LOW CARBON LIVING CRC

VALIDATING AND IMPROVING THE BASIX ENERGY ASSESSMENT TOOL FOR LOW-CARBON DWELLINGS

Cover & Back: Western Sydney Housing Development
Photo: UNSW

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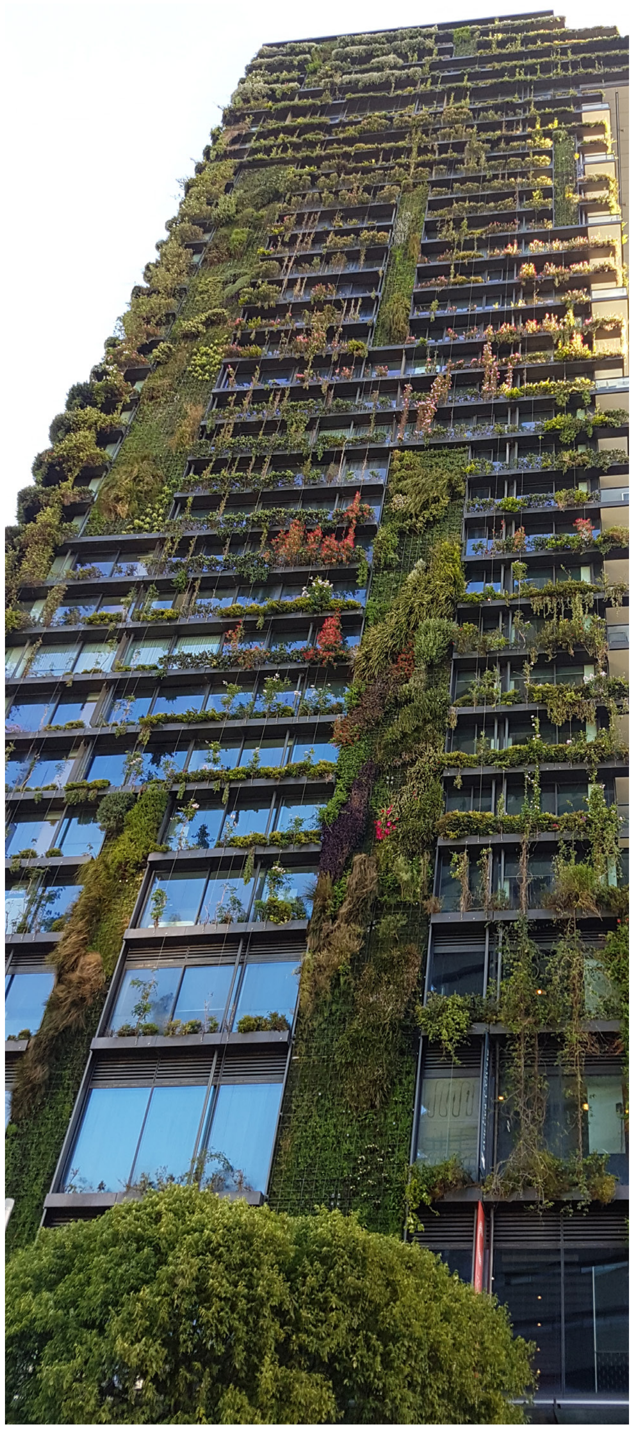

Multi-Unit Dwelling in Eastern Sydney
Photo: UNSW

EXECUTIVE SUMMARY

This report is a product of the collaborative research project 'Validating and Improving the BASIX Assessment Tool for Low-Carbon Dwellings'. Initiated by the Cooperative Research Centre for Low Carbon Living, the University of New South Wales (UNSW) and the New South Wales Government, this project addresses the policy need for post-occupancy evaluation of the BASIX tool by measuring the actual energy consumption of BASIX-compliant dwellings. This report outlines the key findings of this project by highlighting the discrepancies between BASIX estimations and measured energy consumption and provides an in-depth analysis as to why there are discrepancies and what causes them. Project outcomes fill the gap towards achieving a systematic understanding of actual energy performance of BASIX-complaint dwellings, including the complex and interrelated attributes that contribute to these discrepancies.

Findings from this research show that the measured BASIX-compliant dwellings performed well in the overall reduction of greenhouse gas emissions and were close to BASIX estimations, thereby validating the effectiveness of BASIX tool in promoting low carbon dwellings. However, the breakdown of energy consumption measured by this project highlighted discrepancies in energy consumption for space heating and cooling, lighting and plug loads. An analysis of the attributes contributing to these discrepancies between BASIX estimates and actual energy consumption is discussed and recommendations for future improvements are presented in line with:

- Updating and improving the benchmarks utilised by the NatHERS and BASIX assessment models;
- Improving construction and building envelope quality control; and
- Encouraging sustainability awareness and behaviours.

Western Sydney Housing Development
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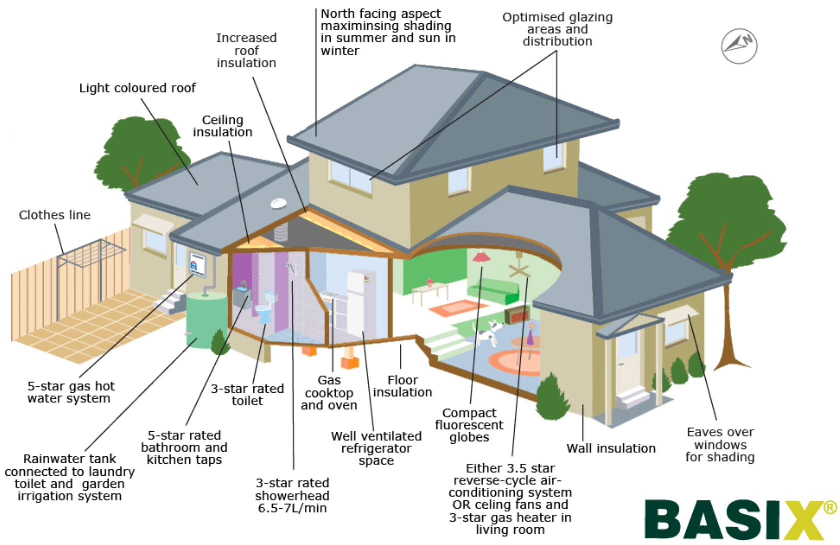
INTRODUCTION

REDUCING RESIDENTIAL GREENHOUSE GAS EMISSIONS

Residential energy consumption represents approximately 25% of global energy consumption and 17% of global CO_2 emissions (IEA, 2016). Urgent global action is required to reduce residential energy consumption, especially within higher energy consuming developed nations such as Australia (USEIA, 2013). Collaborative efforts and commitment across governments, industry and the community are crucial to reducing energy consumption and greenhouse gas (GHG) emissions on the pathway towards low-carbon and net-zero residential dwellings.

To address this challenge, the Australian Commonwealth and State Governments have formulated policies and regulations to reduce residential energy consumption and GHG emissions. The National Construction Code (NCC) mandates a minimum requirement for the thermal performance of all building envelopes. In addition to this, the New South Wales (NSW) Government introduced the Building Sustainability Index (BASIX) in 2004 which requires all new residential dwellings to meet mandatory reduction targets of GHG emissions and water consumption before development can be approved. BASIX also sets water efficiency and GHG reduction requirements of alterations and additions costing over $50,000.



Sustainable Housing Features Encouraged by BASIX (Source: DP&E)

BASIX: BACKGROUND & POLICY FRAMEWORK

BASIX is a State Environmental Planning Policy that is used to assess and regulate the performance of proposed residential dwellings in NSW. It is a performance assessment tool that mandates minimum energy and water use targets as a percentage of GHG emission and water reductions from the pre-BASIX (2002/2003) benchmarks (NSW Department of Planning and Environment, 2019a).

BASIX also sets minimum performance levels for thermal comfort based on the amount of energy required to heat or cool a dwelling. GHG emissions are calculated using the Nationwide House Energy Rating Scheme (NatHERS) rating tools or simplified tools offered by BASIX and integrated with heating and cooling appliance efficiencies.

BASIX is therefore able to assess the performance of the whole dwelling during the design stage before development approval is given. It considers what is happening inside the dwelling – its systems, appliances and occupancy – as well as its design and materials (Smit, 2016).

The BASIX policy framework includes a monitoring component to evaluate the performance of BASIX-compliant dwellings after occupation (NSW Department of Planning and Environment, 2019a). To support this, several studies were conducted to evaluate post-occupancy energy performance which discovered discrepancies between BASIX predicted and actual energy usage (EnergyAustralia, 2010; Landreth, et al, 2011). For example, a comparison of energy billing data from 2007-2009 found that less than 40% of sample households were able to achieve their mandatory GHG emission targets after occupation (EnergyAustralia, 2010). However, existing studies do not provide in-depth insights as to why there are discrepancies and what is causing them.

This project addresses this policy need for post-occupancy evaluation by measuring actual energy consumption and providing a comprehensive analysis of the various attributes that may influence actual energy consumption in residential dwellings.

PROJECT OVERVIEW

This project carries out post-occupancy investigations of energy performance of BASIX-compliant dwellings in NSW. It compares BASIX modelled results to real-time measured data for each type of energy use item in residential dwellings. It identifies performance issues in the building envelope, built-in appliances and household behaviour which could potentially contribute to the discrepancies between BASIX estimation and actual energy consumption (Figure 1). The project outcomes will inform the BASIX policy framework and assessment models as well as provide recommendations for sustainable building design and government education programs to promote behaviour change.

Outcomes from the project include:

- Identification of discrepancies between BASIX estimations and the actual energy consumption of residential dwellings, primarily focusing on the discrepancies in space cooling and heating;
- Analysis of why there are discrepancies and their contributing attributes across three main areas:
  - Actual space cooling and heating energy consumption after occupancy;
  - Construction and building envelope quality; and
  - Social demographics and occupant behaviour.
- Informing Government where the BASIX assessment tool can be improved, e.g. BASIX algorithms on heating, cooling and lighting, NatHERS modelling, etc; and
- Highlighting the need to improve construction and building envelope quality and to encourage sustainability awareness and behaviours.

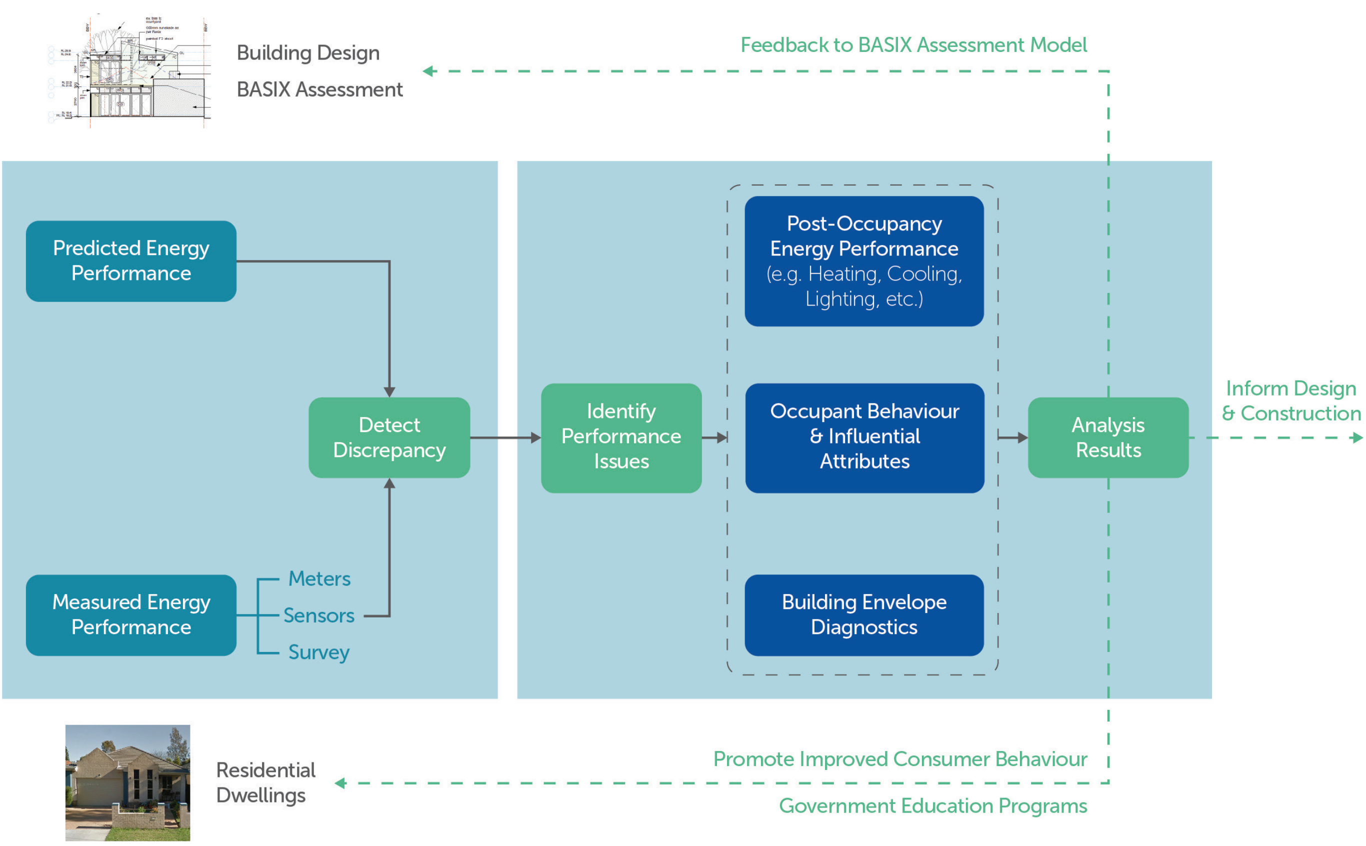


Figure 1: The RP1017 BASIX Project Framework

PROJECT SCOPE

Sample Size

The project collected samples from BASIX-compliant dwellings and pre-BASIX dwellings covering detached houses, multi-unit dwellings and common spaces in apartment buildings. This report is focused on single and multi-unit dwellings, while results from common spaces are presented in a separate report.

During stage one of the project, 286 dwelling samples across 70 suburbs in Greater Sydney and Shoalhaven areas were recruited through an online survey. These samples provided overall information on building characteristics, built-in appliances (e.g. cooling and heating systems), energy use sources, energy bills and social demographic information.

During stage two of project, 54 BASIX-compliant dwellings and 27 pre-BASIX dwellings (among the 286 dwellings) were monitored using metering devices and temperature and humidity sensors. Each type of energy use item was measured except the gas hot water systems used in some of these sample dwellings .

Among the measured 81 dwellings from stage two, 12 dwellings were further examined using in-depth building envelope diagnostic methods and 30 dwellings were interviewed for the analysis of energy use behaviour. Furthermore, 4 dwellings (with alterations) were simulated in as-built form using a NatHERS tool (AccuRate) to analyse the impact of building alterations on discrepancies.

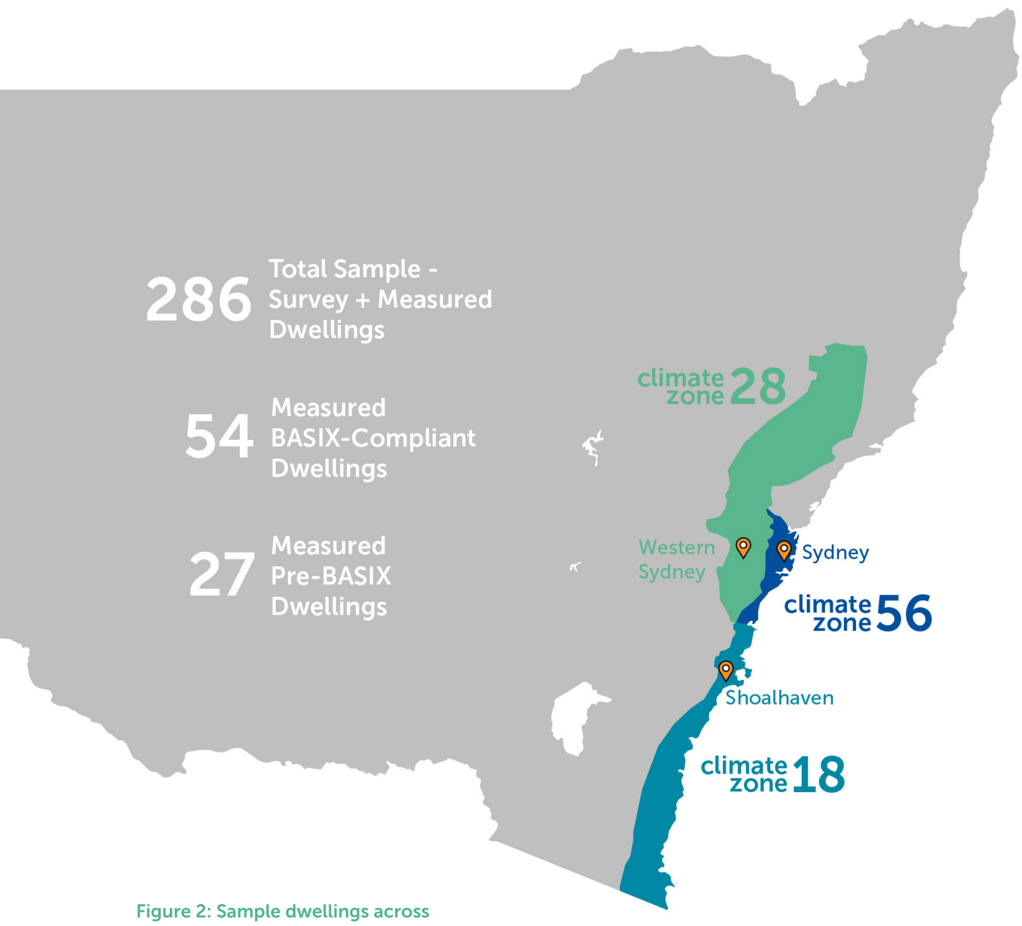


Figure 2: Sample dwellings across NatHERS's climate zones 18, 28 and 56

The sample dwellings are located within NatHERS's climate zones 18, 28 and 56 (Figure 2). Although the sample size is small due to the limitation of the project budget, the measured energy performances of these dwellings provides the necessary in-depth information that can inform the BASIX policy framework.

Measured Data

Measured data from BASIX-compliant dwellings and pre-BASIX dwellings was collected during both the warmer and cooler months between September 2015 - June 2018. High resolution data was collected including 1-minute intervals for electricity data and 15-minute intervals for temperature and humidity data.

Due to the inherent electrical wiring arrangements in dwellings, measured data of lighting energy consumption was combined with ceiling fans and bathroom ventilation, termed as 'lighting & ventilation'. However, ventilation energy from BASIX assessment is generally insignificant compared to the energy usage of the whole dwelling. It therefore does not cause significant inconsistencies when combined with lighting energy use.

Plug loads are defined as the electricity demands of plug-in appliances such as washing machines, fridges, stoves, TVs, etc. Aggregate plug loads were measured for the comparison with BASIX estimations.

Quarterly gas consumption data was collected through the homeowners or the gas provider (i.e. Jemena) with homeowners' consent. Gas consumption data for water heating and cooking was not possible to disaggregate and therefore, water heating was not measured in this project.

ANALYSIS FRAMEWORK: WHY ARE THERE DISCREPANCIES?

BASIX ESTIMATIONS OF SPACE HEATING & COOLING

The BASIX estimation of space heating and cooling is built upon the thermal comfort assessment of a dwelling and modelled heating and cooling loads estimated by NatHERS tools or by DIY methods (NSW Department of Planning and Environment, 2019b). The modelled heating and cooling loads are then adjusted by a set of calibration factors to generate estimated heating and cooling loads. The calibration factors cover the likelihood of using heating and cooling systems by occupants (based on dwelling types), correction factor in energy section, conditioned floor area and air conditioner efficiency (including coefficient of performance (COP) for heating and energy efficiency ratio (EER) for cooling) – see Figure 3.

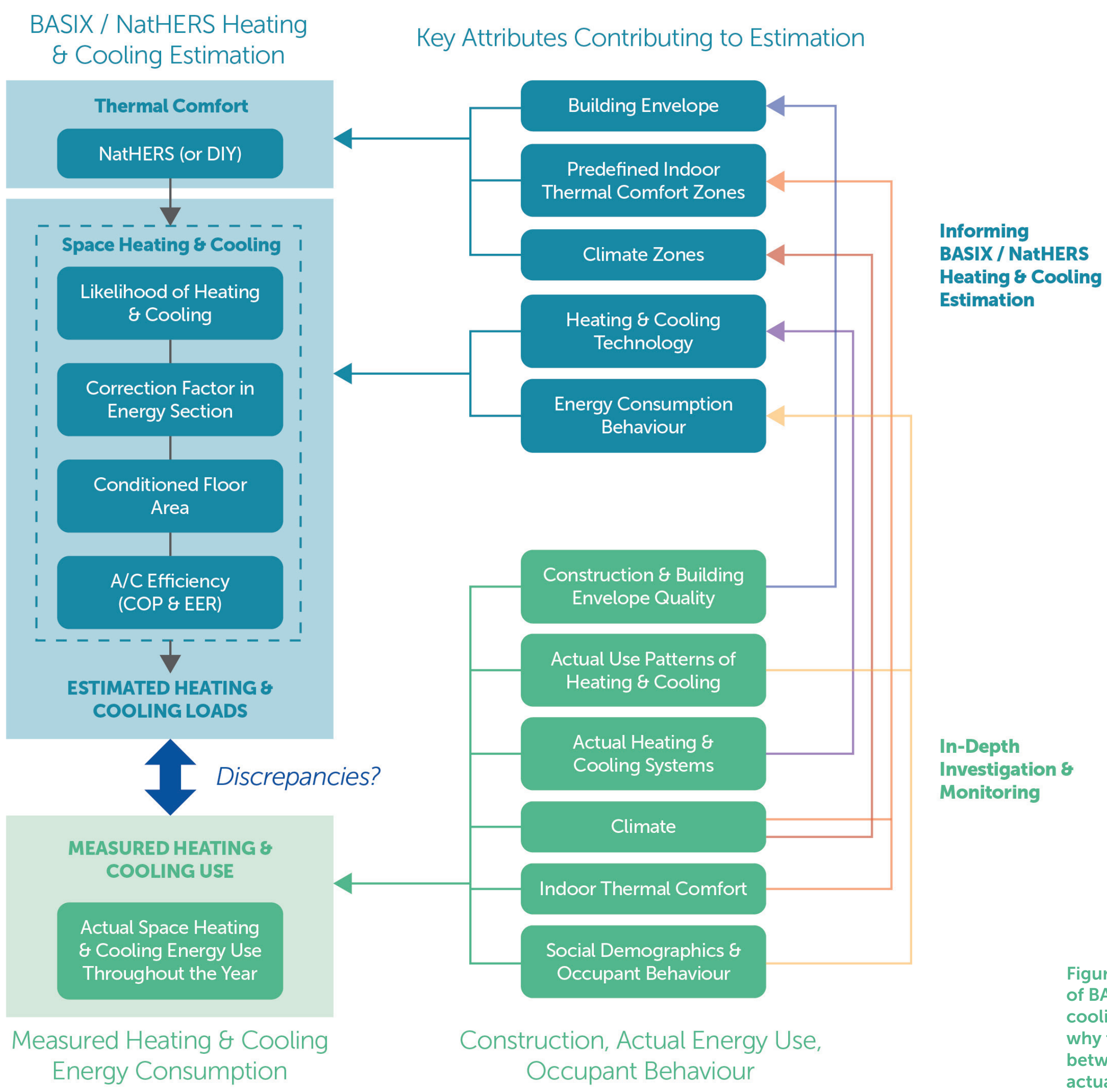


Figure 3: Analysis framework of BASIX space heating and cooling estimations and why there are discrepancies between estimated and actual energy consumption

Key attributes contributing to the assessment of thermal loads are the building envelope, predefined indoor thermal comfort zones and climate, while key attributes contributing to the calibration factors are heating and cooling technologies and energy consumption behaviour (Figure 3). These key attributes can be informed by benchmarks and assumption models drawing from surveys or research. If there are high discrepancies between estimated and actual space heating and cooling it is important to understand why and use this to inform benchmarks, assumptions models and/or energy performance targets accordingly. The in-depth investigation carried out by this project is to inform the assumption models and key attributes which contribute to the BASIX estimation of space heating and cooling.

Western Sydney Housing Development
Photo: UNSW

IN-DEPTH INVESTIGATION & MONITORING OF ACTUAL ENERGY CONSUMPTION

The project investigated and monitored actual energy consumption of dwellings through metering and senor data collection, face-to-face interviews and building envelope diagnostics using thermal imaging methods and blower door tests. High discrepancies were identified between estimated and actual space heating and cooling. Analysis of why there are high discrepancies in space heating and cooling is conducted in line with the analysis framework illustrated in Figure 3. The key findings and analysis for these discrepancies are presented in the following sections covering construction and building envelope quality, actual use patterns of space heating and cooling, actual heating and cooling systems, indoor thermal comfort, NatHERS climate zones and social demographics and occupant behaviour.

THE DISCREPANCIES

OVERALL DISCREPANCIES IN GREENHOUSE GAS EMISSIONS

Project results show that the average measured GHG emissions is 16% lower than those estimated by BASIX (Figure 4). Of the BASIX-compliant sample dwellings that were measured, 61% achieved a higher post-occupancy BASIX score than estimated, 24% achieved a lower score and 15% had no significant changes (Figure 5).

Furthermore, the average measured GHG emissions from BASIX-compliant dwellings was 7% lower than the sample pre-BASIX dwellings (Figure 6). A potential attribute contributing to this close discrepancy of measured GHG emissions between BASIX-compliant and pre-BASIX dwellings is the building construction type. It was found that a high proportion of pre-BASIX dwellings have full brick and mixed construction systems compared to BASIX-compliant dwellings.

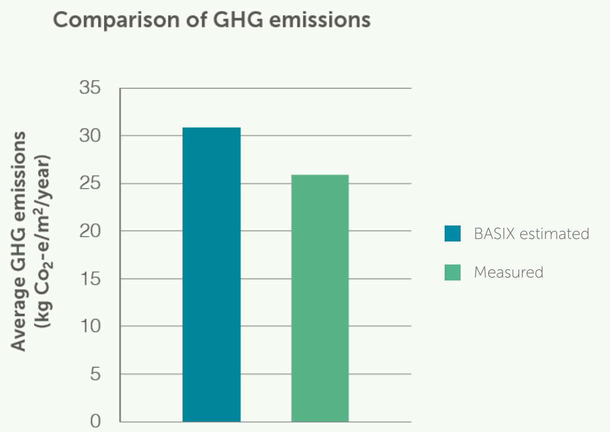


Figure 4: Comparison between BASIX estimated and actual GHG emissions

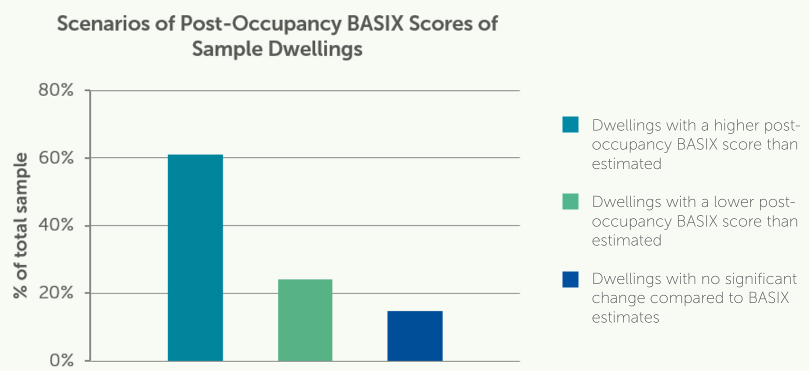


Figure 5: Scenarios of post-occupancy BASIX scores of sample dwellings in comparison with design stage estimates (n=54)

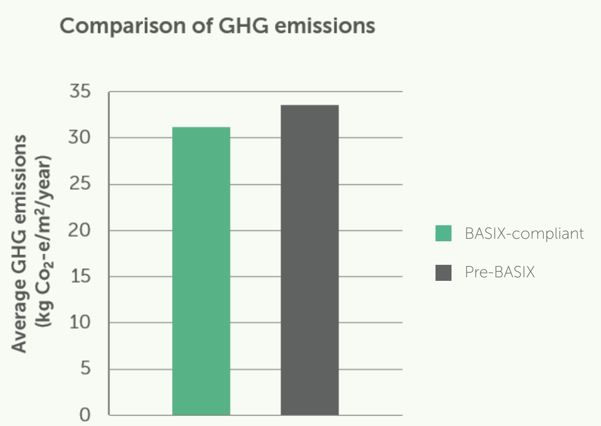


Figure 6: Comparison of GHG emissions between BASIX-compliant and Pre-BASIX dwellings

DISCREPANCIES IN THE BREAKDOWN OF ENERGY CONSUMPTION

In addition to the overall discrepancies in overall GHG emissions, breakdown scenarios of energy consumption were also investigated in this project. Although the measured and estimated energy consumption in BASIX-compliant dwellings is close at an aggregated level, a breakdown of energy use highlights significant discrepancies across four main energy use areas – cooling, heating, lighting and plug loads. It was discovered that BASIX underestimates space heating loads by 38% and space cooling loads by 53%. Results also show that BASIX overestimates lighting energy consumption by 247% and aggregated plug loads by 110% (Figure 7). Analysis of potential contributing attributes to the high discrepancies in space cooling and heating is given in the following sections.

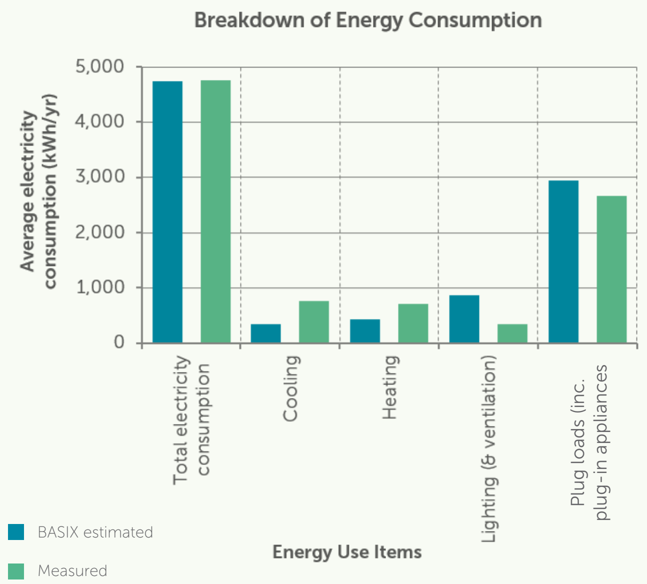


Figure 7: Discrepancies in energy consumption by breakdown of energy use items

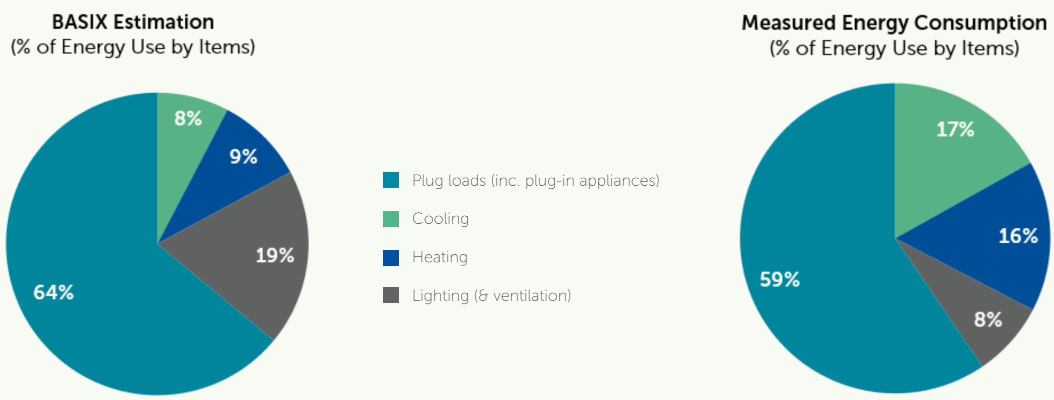


Figure 8: Proportion of energy consumption of plug loads, heating, cooling and lighting for BASIX estimations and measured energy consumption (Note: excluding energy consumption of hot water systems)

Aggregated plug loads contribute to a large portion of energy consumption of BASIX-compliant dwellings. It was found that while they contributed to 64% of the total BASIX estimated energy consumption, they contributed only 59% in the measured energy consumption of the sample BASIX-compliant dwellings (Figure 8). Plug loads are estimated based on appliance efficiencies and assumed behaviour models in BASIX. Therefore, discrepancies in aggregated plug loads could be affected by actual occupancy behaviours and their lifestyle choices (e.g. buying a second fridge or TV).

Lighting energy consumption is estimated based on the number of bedrooms which determines the number of lighting functional areas and the number of occupants. Lighting energy use estimations also consider lighting duration and the efficacy of each type of lamp. Discrepancies in lighting energy use could be affected by assumptions of these attributes and the wide variation in efficacy of LED lighting options.

DISCREPANCIES IN SPACE HEATING & COOLING

The discrepancies in space heating and cooling are the primary focus for the remainder of this report. The BASIX estimates for space heating and cooling were underestimated by 38% and 53% respectively when compared to the measured energy consumption. These figures are based on the energy consumption of air conditioning systems present in all sample dwellings with higher heating or cooling energy use compared to BASIX estimates (Figure 9).

A larger discrepancy between BASIX estimates and actual energy consumption for space cooling was discovered compared to space heating. The key attributes contributing to the discrepancies in space heating and cooling such as increased heat waves, occupant behaviour and building envelope quality will be discussed further in the following sections.

Table 1 outlines the percentage of dwellings that had significantly higher (> 25%) or lower (< 25%) measured energy usage for space heating and cooling compared to BASIX estimations. It was found that 61% of BASIX-compliant dwellings had higher energy consumption in space cooling than BASIX estimates and 50% had higher energy consumption in space heating compared to BASIX estimates.

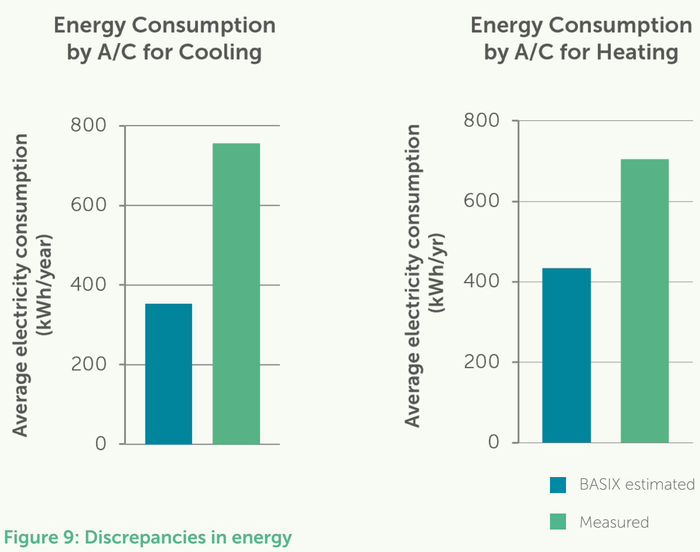


Figure 9: Discrepancies in energy consumption for space cooling and heating

Table 1: Percentage of dwellings with significantly higher or lower energy consumption for space cooling and heating compared to BASIX estimates

Measured Cooling Energy Use	% of Dwellings
Higher (> 25%) cooling energy consumption compared to BASIX estimates	61%
Lower (< 25%) cooling energy consumption compared to BASIX estimates	30%
No significant difference (within +/- 25%) compared to BASIX estimates	9%

Measured Heating Energy Use	% of Dwellings
Higher (> 25%) heating energy consumption compared to BASIX estimates	50%
Lower (< 25%) heating energy consumption compared to BASIX estimates	44%
No significant difference (within +/- 25%) compared to BASIX estimates	6%

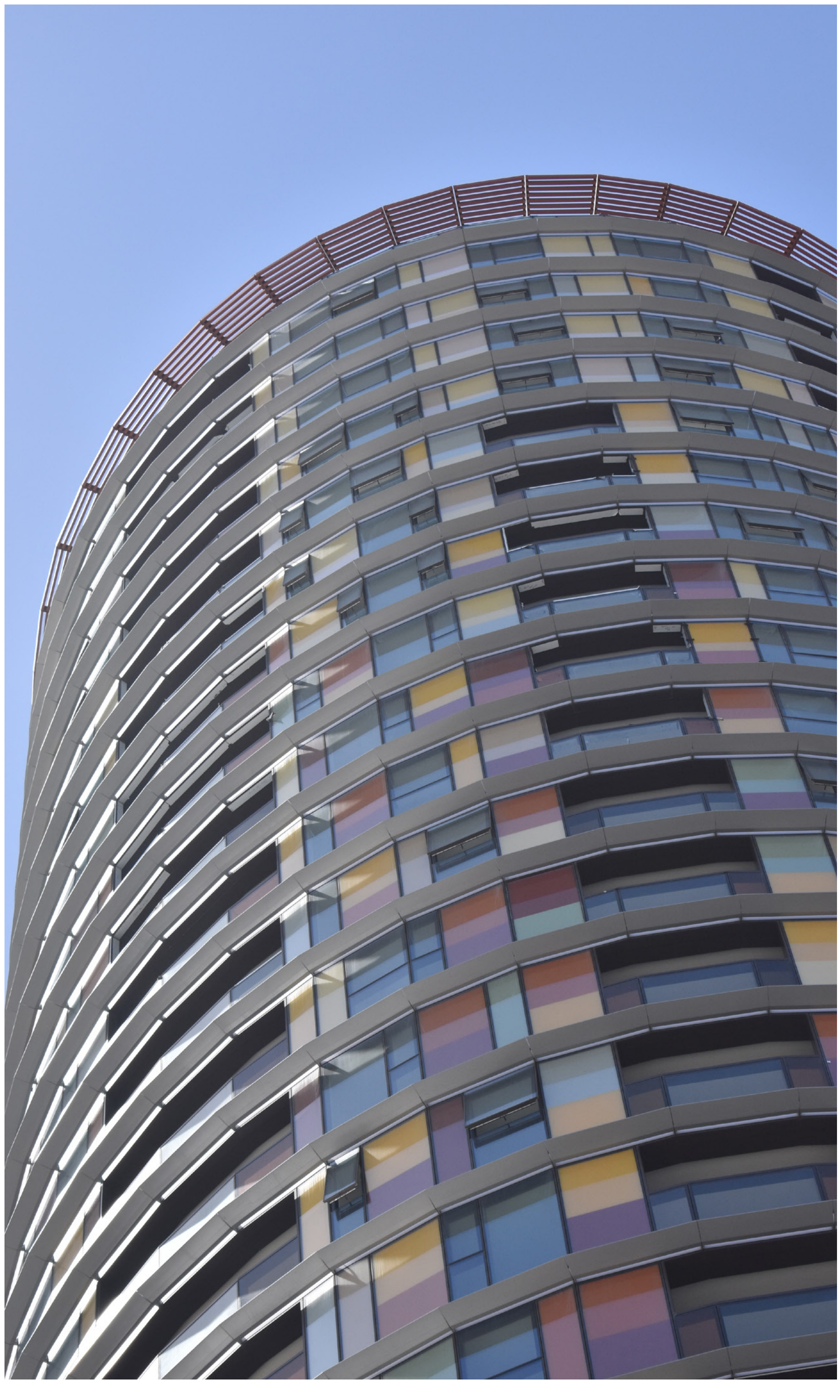
Measured Heating & Cooling Energy Use	% of Dwellings
Higher (> 25%) heating & cooling energy consumption compared to BASIX estimates	39%
Lower (< 25%) heating & cooling energy consumption compared to BASIX estimates	22%

WHAT CAUSES HIGH ENERGY CONSUMPTION FOR SPACE HEATING & COOLING?

This section identifies the key attributes contributing to higher energy consumption for space heating and cooling for BASIX-compliant dwellings. The following analysis of contributing attributes is primarily focused on those dwellings that were identified as having high energy use for heating or cooling (i.e. > 25% of BASIX estimates). This section is structured in line with the analysis framework previously illustrated in Figure 3 and key findings are presented across six key areas.

1. CONSTRUCTION & BUILDING ENVELOPE QUALITY

It was found that the construction systems and building envelope quality of BASIX-compliant dwellings contributed to high energy consumption for space cooling and heating compared to BASIX estimates. Approximately 71% of BASIX-compliant dwellings with higher heating or cooling energy were brick-veneer dwellings and approximately 23% were built using external masonry with an internal plasterboard lining (Figure 10).



Multi-Unit Dwelling in Eastern Sydney
Photo: UNSW

The BASIX calculation engine adjusts the modelled cooling and heating loads from the NatHERS tools based on assumed conditioned floor area, dwelling types, occupancy and actual use behaviour for space cooling or heating by occupants to deal with the actual thermal loads (Figure 3). To inform BASIX calculation engine, the high energy consuming dwellings for space heating or cooling were explored through various dwellings types (Figure 11). It was discovered that a large proportion of single-storey dwellings had high energy consumption for space heating or cooling with significant discrepancies to BASIX estimates (Figure 12). Therefore, it is suggested that the calibration factors associated with conditioned floor area and occupant behaviour for single-storey dwellings may need to be reviewed and improved.

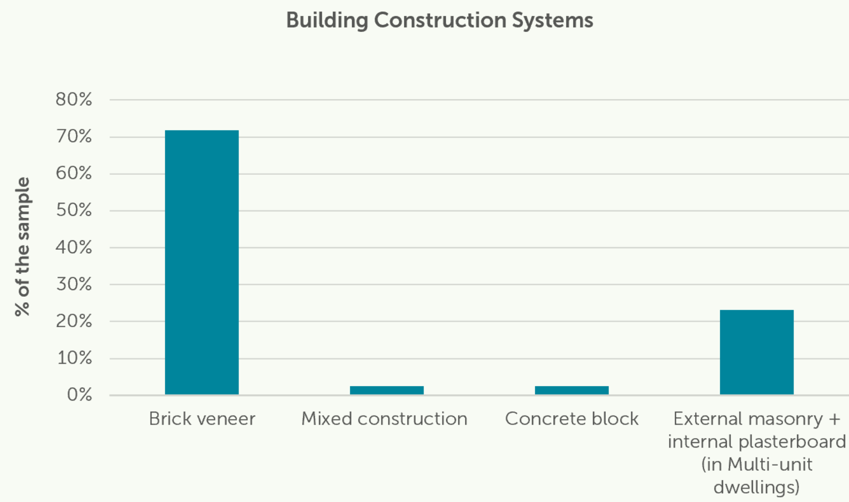


Figure 10: Main building construction system of sample dwellings with higher space heating or cooling energy consumption (n=39)

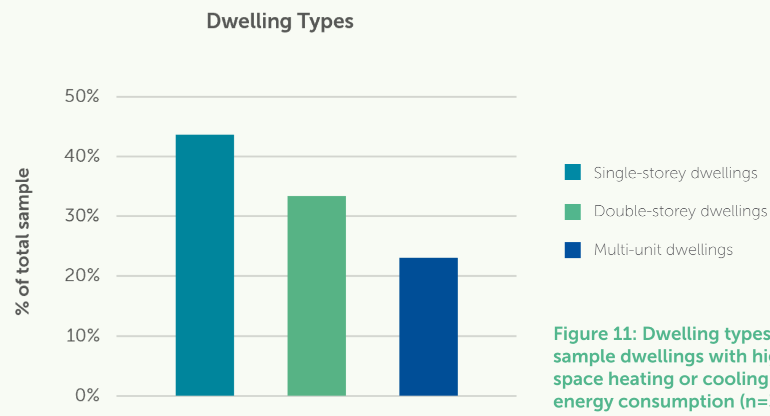


Figure 11: Dwelling types for sample dwellings with higher space heating or cooling energy consumption (n=39)

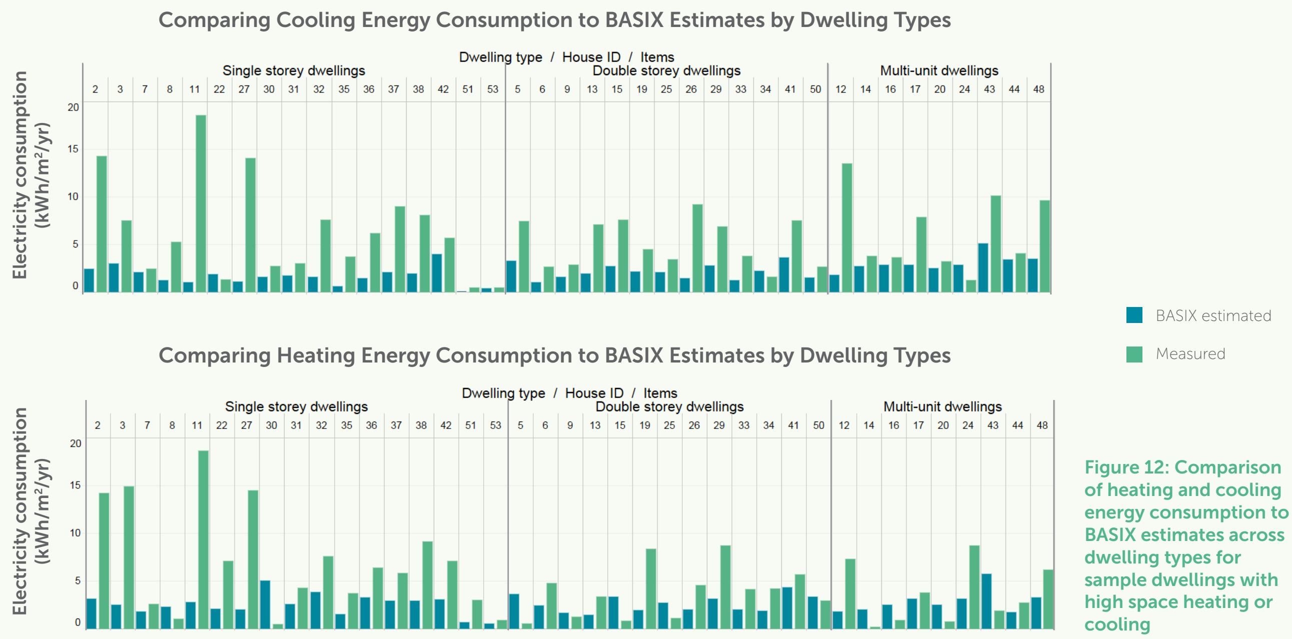


Figure 12: Comparison of heating and cooling energy consumption to BASIX estimates across dwelling types for sample dwellings with high space heating or cooling

Figure 13: Displaced insulation in BASIX-compliant dwellings with high space heating and cooling energy consumption (Munsami, 2019)

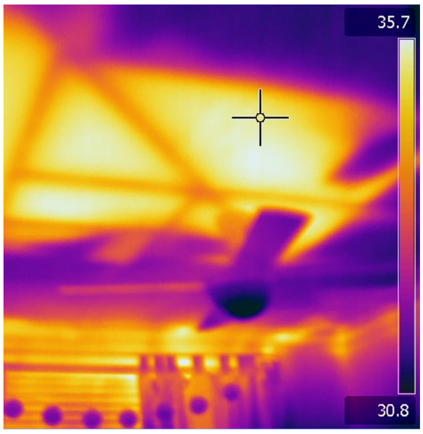


Figure 14: Thermal bridges in the ceiling of BASIX-compliant dwellings with high space heating and cooling energy consumption (Munsami, 2019)

Figure 15: Blower door tests for BASIX-compliant dwellings with high space heating and cooling energy consumption (Munsami, 2019)

BASIX and NatHERS estimates require insulation values for walls, floors, ceilings and roofs. However, several issues with the building envelope construction quality of BASIX-compliant dwellings with high heating or cooling use were discovered. Some of these issues that contributed to higher space heating or cooling energy consumption included displaced insulation, high thermal bridges and air leakages. For example, displaced ceiling insulation in BASIX-compliant dwellings (Figure 13) caused thermal bridges leading to temperatures exceeding the average outdoor temperature of 32°C (Figure 14) which contributed to increased occupant discomfort and energy consumption for space cooling.

Air leakage and infiltration within the building envelope was another problem in these dwellings. Pressure tests using blower doors (Figure 15) were conducted during an in-depth building diagnostic investigation. Results indicated that the pressure in the ceilings of some of these dwellings was almost same as outside and air gaps were found between conditioned and unconditioned zones caused by extractor fans. Other leakages were discovered within air conditioning ducts, ceiling light fixtures and around windows and doors. It was found that average infiltration rates from the BASIX-compliant dwellings with high cooling or heating energy use was higher than the average infiltration rate from international standards (Figure 16).

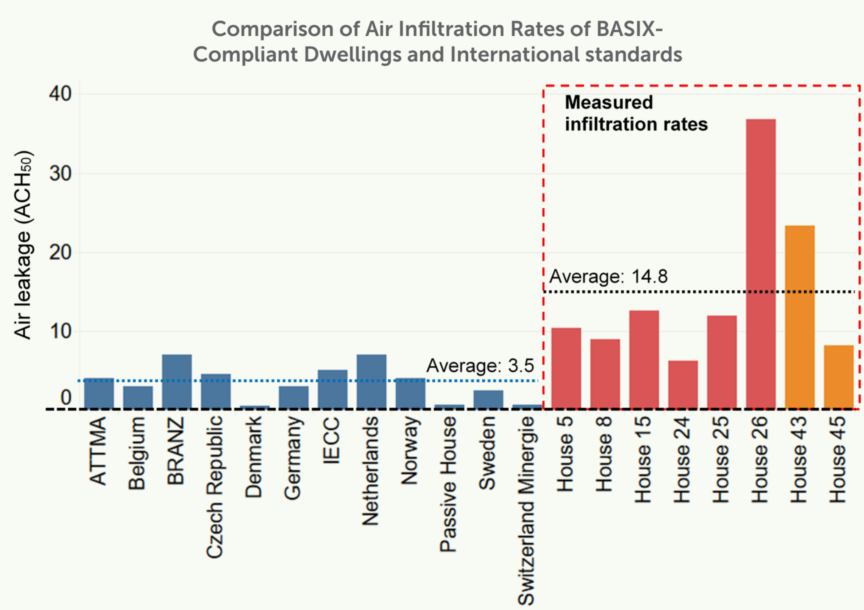


Figure 16: Comparison of air infiltration rates of BASIX-compliant dwellings and international standards (Munsami, 2019)

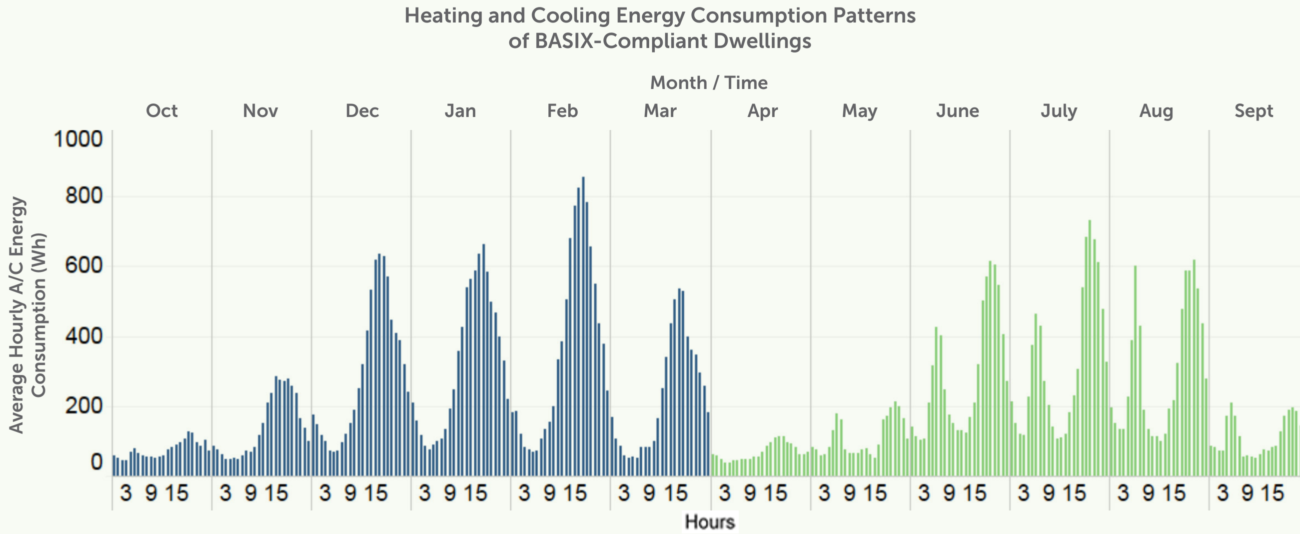


Figure 17: Actual space heating and cooling patterns of higher energy consuming BASIX-compliant dwellings across warm and cool seasons

2. ACTUAL ENERGY USE PATTERNS OF HEATING & COOLING

The BASIX and NatHERS thermal loads estimates integrate an assumption model of occupant behaviour. Therefore, it is crucial that this assumed occupant behaviour is informed by actual energy use patterns. This project investigated the actual heating and cooling energy use patterns for BASIX-compliant dwellings with high energy consumption for space heating or cooling.

The results highlight that A/C systems in these dwellings were frequently used for cooling in four of the warmer months and for heating in three of the cooler months (Figure 17). In particular, high cooling energy consumption was recorded in summer in the Greater Sydney area and this could be due to the changing climate and the increased frequency of extreme heat days. Daily energy use patterns in these dwellings show that higher energy for space cooling was consumed during the late afternoon into the night during the warmer months and higher energy use for space heating was consumed during the early morning as well as late afternoon into the night during the cooler months (Figure 18). The actual energy use behaviour for space cooling and heating was greatly influenced by the climate, indoor thermal comfort, lifestyle choices, attitudes, etc. Further analysis on the climate zones where these dwellings are located, their social demographics and occupant behaviours is given in the following sections.

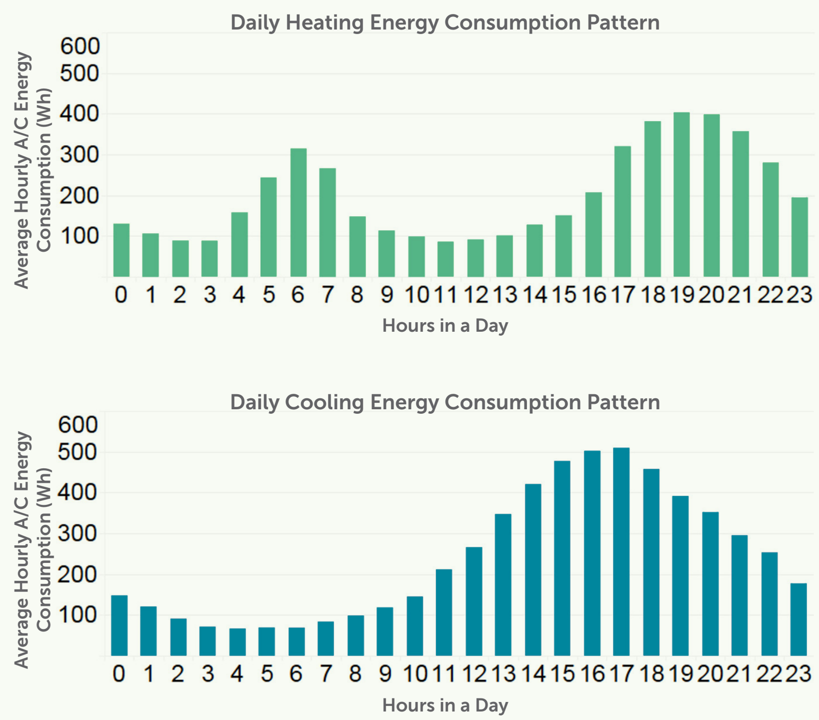


Figure 18: Daily space heating and cooling patterns of higher energy consuming BASIX-compliant dwellings across warm and cool seasons

3. CLIMATE

The thermal loads estimated by the NatHERS tools are influenced by the climate zones in which the dwellings are located. It was found that a large proportion of dwellings with high space heating or cooling energy consumption were located in climate zones 28 (Western Sydney) and 56 (Eastern Sydney) and dwellings in these zones had high discrepancies in both heating and cooling (Figure 23). In particular, large discrepancies in space cooling were identified for dwellings in Western Sydney and this can be attributed to the increased frequency of extreme heat days in those areas.

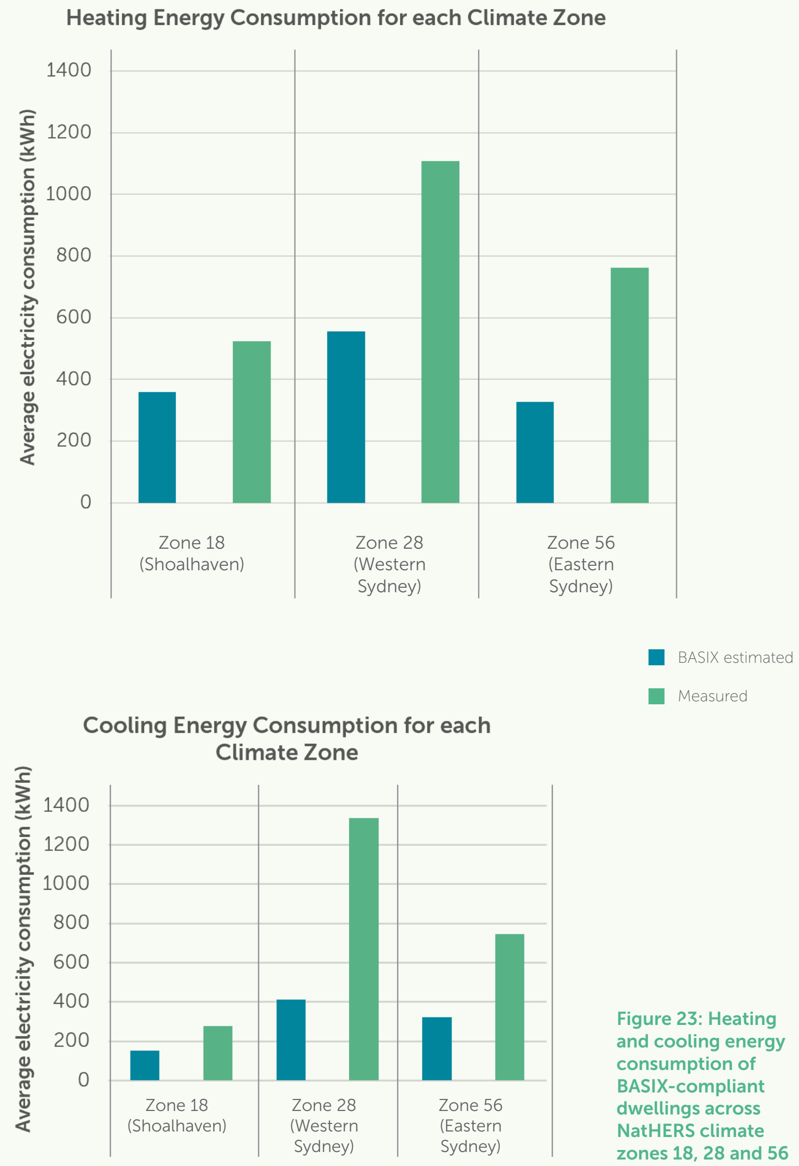


Figure 23: Heating and cooling energy consumption of BASIX-compliant dwellings across NatHERS climate zones 18, 28 and 56

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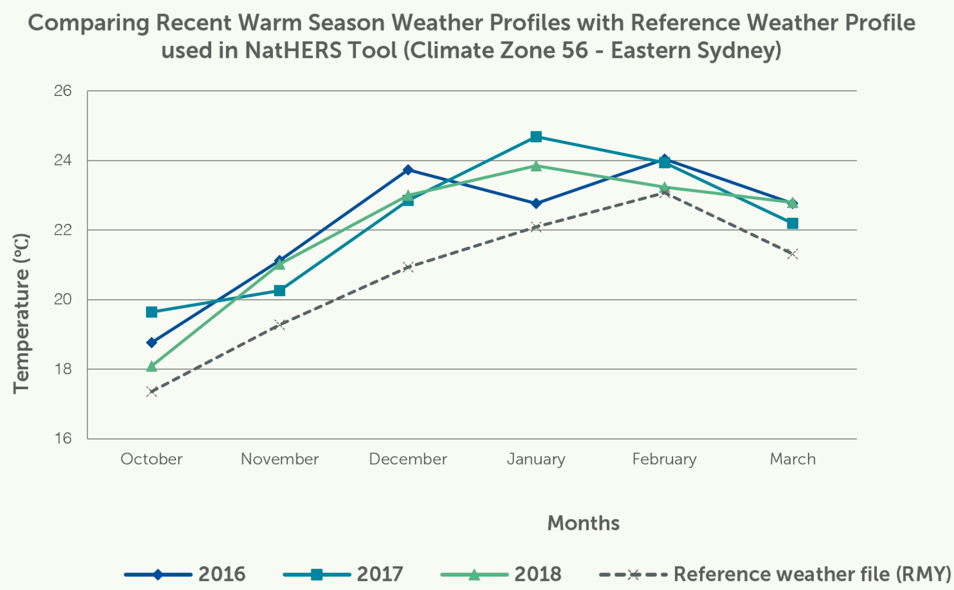


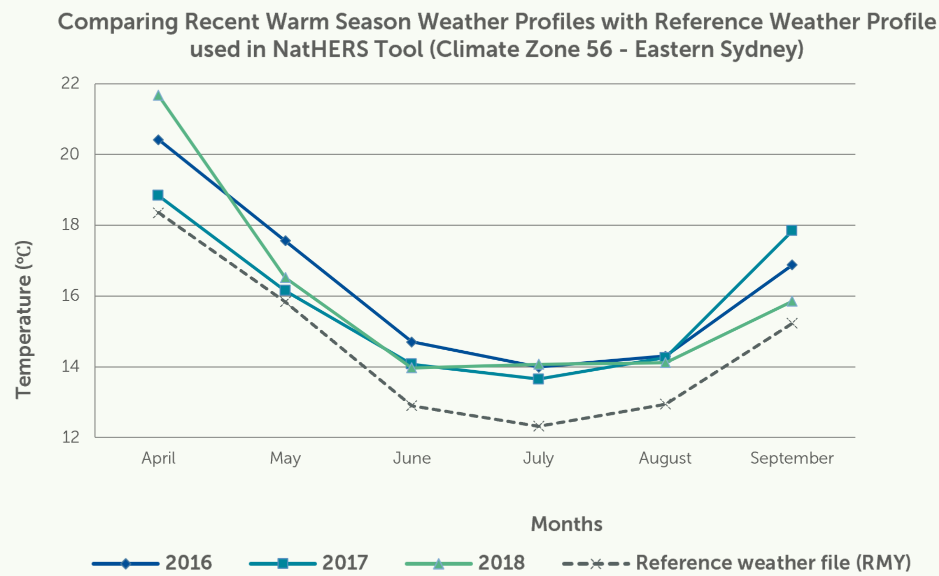


Figure 24: Comparison of recent weather profiles with the reference weather file used in the NatHERS tool for climate zone 56 (Eastern Sydney)

Discrepancies were identified between reference weather files used in the NatHERS tools and the actual weather profiles in recent years, which contributed to increased energy use for space cooling during the warmer months. For example, a comparison of recent weather profiles from 2016 – 2018 for climate zone 56 (Eastern Sydney) with this NatHERS reference weather file highlights an annual average temperature rise of 1.5K. The highest anomaly observed in the warmer months was in December when the average temperature was 2.3K higher than the reference weather file.

These discrepancies suggest that the reference weather files utilised by the NatHERS tools need updating.

4. INDOOR THERMAL COMFORT

The NatHERS tool has predefined indoor thermal comfort zones for the warmer and cooler months to model the space heating and cooling loads. Therefore, this project investigated the actual indoor thermal comfort of occupants across three NatHERS climate zones: 18 (Shoalhaven), 28 (Western Sydney) and 56 (Eastern Sydney). It was found that the actual indoor thermal comfort achieved through A/C systems varied during the warmer months across these three climate zones and was similar during the cooler months.

Average indoor temperatures measured in climate zones 28 and 56 for a period of 12 days during the warmer months were approximately 26°C and approximately 24°C for climate zone 18 (Figure 21). These figures illustrate that for all three climate zones, air conditioning for space cooling is required to maintain indoor thermal comfort when outdoor temperatures rise beyond approximately 25°C. However, the number of days exceeding 30°C in climate zone 28 (Western Sydney) was higher than climate zones 56 and 18 during the monitoring period.

Hourly Cooling Electricity and Indoor Temperature for Zone 28 (Western Sydney)

Hourly Cooling Electricity and Indoor Temperature for Zone 56 (Eastern Sydney)

Hourly Cooling Electricity and Indoor Temperature for Zone 18 (Shoalhaven)

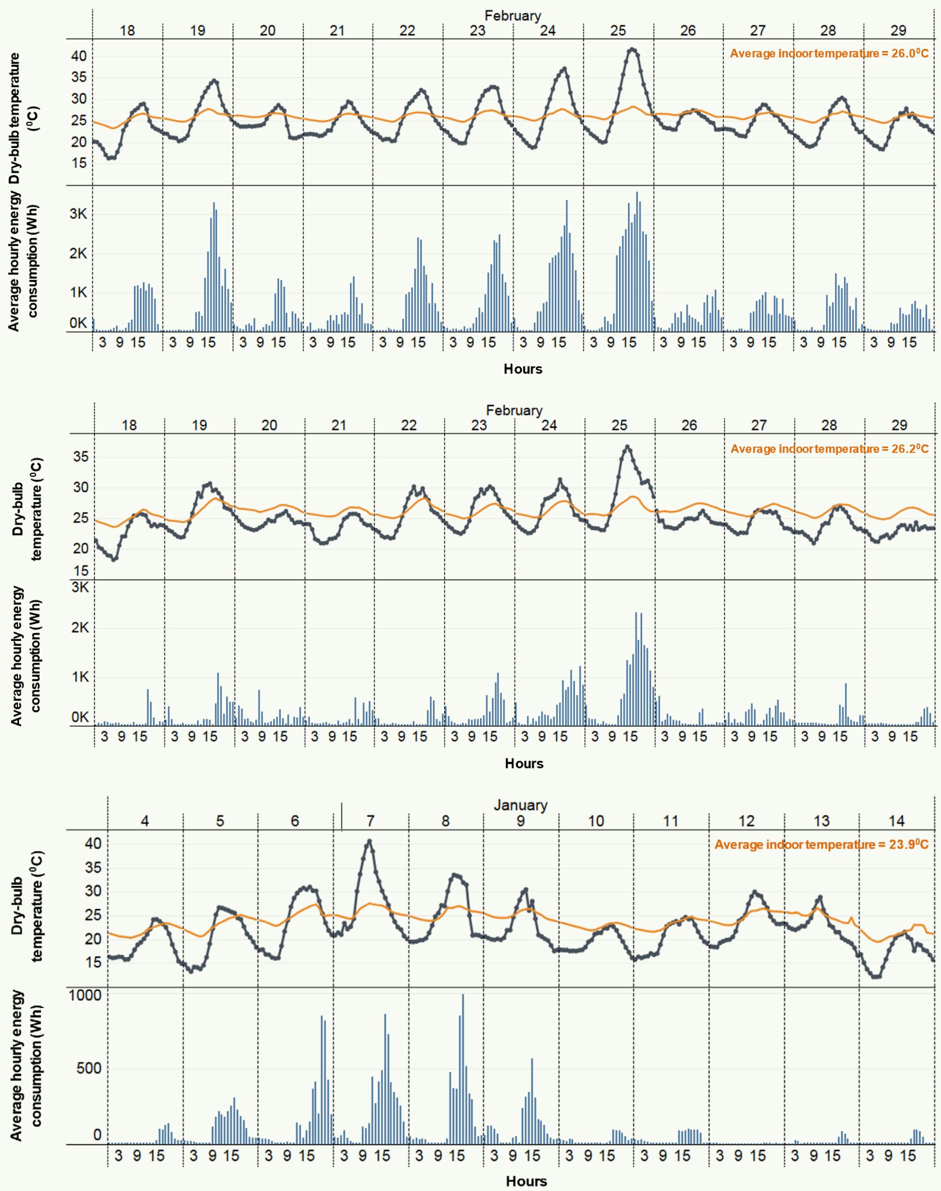
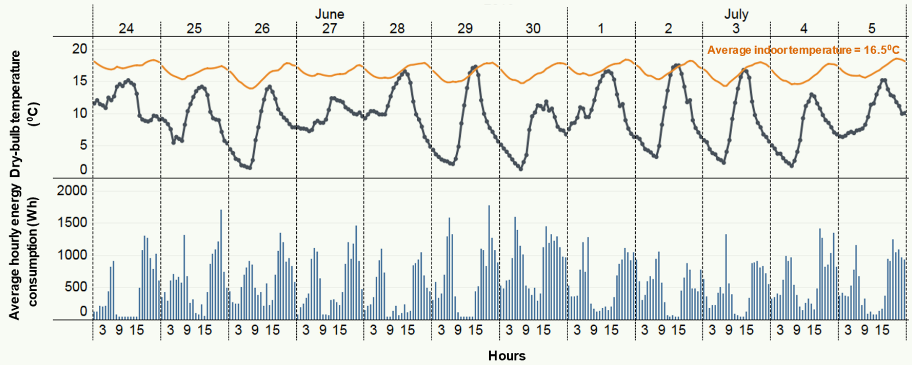
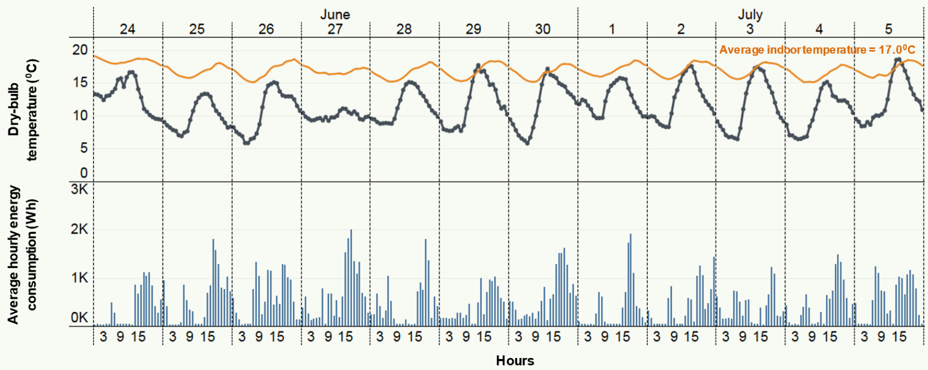


Figure 21: Average indoor temperatures and hourly cooling energy consumption across NatHERS climate zones 18,28 and 56 in BASIX-compliant dwellings

Hourly Heating Electricity and Indoor Temperature for Zone 28 (Western Sydney)



Hourly Heating Electricity and Indoor Temperature for Zone 56 (Eastern Sydney)



Hourly Heating Electricity and Indoor Temperature for Zone 18 (Shoalhaven)

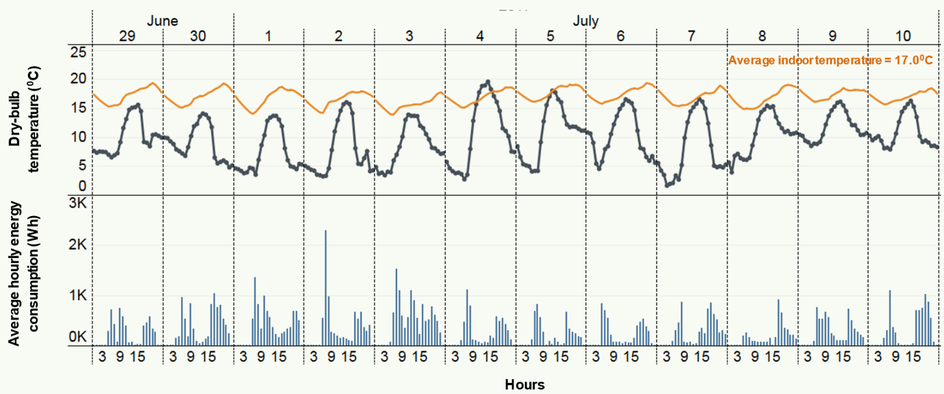


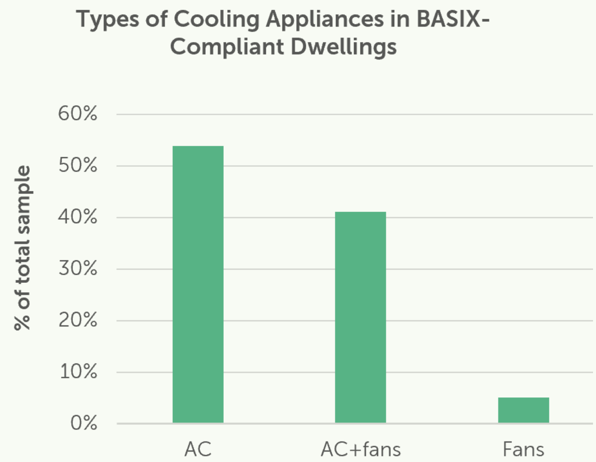
Figure 22: Average indoor temperatures and hourly heating energy consumption across NatHERS climate zones 18,28 and 56 in BASIX-compliant dwellings

Average indoor temperatures measured for a period of 12 days during the cooler months were approximately 17°C across all climate zones (Figure 22).
There were many interrelated attributes identified by this project that could contribute to high space heating and cooling in BASIX-compliant dwellings. Some of these include the changing climate and increased extreme heat days, different thermal perceptions and preferences of occupants and their lifestyle choices and attitudes. These attributes were found to influence the actual use of air conditioning for both space heating and cooling and the set-points they maintained during the warmer and cooler months.

5. ACTUAL HEATING & COOLING SYSTEMS

BASIX estimations of space heating and cooling energy consider the efficiency of heating and cooling systems in terms of coefficient of performance (COP) and energy efficiency ratio (EER) respectively. This project therefore investigated the actual types of heating and cooling appliances within the BASIX-compliant dwellings with high energy consumption for heating or cooling and compared this to pre-BASIX dwellings.

A high proportion of BASIX-compliant dwellings with high cooling or heating energy use were found to use ducted systems for space cooling and heating (Figure 19). However, these ducted air conditioning systems were found to have many challenges related to the zoning configurations (e.g. unused conditioned rooms) and operation (e.g. lack of occupant knowledge to operate efficiently). In contrast to the BASIX-compliant dwellings, a high proportion of pre-BASIX dwellings were found to use electric or gas heaters for space heating (Figure 20). This allowed for greater level of occupant control and flexibility to heat their immediate surroundings instead of the whole dwelling.



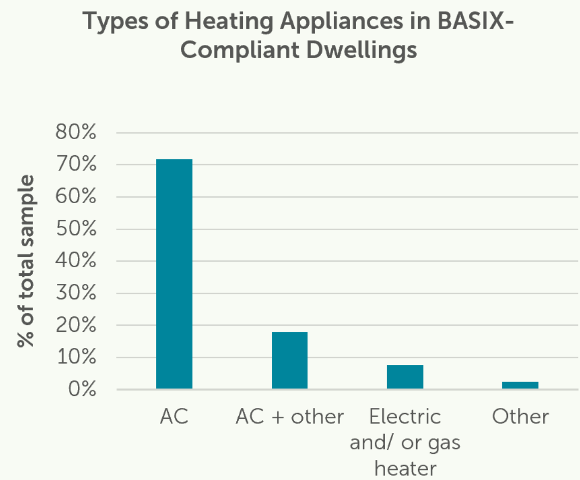


Figure 19: Actual heating and cooling systems for BASIX-compliant dwellings with high space heating or cooling energy consumption (n=39)

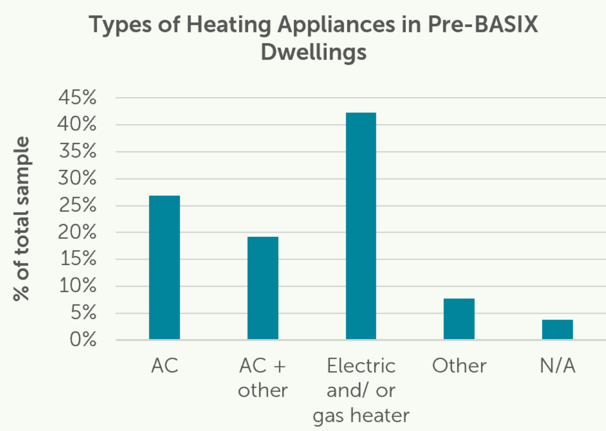


Figure 20: Actual heating systems for pre-BASIX dwellings (n=27)

Example of occupant behaviour to achieve indoor thermal comfort

6. SOCIAL DEMOGRAPHICS & OCCUPANT BEHAVIOUR

Social demographics and occupant lifestyle choices, attitudes, knowledge and thermal perceptions and preferences all influence the actual energy consumption for space heating and cooling in BASIX-compliant dwellings. For example, the majority of dwellings with high energy consumption for space heating or cooling did not have children but some of the dwellings that did would turn on the air conditioner throughout the night as they were concerned about their child's comfort and ability to sleep. Of these dwellings, most also had home offices which supports the growing trend of occupants working remotely and spending more time inside their dwelling during the day (Figure 25).

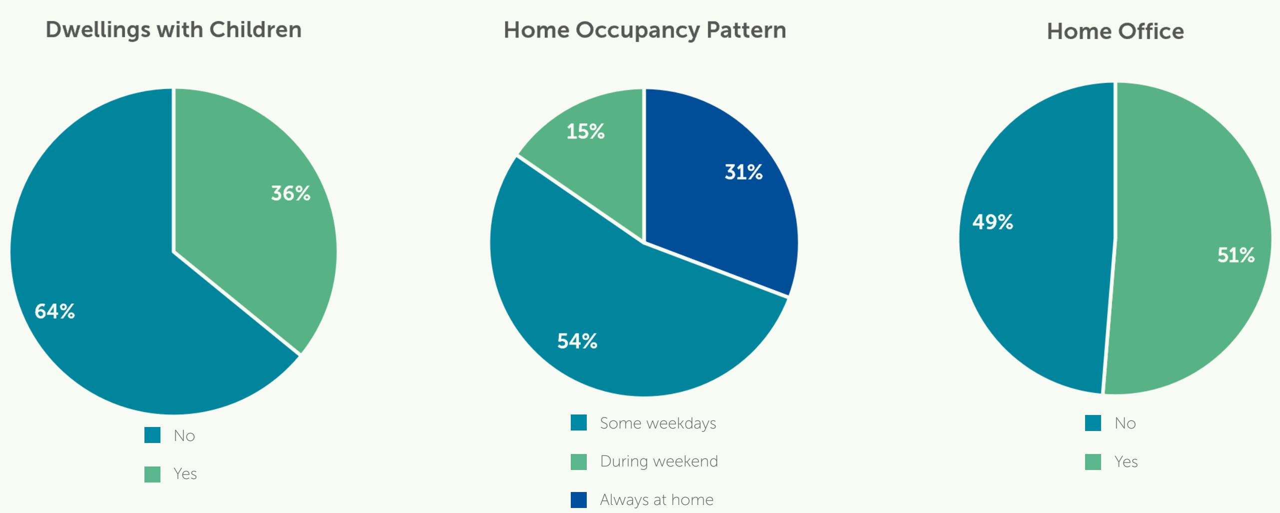


Figure 25: Social demographics of the BASIX-compliant dwellings with high heating or cooling energy consumption

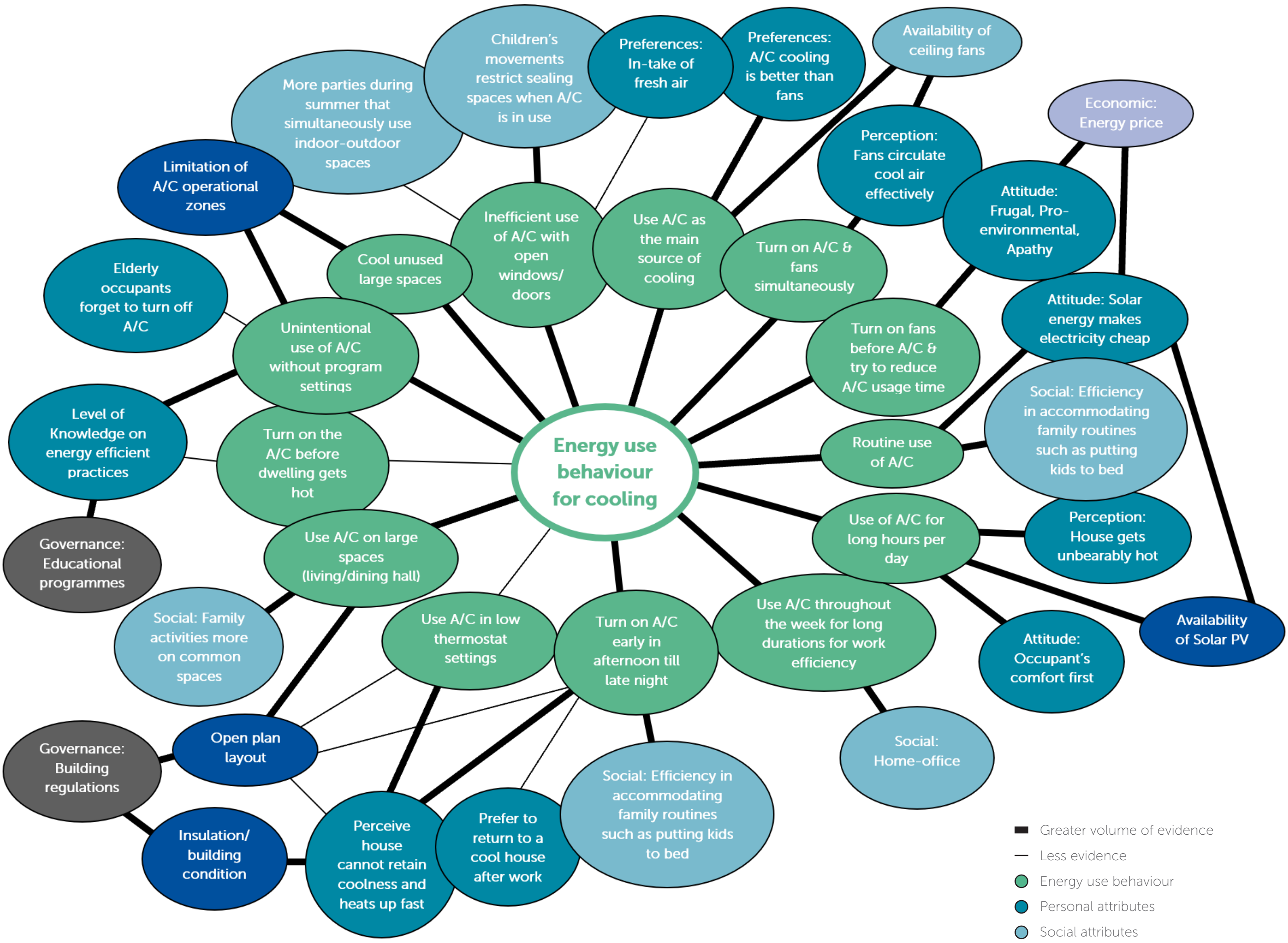


Figure 26: Examples of occupant behaviour and influential attributes discovered in BASIX-compliant dwellings with higher cooling energy use (Samaratunga, 2019)

Examples of actual occupant behaviour in BASIX-compliant dwellings with high cooling energy use are illustrated in Figure 26. The inner layer outlines occupant behaviour for space cooling and the peripheral layer shows interrelated influential attributes. The use of air conditioners in large spaces of the dwelling (e.g. living space), without program settings, with the windows opened, or for a long time throughout the warmer months was discovered in common in BASIX-compliant dwellings with high space cooling energy use compared to BASIX estimates. The use of air conditioners with low thermostat settings (e.g. 16-18°C) and occupants turning on the air conditioner before the dwelling gets warm was also evident in those dwellings with high cooling energy use.

The interrelated influential attributes to the above occupant behaviours include an occupant's perception of the poor indoor thermal environment, occupant preferences such as 'entering a cool home during the warmer months', children moving constantly between indoor and outdoor spaces, as well as environmental and economic factors. Other influential attributes discovered in these dwellings include the open plan layout of the dwelling, the zone control of ducted air conditioning systems, an occupant's knowledge and use of solar energy, etc.

The occupant behaviour and key influential attributes which were common in BASIX-compliant dwellings with high heating or cooling energy use are presented in four categories in Table 2.

THERMAL PERCEPTIONS & PREFERENCES

- Residents perceive the house to be *"unbearably hot and stuffy"* in warmer months due to high exposure to the sun, hence the need for mechanical cooling.
- Residents perceive the house to be cold in the cooler months due to dwelling features such as concrete, floor tiles, smaller windows, air gaps in doors, etc.
- Elderly residents are more sensitive to the heat and cold and will heavily rely on A/C and sometimes forget to turn it off.
- Most residents prefer A/C over fans as humidity is perceived as the main contributor to thermal discomfort in the warmer months. *"A/C solves all problems."*
- Residents prefer fresh air and will leave windows slightly open while the A/C is in use.
- Residents believe that air distribution from the A/C is uneven as one space becomes too cold while another space is warm.
- Location of A/C vents has an impact on the use of heating and cooling use (e.g. if vents blow directly on residents they will use it less).

LIFESTYLE CHOICES

- Residents give priority to their personal comfort and convenience at the expense of using more energy and would not want to give up their lifestyle.
- Residents will use heating and cooling systems for their pets when they are not home.
- A/C is sometimes left on throughout the night to cool bedrooms for concerns about children's comfort and ability to sleep. Multiple heaters are also used at night time to heat up bedrooms during the cooler months.
- Residents will turn on the A/C on predicted warm days to cool their dwellings before it gets too hot and do not use A/C intermittently.
- Residents prefer building aesthetics above consideration for passive design strategies (e.g. decorative door without security screen becomes a barrier for cross ventilation).
- Residents with solar panels will use more energy during the day with the expectation that it would be picked up largely by the energy generated.

KNOWLEDGE OF BUILDING SYSTEM OPERATIONS & PASSIVE COOLING/ HEATING STRATEGIES

- Residents struggle to understand and control their A/C systems and will leave all zones on instead of shutting doors between operating zones.
- Residents find it hard to avoid unused conditioned spaces due to the zoning arrangement (e.g. four bedrooms within one zone but only two bedrooms are in use).
- Residents lack knowledge on the efficient use of their A/C systems (e.g. thermostat setting, timers) and assume it is a faulty device.
- Residents are not aware of the importance of closing openings during warm days and will complain about it being too hot. Some residents are aware of this but fail to keep them closed due to family activities, e.g. kids frequently opening doors to go inside/outside.
- Residents expect professional support for increasing their awareness and knowledge on passive cooling strategies.

EXTERNAL INFLUENCES & LIMITATIONS (PHYSICAL, ECONOMIC & GOVERNANCE)

- Residents feel they cannot open their windows due to privacy concerns of the compact planning of their neighbourhood.
- Residents believe that neighbouring structures block the sunlight coming into their living spaces.
- Residents find that material selections are limited based on builder's preferences/flexibility or financial reasons and that these are drawbacks to the improved thermal performance of their dwelling.
- Residents find it very difficult to organise and coordinate retrofitting work with industry professionals. *"Talking to the guys who have done the original installation was hopeless."*
- Residents are reluctant to retrofit their dwellings due to lack of Government incentives and endorsements

Table 2: Key occupant behaviours that contributed to higher heating and cooling energy consumption (Samaratunga, 2019)

RECOMMENDATIONS

The key findings from the analysis of this project outlined above can inform the future improvement of the NatHERS tools and the BASIX calculation engine. Most importantly, this project has highlighted the need to update the benchmarks utilised by both NatHERS and BASIX assessment models. While the outcomes of this project do not provide sufficient data to update these benchmarks, they have highlighted the key attributes influencing actual space heating and cooling that would need to be considered as part of a future longitudinal study. This project has also highlighted the need to improve residential construction and building envelope quality and the need to encourage sustainability awareness and behaviours. The key recommendations from this project addressing these needs are outlined in Table 3.

Table 3: Key recommendations

Improving benchmarks	**NatHERS Tools**	Improve the space cooling estimations by considering the increasing frequency of extreme heat events and overall rise in ambient temperature in relevant climate zones.
		Improve the accuracy of thermal load estimations by examining occupant behaviour for space heating and cooling, such as the actual set points for air conditioning systems.
	BASIX Calculation Engine	Improve the calibration factors applied to modelled heating and cooling loads estimated by NatHERS tools to account for actual occupant behaviour associated with space heating and cooling.
		Improve the lighting energy estimations by examining the wide range of efficacy of various types of lamps currently available in the market, in particular LED lighting options.
Improving construction quality control		Improve construction quality control measures within the BASIX approval process before occupation certificate is issued to address air infiltration rates and insulation.
Encouraging sustainability awareness and behaviours		Increase awareness of air conditioning system operations through Government led initiatives and programs.
		Energy efficiency disclosure systems to incentivise occupants to design, operate and retrofit their dwellings for improved indoor thermal comfort and reduced energy consumption.

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