RACE for 2030

Scenarios for Future Living

INSIGHTS FROM AN AUSTRALIAN ENERGY LIVING LAB:

UNDERSTANDING HOUSEHOLD ENERGY USE IN TRANSITION

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Insights from an Australian Living Lab: Understanding household energy use in transition

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Project team

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- Monash University
- University of New South Wales
- University of Technology Sydney
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Industry partners

- Ausgrid
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- Red Energy
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What is RACE for 2030?

RACE for 2030 CRC is a 10-year cooperative research program with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future. https://www.racefor2030.com.au

CONTENTS

Cover image by: Stephen Snow

GLOSSARY OF TERMS

CER (Consumer Energy Resources)
Energy technologies located at homes that enable households to generate, store, or manage their own energy, such as rooftop solar systems, home batteries and electric vehicles.

Cheaper Home Batteries Program
An Australian Government initiative that provides financial support to reduce the upfront cost of eligible home battery systems and encourage greater battery adoption.

Demand Flexibility
The ability to alter the timing or amount of electricity use to better match energy supply, reduce pressure on the electricity network, or take advantage of lower-cost energy.

Electrification
The process of replacing technologies powered by fossil fuels, such as gas appliances and petrol or diesel vehicles with technologies powered by electricity.

EV (Electric Vehicle)
A vehicle that uses electricity for propulsion, including battery-electric vehicles and plug-in hybrid electric vehicles.

Kilowatt (kW)
A measure of power, indicating the rate at which electricity is used or generated at a point in time.

Kilowatt-hour (kWh)
A measure of energy, indicating the total amount of electricity consumed or generated over a period of time.

Living Lab
A collaborative research approach that studies how householders use technologies, services, and practices in everyday life. This enables researchers to observe experiences and behavioural changes under real-world conditions.

Photovoltaics (PV) / Rooftop Solar
Technology that converts sunlight directly into electricity using solar cells installed on rooftops or other structures.

Reverse cycle refrigerated air conditoining systems (AC)
Refrigerated air conditioning.

Smart Appliances
Household devices that use digital technologies, automation, or internet connectivity to monitor, control, or optimise their operation.

Thermal Comfort
The extent to which a person feels comfortable with the temperature and environmental conditions of an indoor space. Thermal comfort may be influenced by temperature, humidity, airflow, building characteristics, and heating or cooling systems.

Vehicle-to-Grid
A technology that enables electricity stored in an electric vehicle battery to be exported back to the electricity network when required.

Vehicle-to-Home
A technology that enables an electric vehicle battery to supply electricity for use within a home.

Virtual Power Plant (VPP)
A coordinated network of distributed energy resources such as solar panels, batteries, and electric vehicles that can be managed collectively to provide services to the electricity system.

Working from Home (WFH)
A work arrangement in which paid employment activities are carried out from home rather than from a conventional workplace.

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EXECUTIVE SUMMARY

This report presents findings from the first phase of the Living Lab study within Work Package 7 (WP7) of the RACE2030 Scenarios for Future Living project. It presents insights from a 35-household Living Lab, where longitudinal engagement enabled a nuanced understanding of how households use energy, how decisions are made, and how practices evolve over time. The study employs a mixed-methods approach that combines high-resolution energy and environmental monitoring with householder engagement, including surveys and interviews, informed by WP1. This design allows us to examine how energy is used, and how and why practices shift over time, capturing the dynamic interactions between technologies, household routines, and contextual changes.

The findings in the report reflect broader social science literature, which demonstrates that household energy behaviour is not driven by simple economic logic, but rather a complex interplay of social, technical, contextual, and familial/care factors. Capturing these dynamics is critical for understanding energy behaviour, anticipating emerging pressures on the grid, and informing the design of interventions that are both effective and acceptable to households. The main findings from each section are summarised below.

Together, the findings demonstrate the value of a Living Lab approach for establishing lasting relationships with households, tracking multiple metrics over time, and better understanding how households experience the energy transition.

Lead user insights: Living Lab homes and households

The WP7 Living Lab comprises energy-engaged households with higher-than-average adoption of consumer energy resources. These households are already living aspects of the near-future energy system anticipated to become more widespread, including electric vehicles (EVs), household batteries, and Virtual Power Plant (VPP) readiness, affording us valuable lead-user insights.

Despite their higher engagement and resource ownership, these households share similar motivations with the broader population. The highest ranked priorities among the Living Lab participants — i.e. reducing power bills, caring for family, and health and safety are consistent with the WP1 nationally representative survey, where affordability and comfort, health and safety were also ranked most highly. This finding suggests that differences between the two samples may be less about why energy decisions are made, and more about how they are enacted in everyday life.

Electrification, getting off gas, purchasing and living with batteries and EVs

Electrification among Living Lab households reflects high engagement with solar, batteries, and EVs, but adoption is shaped by timing, household dynamics, and infrastructure constraints. Participants cited their solar generation and work-from-home flexibility as important enablers of their EV purchase. Appliances or vehicles reaching end-of-life can be a further trigger to act upon underlying motivations or intentions.

A key insight from this study is how large-capacity home battery ownership can reshape households' relationships with energy and change perceptions of energy from scarce to abundant. Along with the benefits of 'limitless' electricity, such as eliminating minor family disagreements over energy use, findings suggest large capacity batteries risk facilitating a new norm of excessive consumption. Few households participated in VPPs or exported electricity from their battery at peak times. Reasons for this behaviour appear more aligned with inconvenience than overt unwillingness to share, underscoring the need for more diverse, convenient, and usable demand-side response offerings.

Heating, cooling, and comfort

Air Conditioning (AC) use in Living Lab homes is strongly associated with outdoor temperature, increasing progressively once temperatures exceed approximately 18°C during the study period, with humidity playing a role once cooling is underway. However, heating and cooling decisions are also influenced by working-from-home practices, the cost and availability of solar energy, and social factors. Two-thirds of participants reported that at least some of their AC use was driven by the needs of other household members. Understanding the factors that influence heating and cooling decisions is important, as many participants reported dissatisfaction with their home's thermal performance, particularly during winter, and relied on mechanical heating or cooling to achieve comfort. AC was also used to address indoor air quality concerns, including high humidity and mould associated with prolonged wet weather. While the uptake of air purifiers was relatively modest among Living Lab households, participants' experiences with planned burns, nearby bushfires, and chronic health conditions demonstrated how air quality concerns can quickly become a priority and encourage the adoption of air purification technologies.

Household energy practices and electricity demand

Our findings provide a basis for subsequent analysis of energy use flexibility in households. Energy use in Living Lab households shows strong temporal clustering, with energy-intensive practices peaking in the morning (6–10am) and especially in the early evening (3–8pm), when activities like cooking, hot water use, and heating/cooling often occur together, making this the most energy-demanding period. These patterns reinforce that demand is shaped by the timing and coordination of everyday practices rather than individual appliance choices.

Flexibility varies across activities, with cooking and bathing highly time-bound, while laundry, dishwashing, pool pump operation, and EV charging are more flexible and often shifted to daytime or off-peak periods. Regression analysis indicates that total energy use is strongly influenced by structural and technological factors, particularly dwelling size (with large homes using significantly more energy), EV ownership, and heating/cooling practices. Peak demand analysis further shows that AC is the dominant contributor in high-demand households. EV charging was primarily done at night utilising off-peak tariffs or during the day from excess solar, but the findings show the substantial spikes created from the small number of users charging during peak times, highlighting the importance of continued efforts to discourage peak-time charging.

KEY INSIGHTS

The following paragraphs summarise key highlights from each of the results sections below.

PROFILE OF LIVING LAB HOMES AND HOUSEHOLDS

Energy aware and engaged participants

The WP7 Living Lab brings together households that are energy-aware and technologically engaged.

This provides several advantages for the SFL project, including:

- *Lead-user insight:* These households are already living aspects of the near-future energy system anticipated to become more widespread, including EV ownership, home batteries, and readiness for virtual power plants (VPPs), vehicle-to-home, and vehicle-to-grid technologies.
- *Change catalysts:* Energy-engaged households are more likely to trial, adapt, and normalise emerging technologies, making them important actors in the diffusion of energy innovations.
- *Complementarity with WP1:* The Living Lab complements the more representative sample of WP1 by enabling in-depth, contextualised analysis that is not possible at scale.

Yet, despite being energy aware and owning more CER (solar, batteries, EVs) than the general population, many WP7 Living Lab households are motivated by the same factors as WP1's much larger (n=5012 survey respondents) sample (Kaviani et al. 2025), namely: (1) care and comfort of their families, and (2) reducing costs.

Dynamic households, negotiated living arrangements

Many households accommodated extended family and adult children. Household size was sometimes dynamic, with family homes acting as a backstop for adult children moving in and out of the home. Findings reflect the widespread trend towards children living at home longer, and the role of the family home as a refuge for young adults who may move in and out (Stone & Goodall, 2025). Cost of living pressures and the tight housing market were identified as reasons for several co-habiting arrangements, reflecting wider trends experienced in urban Australia (Cove 2025; Hewitt & Baxter 2025). Shared living arrangements intersected with WFH arrangements, where families negotiated living versus working spaces.

What this means

The WP7 Living Lab provides valuable insight into how future-oriented households engage with energy technologies and practices, helping to anticipate how broader patterns of household energy demand and behaviour may evolve as electrification accelerates. The findings also highlight the importance of taking a whole of family approach to energy research (Dahlgren et al. 2026; Snow et al. 2025); that is, understanding households, not just individuals.

ELECTRIFICATION — CONSUMER ENERGY RESOURCES PURCHASE INTENTIONS, GETTING OFF GAS, ADOPTING AND LIVING WITH EVS, SOLAR AND BATTERIES

The near ubiquitous ownership of rooftop solar, rapid adoption of batteries during the trial and intentions to purchase EVs reflect the energy-motivated nature of the cohort. However, the findings equally underscore the importance of timing and family-related factors in adoption. The unique viewpoint afforded by the Living Lab provides insight into how households navigated and responded to electrification transitions such as battery and EV purchase and ownership.

If it ain't broke, don't fix it

Transitions from intention to purchase to actual purchase intersected with appliance replacement cycles. The satisfactory functioning of participants' existing cars and gas appliances was a reason to not (yet) transition away from gas or purchase an EV. Conversely, appliances reaching end of life were a major reason given for replacing gas appliances with electric alternatives. These findings align with others that suggest that motivation, ability, and a trigger are prerequisites for behaviour (Csutora & Mózner 2025, Fogg 2009) and indicate that a closer understanding of participants' experiences of and responses to end-of-life appliances is valuable for understanding electrification decisions. WP1 similarly report many survey respondents adopting a "wait and see" approach to EVs.

'Limitless' electricity

Certain battery households described the realisation of their 'limitless' electricity, after purchasing large capacity batteries. This heralds a new era of household relationships with electricity, where saving money and acting sustainably has evolved from: (1) saving energy overall (no solar or battery), (2) matching energy use to solar generation and reducing energy use outside of sunlight hours (solar owners) (Haines & McConnell 2016; Hubert et al., 2024; Öhrlund et al., 2020), toward (3) using energy at any time with no financial or sustainability consequences. 'Limitless' electricity reduced family tensions or minor 'battles' over energy such as whether the dishwasher should be run overnight or during the day. Yet some participants questioned the ethics of their new-found 'limitless' electricity and spoke of potential future difficulties teaching their children about energy conservation when there was no longer a need to conserve.

These findings hint at the emergence of new social norms of excess energy consumption among large battery owners, and a possible 'rebound' effect (Sorrell et al. 2009) associated with battery ownership, where efficiency gains lead to increased consumption of a resource (Li and Lin 2017). Rebound effects have been observed in the purchase of insulation and EVs, but future work is necessary to quantify this effect for household batteries. Rebound effects can reduce the effectiveness of energy policy, where the energy 'saved' by policy may be less than anticipated (McCarthy & Liu 2022). The self-reported excess battery capacity also underscores the importance of understanding barriers and opportunities to VPP participation and other means of sharing excess energy. Although not asked directly, no participant self-described their battery as an over-investment. In our future work we will revisit participants' choice of battery capacity relative to current uses and future perceived resilience or independence needs.

'Free' electricity drives EV charging behaviour

Access to 'free' electricity from participants' solar panels and cheap electricity from time-of-use or 'overnight' tariffs was a consequential factor shaping participants' EV charging behaviour, consistent with findings from other Australian studies (Martin 2022). Similarly, the access to 'free electricity' from solar panels and flexibility to utilise it, afforded by WFH arrangements, was influential in motivating EV purchase. In some cases, novated leases offered an additional pathway, allowing participants to trial an EV without fully committing.

HOME COMFORT — HEATING, COOLING, CARING AND COMPROMISE

Heating and cooling appliances in WP7 Living Lab households are overwhelmingly electrified and achieved via split system and ducted air conditioning (AC), reflecting broader trends of the electrification of thermal comfort, particularly in temperate and warm climates (Isaac & Van Vuuren 2009). The reliance on AC for thermal comfort highlights the importance of understanding the drivers of AC demand and identifying solutions to optimise it.

Key predictors of air conditioning use

All but one of the 35 Living Lab households had AC installed. In October, when AC and heating are more discretionary or weather-dependent rather than habitual, AC energy consumption was lowest at around 18°C and increased progressively at higher outdoor temperatures, with humidity further increasing the likelihood of AC operation. Many participants were dissatisfied with the thermal performance of their homes, particularly in winter, and many households highlighted minor 'battles' and negotiations over when and how much to heat.

Care and comfort drive air conditioning behaviour

Caring and consideration for others also influenced heating and cooling decisions, particularly among households with children or where a partner had a health condition. Sixty-seven per cent (67%) of participants reported switching on the AC or heating in response to the needs or desires of another in their household, rather than their own, highlighting the importance of understanding energy use as a social and moral practice (Nicholls & Strengers, 2015). In family settings, participants described how decisions were shaped by care, responsibility, and relationships rather than individual optimisation. These findings underscore the need to better understand heating and cooling as a social process and not to assume that behaviour will be shaped by economic rationality. Our future research will explore how households negotiate opportunities for paid curtailment as the electricity flexibility market develops and the tensions between care and relationships and monetary incentives for curtailing energy use.

Clean air and air conditioning

Air quality concerns have the potential to drive future AC behaviour. Concerns over air quality were prevalent among the sample, with most concerns focused on mould or damp, rather than airborne pollutants. Participants described these concerns as being linked more to the recent wet climate conditions than to the usual performance of their homes, leading to the increased use of AC as a means of dehumidifying as well as cooling.

Although only 23% of participants owned an air purifier, many others reported awareness or concern of outdoor pollutants, such as living near a major road, or smoke from planned burns. Particulate matter and smoke were of critical importance to two participants whose partners suffered from respiratory conditions. As air purification is increasingly incorporated into AC and as air quality awareness increases like others, our findings suggest it is possible that air quality, as well as humidity and thermal comfort may increasingly drive AC demand in the future (Strengers et al. 2024), which will be a focus of our future work.

HOUSEHOLD ENERGY PRACTICES AND ELECTRICITY DEMAND PATTERNS — A BASIS FOR UNDERSTANDING DEMAND FLEXIBILITY

Timing of practices and flexibility

A Living Lab approach and access to the same group of participants provide a valuable basis for understanding demand flexibility. Findings show a clear temporal clustering of energy-intensive practices in morning (6—10am) and especially the early evening (3—8pm) periods. Activities such as cooking, hot water use, and heating/cooling frequently co-occur within narrow time windows, making the evening the most energy-intensive period. The findings reinforce a central insight of social practice theory (Shove, Pantzar & Watson 2012), namely that energy demand is not driven by isolated appliance choices but by the timing and coordination of everyday practices. In subsequent work, we will identify the extent to which peak energy use corresponds to peak energy import, particularly given the rapid adoption of batteries observed so far in the WP7 Living Lab trial.

Understanding residential flexibility is important to designing incentives to encourage households to reduce their peak demand, and by extension reduce electricity prices and minimise additional network build (Ribó-Pérez et al. 2021). Cooking and bathing are highly time-bound among Living Lab participants, while laundry and dishwashing are more dispersed across the day, enabled by WFH arrangements. Pool pumps and EV charging also show daytime or off-peak alignment. The findings provide an initial insight into flexibility which will be explored in our subsequent WP7 research.

Predictors of total energy use: The OLS regression analysis highlights how structural and technology-related factors affect energy consumption. The following are statistically important predictors of October electricity consumption, explaining a substantial proportion of variation across household energy use.

- Large dwelling size (4+ bedrooms) → approximately 331 kWh higher monthly consumption (+63% relative to the reference household)
- EV ownership → approximately 228 kWh higher monthly consumption (+44%)
- Reporting no heating and no cooling use → approximately 461 kWh lower monthly consumption compared with households reporting both heating and cooling practices

Dwelling size remains a significant predictor of total energy use, as has been observed previously (Druckman & Jackson 2008). Analysis of monitored electricity data shows substantial variation in peak electricity consumption among households and energy circuits. AC contributes the largest share of peak consumption in households with high peak demand. EV charging has a low median contribution but a pronounced right-hand skew indicating that a small number of households account for disproportionately high peak demand. Despite most households charging their cars outside peak times (Section 3.2.4), these findings demonstrate that a small number of households continue to contribute disproportionately to peak demand through peak-period EV charging.

SECTION ONE
INTRODUCTION

View other SFL reports online

This report presents findings from the first phase of the Living Lab study within Work Package 7 (WP7) of the Scenarios for Future Living (SFL) project. The WP7 Living Lab comprises 35 households equipped with energy and indoor environmental monitoring, and who take part in surveys and interviews over time. This report summarises current understanding of Living Lab households, their energy practices and technologies, and how these are reflected in their energy data. It provides real-world insights into how households engage with and interpret energy in everyday life. These insights form an evidence base for anticipating future energy demands and practices, which will be explored in the second phase of the study.

The WP7 Living Lab research employs a mixed-methods approach that combines high-resolution energy and environmental monitoring data with qualitative engagement, including surveys, interviews, and pulse surveys. This design allows us to examine not only what energy is used, but when, how, and why practices shift over time, capturing the dynamic interactions between technologies, household routines, and contextual changes.

As new energy and energy-feedback technologies become increasingly accessible to Australian households, understanding how these tools intersect with everyday practices, built environments, climatic events, and broader contextual influences is essential. Insights from this phase of the Living Lab study offer critical evidence for future energy system planning, user-centred technology design, and the development of equitable energy policies that reflect the realities of diverse households and communities.

This report is the first of several reports from WP7 and focuses on the first of three foundational research questions for WP7:

1. **How are everyday practices, technologies, and social trends reflected in households' energy use and demand?**
2. How can the knowledge generated in WP1-6 be scaled up to address national energy challenges?
3. How can research engagement with energy stakeholders be sustained long-term and translated into practical applications for policymakers, industry, and households?

Drawing on initial interviews, surveys, and analysis of monitoring data from the 35 participating households, this report incorporates, where relevant, comparisons with findings from other SFL work packages and existing literature. As the first in a series of outputs from the WP7 Living Lab, it should be read as an interim report focused on participants' living arrangements, households, technologies, behaviours, practices, and purchase intentions.

SECTION ONE
INTRODUCTION

1.1 Project Background

SFL is a multi-disciplinary, collaborative research project designed to strengthen decision-making capacity in the Australian energy sector. It does so by developing scenarios, models, tools, and design innovations that centre people's everyday lives and expectations alongside emerging technology and energy trends. This requires both engagement with energy sector stakeholders and an understanding of how industry expectations about probable, possible, and preferable futures shape current decision-making.

SFL comprises seven work packages that collectively strengthen decision-making capacity for the Australian energy sector (See Table 1 below).

Table 1. Work Packages (WPs) within SFL project.

WP title	Details
WP1: Understanding how people use energy	Delivers real-world foresights into how diverse households and home businesses will interact with energy in the future — tracking changing expectations and analysing the impact of future everyday life values and practices to guide industry and policy decisions.
WP2: Anticipating emerging technologies	From smart home innovations to next-gen energy solutions, WP2 analyses new technologies and industry trends to understand their potential impact on energy use in homes and businesses.
WP3: Developing future energy scenarios	Using social and design research, technology trends and climate science to create SFL — rich, evidence-based narratives that help industry and government plan for plausible energy futures.
WP4: Advancing energy forecasting tools	Designing new modelling tools and processes that integrate real-world social trends into energy sector planning, ensuring more accurate predictions and better decision-making.
WP5: Designing people-centred energy solutions	Exploring how new energy products and services can align with people's evolving needs — helping deliver a low-cost, net-zero future while ensuring fair access for all consumers.
WP6: Leading Australian energy transition workshops	Convenes representative groups of actors from across the energy system to explore alternative futures for the Australian energy transition. It also seeks to build industry capacity in advanced foresighting practices.
WP7: Scaling and sustaining knowledge	**Through collaboration with CSIRO's National Energy Analysis Centre (NEAC), WP7 extends the impact and longevity of our research — establishing a Living Lab of households with energy and indoor climate monitoring.**

SECTION ONE
INTRODUCTION

WP7 complements WPs 1–6 by collecting detailed indoor climate and energy use data from Living Lab households to deepen understanding of householders' practices and their relationship with energy use. It also examines how socio-technical knowledge generated through household instrumentation and engagement can be (1) scaled, and (2) translated to address national level challenges. In doing so, WP7 extends the insights, models, and innovations from earlier work packages to a national scale, facilitating their integration into industry practice and long-term energy transition planning. Figure 1 below provides an indicative overview of (1) WP7 activities, (2) WP7's relationship to other work packages and (3) the focus of this report (shaded green).

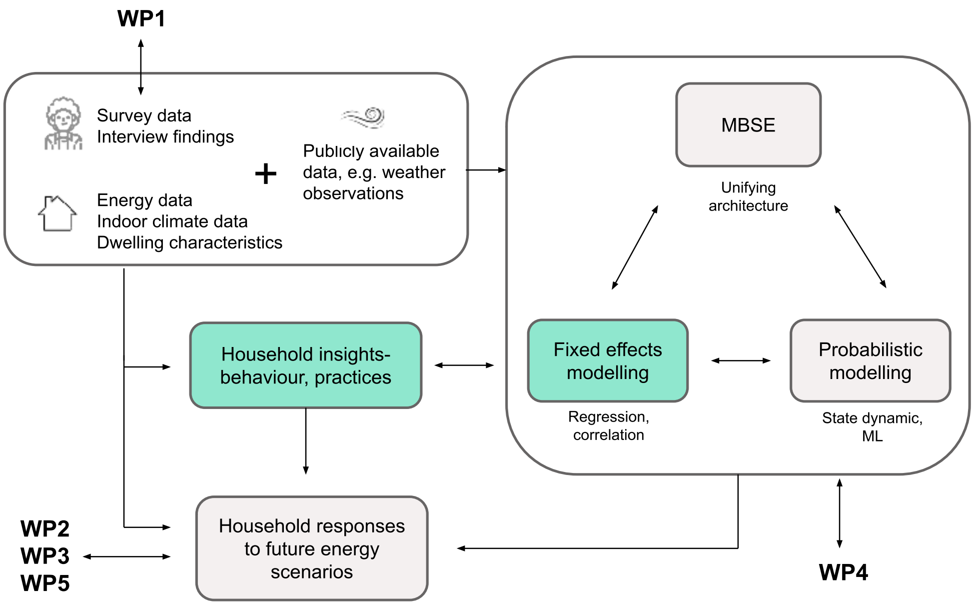


Figure 1. WP7 activities and relationship to other SFL work packages.

WP7 COMPLEMENTS WPS 1—6 BY LINKING HOUSEHOLD-LEVEL LIVING LAB DATA WITH BROADER SFL RESEARCH TO STRENGTHEN UNDERSTANDING OF ENERGY PRACTICES, TECHNOLOGY ADOPTION, AND FUTURE ENERGY TRANSITIONS

WP7 activities

WP7 centres on a 35-household Living Lab, where households share energy use and indoor climate data and engage in surveys and interviews. Household energy-use data, indoor climate measurements, and survey and interview data, combined with publicly available datasets such as weather observations, form the basis for WP7 modelling activities. Modelling includes fixed effects and probabilistic modelling, primarily focussed on heating and cooling activities, and the use of Model Based Systems Engineering (MBSE) as a unifying architecture and structure for data and meta-data (Figure 1).

Relationship to other work SFL packages

WP7 has adopted and adapted a set of survey items from WP1 to ensure alignment between the two WPs and to better contextualise WP7 results. WP1's ethnographic research has informed the design of measures capturing household routines and energy practices. WP7 conducts complementary modelling focused on the prediction of heating/cooling behaviours, alongside WP4's modelling of technology adoption (solar, battery, EV) and associated impacts on energy use. Future WP7 research (after this report) will collect household responses to future energy scenarios (WP3), including perceptions of emerging technologies (WP2) and prototypes (WP5) (Figure 1).

The focus of this report is on the insights gathered through triangulation of interview, survey, and time series data collected from Living Lab households, and some initial results from fixed effects regression modelling of AC behaviour. Other WP7 activities will be reported subsequently, in a dedicated MBSE report and subsequent household reports.

1.2 Research Background

Residential energy consumption is an important consideration in Australia, with households accounting for around 20% of electricity use and 11% of total energy consumption (DCCEEW 2023), and Australia ranks second highest in the OECD for per capita emissions (Leandro 2024). However, this consumption varies widely between households and is shaped by an interplay of factors, including location, household composition, dwelling characteristics, and the appliances in use.

WP7'S LIVING LAB ENABLES REAL-WORLD TRACKING OF HOUSEHOLD PRACTICES AND TECHNOLOGY UPTAKE, PROVIDING INSIGHTS INTO HOW ENERGY BEHAVIOURS MAY EVOLVE UNDER DIFFERENT FUTURE SCENARIOS

Energy-relevant behaviours of householders can be a product of both one-off choices (e.g. purchases of new appliances, changes to energy tariffs) and everyday practices, habits, and household needs, such as preferred AC setpoints, shower length, and routines. The former can have major consequences for long-term energy consumption (e.g. choosing a more expensive but more energy efficient appliance instead of a cheaper but less efficient one). However, routine household practices are equally important and are shaped by social norms, habits, material conditions, and technologies. As an example, heating and cooling practices vary with season, building performance, and what occupants consider comfortable, while laundry practices are often stable and closely related to household size and routines.

Recent technological and policy changes including the rapid uptake of rooftop solar, batteries, EVs, and home energy management systems have further transformed the context in which these practices are performed (APVI, 2026; Graham et al. 2025). Some households are now able to generate, store, and actively manage their energy while others face constraints due to cost, tenure, or access to contributing to growing energy inequity. Understanding residential energy consumption therefore requires attention to how everyday practices are configured and performed. Comprehensive household-level data is essential to capture these interactions and how they may evolve during the energy transition.

Equally, understanding how future trends and conditions will shape household practices and energy use is critical (Dahlgren et al. 2020). Trends such as increased working from home provide households with greater flexibility over activities such as washing, cooking, and EV charging (Hiller et al. 2026). Climate change is driving increased AC use, and the impacts of climate change such as bushfire smoke alongside increased health awareness is driving demand for air purification technology (Strengers et al. 2024). Accordingly, WP7 employs a Living Lab approach where it is possible to (1) track and understand household practices and technology adoption over time, and (2) model existing practices and predict their evolution under different possible future conditions and potential effects.

The Living Lab concept is broadly described as a physical or virtual space in which to solve societal challenges by bringing together various stakeholders for collaboration and collective ideation (Mullin et al. 2023). Living Labs enable a range of methods and often intentional experimentation, rather than rigid static study designs. WP7's implementation of the Living Lab concept is a virtual Living Lab of 35 households, where research privacy and ethics limit direct interaction between participants, however the methodology enables us to track the same cohort of households over time, understanding how appliance ownership, attitudes, and energy use change over time.

SECTION TWO
METHODOLOGY

2.1 Overview and process

The methodology comprised study design, ethical approval, participant recruitment, and the testing, selection, procurement, and installation of energy and environmental monitoring systems, alongside survey distribution and interviews. Ethical approval was obtained from the CSIRO Ethics Committee for Social and Interdisciplinary Research (approval number 024/25).

Full details of the methodology including recruitment, participant screening, selection, study location rationale, sensor selection, and participant data access arrangements are provided in Appendix A. An abridged summary is provided here.

2.1.1 Eligibility

Eligibility was purposefully broad, with the only strict criteria for inclusion being:

- aged over 18 and contributing to household bills and decisions;
- living in a detached house or townhouse (not apartment) connected to the electricity network, and;
- located in South East QLD (SEQ) and Greater Sydney areas (including Newcastle and the Central Coast).

We ensured that participants were over 18 and contributed to electricity and purchase decisions in their household, e.g. they were not boarders or visitors to a household. Excluding apartment dwellers ensured that all participants had the potential to adopt CER such as solar PV, batteries and EVs, which are often less accessible in apartment settings.

Our study areas of SEQ and Greater Sydney were chosen for three reasons: (a) similar climate zones; (b) researcher location, where we wanted researchers to be able to visit participants without extensive travel if they needed assistance installing the devices; and (c) to ensure all participants had a choice of electricity retailer, given QLD electricity customers outside of SEQ have little or no choice of retailer.

2.1.2 Participant recruitment and selection

Recruitment included advertising the study in the study areas via multiple communication channels directing interested participants to a publicly available webpage with information about the trial, participant information, and consent documentation. All interested participants completed a screening survey to gather information on household and dwelling characteristics (appliance and technology ownership, renter status, household size, household type, number of children), as well as their motivation for applying to the Living Lab. The screening also required all participants to submit photos of their electricity and (if applicable) gas meters to assist in determining eligibility for the monitoring.

The selection of participants into the Living Lab was based on a combination of technical, demographic, economic and contextual considerations to ensure diversity while maintaining feasibility for device installation and data collection. We were aware that the free energy and environmental monitoring available to participants through participation would attract an energy-interested cohort and we did not attempt to mitigate this potential bias for several reasons:

1. The longitudinal nature of the study meant we wanted participants who were interested and invested in the nature of the research to minimise attrition and maximise engagement.
2. People who are energy-interested are not necessarily early adopters, nor are they necessarily wealthy enough to adopt smart energy technologies. Many Australians are interested in and engaged in energy due to the increasing cost of electricity and a desire to better understand what they can do to reduce their costs (ECA 2025a).

SECTION TWO
METHODOLOGY

We aimed for good representation of those with smart energy technologies, including EVs, solar PV, and battery storage. Selection also included several practical criteria including:

- Meter box safety and labelling
- Estimated 4G and Sigfox signal strength, required by the monitoring devices to communicate
- Due to the substantial investment of monitoring technology in each house, we additionally assessed (a) motivations for joining and (b) the intention to remain in homes for more than 12 months.

Some phone calls were made to clarify uncertain aspects, including participants whose motivations were unclear and those who indicated they may move house within 12 months. A total of 12 participants were rejected for reasons related to the above.

The final selection of 35 households included 15 in NSW (Greater Sydney and central coast) and 20 in QLD (Greater Brisbane) (See Figure 2).

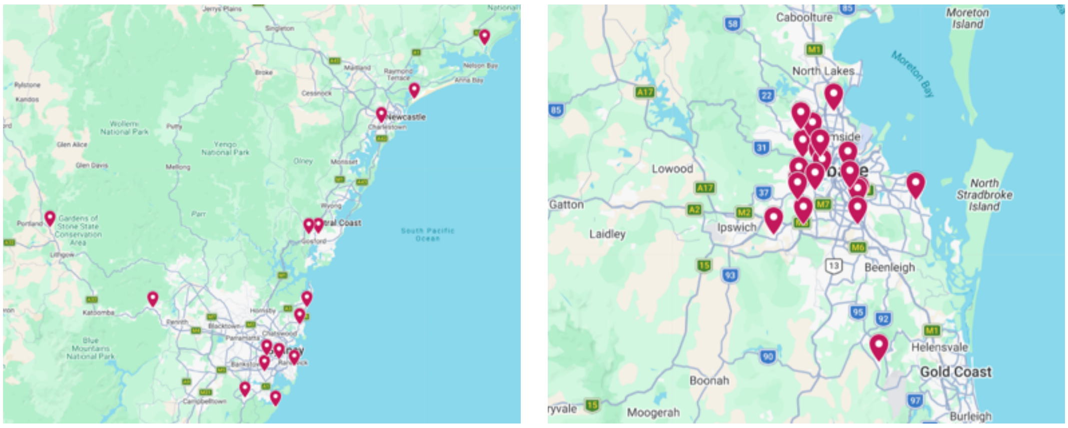


Figure 2. Distribution of Living Lab participants in NSW and QLD (Greater Brisbane).

According to the Australian Bureau of Statistics (ABS) Remoteness Structure (ABS 2026) which classifies areas based on their relative access to services, eight NSW participants were in Major Cities and seven in Inner Regional areas. In QLD, nineteen participants resided in Major Cities and one in an Inner Regional area. As a result of the study area, all participants had a choice over their electricity retailer. The study areas were chosen due to (a) similar climate zones, (b) proximity to researchers, where the novel method of self-installable sensors for environmental and gas monitoring meant we wanted to ensure researcher proximity to assist in-person if issues arose.

2.1.3 Energy and environmental monitoring

WP7 Living Lab households were equipped with electricity monitoring (Wattwatchers 6M Auditor), and indoor environmental monitoring (Tether EnviroQ). Households with a town gas connection were additionally provided with gas monitoring using the (Tether Pulse). These devices are shown below in Figure 3.

Figure 3. (1) Wattwatchers device installed in a switchboard (Source: Wattwatchers), (2) Tether EnviroQ, (3) Gas pulse monitor (Source: Tether).

Electricity monitoring

Each Wattwatchers 6M Auditor provides 5-minute data on up to six circuits in a meter box. Two or (in rare cases) three Wattwatchers were installed in three-phase residences and those with complex electrical configurations. Circuits in each home were clamped according to the following priority list of priorities, ensuring that the largest energy consuming appliances were captured.

1. Grid incomer (the household's "mains" electricity connection)
2. Solar Photovoltaic (Solar PV)
3. Air conditioning
4. Electric hot water
5. Electric vehicle
6. Battery
7. Oven/stovetop
8. Pool pump, pool heater, spa, or other large loads
9. Powerpoints circuits

This prioritisation meant that AC, hot water, EV charger and solar PV data were captured from all houses that had these appliances installed. Several households charged their EVs from power points, meaning not all EV loads could be captured. Additionally, as several households installed batteries with hybrid inverters during the trials, the number of households for which gross solar generation data was available actually decreased, as hybrid inverters have solar and battery DC-coupled to them and therefore gross solar generation is no longer able to be isolated.

Environmental monitoring

The Tether EnviroQ measures temperature, relative humidity, carbon dioxide, dewpoint, light, sound pressure and atmospheric pressure, every 15 minutes. It communicates via the SigFox network. The EnviroQ is battery operated, which enabled participants to self-install the devices based on instructions provided by researchers. All EnviroQ devices were self-installed in participants' main living areas.

Gas monitoring

An IN-Z41 pulse reader was connected to the Tether Pulse monitor and measured pulses from participants' gas meters. Each pulse corresponds to 0.01 m3 of gas per pulse. Data are transmitted to Tether's cloud platform as per the EnviroQ data. This solution cannot measure bottled gas consumption, was therefore not included in this trial. As with the EnviroQ, all gas pulse monitors were commissioned by the lead researcher and self-installed by participants.

Participant access to monitored data

All participants received access to two dashboards (1) The My Energy app provided by Wattwatchers, with access granted shortly after the electrician installed the Wattwatchers energy monitor. (2) The Tether dashboard, through which participants could access data from their EnviroQ and their gas pulse monitor.

2.2 Survey design and instruments

THE WP7 LIVING LAB PROJECT EMPLOYS A PANEL STUDY DESIGN WITH ALL 35 PARTICIPANTS WHO COMPLETE MULTIPLE SURVEYS AND INTERVIEWS OVER AN EXTENDED STUDY PERIOD

The WP7 Living Lab project employs a panel study design with all 35 participants who complete multiple surveys and interviews over an extended study period. This design enables us to track changes in household energy-related behaviours, routines, and responses to external events over time. A core set of items will be repeated across survey waves to allow for longitudinal comparisons (e.g. adoption of technologies, energy practices, behavioural responses), while other items are included only once when they were not expected to vary meaningfully over time (e.g. dwelling characteristics, some household demographics).

The surveys are organised across the following areas:

- Individual and household socio-demographic details;
- home and dwelling characteristics;
- household routines and daily practices;
- energy-related behaviours, values, perceptions and decision-making;
- interaction with energy and feedback technologies;
- responses to external events such as weather changes, and;
- responses to current government energy-related initiatives.

A core set of survey items was adapted from WP1 (Kaviani et al. 2026) ensuring alignment between the two WPs. The methodologies deployed in WP7 enable an integrated analysis of how household energy practices, technology adoption, and measured energy demand interact over time. This linkage to WP1 also strengthens the interpretation and scalability of this analysis: WP1's representative survey provides a population-level benchmark, allowing the WP7 sample to be contextualised and compared with broader Australian patterns.

2.3 Interviews

Semi-structured interviews were conducted with all participants between October and November 2025 using Microsoft Teams or recorded phone calls. The interviews explored topics covered in the survey in greater depth, including participants' considerations regarding appliance purchases, household modifications, working-from-home practices, experiences with the energy and environmental monitoring dashboards, and energy-related plans for the next five years, e.g. plans to move house, downsize, or expected fluctuations in household size. Participants advised which room(s) were used for working from home and which heating/cooling appliances were used in each room. In phone interviews where screensharing was not available, participants described these details verbally and the researcher updated the floor plans accordingly. Interviews were between 45 and 75 minutes in length, conducted over Teams.

Further methodological information including timeline, energy monitoring devices and selections, survey and interview data analysis can be found in Appendices A and B.

2.4 Household energy data and analytical approach

2.4.1 Data source and study period

Household electricity data were obtained from Wattwatchers for all participating households. The study draws on energy monitoring data collected between October 2025 and February 2026 to illustrate variations in household energy use behaviours and associated consumption outcomes. Analysis in this report focuses on battery, EV charging and AC behaviour, primarily derived from household grid incomer, AC, and EV charger circuits.

For quantitative analysis, October 2025 was selected as the focal month to provide a consistent snapshot for preliminary exploration of energy use patterns and their potential drivers (See Section 3.3). This month provided sufficient variation in temperature and cooling demand while minimising seasonal confounding. The analysis presented here represents an initial integration of available quantitative data and serves to demonstrate the analytical potential of close-circuit household energy monitoring in applied energy research.

Three electricity consumption measures were examined:

1. Net electricity used (i.e. net energy profile), defined as the balance between household electricity imports from and exports to the grid, measured from the Grid Incomer circuit(s);
2. AC electricity consumption, measured in kWh at the circuit level; and
3. Total monthly household electricity consumption, measured in kWh, derived from household grid import and export.

The analysis consists of a combination of descriptive statistics, distributional diagnostics, graphical analysis, correlational checks, and regression models to identify recurring patterns and relationships within the observed households.

For details of energy data capture and analysis for points 1–3 above, refer to Appendix A and B.

SECTION THREE
RESULTS AND DISCUSSION

In this section we introduce our WP7 Living Lab participants, their dwelling and household characteristics, and compare these results to those of WP1's national survey (Kaviani et al. 2025). Our focus is then on the activities and appliances with the greatest bearing on household energy use. Including ownership of and purchase intentions for Consumer Energy Resources (CER) such as solar PV, home battery and EV, experiences of "living with" home batteries and EVs (Section 3.2), heating and cooling, including how comfort, caring and compromise shape heating and cooling practices and energy consumption (Section 3.3), and the timing of other household activities such as cooking, cleaning and working from home, which provides a basis for understanding household demand flexibility (Section 3.4).

3.1 Profile of Living Lab Homes and Households

3.1.1 Participant characteristics and motivations

The WP7 Living Lab is comprised of households who vary in terms of household size, demographics and working from home practices (as explored in subsequent sections), but who are predominantly homeowners (n=34) rather than renters (n=1) and families/extended families (n=31) more than shared houses (n=4).

The sample has higher than average ownership of rooftop solar, battery storage and EVs, compared to both the national average and compared to WP1's survey (Table 2).

Table 2. Ownerships of solar, battery and EVs between WP1 (Kaviani et al. 2025) and WP7.

	WP1 (n = 5012)	WP7 (n = 35)
Rooftop solar	37%	83%
Home battery	12%	31%
EV or PHEV	9%	37%

Participants also demonstrated high confidence in their understanding of their energy bill, where only 3 of 35 reported little or very little understanding while the majority reported enough (n=11), good (n=8) or very good (n=13) understanding. Twenty-three participants already had some form of energy use feedback, most commonly via a solar monitoring applications.

Despite being a clearly energy-interested cohort, many listed "Understanding my own household energy use" and "Understand how I can reduce my energy use" as key motivations for joining the Living Lab, despite most self-reporting that they had a good enough understanding of their bill (Figure 4). Others highlighted broader societal motivations, including contributing to sustainability and research.

SECTION THREE
RESULTS AND DISCUSSION

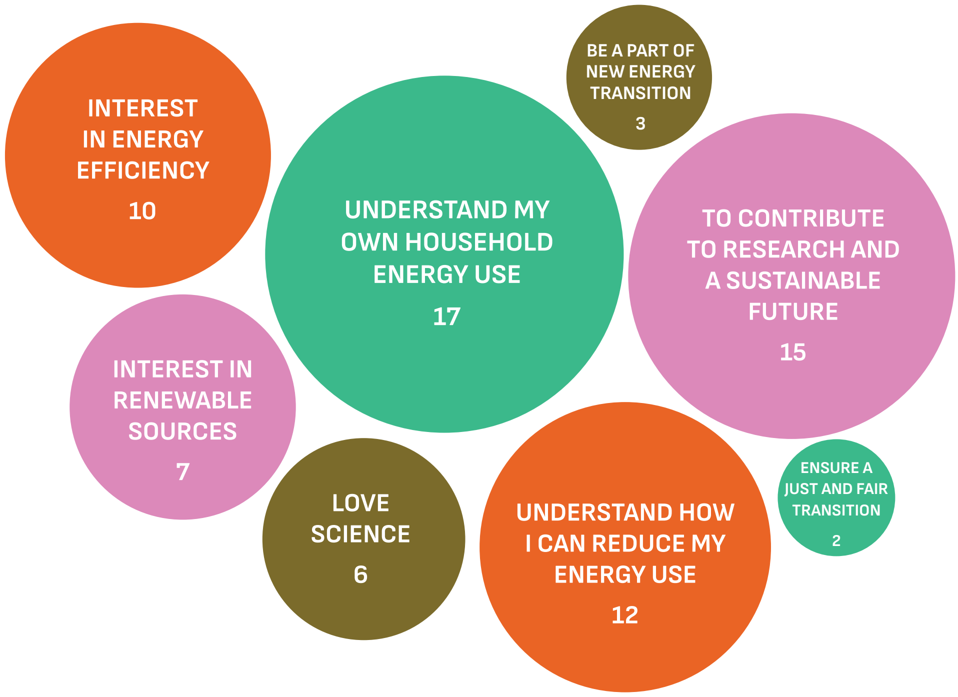


Figure 4. Motivations to join the Living Lab with no of responses (n=35).

The WP7 Living Lab is skewed towards households that are more energy-aware and technologically engaged than the general population. This is unsurprising, given that the energy and indoor climate monitoring likely acted as an incentive for participation. As described above, we did not attempt to correct this potential bias, as we consider an energy-aware sample in this study to be not a limitation but a strength, providing several advantages for the SFL project:

- Lead-user insight: These households are already living aspects of the near-future energy system anticipated to become more widespread, including EV ownership, home batteries, and readiness for Virtual Power Plants (VPPs), vehicle-to-home, and vehicle-to-grid technologies.
- Change catalysts: Energy-engaged households are more likely to trial, adapt, and normalise emerging technologies, making them important actors in the diffusion of energy innovations.
- Complementarity with WP1: The Living Lab complements the representative survey data collected in WP1 by enabling in-depth, contextualised analysis that is not possible at scale.
- Appropriate use of a small sample: Where statistical representation is not achievable, focusing on analytically rich and transition-relevant households maximises the value of intensive qualitative and mixed-methods research.

THE ENERGY-AWARE SAMPLE IN THIS STUDY IS A STRENGTH, PROVIDING LEAD USER INSIGHT

Taken together, the WP7 Living Lab provides critical insights into how future-oriented households engage with energy technologies and practices, helping to anticipate how broader patterns of household energy demand and behaviour may evolve as electrification accelerates.

3.1.2 Participant values and priorities

To understand decision-making drivers, participants ranked eight energy-related goals from 1 (most important) to 8 (least important) to show the trade-offs they were willing to make in their energy use priorities. A Plackett-Luce (PL) model was used to perform likelihood-based estimation that treats each participant's ranking as a series of conditional choices[1]. The Wald test indicated statistically significant differences in the relative importance of the eight motivation items, Wald $\chi^2(7) = 88.16$, $p < .05$.

Because the worth scores are normalised to sum to 1, they can be interpreted as estimated probabilities. For example, a worth score of 0.23 indicates an estimated 23% probability that the item would be ranked as the most important goal from the full set.

Table 3. Motivations driving energy use decisions at home.

Motivation items	**Normalised worth**
Reducing power bills	0.23
Caring for family health and safety	0.22
Minimising environmental impacts	0.20
Improving comfort and convenience	0.15
Meeting the preference or needs of the household members	0.09
Keeping up with technology or innovation	0.04
Encouragement from others	0.04
Setting an example for others	0.03

Reducing power bills had the highest estimated worth score, with an estimated probability of 23% of being ranked as the most important goal. This was closely followed by caring for family health and safety, at 22%, and minimising environmental impacts, at 20%. In contrast, keeping up with technology or innovation, encouragement from others, and setting an example for others had a combined estimated probability of 11%, suggesting that social and technology-oriented motivations were less central to household energy decision-making among participants.

We compared the ranking of values and goals in energy use decisions at home to the WP1's Year 1 national survey (Kaviani et al. 2025). The top two ranked priorities ("Reducing power bills" and "Caring for family health and safety") map closely to the two highest reported in WP1's nationally representative survey of 5,012 respondents, where "Affordability" and "Comfort, health and safety" were listed as the two highest priorities by participants in this survey (Kaviani et al., 2025). This reinforces that, even among highly engaged households, core motivations remain broadly consistent with the general population.

1 Ranking forces participants to make sequential nature of choices in which each selected item constrains the remaining set.

3.1.3 Dwelling characteristics

Dwelling size was large in the sample, with median floor areas of 242 m^2 in NSW and 226.5 m^2 in QLD. All the Living Lab households were owned or mortgaged, with only one participant renting. In terms of passive design features, QLD participants reported significantly more passive cooling features, including shading from trees/plants (9% NSW vs. 37% QLD, $p < .01$), light-coloured roofs (14% vs. 34%, $p < .05$), and appropriate orientation (9% vs. 31%, $p < .05$). In contrast, NSW participants were significantly more likely to report wall insulation (20% NSW vs. 3% QLD, $p < .01$), reflecting different climatic requirements.

3.1.4 Household compositions and the home as a refuge

Most households were comprised of couples, families, or extended families, with few single occupier households (3) and group share households. Table 4 summarises household composition and certain dwelling characteristics for Living Lab participants across NSW and QLD.

Table 4. Overview of some Living Lab household composition by state.

Household type	**NSW** **(N=15)**	**QLD** **(N=20)**
Family with young children	6 (40%)	6 (30%)
Couple with no kids	6 (40%)	5 (25%)
Family with adult children	2 (13%)	2 (10%)
One person	1 (7%)	2 (10%)
Extended family	0	3 (15%)
Group share household	0	2 (10%)

*Median value (IQR)

The interviews provide nuance to these numbers and underscore the fluidity of many family arrangements. Seven participants had adult children living at home, some of whom were expected to move out within the next year or had returned home after previously living independently. Robyn had an adult child return home in late 2025 during SFL trial participation. Some households had further extended family living with them, including a grandchild and an in-law living with them on a permanent basis, while Priya[2] (family with young children) and Grace (shared house) both had international students living with them on a more temporary basis. Aisha had bought a house with their older parents, allowing their parents to co-habit in a separate granny-flat on the same property as Aisha, her partner and two children.

2 Pseudonyms are used throughout this report using diverse Australian first names to ensure anonymity and inclusivity; they do not correspond to participants' real identities.

3.1.5 Working from home and negotiating living spaces

Most participants reported working from home (WFH) one or more days per week. Patterns of working from home also varied slightly, with NSW participants more evenly dispersed across remote-work frequencies, while QLD participants most commonly worked from home more than 3 days per week (Table 5).

Table 5. Working from home by state.

Working from home	NSW (N=15)	QLD (N=20)
1–2 days	5 (33%)	2 (10%)
3–4 days	3 (20%)	7 (35%)
5 or more days	3 (20%)	5 (25%)
None	4 (27%)	6 (30%)

Participants commonly reported using a dedicated study or office room as their home office (60% of cases). Smaller proportions nominated bedrooms (20%), living rooms (16%) and dining rooms (4%). A further 16% indicated they worked from other areas of the home. Overall, this suggests that most participants had access to a purpose-designed workspace, but a sizeable minority worked from shared or multipurpose rooms.

Qualitative interviews revealed how families prioritised WFH and how they shared and negotiated space within the home. Five participants who had purchased their home recently had sought out WFH space as a specific feature. Yet many others needed to share WFH space and reported working from home on alternative days to their partner to share the same office/bedroom space. Nat worried about their son (who had moved back home) working long hours from his bedroom, given that the living room was typically occupied.

Jason noted the lack of dedicated WFH space, where him and his partner often used the kitchen table, but having to move clutter to do so, with the alternative being "living in the bedroom all day". James previously worked from the living room but had moved to a small bedroom when a new baby was born. Working from home was a key consideration in house choice for Noah who worked primarily from home, while others made provisions such as installing AC in the study after "sitting at my desk sweating" when the living room was unavailable (Amy). Ethan indicated that his wife may take on a job entailing 100% remote work, which would cause them to change their current arrangement involving partners working alternative days from home. Jordan intended to insulate and convert a shed into office space, where he felt his current arrangement of working in a shared space intruded on his adult children:

> *"We're working at the moment in a shared family space [...] if the kids are doing something, I don't think it's right for us to, you know, interfere on their shared zone. If they're out watching TV or something, I think it's unfair for me to go, you know, "hey I'm working". I chose to be in this shared space and I can deal with that." (Jordan)*

The return of an adult child meant Robyn and their partner had moved out of their existing WFH space to accommodate them.

These findings highlight how families WFH and navigate the sharing of space in homes that act as residences for extended families with diverse needs.

3.2 Electrification – CER purchase intentions, getting off gas, adopting and living with EVs, solar and batteries

3.2.1 CER ownership and purchase intention

A key benefit of the Living Lab methodology is the ability to track CER adoption and household electrification over time, and to understand the factors that influence purchase intention and its translation into actual technology adoption.

In terms of solar PV, EV's and home battery ownership and purchase intentions, all but four participating households owned a solar PV system and although fewer owned batteries or EVs, many planned on installing batteries or EVs in the next 3-5 years (Figure 5).

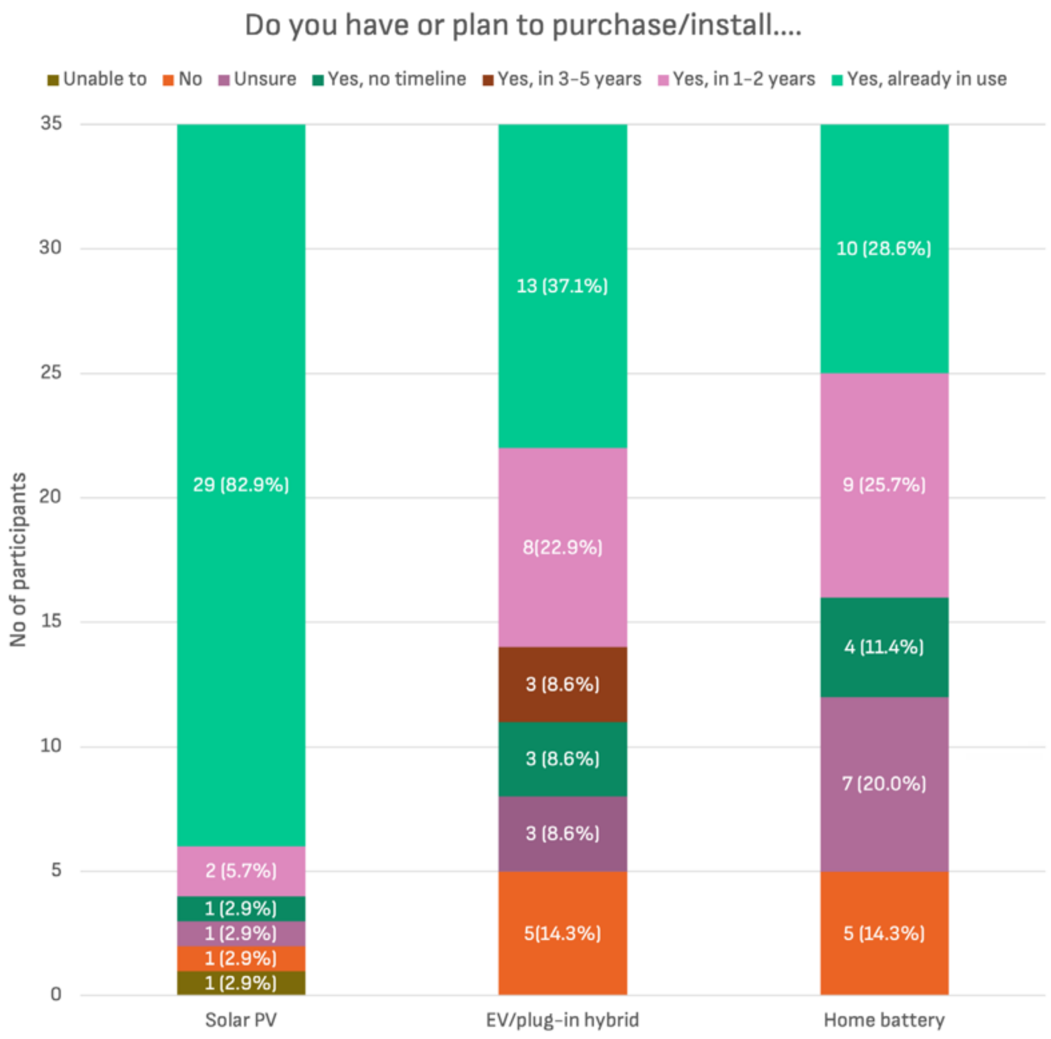


Figure 5. Current and planned adoption of CERs.

At the time of the survey (October 2025), home battery adoption was modest, but with high future interest in purchasing one (Figure 5). However, as described later, many acted on this intention during the trial and battery ownership increased from 7 at the beginning of the trial (August 2025) to 10 at the time of the survey and interview (October 2025, Figure 5) and to 14 at the time of writing (May 2026), which presented challenges in terms of energy monitoring. Overall, the results show widespread solar PV adoption, growing momentum for EV uptake, and strong but uncertain interest in home batteries, indicating ongoing transitions toward low-carbon household technologies.

The interviews provide some nuance to the figures above. Structural barriers limited purchase desires for EV, solar PV, or battery purchase for some participants, including limited income and limited future income capacity for some nearing or already in retirement (n=2) or plans to downsize in the next five years making participants unlikely to invest in their current homes (n=23). Ruby realised only after purchasing their house that there would be no benefit to purchasing solar panels or a battery, owing to the substantial shade cast by nearby apartment complexes. They had purchased the house sight-unseen while living in Melbourne "in one of the longest [COVID] lockdowns in the world" and subsequently discovered issues associated with the property:

> *"...so we went through [...] a buyer's agent and she was looking around at properties. This one, we bought it off market, sight unseen. So any of those issues [that they identified later] didn't occur to us at that stage. It was purely the location in Sydney, you know, close to schools and relatively close to family." (Ruby)*

These factors highlight the range of motivations, facilitators, and structural and circumstantial barriers to CER adoption. Through subsequent surveys we will track purchase intention and CER adoption over the course of the WP7 Living Lab study.

3.2.2 Getting off gas

Participants were asked about their gas connections at home with just under half of participants having reticulated gas connections (46%). The types of gas appliances used is summarised in Figure 6.

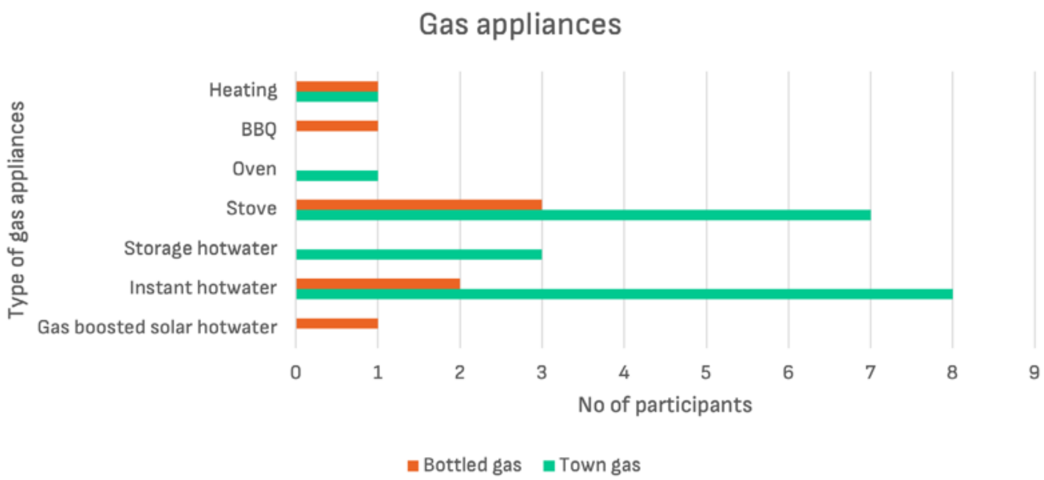


Figure 6. Use of gas and gas appliances.

Most participants with gas currently indicated they would replace their gas appliances with electrical alternatives within the next 1 to 2 years (Yes=5, 33%; Maybe=7, 47%). Only a small minority said they would not transition to electric options (3, 20%). All participants currently using bottled gas (n=5) expressed willingness to transition to electric alternatives, as did most participants on town gas (n=7).

Getting off gas — Motivations

The qualitative interviews found that a further four participants had terminated their town gas connection in the past five years. Motivations for getting off gas the comparable or lower running costs of electric appliances, as well as gas appliances reaching end-of-life and the realisation of the significant standing charge relative to per-unit charge of town gas (n=2). Renovations were a key trigger point for electrification for some participants (n=3). Safety and indoor air quality concerns also featured prominently in Ethan and Devi's household decisions:

> *"I understand there are people who still like to cook with gas [...] but it just seems crazy to have flammable gas piped into your house with possible leaks. We've actually had a small leak before, during the transition, because one of the ports that where there used to be a space heater had to be shut off and then we could smell gas around that [...] It seems like a bonkers idea to have something so dangerous." (Ethan)*

> *"We were using it [gas] for heating, but it was actually giving us headaches and making us sleepy. We had some un-flued gas heaters, which even though we had them cleaned every year they were becoming unreliable." (Devi)*

Getting off gas — Barriers

MOST PARTICIPANTS SAW LITTLE REASON TO REPLACE GAS APPLIANCES WHILE THEY CONTINUED TO FUNCTION EFFECTIVELY

Five participants also did not plan to replace gas appliances in the near-term. The main reason given for not replacing gas appliances was simply that the appliances were still working satisfactorily (n=4). Some accepted that they might consider electrifying completely if they invested in solar panels (n=2) in the future, which could cover the cost of water heating. However, there is a belief amongst some participants that bottled gas currently represents a more cost-effective option for water heating compared to electricity.

Alex, who "can't make the economics work" for solar panels, planned to install a natural gas outdoor BBQ in the summer to make better use of his gas connection. Jason said he preferred the feel and "warmth" of gas heating, relative to the "artificial" feel of heated air from reverse cycle air conditioners, lamenting that his current (rented) house has no gas connection and "I've got to move with the times", indicating a perceived inevitability of gas becoming less commonplace.

Family and partners also acted as barriers for some participants (n=2). After electrifying their space heating, Devi now used gas only for cooking and was well aware of his high standing charge for negligible usage but also felt their partner would not want to give up gas cooking, remarking: "you fight the battles you think you can win (laughs)". Dylan indicated his partner valued the continuous hot water provided by their instantaneous gas unit, relative to the finite capacity of storage hot water services.

SECTION THREE
RESULTS AND DISCUSSION

3.2.3 Living with EVs

Thirteen of the 35 participants owned a total of 15 EVs and 2 PHEVs. In this section we explore EV owners' load profiles compared to non-EV owners as well as participants' motivations and considerations for purchase of EVs, their charging behaviour, and some of the enabling conditions for when any why participants charge their EVs.

Figure 7 shows the average daily load signatures (drawn from the Grid connect circuits) of EV owners, compared with the average of all solar households (ignoring solar and battery status) for the months October, November, and December. The effect of EVs self-consuming participants' solar is visible, where the net export of EV owners is lower than that of all solar. Yet EV households also draw more electricity from the grid during peak times compared to all solar households, indicating the potential to further optimise charging behaviour away from peak times.

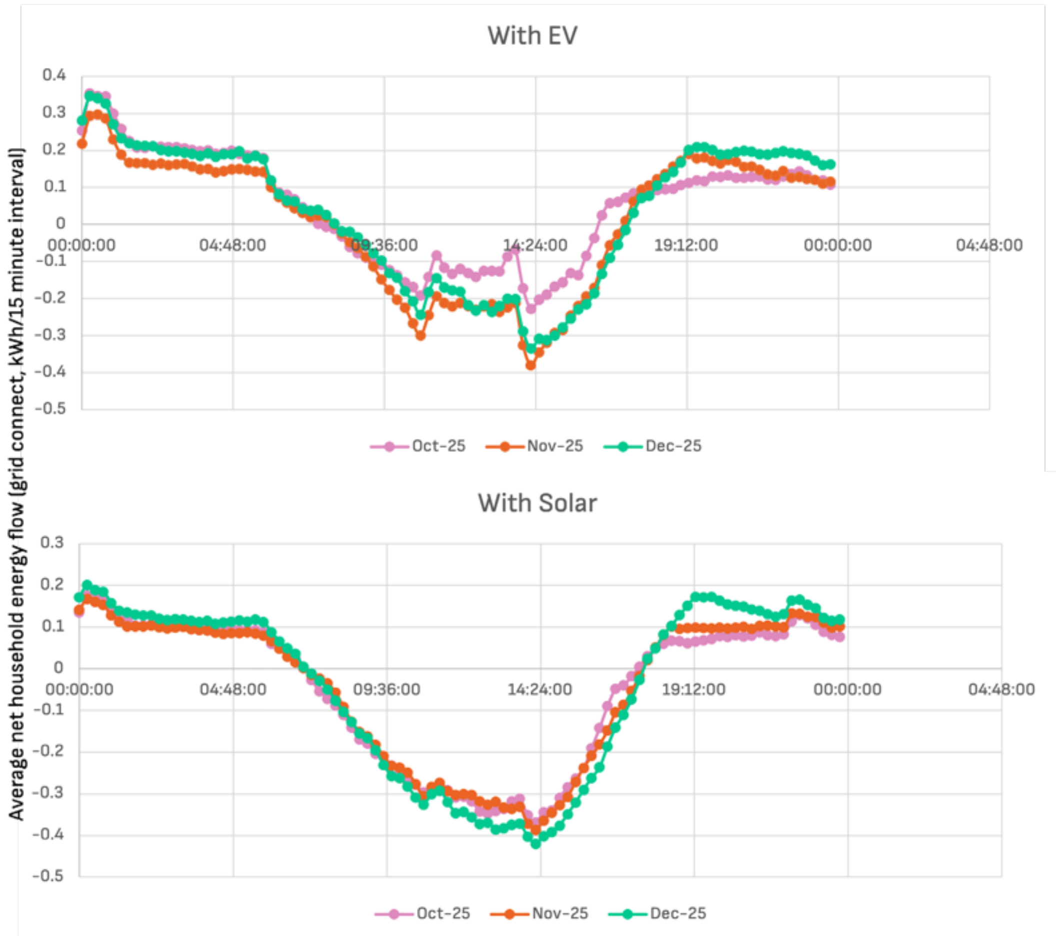


Figure 7. Average net grid connection per household at 15-minute intervals over 24 hours from midnight to midnight for EV households vs solar households. Positive values indicate net electricity import from the grid, while negative values indicate net export to the grid.

Seasonal patterns are evident, with November and December showing deeper daytime exports for these households.

EV purchase motivations and considerations

Participants' EV or PHEV purchases were driven by broad environmental or electrification motivations and in all but one case, having solar panels with or without batteries to assist in charging the car. Yet the trigger for purchase typically coincided with the need for another vehicle or vehicle replacement.

Many participants who were intending to purchase an EV were waiting for this opportunity. For example, Priya mentioned the novated lease contract on their current car would finish the following year, prompting research into leasing an EV. Kim reported trying to keep their existing car "...alive long enough to decide which one (EV) we'll get". Sam intended to replace his 19-year-old car with an EV but could not bring himself to replace it while it still worked satisfactorily. These findings relate to WP1's findings that many households, although interested, adopted a 'wait and see' attitude towards EVs (Kaviani et al. 2025).

EV adoption was described by many as a "trial" or opportunity to "learn about life with an EV [...] live with an EV and figure out how that works" (Jason) and novated leases assisted this trialability. This aspect was particularly important in cases where EV adoption involved the need for persuasion of others in the household (n=5):

> *"My wife was dead against the idea, thought it was a ridiculous amount of money, a ridiculous concept. And we got the first one and within a short period of time that became her car. And she wanted one of her own. So she went from being a complete sceptic to "this is fantastic!" in a very short space of time. [...] It's so fun to drive [...]. So I think having actually used one and found it to fulfil what she needed from a from an electric vehicle, and all the scaremongering that comes with it about range and cost, none of that played true for her." (Dylan)*

Participants also played a role in persuading others, including influencing family members and their peers to adopt EVs. For example, one participant described encouraging their daughter to purchase an EV, and another noted their housemate buying one: "...probably because I banged on about it [my own EV] so much" (Grace). In some cases, participants had pre-empted EV purchase in their choice of solar or battery technologies.

> *"I already knew, like when I was getting solar that I will get an electric vehicle so I opted for a [brand name] inverter. Then installed a [same brand] charger and they talk to each other and they can detect when there is excess solar and charge the car from only excess solar." (Riley)*

> *"So my wife finds it a little bit frustrating because it charges very slowly and if she doesn't leave it on overnight, then, yeah, she won't get much of a charge, so she sometimes tops it up at the fast charger [in town]." (Jason)*

EV charging behaviours and technologies

Of the 13 participants with EVs, six had an EV charger installed, with the remainder using a regular power point, also referred to as a "granny charger" (Table 6). How participants charged their EV determined our ability to isolate EV charging events. Energy use data were analysed for those participants with dedicated EV charger circuits (n=6).

For those who charged their car from a power socket, the EV load signature was visible only if the Wattwatchers device was measuring that power point circuit. Even then, it was sometimes difficult to differentiate from other high-powered devices such as washing machines or tumble dryers (Figure 8). In these cases, substantive analysis would require computational disaggregation of the EV load from other loads, which we have not (yet) prioritised. As an example, Devi charges his EV from a power point in the laundry, meaning the washing machine and dryer are on the same power points circuit, making disaggregation difficult (Figure 8).

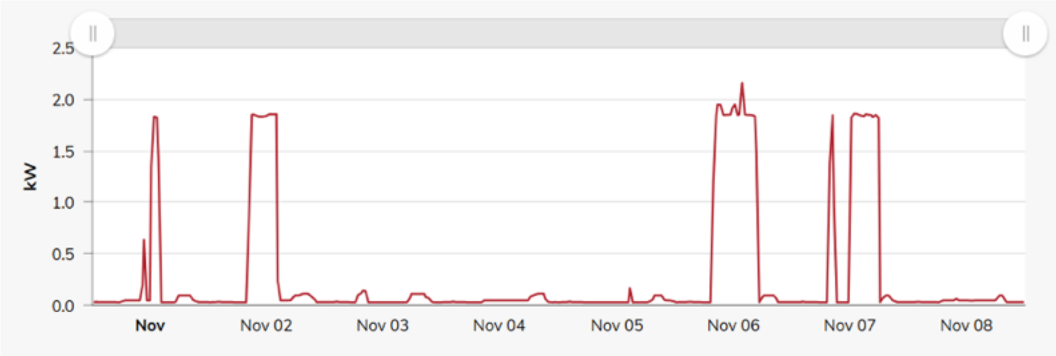


Figure 8. Devi's household: "Laundry and EV" circuit.

For this reason, in our analysis, we draw on survey and interview data for EV owners charging off power points and include quantitative analysis of those with dedicated EV chargers. An exception is Aisha who installed a fast charger during the trial, where the peaks were so substantially higher than all other loads that it was possible to manually identify charging events through visual analysis. Table 6 below details each EV participant in terms of the number and type of EVs owned, the charger they used at home and notes on their tariff type and charging behaviour.

EV CHARGING PRACTICES WERE CHARACTERISED BY SIMPLICITY, WITH MANY PARTICIPANTS USING STANDARD POWER POINTS, TIMERS, OR SMART PLUGS INSTEAD OF DEDICATED CHARGING INFRASTRUCTURE

Notably, Table 6 highlights that only seven of the 13 EV participants owned an EV charger at the time of the interview and the remainder charged from a power socket. Charging behaviour can be grouped into the following clusters:

- Timers (including smart plugs used as timers) programmed to come on at specific times, e.g. 12am-6am (n=2), 2 hours after sunrise and 2 hours before sunset (n=1) or 11am-2pm to make use of free electricity hours (n=1). These timers were used to make use of solar generation and/or tariffs offering cheap electricity overnight.
- Smart technology that controls when the car charges, for example a smart inverter diverting all excess solar to the EV to ensure it is charged exclusively off solar (n=2), or retailer-supplied smart technology where the charging profile is determined by the electricity retailer (n=1).
- Manually: such as plugging in overnight on a controlled load or off-peak tariff, (n=2), keeping the car plugged in "whenever it's in the garage" (n=1), and charging as needed (n=2).

Notably, there is a predominance of low-tech solutions, such as the use of standard timers and manual plug-in practices. Many participants were content with power-point charging and/or simple smart plugs to switch on and off, even for Tay, who drove Uber casually with his EV:

> *"It's on a very simple plug [...] that's set up to turn on it two hours after sunrise and turn off 2 hours before sunset. I've thought of it [buying a dedicated EV charger] but that's several thousand dollars [...] and it'd take you 10 years to get your money back [...] I'll just use the sunrise and sunset method." (Tay)*

Table 6. EV, charger type, and charging behaviour per participant.

EV owner	EV(s)	Charger type	Solar PV / Battery present	Tariff type	Charging behaviour notes
Jason	1x EV	Power socket	None	EV tariff including retailer managed charging	Charged overnight using retailer-supplied EV night tariff, requires internet connectivity to allow retailer to modulate charging.
James	1x PHEV	Power socket	Solar PV and battery	Time of use incl. demand charge	Occasionally topped up using the fast charger in town.
Ethan	1x EV	Power socket	Solar PV	Time of use	PHEV infrequently charged from a standard power point as and when needed.
Riley	1x EV	EV charger	Solar PV and battery	Spot reflective	Uses a timer on the car to charge during daylight hours to utilise solar PV. Timer is manually adjusted to different sunrise/ sunset times as the seasons change. Also manually charges at other times as and when needed.
Nat	1x EV 1x PHEV	EV charger	Solar PV	Flat rate	Solar inverter is paired to smart car charger. Participant has it set to charge exclusively on excess solar PV that would otherwise be exported.
Oliver	1x EV	Power socket	Solar PV and battery	Time of use	EV is manually charged from a power socket 3-4 nights per week.
Daniel	2x EV	EV charger	Solar PV and battery	Time of use including cheap 12am-4am rate	PHEV is charged as needed.
Bailey	1x EV	EV charger	Solar PV and battery	Flat rate	Smart plug on a power socket, programmed to come on when solar export exceeds 1.9kW; the amount he observes the car typically draws.
Grace	2x EV	Power socket	Solar PV	Flat rate	Also occasionally tops up manually at other times using excess battery capacity as and when needed.
Tay	1x EV	Power socket	Solar PV	Time of use with demand charge	Smart plug used to charge during cheap off-peak electricity from 12am-4am.
Devi	1x EV	Power socket	Solar PV and battery (installed recently)	Flat rate	Second car charged manually during the day during daylight hours to maximise solar self-consumption.
Dylan	2x EV	EV charger	Solar PV and battery	Free electricity 11am-2pm, cheap 12am-4pm	Plugged in manually as needed, generally during the day (to maximise solar self-consumption), sometimes during peak hours.
Aisha	1x EV	EV charger	Solar PV	No data	Both cars charged manually. Shared house, both housemates charge according to an agreed schedule to avoid having both EVs charging at once, to utilise solar, and avoid charging at peak hour.

Figure 9 provides analysis of EV charging events from participants with a dedicated EV charger, broken into (a) daytime hours 06:00 to 16:59, (b) typical peak consumption times on the NEM 17:00 to 20:59 and (c) overnight 21:00 to 05:59. Using the EV circuit of the Wattwatchers energy monitor, threshold analysis was applied to the circuit, where a charging event was designated as beginning when consumption exceeded 0.1 kW and finishing when consumption fell below 0.1 kW. The time of day of all charging events was captured, enabling calculation of the total hours charged at different times of the day.

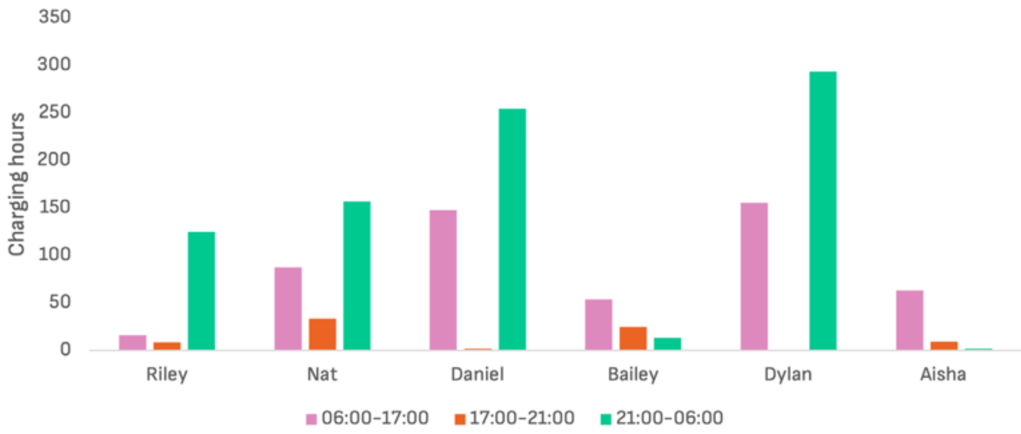


Figure 9. Hours charged by time of day.

DAYTIME CHARGING WAS SUPPORTED BY WORKING FROM HOME FLEXIBILITY ALLOWING SOLAR SELF-CONSUMPTION

Figure 9 shows the substantial extent to which these participants charge during the day off solar, or at night. Solar panel ownership (all participants in Figure 9) and cheaper night tariffs (n=3) appear to strongly influence charging behaviour. Figure 9 shows very little peak time charging by those with dedicated car chargers, while Figure 7 shows the sum of all EV owners in the sample does contribute to peak time electricity use, leading us to infer that much of this contribution comes from those using power-point charging.

The lower wattage of power point chargers may mean these need to be plugged in for longer (than fast chargers) and several of those using power point charging reported charging as and when needed (n=2) or topping up manually in addition to scheduled timer or smart-plug initiated charging (n=3, Table 6).

All EV owners charged primarily at home, describing this as preferable to using public chargers. Only Dylan reported his wife regularly used public chargers owing to her extensive work travel. EV owners reported how their charging behaviour was supported by the flexibility of working from home, enabling participants to charge their cars off their solar power while they worked. Five participants reported charging at home around their WFH schedule. Tay described the convenience of charging at home compared to charging in public.

> *"I had [a period of complementary] free charging through the EV [purchase] which was actually worse. It was free electricity, but I had to go and sit at an EV station and fill it up, either during a [Uber] shift or after a shift. Whereas when that [offer] finished [...] I just drive home and plug it in and go upstairs and knock off. So it was quite doable to run the car hundreds of kilometres a week from a granny charger, no trouble at all." (Dylan)*

> *"If it's a clear day, then I might alter the charge, [...] fill up to 90% instead of 80% because we're getting the power for nothing. But if I'm going to work and I can see that it's rainy or overcast, I'll turn it off for that day and let it run tomorrow." (Tay)*

Participants with batteries also managed their EV charging alongside their battery, for example they would limit car charging on days where they expected an evening price spike on the spot market, instead maximising their home battery's charge to ensure they could export the maximum amount in the evening. Whereas sunny days without a forecast high price event would be used for car charging. Other participants reported taking advantage of their hours of free electricity, charging the car and their home battery from the grid (as well as the solar) each day in the free electricity window of 11am–2pm.

3.2.4 Living with batteries

The WP7 Living Lab commencement (August 2025) unintentionally coincided with the Australian Government "Cheaper Home Batteries" program[3] which commenced in July 2025. This meant that while 7 of the 35 households owned a battery at the commencement of the Living Lab, this number grew to 14 households by January 2026. This rapid home battery adoption reflects national trends, where the amount of new residential batteries installed more than tripled between 2024 and 2025, with expectations of the trend continuing in 2026[4].

Batteries served to flatten household load profiles, compared with the aggregate load profiles of all 31 solar households (ignoring battery and EV status). Figure 10 shows that battery households have less export and lower peak time usage than the average of all solar households.

Figure 10. Average net grid connection per household at 15-minute intervals over 24 hours from midnight to midnight for battery vs solar households. Positive values indicate net electricity import from the grid, while negative values indicate net export to the grid.

3 https://www.dcceew.gov.au/energy/programs/cheaper-home-batteries
4 https://cleanenergycouncil.org.au/news-resources/rooftop-solar-and-storage-report-july-to-dec-2025

However, Figure 10 also suggests that opportunities exist to further optimise battery behaviour. Because battery households still export to the grid once their batteries are fully charged, and the highest level of export among battery households is comparable to non-battery solar households. Additionally, as described below, many batteries stopped delivering electricity to the grid during peak demand times.

Motivations for battery purchase

The significant uptake of batteries among our participants related to previous desires to "better collect the solar" (Amy) and were facilitated by the substantial price reduction created by the Cheaper Home Battery rebate:

> *"I've been waiting for 20 years for the economics to stack up for batteries. Getting frustrated with market offers, watching bills going up despite us doing a lot in the past like full LED lighting, so dying to get a means of insulating us from future rises." (Kim)*

Participants saw batteries as a means of achieving peace of mind, as well as future-proofing against increasing electricity bills, particularly for those participants at or close to retirement who were conscious of limited income in later years.

> *"I want to have something that will save me money in the long-term. Now we have no option of generating income (as retirees). [...] We want to be comfortable and for it (our comfort) not to be dependent on [electricity] prices going crazy." (Casey)*

More technically inclined participants saw batteries as a means of direct energy market participation, where some participants (n=4) reported switching electricity retailers to a retailer who provides direct exposure to the National Energy Market (NEM) spot market. These participants managed their battery (or had their retailer manage their battery) to charge for free from solar panels or low/negative spot prices during the day and sell excess power to the grid at elevated prices during peak demand hours.

Battery behaviour and operation post-purchase

We analysed the behaviours of the batteries installed as of February 2026 from the Grid Incomer Circuit, noting the co-ownership of PV and EVs (details of this analysis are available in Appendix C). From this analysis we identified several general battery behaviours.

1. **Minimal import, daytime export (n=7)**– Batteries used for home use, typically charging off solar and beginning to export to the grid once they are full.
2. **Minimal import, daytime AND peak time export (n=3)**– As per (1) above, but the batteries continue to export into the evening. These batteries are both of a substantial size (24, 48 and 40 kWh respectively). Joshua exported less during the middle of the day, exporting almost exclusively during peak hours 4-8pm.
3. **Variable import and export (n=2)**– Mixed behaviour, both use the battery for EV charging and home use.
4. **Other**– including Riley's largely flat profile, Dylan's substantial imports driven by charging two EVs and Taylor's battery which was no longer functioning correctly.

SECTION THREE
RESULTS AND DISCUSSION

Two findings regarding our participants' battery ownership stand out:

1. The significant capacity of many batteries in the sample. Eight of the 10 installed batteries at the time of the survey were over 20 kWh and two of these were over 40 kWh in capacity. Several of the more recently installed systems reflected participants taking advantage of the low marginal cost of additional storage by installing batteries with capacities that exceeded household requirements, with a view to exporting spare capacity to the grid at peak times.
2. The majority of batteries did not regularly export electricity to the grid during typical peak demand hours.

To further this analysis, we analysed battery households' import/export behaviour on the days where the highest electricity spot prices of the year (to date) occurred for the QLD (Figure 12) and NSW (Figure 11) energy markets. Spot price data was downloaded from the Australian Energy Market Operator (AEMO)[5].

In NSW, the day with the highest spot price spike occurred on the hottest day of the year, 10 January 2026 when maximums temperatures reached 42.2°C in Sydney and 40.5 °C in Newcastle (Williamstown). In QLD, the day with the highest spot price (15 January 2026) occurred on a warm but unremarkable day with a maximum of 31.5°C in Brisbane City and was instead caused by an unscheduled outage at a coal-fired power station[6] against a backdrop of QLD's high AC demand.

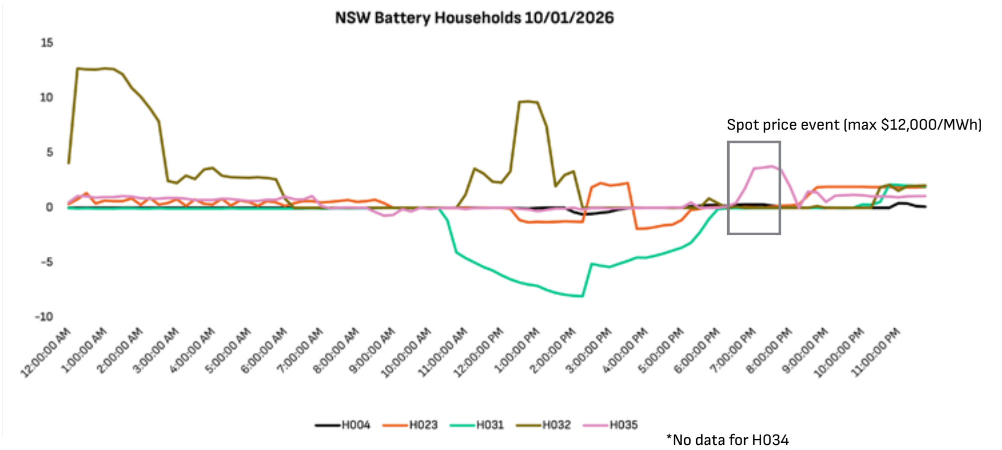


Figure 11. Grid incomer circuit behaviour of NSW households with home batteries on the day where the highest spot price of 2026 was observed.

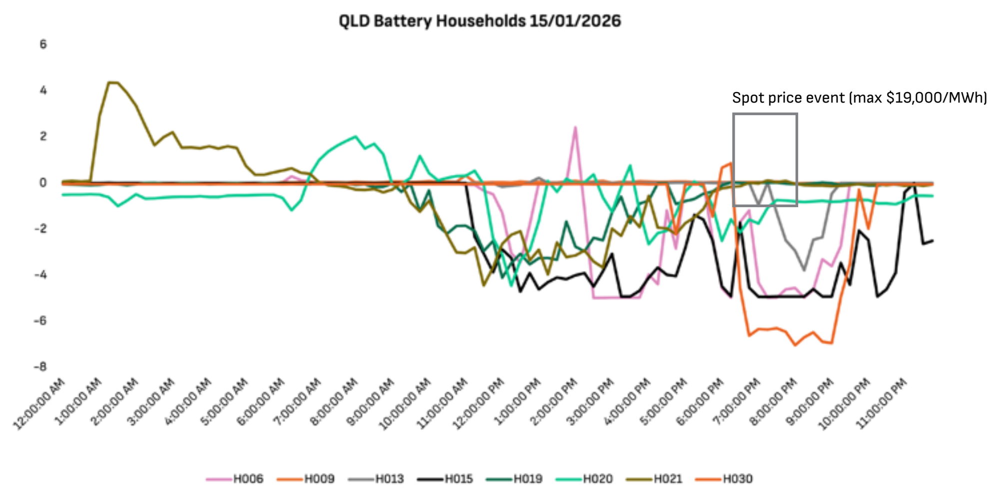


Figure 12. Grid incomer circuit behaviour of QLD households with home batteries on the day where the highest spot price of 2026 was observed.

5 https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/aggregated-data
6 https://wattclarity.com.au/articles/2026/01/15jan-frequencyweakness-causes/

These figures show that battery households imported little power from the grid, including during the peak hours (16:30 to 20:30). Yet equally notable is the lack of correlation between battery behaviour and electricity spot price. None of the five NSW battery households and only four of the eight QLD battery households appear to react to spot price signals. One participant was also exporting on the afternoon of 15 January 2026, but their behaviour was more coincidental than reactive, and the battery reduces its export prior to the end of the peak price event. Another participant, whose battery was later found to be malfunctioning was importing power during peak demand hours. It is important to note that not all battery models are capable of VPP participation. But nonetheless, only 5 of the 13 batteries were delivering power to the grid during these peak demand events, suggesting the need to unlock greater home battery participation in responding to critical peak demand events.

All those households with batteries exporting during peak times were subscribed to an electricity retailer which offers direct spot price exposure. These participants used either the retailer's VPP or their battery's own energy management algorithm to operate their batteries. Two of these participants did not trust that their battery was making the right decisions for them. In response, Kim had a workaround:

> *"I manually control it at the moment. Basically every afternoon I look to see what the forecast (spot) price is and they go "OK, so from 5:30 onwards, we're going to dump, you know, 20 kilowatt hours into the grid" [...] to try to keep our heads above water [meaning to make money from the battery]." (Kim)*

These findings highlight the potential complexity of battery management and VPP participation.

On the other hand, we found no evidence of overt unwillingness to share electricity from their battery. Rather, that sharing electricity was (presently) inconvenient and time consuming; and some participants did not trust their battery to make the right decisions to maximise their financial returns. Our subsequent research will more specifically target participants' experiences of battery ownership, and their attitudes towards other forms of sharing electricity more generally, including beyond VPP participation such as behavioural demand response offerings and changing the settings of their batteries to maximise the return of spot-price exposed tariffs.

Living with a battery: A new era of abundance

Battery purchase and the ability to store (and sell) solar energy represented a shift in the way electricity was conceptualised in the home. Those who had purchased larger batteries spoke of coming to terms with their new-found "free" electricity:

> *"At first it was like 'am I allowed to do that?' [...] But then we were waking up with still like 80% battery capacity, so our mentality changed to 'use electricity like it's free!' [...] We run the dryer whenever we want." (Liam)*

Abundant electricity led to participants describing how previous conservation behaviours, such as minimising consumption or load shifting to make use of solar, become unnecessary or optional, depending on whether they wished to conserve battery power to maximise exports during peak times.

> *"We generally try and run that [washing machine] during the day, but obviously once the battery is here, all that goes out the window, because the battery will store everything we need, it's not going to be an issue." (Joshua)*

"IT'S MADE US MORE WASTEFUL OF ELECTRICITY

> *"It's made us more wasteful of electricity and lazy, cos I rarely put clothes on the line, I whack it in the dryer" Our dryer died 12 months ago and normally you'd replace it with a heat pump [dryer], but why bother, because its free electricity." (Dylan)*

This lack of needing to worry about conservation or load shifting was also described as a mediator in families and an end to minor family disagreements around preferences for load shifting versus everyday practices:

> *"Before [the battery] I was worried about the dishwasher being put on during the daytime. [...] I don't object to the full dishwasher being there [unwashed] all night. Whereas they [wife and daughter] want it cleaned. And before we had the battery, that used to worry me. Now with the battery, it just doesn't matter. Doesn't matter. Because the battery will do everything. And it's solar energy that I'm using." (Daniel)*

> *"[In the absence of any more electricity disagreements]...the only issue now is me wanting to turn up the telly because I'm going deaf and my wife saying that 'that's too loud!'. That's about it." (Kim)*

These findings describe the largely positive impact batteries had on families, both in terms of reducing concerns about electricity use and in removing previous minor "battles" around conservation, load shifting, convenience, and routine. However, battery ownership also gave rise to ethical considerations for some participants.

Ethical conundrums of limitless free energy

Some participants reflected on ethical aspects of their new-found (essentially) limitless free electricity. As described by Dylan, the unease stemmed from the fact that these behaviours were not accessible to everyone:

> *"The wastefulness that this electricity setup I've got is encouraging; I'm not sure whether it's a positive thing or not. We're drying clothes in the dryer, you know, the dishwasher is always on the hottest possible cycle, as is the washing machine. So we use a lot more than we would if there was a cost driver. In the middle of the day, if spot price is negative, there's an abundance of renewables, sure. But this excessive usage, it's not something that's sustainable for the whole of the population long-term, I don't think."*

3.3 Home comfort — Heating, cooling, caring, and compromise

Here we explore comfort in Living Lab participants' homes. All but one of the 35 households had refrigerated AC installed, compared to only 56% of the 5,012 sample WP1 survey (Kaviani et al. 2025), which may reflect QLD's warm climate and the majority home-owners status of our living lab households. We analyse AC energy consumption data and understand the overall relationships between AC usage and outdoor temperature. We then explore thermal comfort as reported by participants and some of the human factors driving AC usage, including the ways in which AC use was mediated by caring for others and compromise with other household members.

3.3.1 Air conditioning energy consumption

We surveyed participants on the appliances they used to heat and cool their homes, then based on these results, focused our analysis on AC use and the factors predicting it. Our focus on AC is due to (a) most heating and cooling achieved in all Living Lab households was electric, with very few utilising gas or solid fuel heating (Figure 8). (b) Air conditioners were the most common heating and cooling source in households (split systems and ducted ACs combined, Figure 13). Ceiling fans were also widely used for cooling but draw very low current and cannot be observed through energy use data.

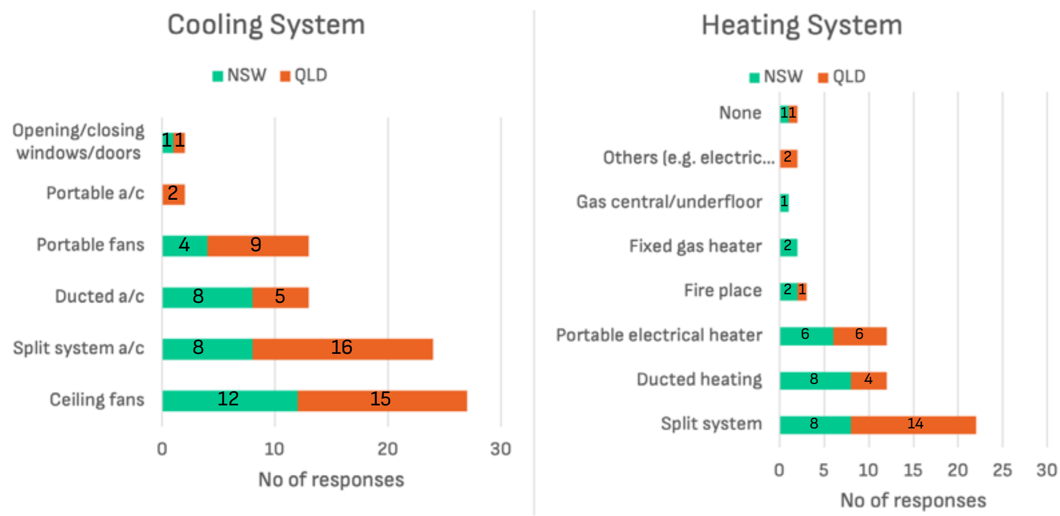


Figure 13. Heating and cooling systems adopted by participants by state.

We then used fixed effects regression analysis to understand the drivers and predictors of AC use in Living Lab households.

Model A: What drives daily AC use within Living Lab households?

The first AC use model was designed to examine associations between factors that vary day-to-day and AC electricity use within households, rather than to identify causal drivers. The focus is on identifying contextual conditions that drive household cooling decisions excluding time-invariant household characteristics such as dwelling design, appliance configuration, and occupant preferences.

Model specification

A household fixed-effects regression of daily AC electricity on a quadratic function of outdoor temperature shows a strong and statistically significant within-household response to outside temperature, $F(3, 25)=10.53$, $p< 0.01$). The model explains about 16% of within-household day-to-day variation in AC consumption (within $R^2=0.16$; Root MSE=3.55 kWh/day). Both the linear outdoor temperature term ($\beta=0.67$, SE=0.12, $p< 0.01$) and the quadratic temperature term ($\beta=0.074$, SE=0.022, $p<0.05$) are statistically significant, indicating a non-linear response where the marginal effect of temperature increases at higher temperatures.

OUTDOOR TEMPERATURE WAS THE DOMINANT DRIVER OF SHORT-RUN COOLING BEHAVIOUR WITHIN HOUSEHOLDS

After accounting for the non-linear temperature response, outdoor humidity does not independently explain additional within-household variation in AC use (β=0.0005, SE=0.0094, p>.05). This suggests that, during October, household cooling behaviour was primarily driven by perceived heat stress associated with rising outdoor temperatures rather than humidity. Overall, these results indicate that outdoor temperature is the strongest environmental correlate of day-to-day variation in household AC electricity use. AC demand increased with temperature, with evidence of a modest non-linear relationship whereby sensitivity to temperature became stronger at higher temperatures.

Importantly, the quadratic specification implies that the relationship between temperature and AC use is not strictly monotonic across all temperature ranges. The fitted relationship reaches a minimum at approximately 18°C above which AC electricity use increases with temperature. This may reflect the onset of more active cooling behaviour as outdoor temperatures become warmer (See Figure 14). It is also important to note here that while the quadratic term is statistically significant, the predicted margins indicate that the relationship appears approximately linear over the observed temperature range, with only modest curvature.

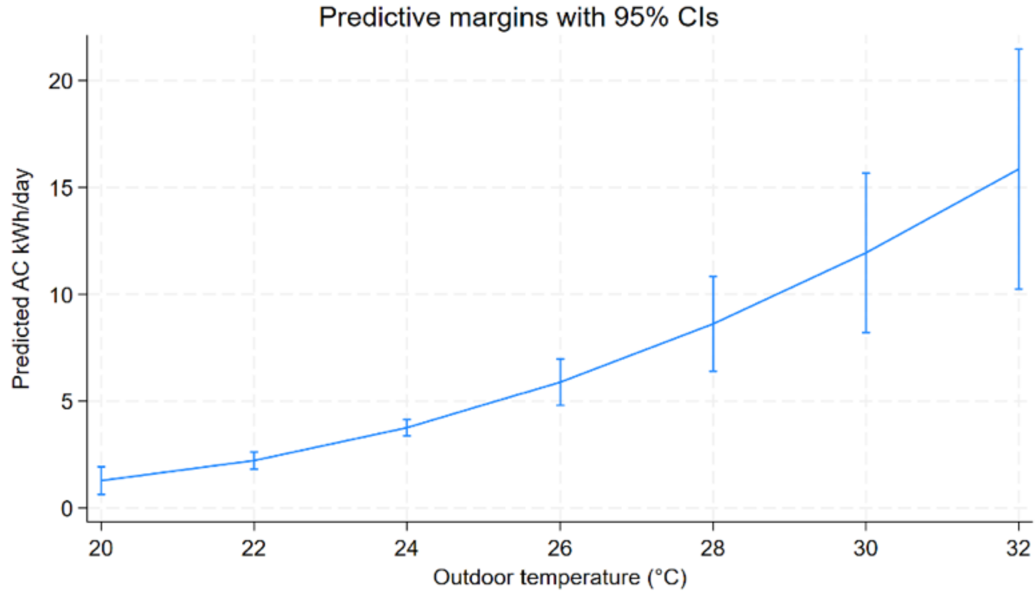


Figure 14. Predicted AC consumption increases once outdoor temperatures exceed approximately 18°C, with demand rising progressively at higher temperatures (CIs stand for Confidence Intervals).

Table 7. Predicted daily AC electricity use at selected outdoor temperatures.

Outdoor temperature (°C)	Predicted AC use (kWh/day)	95% CI	Interpretation
20	1.28	0.63, 1.92	Low AC use on mild days
22	2.21	1.81, 2.62	Modest AC use
24	3.75	3.37, 4.13	Cooling demand begins to rise
26	5.89	4.80, 6.97	Moderate increase
28	8.61	6.39, 10.83	Clearly increasing demand
30	11.94	8.21, 15.67	High AC use on hot days
32	15.86	10.25, 21.47	Very high cooling demand

Adjusted predictions were computed to illustrate how daily AC electricity use varies across outdoor temperatures, holding outdoor humidity at its mean and household fixed effects constant (Table 7). On a mild October day of 22°C, predicted AC use is approximately 2.2 kWh/day. By contrast, on a hotter day of 30°C, predicted AC use increases to roughly 11.9 kWh/day, and at 32°C reaches approximately 15.9 kWh/day. Taken together, these results show that outdoor temperature is a strong determinant of daily AC demand with participants becoming progressively more sensitive to heat on hotter days. This pattern is again consistent with the estimated quadratic temperature specification and reflects an increase in AC use as outdoor conditions become hotter.

Model B: Once AC is being used, how do participants achieve thermal comfort?

Utilising indoor temperature and humidity as thermal comfort indicators, Model B examines the effort households undertake to maintain their comfort under varying indoor and outdoor conditions whilst holding household fixed effects constant.

Because indoor temperature and humidity are jointly determined with AC operation (i.e. AC use directly influences indoor conditions), these variables should not be interpreted as independent causal drivers of AC use.

Similarly, outdoor temperature may influence AC use both directly and indirectly through its effect on indoor conditions. As such, including both indoor and outdoor variables means that coefficients capture conditional associations rather than total causal effects.

As indoor conditions are jointly determined with AC operation, Model B should be interpreted descriptively rather than causally.

Model specification

The fixed-effects model of AC use with indoor and outdoor temperature and humidity levels is statistically significant $F(5, 25) = 8.32$, $p<.01$). The model explains approximately 24% of within-household day-to-day variation in AC electricity use (within $R^2=0.243$; Root MSE=3.37 kWh/day). The estimated intra-class correlation ($p=0.61$) indicates that a substantial share of total variation in AC electricity use is attributable to time-invariant household-specific factors, justifying the use of a fixed-effects specification.

Table 8 shows that outdoor temperature continues to influence AC electricity use in a non-linear manner. While the linear outdoor temperature term was not statistically significant, the quadratic temperature term was positive and statistically significant.

Table 8. Results from Model B fixed effects model.

Variable	Coefficient	Robust standard error	t	*p*-value
Outdoor temperature	-0.93	0.96	-0.97	0.34
Outdoor temperature* outdoor temperature	0.06	0.02	2.86	0.008
Outdoor humidity	0.17	0.04	4.20	0.000
Internal temperature	-1.56	0.04	-2.91	0.008
Internal humidity	-0.22	0.05	-3.98	0.001
_cons	35.59	10.03	3.55	0.002

The combination of a negative linear term and positive quadratic term reflects a non-linear relationship, rather than implying that AC use decreases as temperatures rise. Instead, AC use increases more rapidly once outdoor temperatures exceed a threshold, consistent with the onset of active cooling demand.

Outdoor humidity was positively and strongly associated with AC electricity use. This result indicates that more humid outdoor conditions were associated with higher AC electricity use, consistent with increased cooling and dehumidification demand.

Indoor temperature and indoor humidity were both negatively associated with AC electricity consumption. Lower indoor temperatures were associated with higher AC use, and lower indoor humidity was similarly associated with higher AC use.

These associations should not be interpreted causally, as AC operation itself drives reductions in indoor temperature and humidity. Therefore, these variables reflect achieved thermal comfort conditions rather than independent determinants of cooling behaviour.

Overall, Model B provides a descriptive characterisation of how AC electricity use co-varies with indoor and outdoor environmental conditions, rather than identifying causal drivers of cooling behaviour.

3.3.2 Thermal comfort

Participants rated how satisfied they were with how their home felt (before cooling/heating) during summer and winter months on a five-point Likert scale (Figure 15). Participants were generally more satisfied with how their homes felt during summer than in winter. In winter, satisfaction was lower, and this was particularly prominent in NSW where the median rating was 2 with an IQR of 2–4 when compared with QLD's median of 3 and IQR of 2–4. Participants who were satisfied with the comfort of their home in one season were generally more likely to be satisfied in the other season (r=0.55, p<0.05).

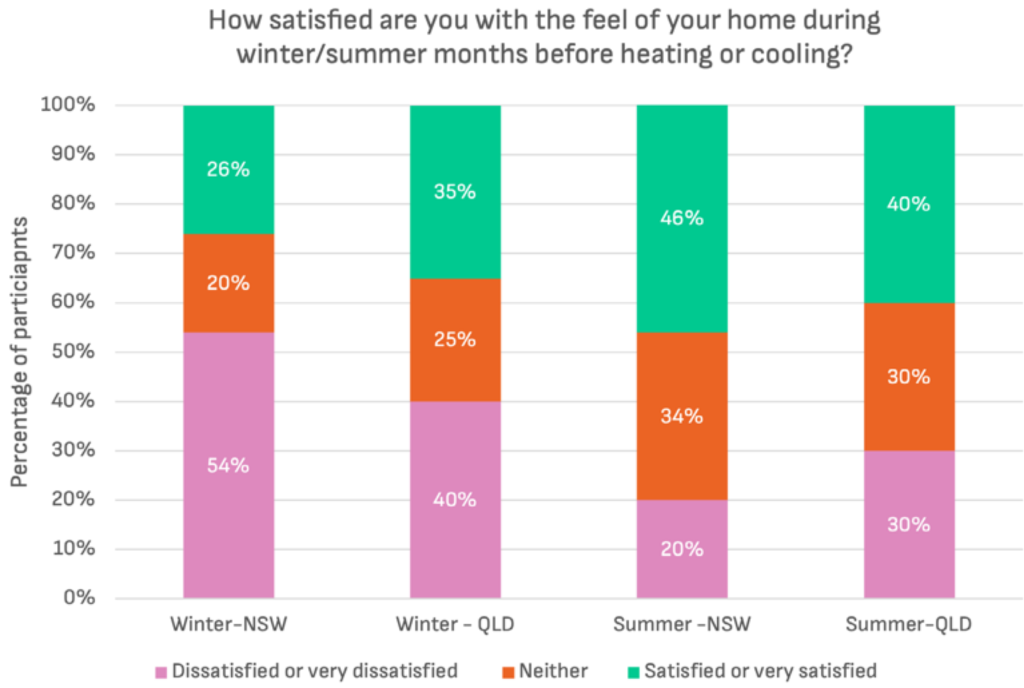


Figure 15. Perceptions of thermal comforts at home.

Participants were asked what they thought could have contributed to the (cold/warm) conditions in their homes. Most responses were related to building design and materials such as uninsulated walls, floors, large areas of single-pane glass, older building standards, draughts, and inadequate sealing. A few participants described room-level variation, where parts of the home (e.g., upstairs vs downstairs) behaved differently thermally. A smaller set of responses reflected personal or household preferences, such as differing temperature needs among household members, or strategies like using fans, blankets, or selective heating.

Overall, participants' explanations suggest that home thermal comfort was influenced primarily by structural thermal performance, climate and seasonal conditions, and household needs or routines.

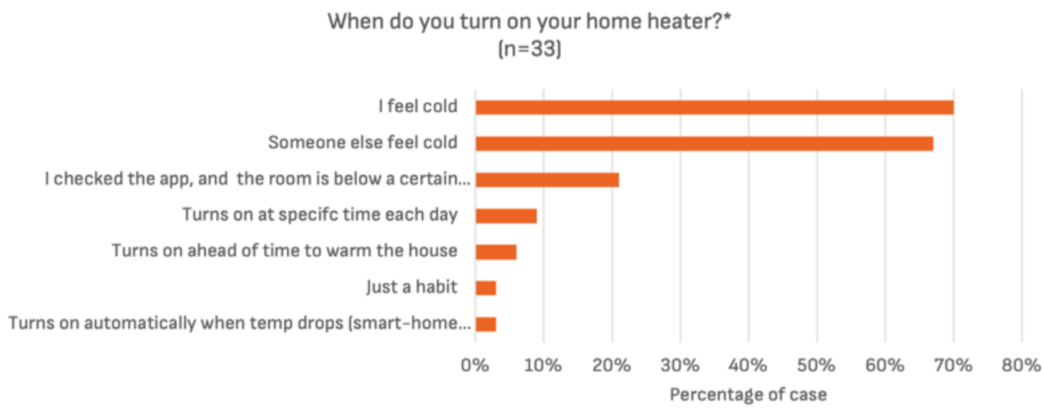
For example:

> *"Our house is constantly at around 15 degrees during the winter" (Chloe).*
>
> *"It's a difficult house to keep warm in winter because of the design and building materials." (Devi)*

3.3.3 Thermal comfort needs – caring for others

CARING AND CONSIDERATION OF OTHERS FACTORED INTO MANY HOUSEHOLDS' HEATING AND COOLING BEHAVIOUR

Participants were asked whether they had anyone in their household (including pets or plants) who required the home to be kept warmer or cooler for comfort. Nearly half of participants (46%) said yes, and an equal proportion (46%) said no, with a small group (9%) unsure. Participants were also asked to select up to three reasons that typically drive their decision to switch on heaters. Their responses are captured in Figure 16.



*Participants were allowed to provide up to 3 responses and therefore percentages may not add up to 100%.

Figure 16. Decisions to turn on heating systems at home.

Some participants reported that they did not use a heater at home. One participant noted that they turned on the heater simply to enjoy sitting in front of the fire, while another mentioned using it to take advantage of "negatively priced wholesale energy if [they] anticipate it will be cold later." For most participants, heating use was triggered by immediate comfort needs: they switched the heater on when they felt cold (70%) or when someone else in the household felt cold (67%). Far fewer participants relied on checking an app, following a schedule, or using automation. This suggests that heating behaviour is intuitive and reactive rather than routine or technology driven.

The qualitative responses also captured the substantial way in which caring for others influences how participants make comfort decisions and operate heating and cooling in the home. This was particularly evident for participants with children, extended families, and households with someone with specific comfort needs (n=12). In many cases, this meant participants setting aside their own aspirations for optimisation in favour of care for others:

> *"A funny thing happened when I became a parent. I sort of recognised over a period of time that the house needs to serve mum first [referring to his wife]. [...] Prior to that I, you know, I'm naturally inclined towards efficiency and monitoring and making the best use of energy and all that sort of stuff. [...] I'd be putting on a jumper instead of going to the heater, or I'd be implementing like morning and nighttime routines where we close all the blinds on this side of the house [...] And then when we had kids, if mum's cold and if I say, "oh you can just wear a jumper" it's just not gonna go down anymore. So I think now, our energy use is for the humans first. That's the primary consideration." (Jason)*

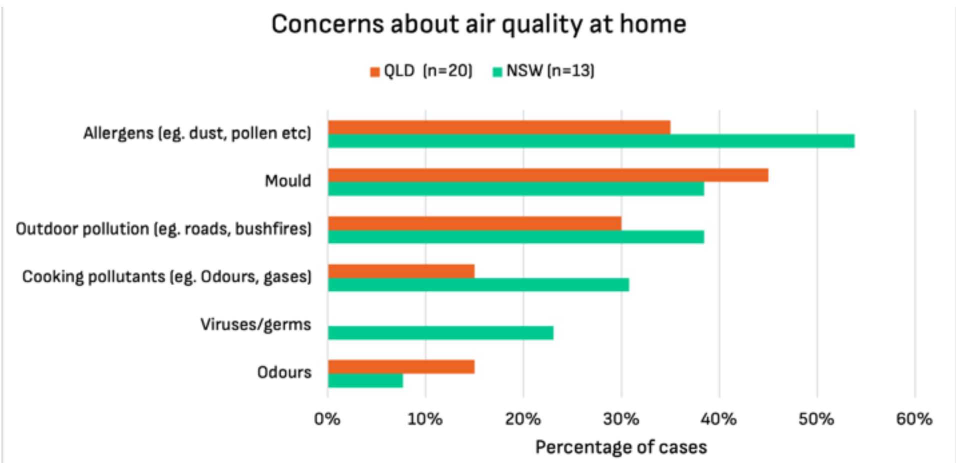
Aisha lived in a house with her family as well as her parents, who lived in a separate flat, but with only one electricity meter (and hence one bill) received for the property. They had chosen to split bills evenly, despite acknowledging this was not always going to be a correct reflection of actual energy use:

> *"I think my parents probably turn on the air con quite a bit. [...] I think they probably put things on, like they put on heating in the winter. They heat their lounge room in the evenings right up until like October. But that's just like, they have the right to do that because they've lived a long life. [...] We have just decided to split [the bill] straight down the middle 50-50. We don't ask questions around usage or kind of point fingers. We just split it."*

In other cases, heating and cooling were often determined by others in the house, including Ava, Morgan and Taylor, whose partners had medical conditions requiring lower humidity or cooler temperatures.

3.3.4 Air quality — concerns and caring for others

Similar to WP1, Living Lab households were asked about the air quality in their home. Over half of households (57%) expressed concern about indoor air quality in WP1, compared to a higher share (67%) among Living Lab participants. Just over one third of participants in NSW (n = 5, 38%) and around one third in QLD (n = 6, 30%) stated that they were not concerned. Among those who did express concerns, the most common issues were allergens (NSW = 56%, QLD = 35%), mould (NSW = 38%, QLD = 45%), and outdoor pollution (NSW = 38%, QLD = 30%) (Figure 17).



*multiple responses were allowed and therefore percentages may not add up to 100%

Figure 17. Concerns about air quality at home.

Participants were further asked whether they took any actions to manage indoor air quality. In NSW, fewer than half of participants (n = 7, 47%) reported taking action, compared with just over half in QLD (n = 11, 55%), with additional smaller proportions indicating "maybe" (20% and 5%, respectively). Participants were also asked whether they had experienced events that increased their awareness of indoor air quality. Under half of participants in NSW (n = 7, 47%) and fewer than two thirds in QLD (n = 12, 60%) reported such events, although these differences were small and not statistically significant. Although QLD participants showed slightly higher rates of both management behaviours and awareness, these differences were small and not statistically significant.

When given the opportunity to describe the events that raised their concerns about indoor air quality, participants most often referred to wet or humid weather that led to mould growth in their homes. Several also mentioned exposure to air pollutants such as dust (including quarry dust), traffic emissions, musty or drain-related odours, and smoke from cooking or bushfires. Some participants noted household allergy or respiratory experiences, and one participant reported being alerted to high CO_2 levels by an environmental monitor that was installed as part of the study. Just under one quarter of participants reported owning air purifiers (23%). Air quality was of particular significance for some participants whose partners had health conditions that required consideration.

WP7 FINDINGS ALIGN WITH THOSE OF WP1, WHERE MOULD WAS A COMMON INDOOR AIR QUALITY CONCERN

Overall, WP7 findings align with WP1 in identifying indoor air quality, including mould, as common concerns. WP1 also reports a modest (17%) ownership rate of air purifiers (Kaviani et al. 2025). Despite heightened awareness of indoor air quality, the uptake of air purifiers remained modest, suggesting that while concern for air quality exists, responses vary in intensity and may be shaped by specific triggers such as health conditions or environmental events. Similarly, WP1 found households prefer to utilise low-cost, simple solutions (e.g. natural ventilation, ceiling fans) to manage their household indoor air quality.

In the interview, Taylor whose partner lived with a health condition described the substantial impact that occurrences such as planned burns and neighbourhood wood heaters had on their comfort. For this reason, Taylor had installed a heat recovery ventilator (HRV) and had been an early adopter of purifiers:

> *"We have more purifiers than people [in the house] at the moment. When they became readily available we purchased consumer grade ones. [...] They're pretty good. But I thought well with my wife's health issues, I wanted something better. So I went hunting and I found an Australian company that makes ones that are not as sophisticated, but a good deal bigger, very very large filters. We don't use them much, but they're there for when they're needed." (Taylor)*

> *"One of the reasons I got the air purifier was because, well, my daughter's a GP and she was starting to get sick quite often. I said you might not believe in it, but I during I read up on what the health clinicians were doing for themselves during COVID and most of them said that they used an a purifier and that they actually do make a difference. So that was why I got one for her and I got one [for me]." (Ava)*

Several Brisbane participants noted the challenges of managing humidity and dampness indoors after recent high rainfall years. Robyn described the feeling of her work-from-home chair in the room under the house going damp and the balance between managing humidity and high energy use:

> *"We go away for three or four days and the house is locked up, you come back and you walk in and the smell, you know it's an old house.... Trying to get the internal environment feeling good, but not at the risk of using too much energy. Its been a real tough one."*

3.3.5 Compromise: "Battles" over thermostat

We asked participants about any "battles" or differences in opinion they faced with their families regarding energy. Many of these light-hearted "battles" were typically about thermostat settings or AC operation (n=7), including covert thermostat adjustments (n=3), finding the thermostat has "crept up again" (Amy), their partner adjusting the thermostat up or down as they walked past it (Noah), or suggestive comments such as: "gee it's getting a bit hot in here". Bailey described a compromise reached in the winter:

> *"I'd prefer to put on a jumper, but my wife likes it to be warm. That's a big contention point. We've found a happy medium. It [heating] is on, which I don't like, but at least it's not as hot as she'd like it. So we're both compromising. But then of course my son will come in and turn it up anyway."*

In shared living arrangements such as those of Nat and Grace, concerns over heating and AC use were internalised rather than vocalised. Nat had an extended family member living with them and was quietly frustrated by their substantial use of heating and cooling. Nat felt their housemate used the heating and cooling more than they did and more than was necessary but had no intention of ever mentioning this to them. In both cases, electricity costs were included in the rent.

In families, a key source of these compromises was differences in preferred temperature between partners and children. Almost all male participants in families or couples mentioned their female partner preferred it warmer than they did. This is supported by substantial science, with meta-reviews highlighting that women feel the cold more than men (Vellei et al., 2025). However, optimisation also featured strongly, where Dylan joked his family felt he had "weaponised" the Tether (indoor climate monitor), and noted that he would point to the Tether data showing the home was within a "comfortable" range as justification for not switching on the heating when others felt cold.

3.4 Household energy practices and electricity demand patterns – A basis for understanding demand flexibility

The findings presented here provide a basis for our future analysis of energy use flexibility. In the initial WP7 survey (reported here) we have focused on the timing of practices, while further surveys will focus on the flexibility of practices and willingness to shift.

3.4.1 Household routines and appliance use

Participants were asked a series of questions about their household routines and appliance use, and for each activity, were asked to select the time of day when it is most often performed. The tables below show the percentage of participants whose households undertake each listed activity during specific time slots. The tables use colour shading to illustrate the distribution of activities across time. Darker shades correspond to higher percentages of participants reporting an activity in a given time slot, whereas lighter shades indicate lower participation.

Table 9. Household morning and evening activities on weekdays.

Weekday morning activities	6am–10am	10am–3pm	Varies	Always on	N/A
Making breakfast with electric stove	86%		3%		11%
Heating your home (cold days)	35%	15%	21%	6%	24%
Cooling your home (hot days)	6%	43%	23%	6%	23%
Hot water for bathing	46%	3%	29%	3%	20%

Weekday evening activities	3pm-8pm	8pm-6am	Varies	Always on	N/A
Making meals with electric stove etc	89%	6%	6%		
Heating your home (cold days)	40%	9%	23%	9%	20%
Cooling your home (hot days)	40%	6%	26%	11%	17%
Hot water for bathing	54%	17%	20%		9%

Table 10. Household working from home activities.

Working from home	6am–10am	10am–3pm	3pm-8pm	8pm-6am	Varies	Always on	N/A
Starting work (turning on devices etc)	80%	4%				12%	4%
Video calls/online meetings with devices	8%	56%			24%	8%	4%
Making meals/ break in kitchen	8%	64%	12%		8%	4%	4%

HOUSEHOLD PRACTICES SUCH AS LAUNDRY, DISHWASHER USE, EV CHARGING, AND SOME HEATING OR COOLING WERE MOST LIKELY TO VARY IN TIMING, SUGGESTING POTENTIAL FLEXIBILITY IN DEMAND

Similarities are evident in household practices that align with electricity peak demand during weekday mornings and early evenings. High-participation activities such as cooking, hot water use, space heating or cooling, and the start of work-from-home activities are clustered within narrow time windows, reinforcing the key role of everyday practices in shaping household electricity demand. The presence of "varies" and "always on" household practices highlights that not all practices are uniformly fixed. Household practices such as laundry, dishwasher use, EV charging, and some heating or cooling were more likely to vary in timing, suggesting potential for shifting, whereas "always on" loads reflect less flexible baseline demand.

In the morning period (6am—10am), several high-participation and energy-intensive activities occur concurrently. Breakfast preparation is overwhelmingly undertaken during this time, alongside substantial hot water use for bathing (Table 9). Space heating on cold days also contributes to morning demand. However, a proportion of participants reported that heating, cooling, and hot water use for bathing occur at varying times, indicating that for some households these activities may offer flexibility for shifting energy use outside the morning peak.

Meal preparation was again nominated by most participants as the most prominent household activity during the evening period (3pm—8pm). Hot water use for bathing is also most prevalent in the evening, while both heating and cooling are frequently reported, indicating that thermal comfort demands coincide with cooking and leisure activities. The convergence of multiple high-participation, energy-intensive practices highlights the evening as the most consistently energy-intensive period of the day.

Working-from-home activities contribute to both peak and non-peak demand (Table 10). While the start of the workday reinforces morning electricity use, activities such as video calls and kitchen use during breaks are most commonly undertaken between 10am and 3pm. This shifts a portion of household energy demand into daytime hours when overall system demand may be lower and renewable generation may be higher. However, the concentration of work start-up activities in the early morning may also intensify existing morning peaks.

Table 11. Household cleaning activities

Cleaning activities	6am—10am	10am—3pm	3pm-8pm	8pm-6am	Varies	Always on	N/A
Using washing machines	35%	47%		3%	15%		
Using clothes dryer	9%	29%	6%		26%		31%
Using dishwasher	17%	17%	9%	26%	20%		11%
Running pool pump (n=12)		92%			8%		

Table 12. Household charging and entertaining activities

Charging & entertaining activities	6am—10am	10am—3pm	3pm-8pm	8pm-6am	Varies	Always on	N/A
Watching tv or streaming	3%		57%	31%	6%	3%	
Charging EV cars (n=13)		62%		23%	15%		
Charging devices for entertainment	6%	9%	3%	46%	29%	9%	
Playing videos games, baking, or other stuff for fun	3%	14%	23%	6%	40%		14%

Cleaning activities appear to be more temporally flexible than cooking, or bathing (Table 11). Participants often use their washing machines during the middle of the day whilst dishwasher use was spread out throughout the day. Similarly, clothes dryer use is more dispersed across the day. Of those with pool pump, most participants used it during the daytime hours — this may indicate participants were trying to utilise it during periods of high solar availability.

There is a clear split between peak and off-peak activities for charging and entertainment routines (Table 12). Television viewing and streaming are heavily concentrated in the early evening. In contrast, EV charging is most commonly undertaken during the middle of the day and overnight, suggesting responsiveness to solar generation or off-peak pricing. Charging of smaller entertainment devices is predominantly undertaken overnight, while leisure activities such as gaming or baking show substantial variability in timing. Understanding patterns of household practices amongst Living Lab households demonstrate that while many practices remain tightly anchored to daily routines, others offer opportunities for flexibility. Subsequent WP7 research will examine the flexibility of certain household activities, particularly in relation to demand management and participation in flexibility markets.

3.4.2 Factors affecting household October energy consumption

An Ordinary Least Squares (OLS) regression was performed to examine the relationships between a range of household and dwelling characteristics and October energy consumption. The month of October was chosen for analysis due to (a) all households had been fully equipped with energy monitoring systems and any troubleshooting had been completed, and (b) October in Brisbane and Sydney is a month in which AC and heating use are generally more discretionary or weather-dependent rather than habitual. Table 13 reports the final model which significantly explains the variation in household energy consumption in October. Dwelling characteristics, EV ownership, and the combined practices of heating and cooling are all found to be important predictors of energy consumption, explaining about 72% variation in monthly energy consumption (R^2= 0.72; adjusted R^2=0.64) with strong overall statistical significance, $F(6,20)=8.62$, $p<.01$.

Table 13. Final OLS model

Variable	**Coefficient**	**Standard error**	**t**	***p*-value**
Bedroom group				
3 beds	-151.96	144.86	-1.05	0.31
4 beds and more	330.66	148.65	2.22	0.04
Have EV	228.14	103.37	2.21	0.04
Heating*cooling practices				
Heat but does not cool	49.44	157.77	0.31	0.76
Does not heat but cool	-229.79	147.29	-1.56	0.13
Neither heat nor cool home	-460.93	129.23	-3.57	0.00
_cons	521.24	119.33	4.37	0.00

Specifically, the final OLS model implies that:

- Dwelling size
  - Relative to households living in smaller dwellings, households in large dwellings with four or more bedrooms consume, on average, about 330.66 kWh more electricity in October. Given that the predicted consumption for the reference household (i.e.. 2 bedrooms or less) is ~521 kWh, this represents an increase of about 63% indicating a large effect.
- Ownership of EVs
  - EV ownership is associated with a substantial increase in household energy consumption. Households that own EVs consume, on average, 228 kWh more per month than households without an EV, holding all other variables constant, including dwelling size and heating and cooling practices. This corresponds to about a 44% increase in energy consumption, highlighting the meaningful contribution of EV charging to total household energy demand.
- Reported heating and cooling practices
  - Heating and cooling practices are modelled as an interaction term between heating use and cooling use, allowing combinations of these behaviours to be examined. The reference category is households that reported using both heating and cooling practices.
  - Households that reported using neither heating nor cooling consume about 461 kWh less energy per month than the reference group, representing a significant reduction ($p<.01$)
  - Households that use heating but not cooling exhibit only a small and statistically insignificant difference, indicating no reliable difference from households that use both heating and cooling.
  - Similarly, households that do not heat but do cool show a negative coefficient. This effect is, however, not statistically significant (p-0.13), and should be interpreted with caution.
- Baseline consumption
  - The constant term indicates that the expected monthly energy consumption for the reference household (that is, a smaller house without an EV that uses both heating and cooling) is about 521 kWh ($p < 0.01$). This provides a useful benchmark against which the magnitude of all other effects can be interpreted in the regression model.

Summary interpretation

Overall, the results show that structural factors (dwelling size), technology adoption (EV ownership), and energy service use (heating and cooling) jointly shape household energy consumption. The largest substantive effects are associated with large dwellings, EV ownership, and the complete absence of heating and cooling, underscoring the importance of both built form and energy end-use behaviour in determining household energy demand.

AMONGST THE HIGHER IMPACT CIRCUITS, AC CONTRIBUTES THE MOST TO PEAK ENERGY CONSUMPTION

3.4.3 Understanding the use of electricity during peak

The peak energy consumed was calculated for each household based on the electricity used in kWh across monitored circuits during weekdays between 3pm and 8pm. The median was 36.12 (mean = 60.82). The interquartile range (IQR = 16.06–75.33 kWh) shows that the middle 50% of households fall within this range, highlighting substantial variability in typical peak usage. Figure 18 shows substantial heterogeneity in household peak energy consumption across circuits with clear differences between the higher-impact and lower-impact groups. Amongst the higher impact circuits, AC contributes the most to peak energy consumption. Lighting and power circuits and general power circuits display wide distributions and large upper-tail values, indicating that extreme peak energy use is driven by a small number of households rather than being widespread. EV charging showed a low median but a pronounced right skew. This may indicate that most EV owners contributed little to peak energy consumption, whereas a small subset accounted for disproportionately high peak usage. Lower impact circuits such as hot water, cooking lighting and pool pumping showed tightly clustered peak energy consumption, indicating more stable background energy demand with limited influence on extreme peak outcomes. The figure highlights that peak energy demand was concentrated in a small number of high-impact circuits and households, rather than evenly distributed across all households in the Living Lab.

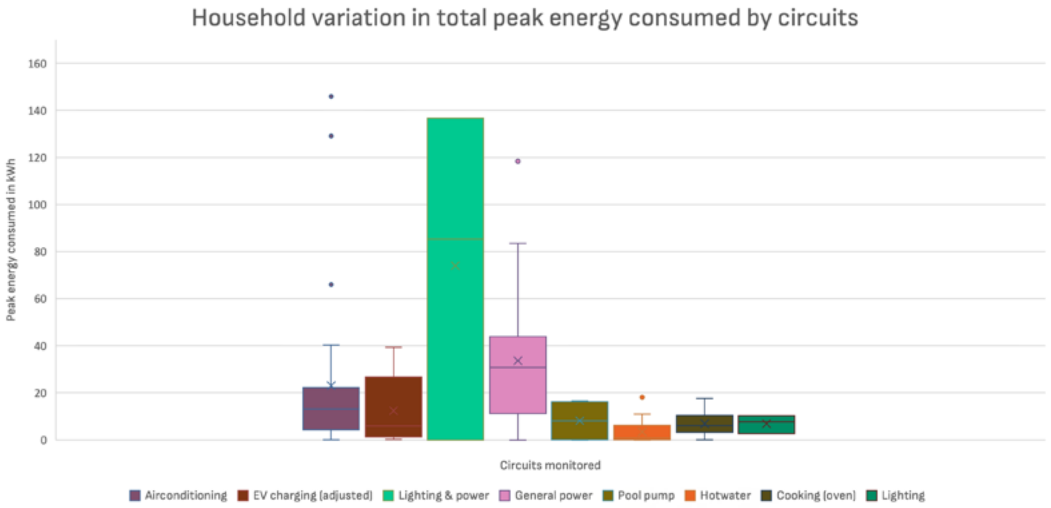


Figure 18. Box plots of peak energy consumption in monitored electricity circuits in October

Figure 19 shows how solar and non-solar households' electricity use across the peak hours. The y-axis represents the peak intensity ratio, that is, the share of total electricity use occurring during peak hours, with higher values indicating a greater proportion of peak consumption. The x-axis shows total electricity consumed in October.

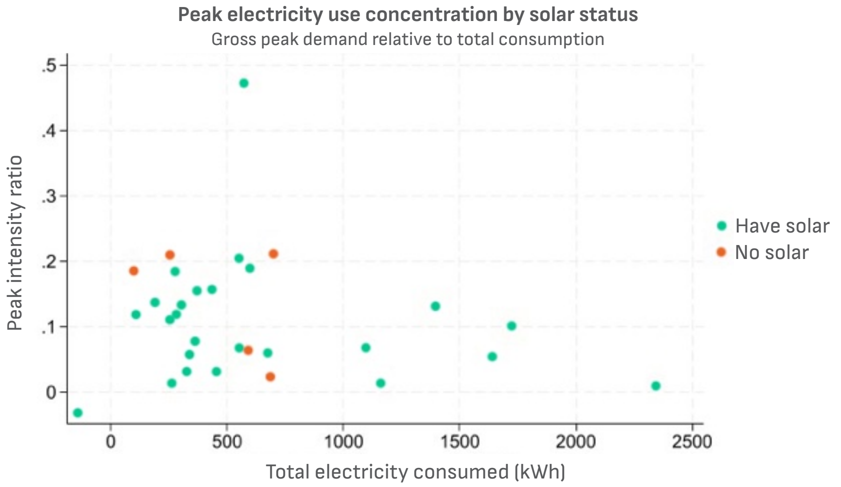


Figure 19. Ratio of peak period electricity consumption against total electricity consumed in October

Households without solar show higher peak intensity ratios, indicating that a larger proportion of their overall electricity use is concentrated during peak periods, even at modest levels of total consumption. As expected, most solar households display lower peak intensity ratios across a wide range of total electricity consumption in October. This indicates to us that rooftop solar reduces the concentration of demand during peak hours rather than overall consumption. The dispersion among solar households is substantial, with a few exhibiting high peak intensity ratios similar to or exceeding those of non-solar households. The figure highlights that while solar households tend to be less peak-intensive on average, rooftop solar does not eliminate peak-driven behaviours, and considerable heterogeneity in peak demand patterns remains across households.

3.5 Early insights from living with eco-feedback dashboards

Providing participants with access to the data we were collecting from their homes was a key tenet of CSIRO's WP7 Living Lab prototype, where we aimed to: (1) build trust with participants though providing transparency of what data we were collecting and (2) provide a meaningful incentive for sustained participation over a longitudinal trial and multiple researcher engagements. In providing households with energy and indoor climate feedback (details in Appendix A), we wished to understand if and how these dashboards were used, and how they were used together or alongside other sources of similar information.

Participants' experiences of and interactions with the eco-feedback dashboards will be reported in greater detail at a later date, however some key findings from the research to date include:

- Unlike earlier studies of energy use feedback, where real-time feedback is a novelty, we found that 28 of the 35 households already had a form of app-based feedback on their energy consumption, most commonly apps native to participants' solar and battery manufacturers or web portals provided by their electricity retailer. Accordingly, many households' interest in the My Energy app related primarily to its points of difference from what they already had.
- Yet despite using different (and sometimes multiple) apps for energy use feedback, many desired more specific and consolidated information on their energy use, and its relationship to other parameters such as indoor climate or air quality metrics.
- Battery households were more likely to abandon the My Energy app. Because the app (at the time of writing) does not accommodate batteries, participants with batteries tended to stop using My Energy and referred instead to their battery app which included important parameters such as state of charge.

These findings highlight how households' bespoke energy feedback needs including information on solar, battery, and EV ownership are not currently being met. Equally, they demonstrate that household information needs are diverse and one size does not fit all in eco-feedback design (Khosrowpour et al. 2016). Future work is required to understand how households' desires for energy use feedback extend beyond energy use alone, towards better understanding their how their energy use and indoor air quality interact (Pantzaras et al. 2018). Our future work aims to better understand participants' information needs and desires with respect to the increasing complexity of home energy use. We aim to collaborate with WP5 to explore alternative designs for eco-feedback.

SECTION FOUR
NEXT STEPS FOR WP7 HOUSEHOLD RESEARCH

In this last section, we present next steps for the WP7 household research, including how the Living Lab model will continue to add value as we continue to track and engage with the same households throughout the project, providing a novel longitudinal dataset and a stronger basis for modelling and prediction.

4.1 Keeping a finger on the pulse — Pulse surveys to track experiences over time

Having the same cohort of participants engaged over time means Living Labs represent a unique means of tracking participants' sentiment and attitudes over time and understanding how they respond to stressors and shocks. To do this, WP7 is implementing "pulse surveys"- short and easy to complete surveys that gather information specific to a given event or time period. To date we have completed two successful pulse surveys, one gathering experiences of the severe storms in Brisbane in October/November 2025[7] and a second sent to all WP7 Living Lab participants to gather attitudes towards and intention to adopt the "Solar Sharer Offer"[8]. The results of these surveys will be detailed in the next WP7 Household Report, with results summaries already shared with participants through our emailed newsletters.

Our upcoming pulse surveys will build on the insights reported here on battery ownership, capturing further attitudes, experiences, and intentions regarding battery ownership, including barriers and enablers of sharing control of their battery (e.g. through a VPP).

4.2 Better prediction of air conditioning use using probabilistic modelling — complementary modelling to WP4

Understanding when occupants switch on their AC and why they do so is crucial for demand forecasting, demand response design, pricing mechanisms, and grid planning. In this report (above) we have applied regression analysis to understand what factors may affect air conditioner electricity usage. The first model showed that the relationship between outdoor temperature and air conditioner electricity usage is non-linear. The second model showed that air conditioner electricity usage is dependent on multiple factors and variables such as indoor temperature, outdoor temperature, and humidity.

In our future work we will apply State Space Models (SSMs) to provide a principled probabilistic framework for modelling dynamic systems governed by hidden states that evolve over time and give rise to observations. In a SSM, uncertainty is explicitly represented, temporal dependencies are naturally handled, and multiple data streams can be integrated. This makes SSMs particularly well suited for modelling human-in-the-loop systems, where behaviour is stochastic, context-dependent, and partially observable.

These ongoing efforts to better understand and predict AC usage, and its potential effects on household energy use and the electricity grid are complementary to WP4 modelling. WP4 is developing an interactive prototype that models the effect of household adoption of different Consumer Energy Resources (CER) technologies and the corresponding effect on household energy use and load profiles. In this respect, SFL (as a whole) can offer solutions to understand how different technology adoption trends (WP4) and appliance behaviour (WP7) can affect households' energy use and energy demand under different future scenarios.

7 https://www.abc.net.au/news/2025-10-27/brisbane-power-outage-storms-hot-weather/105936886

SECTION FOUR
NEXT STEPS FOR WP7 HOUSEHOLD RESEARCH

4.3 Scaling and translating knowledge

This report is the first report from WP7. Scaling will be a particular focus for subsequent reports. However, we are already progressing towards delivery on WP7's commitment "...to scaling, translating, and sustaining the project outputs from WPs 1-6 through CSIRO's [...] National Energy Analysis Centre". In particular, we are:

- Collaborating with WP1 to ensure consistency in survey questions and enable comparison between the 35 WP7 Living Lab households and the nationally representative WP1 survey (> 5,000 responses).
- Working with WP4 to ensure complementarity between our respective modelling approaches (to be detailed in the following WP7 Household Report).
- Running SFL surveys in the growing NEAC National Living Lab to gather these data at greater scale.

NEAC is an open, collaborative, national energy data, and research centre, helping planners, governments, industry, and users coordinate and guide the energy transformation in a holistic way. As NEAC's own Living Lab grows (currently over 900 members nationally) and research infrastructure develops, NEAC offers further opportunities to scale outputs from WP1-6. As an example, the NEAC Data Explorer (https://research.csiro.au/neac/data-tools-and-energy-modelling/) aims to grow into a broader open-source energy data repository. This Data Explorer offers a storage and access point for anonymised energy data from WP4 and WP7, including time series data and modelling.

In this next phase WP7 will additionally work closely with WP3 in scenario development, with WP5 to collaborate with prototype testing and with WP4 to refine our energy data analysis and modelling approaches, providing complementary modelling using Model-Based Systems Engineering (MBSE).

SECTION FIVE
CONCLUSION

This report marks the first of several WP7 outputs and focuses on households' existing relationships with energy. Our Living Lab participants (WP7) represent an energy-engaged and technologically advanced cohort, complementing WP1's more nationally representative sample. However, the underlying motivations that underpin their household energy practices, particularly supporting household wellbeing and reducing costs closely align with those observed in the WP1 sample. This suggests that differences between the two groups lie less in why certain energy decisions are made, and more in how they are enacted in everyday life. Together, WP1 and WP7 provide complementary insights: WP1 establishes a population-level benchmark, while WP7 offers detailed, real-world evidence of how the shared motivations translate into practice under conditions of higher engagement and technology adoption. This alignment strengthens the relevance and scalability of Living Lab findings for informing broader energy transition planning.

Energy use in our participating households was shaped by practices, technologies, and social relations. We find that electrification pathways can be opportunistic and tied to appliance replacement cycles rather than deliberate, strategic, or system-wide household purchasing decisions. Users' relationships with energy were increasingly mediated by technology such as apps. Yet despite using different (sometimes multiple) apps for energy use feedback, many desired further information, including the relationship between energy use and indoor climate or air quality metrics.

A key emergent finding from this study is how large-capacity home battery ownership can reshape households' relationships with energy and change perceptions of energy from scarce to abundant. The emergence of limitless' energy among large-capacity battery households needs to be better understood; including whether it risks eroding tacit knowledge of conservation and reshaping household practices and social norms toward more excessive consumption.

Equally important is tracking these households over time to determine whether the initial experiences of limitless electricity are eventually replaced by a greater willingness to share this excess with others for the right opportunity, and whether the amount available to be shared is eroded via wasteful consumption (i.e. the "rebound" effect). A Living Lab approach is critical to achieving both these ends.

Together, these findings demonstrate the value of a Living Lab approach for establishing lasting relationships with households and tracking multiple metrics over time. A living lab enables us to understand change in households over time, the catalysts that move households from purchase intention to technology adoption and help us to develop a rich picture of energy use, obtained by the triangulation of energy use data, indoor climate data, survey and interview data. In our future work, WP7 will continue to draw upon these benefits of a Living Lab approach to (a) more deeply understand our households' motivations, ability and opportunity to share electricity from their batteries (b) understand their adoption of and experiences with the Solar Sharer Offer; and (c) co-develop and test future scenarios with participants, including alternative demand-side participation options and ways in which battery households may be encouraged to share their excess electricity. We will build on our preliminary modelling of the factors affecting AC use to develop better predictive capabilities, complementing WP4's modelling of CER uptake, and we will integrate with WP5 by assisting in the design of novel place-based eco-feedback mechanisms for households.

APPENDICES

APPENDIX A

ADDITIONAL METHODOLOGICAL DETAILS

Timeline of WP7 Living Lab research

An indicative timeline of WP7 activities to date that contributed to this report is below.

- January — March 2025: Study design, ethical approval sought and obtained
- February — April 2025: Procurement processes of monitoring equipment (including testing at researcher homes)
- May — July 2025: Trial advertisement and recruitment, analysis of pre-screening survey responses, determination of compliant meter boxes for installation
- July — September 2025: Installation of monitoring devices (including pre-configuring and shipping environmental monitors to participants for self-installation)
- September 2025: Survey 1 finalised, distributed and returned by all participants
- October — November 2025: Hour long semi-structured interviews with all participants
- November 2025: Pulse survey 1: Impacts of severe October thunderstorms (Queensland participants only)
- December 2025 — February 2026: Ongoing data collection from energy and environmental monitoring, analysis of survey and interview data
- March 2026: Pulse Survey 2: Solar Sharer Offer- awareness and intentions
- February — May 2026: Household report drafting

Details of electricity, gas, and environmental monitoring

The selection of all monitoring hardware was guided by: (1) the need for monitoring technology capable of capturing aspects of appliance usage and household practices, allowing us to address the WP7 research question: “How are everyday practices, technologies and social trends reflected in households’ energy use and demand?” (2) Cost and value for money considerations; (3) An evaluation of publicly available environmental and energy monitoring technology via CSIRO’s concurrent Apartment Energy Behaviour Study. (4) Further requirements as identified by researchers during study planning the study, including:

- Dashboard access: Monitoring solutions must include a usable end-user dashboard, to ensure households themselves can access the data we collect from them and hence benefit from trial participation.
- Independent communication: Monitoring equipment does not rely on participants’ Wi-Fi to operate
- Self-installable environmental monitors: Eliminates the need for researcher site visits to each property
- Aesthetics: To minimise participant objections to hosting monitors in their homes.
- Data stored on Australian servers: A requirement of CSIRO Privacy and Ethics approval

The final selection of the monitoring technology used is provided below.

ELECTRICITY MONITORING

Wattwatchers 6M Auditor devices were used for monitoring electricity at each participating household. Each Wattwatchers device can measure six electrical circuits, recording energy consumption, voltage, power factor, and reactive power at 5-minute intervals. Full details and technical specifications are available at: https://wattwatchers.com.au/product/auditor-6m-device-only/

Wattwatchers' preferred installer Sustainability Wise were engaged for the supply and install of all monitors. Researchers provided meter box photos for participating households to Sustainability Wise following receipt of consent materials from each household.

Because of the inevitable trade-offs posed by each unit being able to measure six circuits, researchers also provided Sustainability Wise with a prioritised list of circuits to measure at each house, namely:

1. Grid incomer (the household's "mains" electricity connection)
2. Solar
3. Air conditioning
4. Electric hot water
5. Battery
6. Electric vehicle
7. Oven/Stovetop
8. Pool pump, pool heater, spa, or other large loads
9. Power points circuits

In the case of three-phase households, two Wattwatchers devices were deployed, in which case the first device's six inputs were typically taken up with Grid Connect (Phases A, B, C) and Solar PV (Phases A, B, C). The second device was then used to capture a further six circuits following the hierarchy above. In isolated instances, a third or fourth device Wattwatchers device was required to fully capture parameters of interest. These processes mean there is good consistency in our capturing of the main appliances operated (Table 1):

Table 1. Circuits monitored in the study

Circuit	Appliance is captured by Wattwatchers	Living Lab Households with that circuit
Grid incomer	35	35
Solar	31	31
Air conditioning	34	34
Electric hot water	21	22
EV charger (dedicated circuit)	4	5

However, the substantial diversity in appliance ownership and appliance level differences (for example three-phase versus single phase air conditioning, EVs charged from dedicated chargers or simply a lead from a standard power point) meant fully capturing aspects of household energy use was sometimes challenging.

Indoor environment monitoring

Tether EnviroQ (https://www.tetherhq.com/enviroq) was used for indoor environment monitoring. The EnviroQ measures temperature, relative humidity, carbon dioxide, dewpoint, light, and atmospheric pressure, transmitting data every 15 minutes via the Sigfox network to Tether's platform. The unit additionally calculates derived values for "Mould Risk" and "Health Score", which are not provided as raw data outputs, nor is there sufficient information for how these values are calculated.

Participant self-installation: All EnviroQ's were commissioned by the researcher, which involved connecting the device to the Sigfox network, assigning each device to a household ID, initiating data capture, affixing wall-mounting strips on the back (to allow participants to stick it to their wall) and posting the device to participants (Figure 1). While in transit, participants were emailed a link to access their data on the Tether dashboard, and a short PDF guide titled "What to do with your EnviroQ". This guide provided information on how to access the data and guidance on where to place it (and where not to place it), which provides some consistency in device placement despite the participant self-install.

Figure 1. Photos taken from the "What to do with your EnviroQ" self-installation guide

Once installed, if devices were found to be communicating irregularly due to low Sigfox signal, the lead researcher would arrange for a Sigfox booster to be sent to each participant by post.

GAS MONITORING

The Tether Pulse monitor (https://www.tetherhq.com/items-1) utilising an IN-Z41 pulse reader, was used to monitor participants' gas consumption from their town gas meter. The pulse monitor captures each pulse transmitted by the gas meter which corresponds to 0.01m3 of gas per pulse, with data sent to Tether's cloud platform as per the EnviroQ data. This solution cannot measure bottled gas consumption, which is not measured in this trial.

Figure 2. IN-Z41 pulse reader being connected to a gas meter (Source: Tether)

As per the EnviroQ, all gas pulse monitors were commissioned by the lead researcher, which involved connecting the device to the Sigfox network, assigning it to a household ID, initiating data capture (logging zero values until it is installed) and posting it to participants to self-install (Figure 2). The pulse reader clips onto the pulse output of the meter, does not measure physical gas flow, does not modify the meter at all, and hence can be self-installed. Participants were emailed instructions for fitting and a short explanatory video (https://youtu.be/3lZA35eQa6Q) provided by Tether.

PARTICIPANT ACCESS TO DATA DASHBOARDS

All participants' received access to two dashboards (1) The My Energy app provided by Wattwatchers, with access to the app provided shortly after the electrician install of the Wattwatchers energy monitor. (2) The Tether dashboard, through which participants can access data from their EnviroQ and their gas pulse monitor. Access to the Tether dashboard was granted to each participant while their EnviroQ was in transit, allowing them to have immediate access to the readings when the device arrived.

Providing participants with access to their energy and environmental data captured, was utilised as both (1) a means of studying users engagement with energy use feedback, and (2) a means of avoiding "extractive" research, building reciprocity between researchers and participants and potentially also building trust, making visible to participants the type of data we were collecting from them.

DETAILS AND JUSTIFICATION FOR STUDY LOCATIONS

The Living Lab study was conducted across two Australian regions – Sydney and Central Coast (NSW) and South-East Queensland (SEQ) – selected due to their neighbouring climate zones; warm temperate (Climate Zone 5) for Sydney and Newcastle and subtropical (Climate Zone 2) for Brisbane. Two participants were accepted west of Sydney in Climate Zones 6 and 7 as an early trial of regional installs (which were not continued due to logistical constraints) and provide a limited reference for cooler climates. The SEQ, Sydney/Central Coast focus is due to the regions shared proximity to the coast, similar annual rainfall and similar rainfall and temperature distributions (Table 2 below). Brisbane is between 1-3 °C warmer in each month, and Sydney and Newcastle's rainfall maximums occur in late summer/autumn compared to Brisbane's summer dominant rainfall.

Table 2: Climate data for SFL study locations

	Average maximum temperature (°C)			Rainfall (mm)		
Month	**Brisbane**	**Sydney**	**Newcastle**	**Brisbane**	**Sydney**	**Newcastle**
January	29.2	27.0	28.3	125	101	100
February	29.1	26.8	27.7	155	119	118
March	28.0	25.7	26.4	131	132	127
April	26.1	23.6	23.8	74	127	112
May	23.6	20.9	20.4	97	117	116
June	21.3	18.3	17.7	60	133	121
July	21.0	17.9	17.2	33	96	76
August	22.1	19.3	18.8	35	80	74
September	24.2	21.6	21.6	31	68	60
October	25.6	23.2	23.9	81	77	75
November	27.0	24.2	25.7	98	84	82
December	28.3	25.7	27.5	121	77	76
Annual	**25.5**	**22.8**	**23.2**	**1039**	**1211**	**1137**

* Climate date taken from the Bureau of Meteorology "Climate statistics for Australian locations" (https://www.bom.gov.au/climate/averages/) using Brisbane Aero, Sydney Observatory Hill, and Williamstown RAAF. Data from 1991-2026 selected, 1942-2026 (Newcastle only). Williamstown RAAF used as a point of reference, given 'Newcastle Nobby's' weather station is located directly on the beach, when none of our Newcastle or Central Coast participants shared such proximity to the beach.

These comparable climatic contexts allow for meaningful cross-state comparisons of energy use, responses to weather events, and variations in household routine throughout the year.

Recruitment activities in NSW covered a broader geographical area, including Sydney and Newcastle, resulting in a more dispersed participant distribution. Recruitment in SEQ was concentrated primarily in Brisbane and the Gold Coast. In total, 15 households in NSW and 20 households in SEQ were enrolled in the study.

Sensor selection process

The choice of the specific monitoring technology deployed was guided by requirements elicited by the project team, covering cost, value for money, accuracy, useability, communications protocol and CSIRO Human Research Ethics and Privacy requirements. These included:

- **Data granularity:** Monitors with a logging frequency greater than 30 minutes was required to provide more detailed insights than smart-meter data alone.
- **Value to end-users and usability:** We wanted households themselves to benefit from their trial participation and have access to the monitored data, so we chose devices with user-friendly apps or dashboards that provides participants with access to their own data.
  - **Avoid multiple platforms:** To assist in usability we looked for opportunities where one manufacturer or platform can provide multiple services. This reduces the participant burden of having to access multiple platforms to gather ones' information.
- **Independent communication:** We avoided devices which require participants' Wi-Fi to operate. This choice was to reduce the personal information gathered and the cyber security risk of capturing each household's Wi-Fi password.
- **Installable by participants:** Energy monitoring requires an electrician install, however, for indoor climate and gas pulse monitoring we chose solutions that participants can install themselves, which saves on researcher time and cost compared to home visits to 35 geographically dispersed households.
- **Battery powered (for indoor climate loggers):** Battery powered indoor climate loggers reduce the risk of data loss via other householders unplugging wired monitoring devices. Battery powered devices were also central in facilitating the participant self-install process (above), where loggers can be commissioned by the researcher interstate and posted already logging to the participant who simply places them on a wall or table.
- **Aesthetics:** Users may be unwilling or hesitant to adopt monitors that are considered ugly or bulky.
- **Data stored on Australian servers:** A condition of SFL's CSIRO Privacy and Ethics approval was that participant data must be stored where possible on Australian servers, which further guided our choice of hardware providers to Australian/New Zealand based companies.

DATA ACCESS FOR PARTICIPANTS: ECO-FEEDBACK

An extensive literature finds "eco-feedback" (i.e. digital feedback on resource use at home (Froehlich et al., 2010) can improve energy literacy and support households to better understand and (in some cases) optimise or decrease their energy consumption (Fischer et al. 2008, Ma et al. 2018). Providing participants with access to their energy and environmental data captured, was a core consideration in the trial design and seen as important in increasing the value proposition to users and (potentially) increasing their likelihood of remaining as Living Lab participants if they continue to receive value from their participation.

All participants' received access to two dashboards (1) The My Energy app provided by Wattwatchers, with access to the app provided shortly after the electrician install of the Wattwatchers energy monitor. (2) The Tether dashboard, through which participants can access data from their EnviroQ and their gas pulse monitor. Access to the Tether dashboard was granted to each participant while their EnviroQ was in transit, allowing them to have immediate access to the readings when the device arrived.

Example screenshots from each device are provided below. My Energy provides a "live" overview of energy use incorporating interactions between the home, grid and solar generation (if fitted) and different visualisations of energy use over time, including grid consumption, solar self-consumption and the contribution of the circuits monitored to total energy use (Figure 3).

Figure 3: Screenshots from My Energy app.

The Tether app involves a first page showing an overview of the derived parameters from the environmental monitoring, including Comfort Index, Focus Index, and Health Score, among others. The raw data can be accessed by clicking on “Performance”, which provides time series graphs of all monitored parameters which can be easily clicked between, as well as a time-picker function to select the time period of interest to view the historic data (24 hours, 7 days, 30 days etc) (Figure 4).

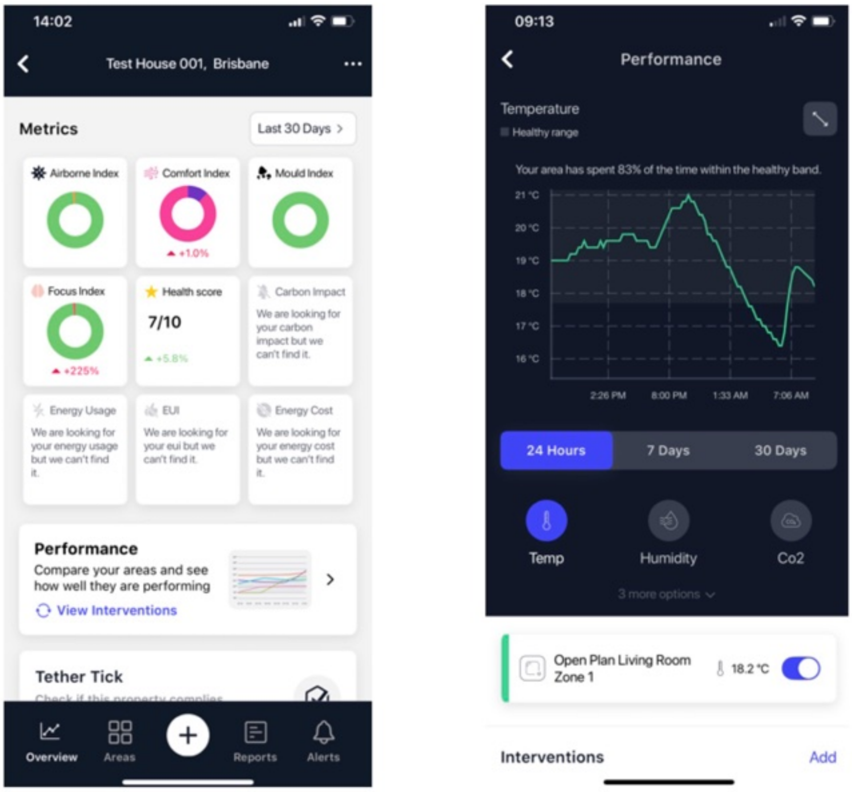


Figure 4: Tether app showing the overview page (LHS) and "Performance" page (RHS) which displays the temperature, humidity, and CO2 data over time.

Survey Implementation

To minimise participant burden and reduce survey fatigue, WP7 used a multi-stage implementation strategy. Survey waves were grouped into two types:

- Three 25-minute household surveys, designed to capture detailed contextual and behavioural information;
- Three 5-minute pulse surveys, designed to provide time-sensitive insights into participants' behavioural responses to specific events or initiatives.

This report summarises findings from the pre-screening survey and the first 25-minute household survey, which provided baseline information about participants' demographic profiles, household contexts, and initial energy-related behaviours and perceptions.

The first survey was delivered via Qualtrics using personalised survey links for each participant in late September 2025. The link was active for about six weeks following distribution. To encourage participation, a reminder email was sent at three weeks to participants who had not yet responded. All 35 participants responded in the first survey.

APPENDIX B

DATA ANALYSIS DETAILS

Survey Data Analysis & reporting

Data analysis was conducted using STATA[1] version 18 To support clear interpretation of results, descriptive analyses are presented primarily as percentages, accompanied by the relevant number of participants in each category (n) where possible. Statistical significance was assessed using predefined criteria, with p-values of < .05 and < .01 used to determine differences between participant groups.

Due to the small sample size, the report utilises median and/or Interquartile range[2] (IQR) as the primary measure for central tendency. Means are provided for completeness but should be interpreted with caution.

Participants' responses to open-ended survey questions were coded by researchers using an inductive categorisation approach. As participants were allowed to provide multiple responses, percentages for these items represent the percentage of participants who mentioned each response (i.e. percentage of cases). Because multiple responses were permitted, the percentage for these items do not sum to 100%. All percentages presented have been rounded to the nearest whole number.

Interview analysis

Interviews were audio recorded and transcribed. Analysis involved a two-step process, firstly arranging responses to key interview questions for rapid cross referencing of survey and interview responses. Secondly, a process of thematic analysis, drawing from Reflexive Thematic Analysis (Braun et al., 2023), using the NVivo (by Luminero) software package was used to surface further emergent themes which occurred independently of research. Reflexive Thematic Analysis emphasises the consideration of the researcher's positionality with respect to the interviewees; making space to question how ones' positionality might be delimiting our analysis, and how ones' values may contextualise the knowledge (Braun et al. 2023). In this case, the relationship between the interviewer and interviewee was not one of complete objectivity, but rather a more cultivated relationship, involving previous email exchanges, sometimes phone calls to discuss the nature and expectations of the trial, or trouble-shooting the hardware installed.

Following Reflexive Thematic analysis (Braun et al., 2023), a process of (1) familiarisation with data, (2) coding, (3) initial theme generation, (4) reviewing and developing themes, (5) refining themes. Familiarisation with the data was achieved by the lead researcher completing all interviews and the short period in which the interviews were conducted, meaning the researcher was already highly familiar with the data at the time of analysis. Initial coding was completed on the interview notes, with the researcher referring to the full transcripts for context where required. Theme refinement occurred through a process of reflection on the themes, a greater reading of the full transcripts to validate and contextualise themes, which resulted in several themes merged or separated into themes and sub-themes.

1 https://www.stata.com/

2 The median is the middle value; this means 50% of participants fall below it and 50% fall above it. It gives us a clear picture of what a "typical" household looks like in our small sample. The Interquartile Range (IQR) shows how spread out the middle 50% participants are. The IQR is reported here because it works well in small samples; it focuses on the values between the bottom 25% and top 25% of the data, and is not affected by unusually high or low values.

HOUSEHOLD ENERGY DATA ANALYSIS AND ANALYTICS APPROACH

The net energy profile for October 2025 was calculated by summing the electricity imported minus electricity exported for each participant for the whole month of October. Positive values indicate net electricity import, while negative values indicate net export to the grid.

Daily air conditioning (AC) electricity consumption (kWh) for October 2025 was obtained directly from the AC circuit for each household. To contextualise cooling behaviour, average daily external and internal temperature and humidity data corresponding to each household's location were incorporated into the analysis. Environmental data for Queensland households were sourced from the QLD Government air quality database, while equivalent data for NSW households were obtained from the NSW Government air quality portal. This study focuses on within-household variation in AC use, which provides stronger identification of behavioural responses to thermal conditions than cross-sectional comparisons. While households differ in baseline energy use, the limited data on dwelling and household characteristics constrain reliable between-household inference. The analysis therefore prioritises within-household models that utilise day-to-day AC use variation.

Total household electricity consumption was calculated as the sum of solar generation and grid imports, minus electricity exported to the grid.

Analytical strategy

Given the modest number of households in the sample (N = 35), the analytical strategy prioritised internal consistency, behavioural plausibility, and triangulation across multiple forms of quantitative evidence rather than trying to make inferences about the general population. The study draws on a combination of descriptive statistics, distributional diagnostics, graphical analysis, correlational checks, and regression models to identify recurring patterns and relationships within the observed households.

Analyses therefore focused on:

- the direction and relative magnitude of observed relationships;
- consistency of patterns across different energy outcome measures; and
- alignment between circuit-level behavioural indicators (AC use) and aggregate consumption outcomes.

APPENDIX C

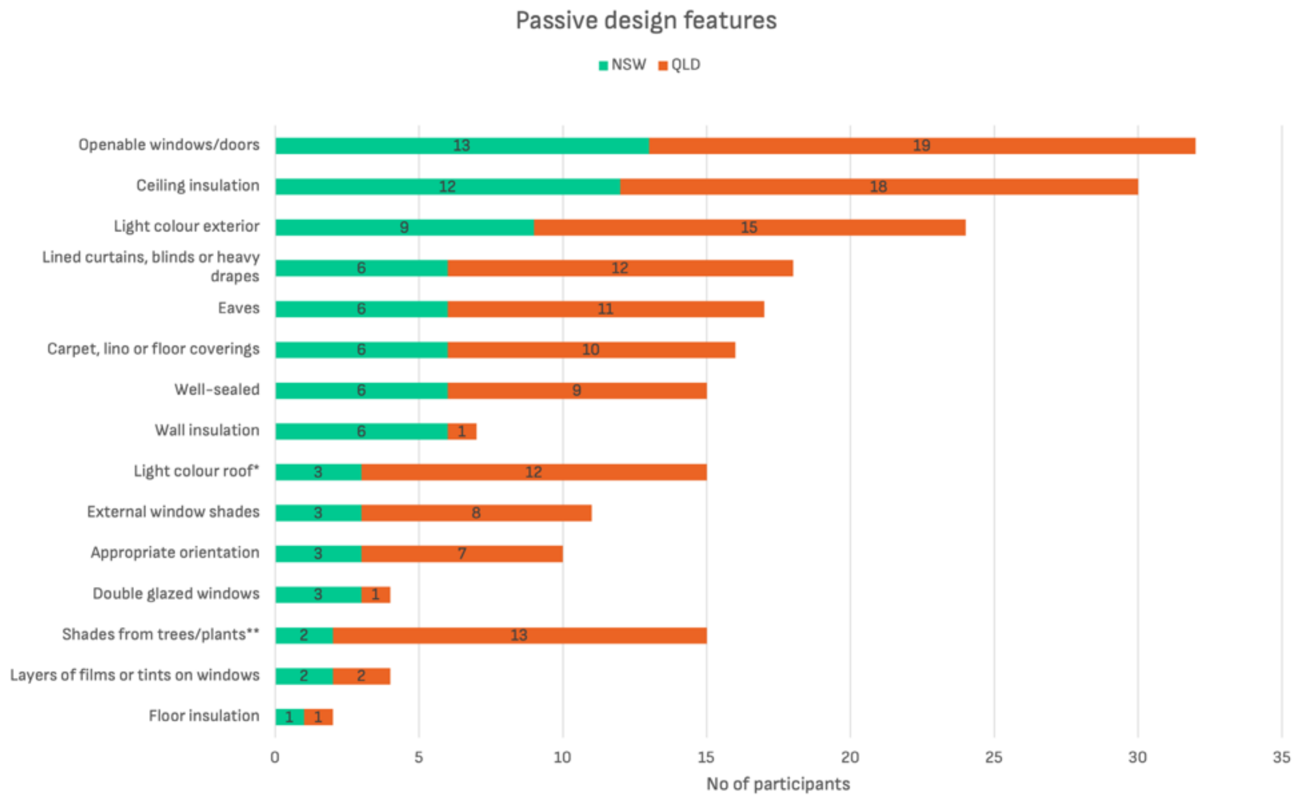
LIVING LAB HOUSEHOLD CHARACTERISTICS

Materials of home, renovations, and energy efficiency ratings

Most Living Lab participants lived in brick-based homes (single or double brick), accounting for approximately two-thirds of the sample (Single brick: 43%, n=15; double brick: 26%, n=9). Timber-constructed homes (including weatherboard and plywood cladding) were reported exclusively by QLD participants (n=7). Other participants said their home was constructed with either fibro cement (n=2), a mix of timber and brick veneer (n=1), or steel frame and concrete (n=1).

Passive design features

Figure 1 shows the distribution of passive design features in Living Lab participants' homes between states. Good passive design according to the local climate helps to maintain thermal comfort of households reducing the need for additional heating or cooling (Australian Government, 2026). The most reported features in both states were openable windows/doors (NSW = 37%, QLD = 54%) and ceiling insulation (NSW = 34%, QLD = 51%).



*significant different between states at p<.05 **significant different between states at p<0.01

Figure 1. Home solar passive features by states

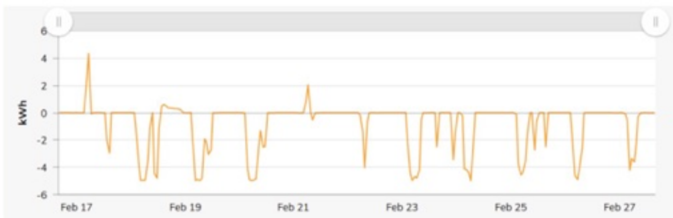
Crosstab analyses revealed several differences in the passive design features between Living Lab participants in NSW and QLD. QLD participants reported significantly more passive cooling features, including shading from trees/plants (9% NSW vs. 37% QLD, $p < .01$), light-coloured roofs (14% vs. 34%, $p < .05$), and appropriate orientation (9% vs. 31%, $p < .05$). QLD participants were also more likely to report external window shades (9% vs. 23%), although this difference did not reach statistical significance.

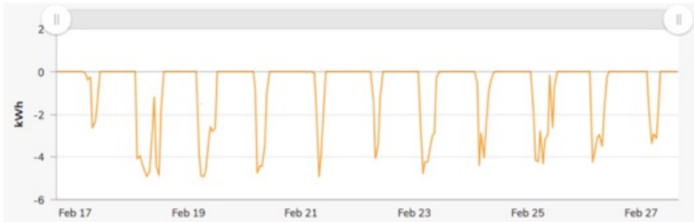
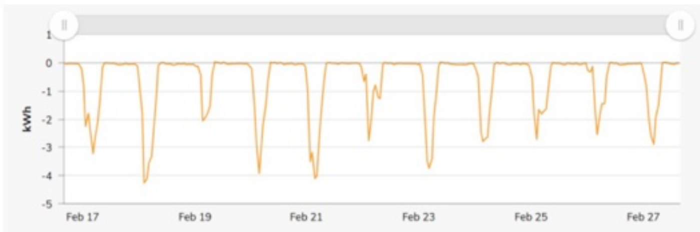
In contrast, NSW participants were significantly more likely to report wall insulation (20% NSW vs. 3% QLD, $p < .01$), reflecting different climatic requirements. Features such as double-glazed windows (6% NSW, 3% QLD) and floor insulation (3% each) were rare in both states. Overall, QLD participants reported higher use of passive cooling features, whereas NSW participants more commonly reported insulation-related features, consistent with the different seasonal temperature profiles of the two states.

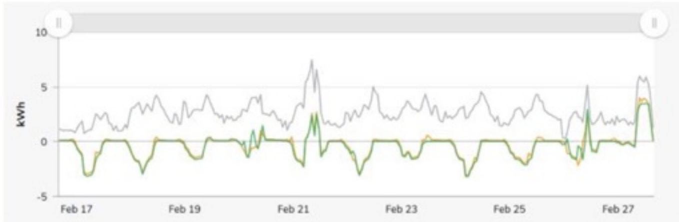
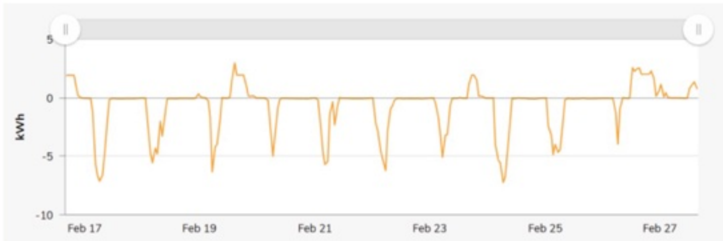
Characterisation of household battery behaviour

We analysed the import/export behaviours of the households with batteries installed as of February 2026, noting the co-ownership of PV and EVs. This analysis is based on the Grid Incomer circuit observed during the period 17-27th February (Table 1). This period was chosen because it which represented typical summer weather, and did not include heatwaves or rainfall, in both Brisbane and Sydney, providing an indication of typical summer weather battery operation.

Table 1. Home battery adoption information

Battery owner no	Batter y size (kWh)	Solar PV system size (kW) and EV ownership	Import / export behaviour- batter households
1	30	Solar: ~10 kW EV: 1x PHEV	**Minimal import- Daytime export:** Charges 1x PHEV  ***Note:*** *Connectivity issue resulted in data gaps over February, period 25/02/2026 to 08/03/2026 used above*
2	24	Solar: 16.63 kW EV: N/A	**Minimal import- Daytime and peak-time export** 

3	13	Solar: ~1.5 kW EV: N/A	**Minimal import- Daytime export** 
4	22	Solar: 7.92 kW EV: 1	**Generally flat profile:** Occasional daytime import, charges 1x EV from solar that would otherwise be exported. 
5	48	Solar: 10 kW EV: N/A	**Minimal import- Daytime and peak-time exports**: Zero imports, exports to grid during daylight hours and continues exporting into the evening on certain nights. On spot-reflective tariff, using battery's own software. Participant reported manually overriding the software to export at peak times when the battery did not. 
6	15	Solar: 6.1 kW EV: N/A	**Minimal import- Daytime exports**: Zero imports, exports to grid during daylight hours. 
7	30	Solar: 13.3 kW EV: 1	**Minimal import- Daytime exports**: Three phase power 

8	13.5	Solar: 17.2 kW EV: 2	**Variable- mixture of import and export**: Dual phase- Charges 2x  EVs
9	12.8	Solar: ~13 kW EV: 1	**Variable- mixture of import and export**: Three phase- Charges 1x EV 
10	40	Solar: 6 kW EV: N/A	**Minimal import, daytime and peak time exports:** Occasional daytime charging from grid. Spot reflective tariff. Exports exclusively 4-8pm. 
11	9.6	Solar: 13.2 kW EV: 1	**Minimal import- Daytime exports** 
12	13.5	Solar: 5 kW EV: 2	**Substantial imports, few exports:** On a tariff with free electricity (11am-2pm) and cheap night rates, charges battery from the grid. Owns and charges 2x EVs, accounting for the substantial grid import despite battery ownership. 

13	5.8	Solar: 9 kW EV: N/A	**Minimal import, daytime exports**  ***Note:*** *Connectivity issue resulted in data gaps over February, period 05/03/2026 to 15/03/2026 used above*
14	14.4	Solar: 9.1 kW EV: N/A	**Battery malfunctioning-** night time import, daytime export 

Full circuit list for electricity monitoring

Correct as of February 2026. Note that some subsequent changes may be possible due to further battery installations.

Circuit monitoring	Total channels	No of households	Notes
Grid connections	55	35	Present in all households. High as some households have 3-phase power
Air conditioning	53	34	One of the most dominant end-uses; many households have multiple units/phases
Oven / cooktop	36	31	Includes oven, cooktop, oven + stove
Solar generation	35	23	Explicit solar circuits only (hybrid excluded)

General power / lighting (incl. "power", "lighting", combined circuits)	29	23	Includes kitchen power, garage, combined backup circuits (n=3)
Hot water	22	24	
Battery / hybrid solar-battery systems	14	12	Includes battery, hybrid solar+battery, Powerwall
Pool / spa / pump	7	5	Includes pool pump, heaters, spa
Dedicated EV charger (isolate-able)	7	6	
Outbuildings / sheds / sub-mains	9	4	Includes shed, outbuilding, sub-main
Backup / essential circuits	2	2	Explicit backup-only/load circuits
Inverter (separate monitoring)	2	1	Only where independently labelled (not hybrid)
Heat bank	1	1	
Caravan	1	1	

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