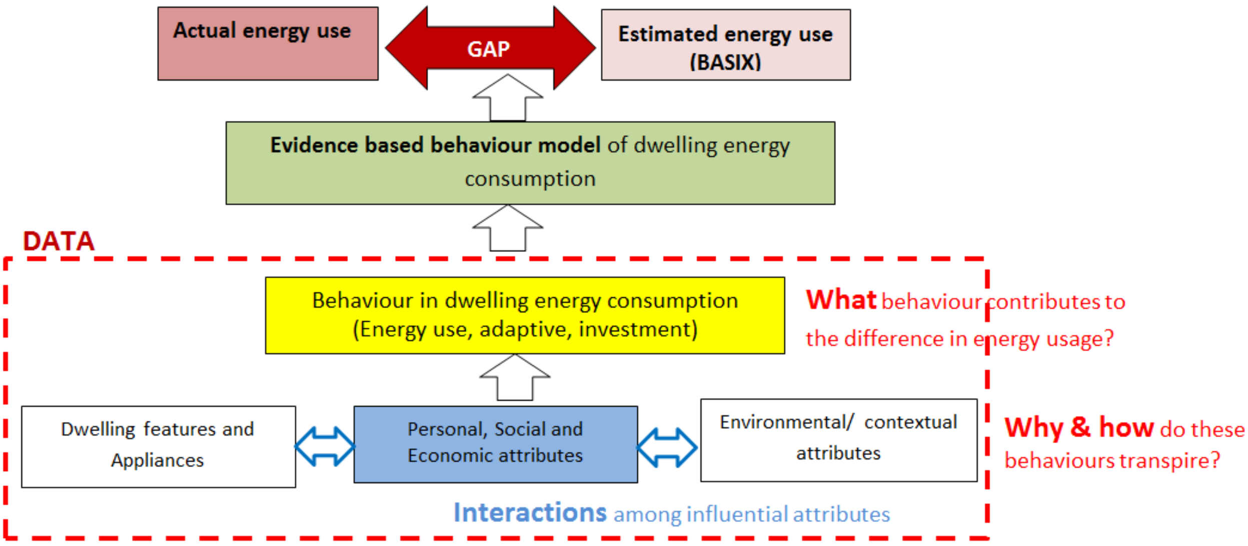

Fig. 4. Framework of data analysis to inform BASIX sustainability assessments

4. Data collection and analysis

4.1. Sample selection

The sample population in this research project consists of 55 BASIX-affected dwellings in the Greater Sydney region in Australia, including Penrith, Blacktown, Hornsby, Parramatta, Randwick, Camden, Liverpool, Fairfield, Campbelltown, Ku-ring-gai, Bankstown and Sutherland. Sample dwellings recruited are a mix of single detached dwellings and multi-unit dwellings constructed after implementation of BASIX in 2004.

This paper focuses on nine BASIX-affected detached dwellings where initial data was collected for the cool season. As illustrated in the Figure 5, the initial study compared BASIX estimated energy consumption and actual energy consumption based on yearly electricity bills from these dwellings and identified dwellings with high energy consumption.

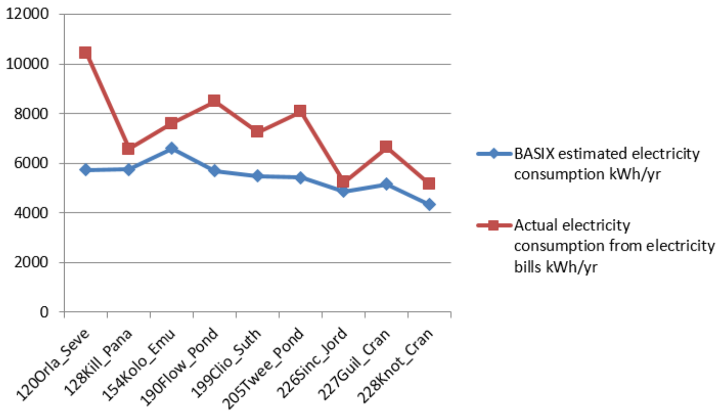

Fig. 5. Selection of nine dwellings with high energy consumption through the comparison between the BASIX estimated and the actual consumption based on energy bill data per household

Table 1: Features of the selected nine dwellings with high energy consumption

Dwelling code	Number of occupants	Children	Elderly over 65	Home office	Single/double storied	Total floor area (m^2)	Orientation	BASIX estimate kWh/yr.	Actual energy consumption kWh/yr.
120Orla_Seve	5	3	0	yes	single	201	South facing Living: East-West	5724.35	10448
128Kill_Pana	4	2	1	yes	single	220	East facing Living:North-West	5751.06	6570
154Kolo_Emu	4	2	0	yes	single	148	West facing Living: South	6603.83	7613
190Flow_Pond	4	2	0	yes	double	246	South-East facing Living: North-West	5689.28	8490
199Clio_Suth	2	0	0	no	single	264	North facing Living:South-West	5471.77	7261
205Twee_Pond	2	0	2	yes	single	158	West facing Living: North-East	5426.32	8071
226Sinc_Jord	2	0	0	no	single	160	East facing Living: North-South	4870.83	5243
227Guil_Cran	4	2	0	yes	single	172	North-West facing Living: North-East	5155.55	6632
228Knot_Cran	2	0	2	no	single	138	South-East facing Living: North-West	4319.09	5161

Features of the selected nine dwelling sample with high energy consumption than the BASIX estimations, are depicted in the Table 1. Five out of nine dwellings have children less than 15 years. Three houses have elderly residents and only one house (228Knot_Cran) has pensioners. Furthermore, six out of nine dwellings use a home office for more than 20 hours per week because at least one of the residents works several days from home. Except one house (190Flow_Pond), all the other eight dwellings are single-storey houses. All the houses are brick-veneer houses with similar construction quality and floor area ranging from 138 to 264m2.

4.2. A qualitative approach to data collection and analysis

Due to the highly subjective nature of this research and the need of in-depth exploration on resident behaviour, it is identified that the most apt research methodology for this study is qualitative. Qualitative research has the capacity to derive rich information from people's experiences and also to relate to multiple contextual influences that shape their experience, which makes it appropriate for this study [25].

4.2.1. Semi Structured Interviews

The principal method used in this study for data collection is a semi-structured interview. The interview structure is developed in alignment with the conceptual framework and research questions discussed previously. The structure mainly has three areas which cover three potential energy consumption behaviour categories, i.e. energy use, adaptive and investment behaviour. Open ended questions are designed within these sections to trigger potential influential attributes such as perceptions, preferences, attitudes, beliefs, social norms, and financial concerns. The dwellings were visited by the researcher during the cool season (May-September) to conduct interviews and collect dwelling design information. One or two representatives from each dwelling participated in the face to face interviews of 60-90 minutes. The interviews were recorded and subsequently transcribed for analysis.

4.2.2. Thematic analysis

Thematic analysis is a popular tool used in qualitative research, where it facilitates the ability to identify evidence of themes or patterns in the narrative data collected [26]. The data generated via interviews in this study are narrative data which require qualitative analysis. Therefore this study uses thematic analysis to identify, analyse, and report patterns (themes) within the collected comprehensive narrative data.

5. Preliminary data analysis and findings

This preliminary analysis is an attempt to generate a partial snapshot of the ongoing research. As mentioned in the introduction of this paper, the initial analysis would confirm the relevance of the data collected as evidence in developing the behaviour model of energy consumption.

The findings being discussed are organised based on the research questions and analysis framework (Figure 4), where categories of behaviour of residence in energy consumption, influential attributes and their relationships are explored. The findings discussed are limited to the scope of the paper which focuses on how residents behave to achieve thermal comfort in the cool season.

5.1. Key Behavioural outcomes in achieving thermal comfort

Residents demonstrate different types of behaviour in achieving thermal comfort. Some residents attempt to achieve thermal comfort without using energy, while others use energy to be thermally comfortable in their dwellings. The conceptual framework defines these behaviour as adaptive and energy use behaviour (Figure 3). Since the nine dwellings in this preliminary analysis use more energy than the BASIX estimates, the following sections attempt to analyse energy use and adaptive behaviour that may contribute to the energy use difference.

5.1.1. Evidence of energy use behaviour in achieving thermal comfort (with energy)

Energy use behaviour by residents in achieving thermal comfort where occupants use energy in operating heating devices were identified in the data analysis. The analysis revealed heating patterns and residents' reasons for such activities. This enables the possibility of identifying actual energy use behaviour in achieving thermal comfort in dwellings in the cool season. Major findings of the research in relation to energy use behaviour in achieving thermal comfort are as follows:

a) Routine use of heaters: Most residents use mechanical heating routinely to achieve thermal comfort during the cool season. Heaters are mostly used in the morning and at night routinely during the cool season.
b) Excessive use of heating appliances: Residents mostly give priority to the preference of personal comfort and life style and this lead to excessive use of appliances as a habit.
c) Spaces that are mostly heated in dwellings: living spaces are heated for long hours and bedrooms are the most frequently heated spaces in a dwelling.
d) Use of an air conditioner throughout the week for work efficiency: Most dwellings with home offices have a high use of an air conditioner throughout the week for heating due to expectations of work efficiency in home offices.
e) Energy curtailment practices: Most residents are conscious of exploring curtailment practices such as breaking up the duration of heater usage, using the night mode, use of timer, setting a low temperature on the heater, etc. but they lack confidence in their practice due to a lack of awareness or due to prioritising convenience or simply due to laziness.
f) Heating of unused spaces in the dwelling: Most residents perceived that the available heating system has issues in relation to its suitability to the open plan design of the dwelling and their lifestyle. Also due to zoning limitations they have little control over heated spaces.
g) Heat the dwelling before it gets too cold: Residents are used to rely more on weather forecasts and they perceive that it is energy efficient to heat the house before it gets too cold.
h) Use of several heating systems to suit activity and dwelling space: Knowledge and awareness of heating systems and how to use them efficiently seems to influence energy used to achieve thermal comfort. Awareness of the available technologies enables the use of a variety of heating appliances appropriate to different activities. Residents, who are concerned about energy wastage and the efficiency of heating devices, use more appliances than their air conditioner for heating and use a mixture of devices suitable for different spaces and activities.
i) Use of heaters without changing settings: some residents do not have much knowledge about the operation of the heating system which could lead to energy wastage. Some are reluctant to change settings on the air conditioner due to convenience or lack of knowledge.
j) Choice in heating system during construction: In most cases, due to the lack of flexibility and restrictions on the client involvement in the design/construction process, residents do not have a choice on the selection of heating/cooling appliances.

All the above energy use behaviour activities could be broadly categorised into two activities, i.e. usage pattern of heaters (frequency, duration, time of the day, space & activity of use) and operation of heaters (thermostat setting, curtailment practices).

5.1.2. Evidence of adaptive behaviour in achieving thermal comfort in dwellings (without using energy)

Adaptive behaviour in achieving thermal comfort where actions taken by residents to keep themselves warm during cool season without using energy or mechanical devices were identified in the data analysis. This revealed actions which are used to achieve thermal comfort without using energy and the reasons why such actions are adopted by residents. A few significant findings from the data gathered in relation to adaptive behaviour identified in the nine dwellings are as follows:

a) Shared space utilisation: Space utilisation patterns influence energy consumption by affecting adaptive behaviour. Families which have more common activities such as common entertainment interests prefer to be in one space in the night-time. This leads to adaptive behaviour in achieving thermal comfort by using couch blankets, or through each other’s body heat and heat emitted by the entertainment devices. However sharing common activities has become more difficult due to the large variety of entertainment devices and conflicting interests that has dispersed family times spent together in one space. This leads to difficulties to implement shared adaptive strategies in achieving thermal comfort.

b) Multi-layered clothing in home offices: Warm clothing is the most popular and sensible adaptive behaviour but unfortunately there are many people who do not make use of this adaptive strategy due to two main reasons. The first reason is due to personal attitude or accepted family norms that consider multi-layered clothing to be uncomfortable to wear at home. The second reason expressed for discouraging multi-layered clothing is due to the perception leading to the negative impact on work efficiency in home offices. Home offices have become popular and many residents prefer an office environment in their dwellings for work efficiency. Therefore they consider "rugging-up" (words used by elderly male interviewee of 128Kill_Pana) in home-offices as an inappropriate and inefficient solution to thermal comfort.

c) Innovative ideas in multi-tasking: Some residents try to be creative to combine day to day activities with methods of achieving thermal comfort. One example is utilising the kitchen area during cooking. This is an adaptive strategy to keep warm with the heat emitted in the cooking process which can heat up the adjacent spaces.

d) Home repairing skills: Abilities to do minor repairs at home also contribute to achieving thermal comfort as they enables resident to fix issues in the dwelling that lead to thermal discomfort. As an example, in the case where there is an air gap in an opening, resident are reluctant to obtain professional services due to the expenses involved. Residents who can do minor repairs tend to fix such faults faster than others and save energy wastage.

e) Switching off stand-by power: Most residents are aware of stand-by power but fail to switch appliances off at night or when not in use due to three reasons. The first reason is that they perceive that it draws only a negligible amount of energy; the second reason is as it would change the appliance setting and the third reason is the difficulty of reaching plug-in points.

Less implementation of the above identified adaptive behaviour due to the discussed various reasons may have led to high energy use in the nine dwellings during cool season.

5.2. Key influential attributes on energy use choices: Thermal perception

Among many influential attributes scoped in the conceptual framework, thermal perception analysis is focused in this paper. Findings include:

a) Perceptions about the dwelling's thermal condition: Most residents perceived that their dwellings are cold in the cool season and require mechanical heating to achieve thermal comfort. This is because they thought that their dwellings are designed to respond better to the warm season than to the cool season. They also thought that the Australian warm season is more challenging for managing thermal comfort than the cool season. They are aware that dwelling finishes such as floor tiling contributes to this perception.

b) Perception of feeling cold is being associated with higher risk of getting sickness: This social belief influences the thermal perception of occupants with health concerns. Therefore, an even slightly lower temperature makes them react and use mechanical heating excessively.

5.3. Relationships between energy consumption behaviour and influential attributes

The following provides an initial analysis of the relationships between energy use and adaptive behaviour and influential attributes (Figure 6):

a) Between energy use behaviour and influential attributes such as dwelling features and personal attributes: Perceptions such as "Australian houses are cold and need mechanical heating" (as said by the female interviewee of 199Clio_Suth) has led to energy use behaviour such as using heaters more often. All the dwelling samples have brick veneered walls, single glazing on windows and ceramic tiled floor in common areas, which has made residents to perceive that the houses are cold in winter.

b) Between energy use behaviour and influential attributes such as dwelling features, appliances and economic attributes: Heating unused spaces in the dwelling is a common issue among the dwelling sample. This is due to the sub-optimal zoning arrangements of the operations of central ducted air conditioner systems and the open plan layout of the dwelling design. For example, most dwellings are provided two zones, where one zone operates for three bedrooms and the other zone operating on the living, dining, and kitchen areas. In this situation, dwellings that use only one bedroom would have to heat two other unused bedrooms in the process of heating. Furthermore, the open plan layout also contributes to inefficiencies of heating spaces. Open plan minimize wall partitions between spaces and unrestricted air flow leads to heating inefficiency.

c) Between energy use behaviour, adaptive behaviour and knowledge on appliance usage: Most residents intending to save energy were not confident about the operation of their heating system. Some of them does not know how to change the settings of their heating system and also ways to increase the efficiency of usage.

d) Between adaptive behaviour, energy use behaviour and influential attributes such as family structure, social beliefs and attitude: Families with young children and elderly use heaters more often to achieve thermal comfort. Five out of nine sample dwellings in this research had young children. Residents of all those five dwellings believe that feeling cold would increase the risk of getting sick and tend to use heaters often to keep the children warm. Two dwellings had elderly, who has the attitude that comfort is the first priority in their dwellings and therefore use heaters more often.

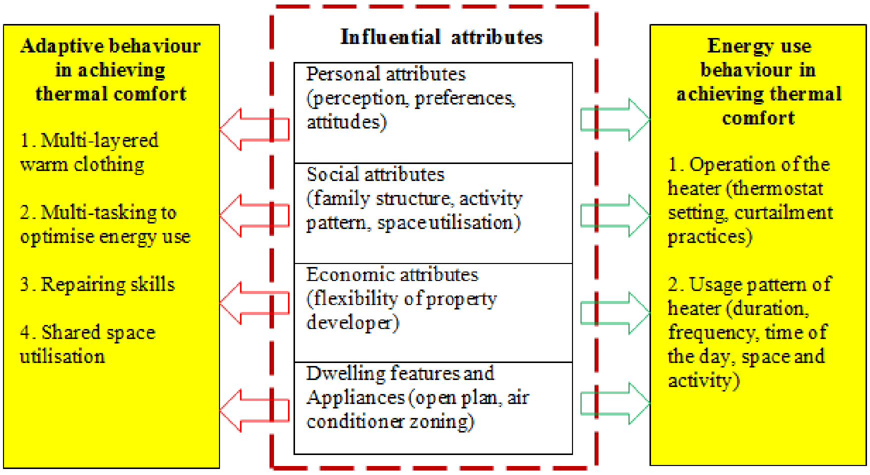

Fig. 6. Diagram depicting potential inter-relationships between identified adaptive behaviour, energy use behaviour in achieving thermal comfort in dwellings and their influential attributes

6. Discussion

The data collected from dwellings with high energy consumption rates (Figure 5), show that the residents in those dwellings exhibited less adaptive behaviour and more energy use behaviour in achieving thermal comfort. Similar to the nature of behaviour described by Tweed et.a [27], residents who participated in this study were aware of possible adaptive behaviour such as adding multi layers of warm clothing, shared space utilisation, innovative ideas in multi-tasking and home repairing skills but they were not able to implement them to achieve thermal comfort due to various reasons discussed in this paper. Personal attributes such as preferences, perceptions and attitudes restricted occupants from wearing warm clothing and social factors such as family activity patterns added restrictions to shared space utilisation. Personal attributes such as education and awareness influenced their ability in multi-tasking and home repairing skills. Wilson and Dowlatabadi [28] in their integrated model of pro-environmental behaviour discussed the correlation of pro-environmental behaviour and dwelling energy consumption behaviour and similarly identified the above discussed personal attributes such as attitude, knowledge, capabilities and technical skills such as home repairing skills as significant contributors to the adaptive behaviour in achieving thermal comfort.

Energy use activities in the dwellings identified in this study confirm the notion that “Home life has become inherently energetic” [28]. In addition to the findings of the study conducted by Verhallen and Van Raaij [29] on general dwelling energy consumption behaviour, findings from this study reveal resident's behaviour in achieving thermal comfort that contribute to the discrepancy between actual energy consumption and the BASIX estimates. Resident's energy use behaviour in achieving thermal comfort which are identified in this study can be broadly divided in to two groups: 1) usage pattern of heaters (frequency, duration, time of the day home office, zoning issues, open plan issues,) and 2) operation of the heater (thermostat setting, curtailment practices). Reasons for such usage pattern of heaters and the behaviour in operating the heaters by residents are well understood in this study through the exploration of the influential attributes.

In keeping with the findings of this study, Stephenson et.al [12] in developing the energy cultures framework identified key influential attributes at the level of the individual which have a bearing on energy consumption behaviour such as education, upbringing, demographics, expected comfort level, environmental concerns, respect for tradition and social aspirations. Previous studies have also revealed that people's concept of lifestyle and their behavioural routines such as sleeping pattern, physical activity pattern, cooking pattern, etc. are crucial to dwelling energy consumption [29]. Resident's perceptions or views on thermal comfort greatly influence their lifestyle choices and behavioural routines related to energy consumption behaviour in achieving thermal comfort. Therefore in this study perception, at the levels of both the family and the individual, is identified as a key influential attribute that influences adaptive and energy use behaviour for people in achieving thermal comfort in dwellings.

Furthermore, similar to findings of Verhallen and Van Raaij [29], this study reveals that the energy used to achieve thermal comfort is significantly influenced by other identified attributes such as dwelling features, appliances and economic attributes. Most residents perceive that heating in the dwelling is wasted due to limited control over the operational zoning system of the central air conditioning system and also due to the open plan layout of the house design. Common selections of heating systems and operational zone layout may have led to high energy consumption after dwelling occupation.

In general all residents prioritise thermal comfort within the dwellings and they perceive that it is connected with work efficiency and good health. Therefore, they use mechanical heating routinely to achieve thermal comfort. Personal perception, attitude and preferences are governing influential attributes of this behaviour. This analysis also proves the fact that people do not implement all that they say or think they do [27]. This is because of the indefinite views given by occupants on energy curtailment practices. Most of the occupants are concerned about energy curtailment practices but they do not implement them, mainly due to a lack of motivation and confidence. In case of using ducted air conditioners for heating, residents show lack of confidence in changing settings and usage pattern such as switching on and off in short intervals. Residents expect periodic involvement by professionals in making them aware of energy efficient practices.

7. Conclusion

The initial findings from this study reveal that resident's behaviour in achieving thermal comfort is diverse and influenced by attributes of a complex nature. Exploration on the relationships between potential behaviour in achieving thermal comfort and their influential attributes provide a comprehensive perspective towards the actual energy consumption in dwellings. Furthermore, the initial analysis reveal that the evidence generated by this study provide a valid base for the development of the behaviour model for dwelling energy consumption, which would inform the BASIX assessment tool, sustainability policy, building designs and government educational programs on sustainability.

This paper represents only a component of a larger study. While this paper is focused on a limited sample in the cool season, the study includes a larger dwelling sample and would also cover energy consumption behaviour in warm season. Furthermore, the data collected through interviews on dwelling energy consumption behaviour could be triangulated with the meter readings of the same houses for accuracy. Actual energy consumption breakdown and the temperature/humidity inside the dwelling recorded by the metering devices that are installed in those dwellings during the project period would provide a valuable reference to further understand the energy consumption behaviour of residents.

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