Fairwater Living Laboratory – Implications for Networks

CURTIN UNIVERSITY REPORT

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INTRODUCTION

The Fairwater Living Laboratory project aimed to understand the sustainability, resilience, well-being and commercial benefits of the precinct scale development of renewable thermal energy heat pumps, coupled with PV and demand management, in a master-planned residential community. This community was one of Australia's first communities to incorporate up-front deployment of these ground source heat pumps in each lot. The performance of these heat pumps at this scale and understanding how occupants will utilise these systems was untested and unproven. Hence, this living laboratory provided information regarding the user experience and performance to inform further development and deployment of this renewable technology.

Curtin University developed a machine learning algorithm to identify energy consumption patterns and related them to occupant practices and habits. This is important to assessing how effective this technology is and whether it is achieving the expected reductions in energy consumption. Households with solar PV and battery systems as well as changes during the COVID-19 lockdowns were also assessed.

The key takeaway is that the detailed energy data for the homes involved in the study reveals a series of Home System of Practices (HSOP) that people follow regularly throughout the year based on their routines and habits. Each home has a series of HSOPs which are identified by machine learning algorithms. The algorithms can connect into the home energy management system to provide information to occupants and into the Building Automation System to regulate devices. The results will be greatly improved energy efficiency in the home and reduced grid impacts. For the local network this can enable connection of the machine learning algorithms, home energy management systems and building automation systems into distributed energy resource systems on strata and precinct level developments to provide an improved and intelligent orchestration of energy demand and storage.

RESULTS SUMMARY

ENERGY USAGE PATTERNS

Curtin researchers developed a machine learning algorithm that identified patterns and practices in the household energy and data. The algorithm demonstrated how the Fairwater homes followed different daily routines and HSOPs throughout the year. These HSOPs provide insight into the practices and routines of the residents by analysing the timing and magnitude of the peaks in these profiles. The timing and magnitude characteristics are important when discussing the impacts of households on the distribution network and the amount of stress applied to the network. Fairwater homes that synchronise and follow similar energy patterns can result in significant aggregation subjecting the network to heavy stress loads, known as peak demand periods. This analysis was able to explain why this aggregation occurs and how practices can be changed to consume energy, or provide storage, at times that is optimal for the network.

Different daily consumption profiles were identified for each Fairwater home with some households observing unique energy profiles. This suggests that not all homes synchronise and contribute to the aggregation effect but instead, are able to consume energy outside of these peak periods. This is beneficial for the distribution network as it reduces the amount of stress on the network. Further investigation into the context of the home demonstrates why a particular household does not follow the typical energy patterns. A common explanation was the impact COVID-19 lockdowns had on household consumption and shifted a lot of energy practices due to occupancy patterns changing. Additionally, COVID-19 restrictions resulted in working lifestyles changing for households even after lockdowns are removed with the ability to work from home. The pandemic led to an increase in homes being occupied during the day resulting in variations in energy consumption levels but not always in the timing. Peaks in energy use were observed occurred at three times in the day, morning (5-9am), midday (11am-2pm) and evening (4-11pm). Pre-lockdown, these peaks were much smaller, although they had similar times of their occurrence. This indicates that people are still performing energy consuming practices at a similar time, however the magnitude of the energy use is increased. For homes that have solar PV systems, this results in less energy being exported to the grid during the middle of the day, reducing the stress on the distribution network. However, the greater evening peak negates the benefits of consuming renewable energy during the day as this energy is sourced from the grid during that time.

Curtin researchers identified significant variation in summer and winter practices of the Fairwater residents. This was observed for the energy consumption data where the peaks occurred at different times of the day. This provides insight into the utilisation of the Ground-Source Heat Pump and the time of use throughout the year. The Fairwater residents often used the Ground-Source Heat Pump powered air-conditioning systems more frequently in the winter during the morning and late afternoon to heat the home compared to the summer period. During the summer, the residents did not regularly use this system in the morning at all to cool the home and only rely on it for thermal comfort in the afternoon. This observation outlines the different practices, routines and habits within the home that often impact energy demand.

In terms of the network, the ability to shift the timing of air conditioning use will be beneficial in reducing the magnitude of peak periods. The incorporation of automation can shift air conditioning consumption to early in the afternoon by the use of timers. Typically, homecoming events where people return from work or school result in air conditioners being turned on to cool/heat the home that has been exposed to extreme temperatures (hot or cold) during the day. The ability for air conditioners to sense when the indoor temperature is rising or falling outside the range of comfortable temperatures and turn on to maintain this temperature can achieve load shifting. Additionally, running the air conditioning before occupants return home will move this consumption outside of the peak periods which will benefit the distribution network. Combining this automation with solar power, the air conditioner can be linked to the PV system and use solar power to maintain comfortable indoor temperatures during the day, so occupants feel thermal comfort without any interventions.

The development of software and energy intelligence that can be utilised within the home offers a novel way of managing energy in combination with emergent Home Energy Management Systems (HEMS). This software can connect devices that consume, produce, or store energy, and allows them to communicate to each other and to the user. This can offer energy management services for homes which will benefit the user as well as the distribution network. This report assessed the utilization of solar PV technology and concluded that the majority of solar power produced was exported back into the grid. This does not benefit the user nor the distribution network as the household still has a high reliance on grid energy. The use of this energy intelligence software can assist users in increasing their utilization of solar energy by providing feedback and recommendations to shift energy consumption. Additionally, precincts that are exposed to time of use tariffs can benefit from management systems to consume energy when the cost is low and possible, export energy when the cost is high.

COVID-19 restrictions impacted energy practices and the performance of solar PV systems. Generally, the Fairwater homes observed an increase of energy consumption during the day which is expected as occupancy is much higher. Figure 1 demonstrates how the daily energy profile aligns better with solar power production during these COVID periods. A peak relating to energy consumption occurs later in the morning which utilizes the solar energy produced at this time. This peak is not seen in the comparative figure as the residents are not typically at home without restrictions in place. The presence of delayed peak during the day outlines the changes in energy practices. This peak is due to the use of air conditioning during the day when the occupants desire thermal comfort. Typically, the office or workplace would provide thermal comfort to these individuals. These patterns of energy use through practices has been shifted from the workplace to the home resulting in higher consumption in residential homes.

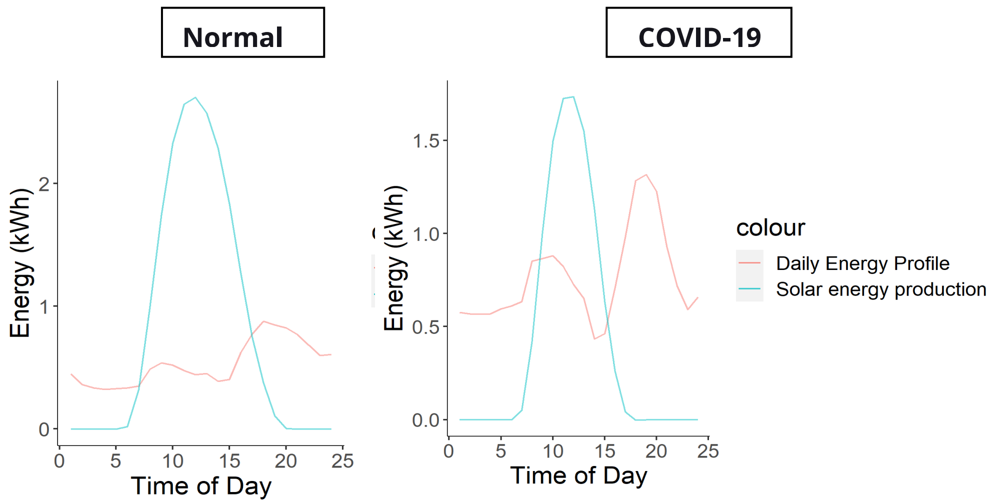

Figure 1 Alignment between demand and solar production for normal and COVID time periods (from the report)

This impact can be scaled up to the precinct and community level where the majority of occupants are relying on their own home to provide thermal comfort instead of their workplace. This can cause higher consumption during the day which is beneficial for solar PV systems. This shifts the demand stress away from the distribution network to the PV system achieving high self-sufficiency and self-consumption. However, the figure displays another peak period in the late afternoon which suggests the household is still consuming energy as they would usually in the afternoon. The presence of this peak demonstrates that the impacts of the homecoming event is still observed in the daily energy profile. This negates the benefit of consuming energy during the day utilising the PV system as the afternoon peak still relies on the grid energy.

RECOMMENDATIONS

LOAD SHIFTING

The idea of load shifting for residential households is to reduce the impact of peak energy demand on the distribution network and to consume energy when energy prices are lower (based off a tariff system). The performance of the network can reduce when the demand for energy is high and can result in major problems. These peaks in the energy profile are due to the synchronisation of occupant's lifestyles and their practices being similar between households, which is evident in the energy data for this Fairwater project. The analysis identified when these practices synchronized, typically in the morning and the afternoon. Even with the impact of COVID-19 lockdown restrictions and work from home practices, people performed similar daily practices in the morning and afternoon that aligned across many households.

People often follow routines because they feel comfortable in doing so and it fits with their commitments, any change to their normal lifestyle can result in discomfort. This idea of comfort can explain why people follow such a routine lifestyle as seen in the energy data. There are slight differences between the weekend and weekday with more differences in energy profiles between winter and summer. This difference between winter and summer can be explained by a different type of comfort being sort at these times. Thermal comfort is often achieved by people through energy-intensive means such as air conditioning. The feeling of being too hot or too cold can feel uncomfortable for residents when they are home. This impacts on the idea of the home as it is often considered the place of comfort for people hence, air conditioning is relied on to achieve thermal comfort. These different types of comfort results in people being locked into their energy practices. Hence, it is difficult to achieve load shifting within households as this can impact one or two of these comforts.

An additional purpose of load shifting is to increase household's utilisation of solar power generated onsite. The natural rhythms of everyday life often constrain the use of solar power. This misalignment between natural rhythms of people and the sun demonstrates the need for load shifting to move energy consumption to times where solar power is produced. The major problem for this objective is the natural occupancy patterns of households resulting in the household being empty during the day. However, the impact of COVID-19 restrictions and how people's working lives are changing to rely on working from home more often presents an opportunity to utilise solar PV systems better. This can allow residents to shift their energy practices to during the day without the need for any complex home energy management systems or home automation. Home energy management systems and automation can assist in people shifting the timing of their practices to those that align with renewable energy generation to reduce the load on the energy grid.

HOME ENERGY MANAGEMENT SYSTEMS

The development of home energy management systems is becoming more popular around the world as the technology improves and renewable energy sources become more prominent. These systems allow users to monitor their energy consumption and production (if applicable), and to provide manual control of their energy use within the household. Typically, a hub device is installed within the home that communicates energy consumption performance to the user. This is supported with software that moderates the communication and allows an effective interface with the users. The goal of this software is to achieve engagement with the user and increase the energy effectiveness or efficiency of the household. Additionally, it can provide users remote control of devices to either turn on or off based on recommendations from the management system.

There are for main aspects of household energy that these systems can be involved in:

- **Electricity**: The system should make energy 'visible' and allow the occupants to observe what devices are doing and consuming, and to remotely modify their operation if required.
- **Battery storage**: The use of battery storage allows greater self-sufficiency and energy management systems aim to maximise the value of battery storage. There are many variables to account for such as, whether the house is a part of a time of use tariff and whether there is any incentive to sell stored energy to the grid
- **Solar PV:** This technology can have two focuses whether to prioritise 'self-consumption' of the solar energy or export the energy back to the grid. Energy management systems educate the consumer on how much solar they are producing, utilising and exporting back into the grid. This information can be used through our ML algorithms to manage times of energy consumption that make the most of their solar, either through use or storage.
- **Solar thermal:** These systems operate independently from other electrical devices and the management systems can improve the value of these systems further.

A continual theme observed in the research regarding HEMS is achieving occupant engagement and participation in the system. Often research concludes an uptake period of the technology in the initial stage of utilising the management systems however, this engagement falls after a period of time where occupants revert back to their normal routines and habits. A major challenge this technology faces involves achieving long-term participation and long-term impact of household's energy consumption.

The results of this report outline the potential these management systems can have on the performance of households. The focus on studying the practices of the Fairwater occupants provide insight for how energy can be managed. Households follow different energy practices during the day as shown and discussed previously. The difference between summer and winter consumption as well as the variation in consumption between households outline how energy needs to be managed differently depending on the time of year and type of home. There are a lot of variables to consider when managing and predicting energy use.

BUILDING AUTOMATION

The development of Building Automation Systems can assist occupants to manage their energy consumption and achieve load shifting. Relating to the discussion on load shifting and home energy management systems, the implementation of building automation can reduce the impact of peak energy demand on the distribution network. Smart homes have the potential to conserve energy and reduce household's impact of the network, based on occupant practices.

A major saving that can occur relates to heating, ventilation and cooling to regulate the climate within the home. The utilisation of sensors, timers, heating and cooling units, ceiling fans, windows, windows covering, and exhaust fans can be controlled and programmed to provide comfort for the occupants. This technology aims to make the most of natural heating and cooling when needed. Furthermore, this approach can be operated in zones and when required based off occupancy sensors to only consider areas that are occupied.

The analysis of the data was linked to multiple social and psychological theories that explain people's lifestyles and routines. A major principle of these theories is people often are not flexible in changing the way they consume energy. Lifestyles that do not have flexibility restrict energy practices to a certain time of day which may not be beneficial to the distribution network, performance of the home or utilising of renewable energy sources.

IMPLICATIONS

The results of this report relate to the performance of the Fairwater households and the impact on the distribution network. The report focused on the occupant's practices, routines and habits, and how this impacted household energy consumption. This energy demand and the nature of household energy profiles have implications for the network.

Firstly, the variation in energy consumption that was observed for most of the Fairwater homes provides insight into how the distribution network needs to perform and provide energy supply to the residential sector. The significant difference between heating and cooling practices, and how this impacted the daily energy profile of the homes results in different peak demand periods during the day for the network to respond to.

Demand management is a key principle for the operation of distribution networks and can impact the performance of the network. The networks are exposed to peak demand especially during extremely hot and cold days when air conditioners are in use. One way to manage this demand is to upgrade the network to increase the overall capacity to achieve the appropriate supply of energy. This also increases the safety and reliability of the power supply during these peak times. However, there are some non-network options that can help reduce this peak demand such as demand management technologies that help manage these networks efficiently.

Embedded generation is one way to respond to peak demand periods by installing large systems close to substations to meet excess load requirements. These systems often utilise gas engines to fill this gap between supply and demand. This approach can achieve secure power reliability during high demand periods, defer the requirement for upgrades and expanding the transmission and distribution networks, reduce the cost of line losses, reduce carbon intensity, and reduce overall cost of electricity[1].

Mobile generation is another way to respond to stresses on the distribution network. These mobile generators can provide flexible supply to reduce stress caused by overloading network assets and can be utilised to minimise the impact on communities of extended outages related to asset damage [2]. Utilising energy storage can assist the network by storing electricity to be used during times of peak demand. AusNet Services were the first to trial large scale battery energy storage which results showing high reliability of energy supply when network faults are presence[3].

Additionally, developing engagement with commercial and industrial consumers and shifting their activities outside of these peak periods can reduce the risk of overloading network assets before and during peak demand periods

With the rise of distributed energy resources, it is becoming clear that the home is not just a consumer of one way delivered electricity, but now a two-way system of local renewable energy production, use and storage. The Fairwater study is the first attempt to link occupant practices to home energy management systems and building automation systems through machine learning algorithms and provide the basis for true, intelligent interconnection into the local network.

Please contact Troy Malatesta, Dr Jessica Breadsell, Curtin University Sustainability Policy Institute or Belinda Whelan, Director Climate-KIC Australia to learn more.

[1] Microsoft Word - DM Case_study_Embedded Generation_AS.docx (ausnetservices.com.au)
[2] Demand Management (ausnetservices.com.au)
[3] Microsoft Word - DM Case_study_GESS_Mar_2017 - final web version.docx (ausnetservices.com.au)