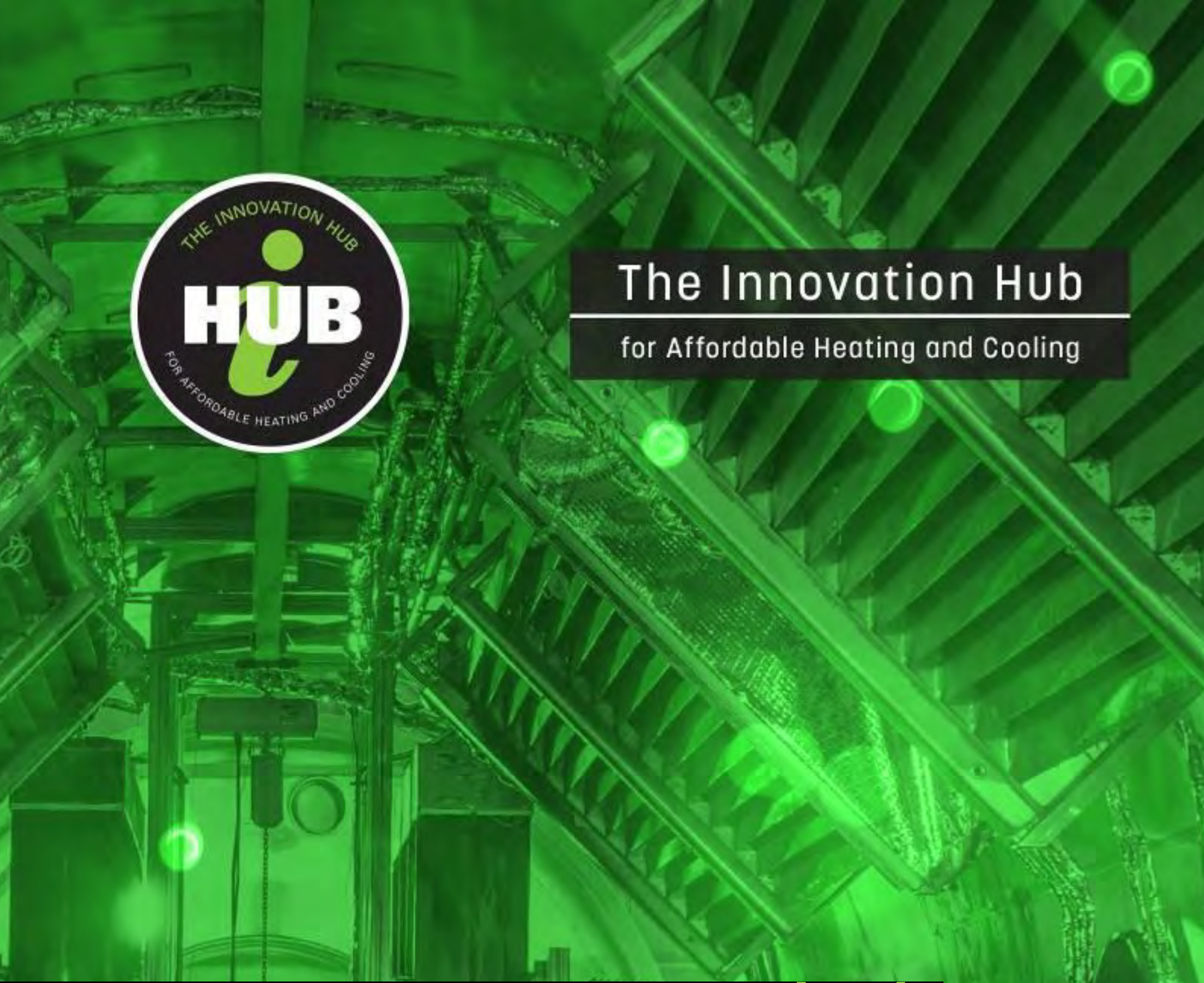

The Innovation Hub
for Affordable Heating and Cooling

Final Knowledge Sharing Report

Development and experimental implementation of transactive demand response management system through open ADR-approach for institutional buildings

Project DCH5

27th May 2022

Swinburne University of Technology

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry's transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Primary Project Partner

i-Hub DCH5 Knowledge Sharing Report

Lead organisation	Swinburne University of Technology		
Sub-Project number	DCH5		
Sub-Project commencement date	26th February 2021	Completion date	29th June 2022
Report date	27th November 2022		
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Executive Summary

Demand Response (DR) could play an important role in addressing the numerous technical and operational challenges due to the high level of penetration of renewable energy in the electrical network. This can be done by delivering a proper power balance between the demand and supply sides of the network through flexible load shifting/shedding in buildings. In this context, as part of the Data Clearing House (DCH) initiative, Swinburne University of Technology collaborates with other industry partners to install a photovoltaic battery storage system and control of the HVAC system in two commercial buildings located on the Hawthorn campus of Swinburne University. Furthermore, the system is expected to be able to participate in DR events through a novel openTDR framework. This document outlines the activities carried out throughout the project. The identification of potential buildings, the design and implementation of an on-site renewable system and the design of the different data monitoring systems that include occupancy rate, weather information, and energy consumption data from the existing BMS system were carried out. In M6 Milestone, the finalization of the design and implementation of the above mentioned data monitoring systems along with the development of the Game theory based OpenTDR energy management algorithm and the multi-agent framework has been developed and tested using synthetic data. In the upcoming months, the results obtained from the experimental verification's will be recorded in journal publications.

Swinburne University of Technology, as the project's host member, identified the potential buildings for the onsite renewable installation during milestone M5. The Advanced Technology Center (ATC) and the Advanced Manufacturing and Design Center (AMDC) have been identified as potential buildings for the implementation of the openTDR framework. The initial investigation revealed numerous inconsistencies in the legislative rules and operational safety of functional buildings. Swinburne collaborated with all stakeholders to resolve these issues and developed a design concept to evaluate the proposed OpenTDR framework, which is detailed in the technical report. Furthermore, the solar PV system along with battery storage is installed on the roof of ATC and the system is committed to operating to full potential during the M6 phase.

The concept of sharing energy between entities is critically reviewed, and the final design of the infrastructure requirements is discussed with our partners KIG and GHGP. The other component of the project is the control of the HVAC system based on feedback received from the OpenTDR framework. The HVAC control schedule is determined by the intelligent algorithms built into the openTDR framework, which assist in shedding or shifting load to increase the system's efficiency.

Several forecasting techniques have been investigated for use in the openTDR during the milestone M5, and in milestone M6 the developed model was evaluated with the data extracted from the local BMS in the identified buildings. Swinburne anticipates publishing the findings of the investigation in peer-reviewed academic journals by the end of June 2022. In addition to forecasting models, Swinburne researchers also created a prototype to evaluate the operation of the OpenTDR framework, which would be further used in future evaluation of community microgrid simulation.

The research team at Swinburne University of Technology has developed a custom BMS, weather, occupancy integration tool (BACnet gateway), Inverter MODBUS gateway and a community microgrid emulator system that is required for the experimental verification of the openTDR framework during Milestone M6. Additional information on the finalized design concepts of all data monitoring

devices and the manner in which the proposed OpenTDR framework and the OpenTDR algorithm incorporated within the framework are explained in more detail in the final technical report and summarized in this document.

Finally, various data monitoring and control signals have been sent to the DCH platform using an openADR to BuildingJSON parser developed in-house. To ensure that the proposed OpenTDR framework is standardized, all data communication within the network and to the DCH is developed based on the OpenADR standard schema. This implementation was the main focus of the last phase of the project, along with the implementation of HVAC control and the evaluation of the performance of the algorithms in real-world applications. The outcome of this implementation is also summarized in this Knowledge sharing report.

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1 DCH5 Overview

1.1 i-Hub DCH5

Swinburne University of Technology presents DCH5: Development and experimental implementation of Transactive Demand Response Management System using the Open ADR approach for Institutional Buildings in collaboration with CSIRO, AIRAH, Bramec, and KIG. In this project, demand-response is employed to address the technical and operational problems caused by the increase in the intake of DER into the electrical grid. In this regard, the precise scheduling of changeable load may be essential to coordinate the optimal use of on-site generation within a microgrid community. In view of this, an open ADR-based Demad Response (OpenTDR) platform is being developed. The fundamental objective of this OpenTDR framework is to improve the efficiency of distributed energy resource (DER) generation on site by adding demand response events associated with HVAC systems. The Hawthorn campus of Swinburne University is considering the use of two commercial buildings for the experimental installation of the OpenTDR framework and the evaluation of the impact of transactive demand response events. The OpenTDR framework incorporates a multi-agent model to help simulate microgrid energy management in communities. The objectives of this framework are to enhance the efficiency of HVAC operation within each building/microgrid and the utilization of on-site renewables. The primary component of the model is the game-theory-based optimization of energy consumption based on activity type, weather conditions, and occupancy rate.

1.2 Importance of the project

This DCH5 is particularly significant in evaluating demand response programs that encourage users to match their demand to the circumstances of the power supply, enhancing the dependability of the power system and its capacity to operate economically. In the context of this discussion, transactive energy refers to a variation and a generalized form of demand response in which both the supply side and the demand side are handled in an integrated fashion. It is designed to work in dynamic environments that contain a growing number of intelligent devices and resources. To maintain a dynamic equilibrium between supply and demand, it makes use of the adaptability provided by having a variety of power sources and locations at which power is used. The energy units will become more competitive as a result of this, and the community will benefit from having access to a physical resource. Additionally, it will provide better energy use, leading to reduced energy expenses for the buildings that participate in the program. The proposed system offers energy management throughout the day through the use of an intelligent algorithm. This algorithm not only considers the current demand but also makes projections regarding the demand based on historical data related to both the occupants and the weather. Both the party using the energy and the company providing it will benefit from this endeavor. The user will gain from the system's increased efficiency in the utilization of available energy resources, as well as from the decreased amount of energy that will be wasted as a result of the system's lack of intelligence. The data obtained from the various components, along with the related analytics, form the basis of this intelligence. This system offers a form of money to energy providers in the form of energy itself. In contrast to the conventional building energy transaction, which is an up-down transaction and only receives power from the grid, this transactive energy management allows the sale of energy within the community, thus reducing the peak demand for energy and actively participating in the dynamic energy platform.

1.3 Deliverable of DCH5 Project

Phase 1: Implementation of DER system with controls

Development of a real-time HVAC DR management, control, and monitoring system in two institutional buildings that consider occupancy level, type of activity, and weather conditions.

Phase 2: Application development and deployment

Implementation of the TDR management strategy using open ADR standards to improve energy storage and generation systems on site within two buildings located on the Hawthorn Campus of the Swanburne University of Technology.

Phase 3: TDR implementation in real-world conditions

Real-world demonstration of the proposed TDR operation through the DCH platform using the NI-LabVIEW-based control system. Development of "TDR-APP" to demonstrate the application hosting capability through DCH in Swinburne buildings.

1.4 Site Description

The Swinburne Community microgrid precinct consists of the ATC and AMDC building considered for the evaluation of the OpenTDR framework. A detailed analysis of the buildings of Swinburne University of Technology, Hawthorn Campus, was performed to ensure that all the following criteria were considered:

- Proximity of the two potential buildings for energy sharing.
- Distribution of different zoning areas in the floor plan.
- Access to the required roof space for the integration of the solar-PV system.
- Access to timetabling and scheduling of the spaces in the buildings.
- Feasibility of interaction with existing BMS to control the HVAC system.

Taking into account two adjacent buildings at a time, as illustrated in the aerial view of the Swinburne Hawthorn Campus shown in the Fig. 1 several combinations of buildings are possible. Among them, the combination of ATC-AMDC building is the best suit for the project case. Further analysis of the system showed a legislative prohibition against connecting two sources originating from two separate transformers. As a consequence, the application to share energy with two DSBs connected to the same electricity meter was ultimately discarded.

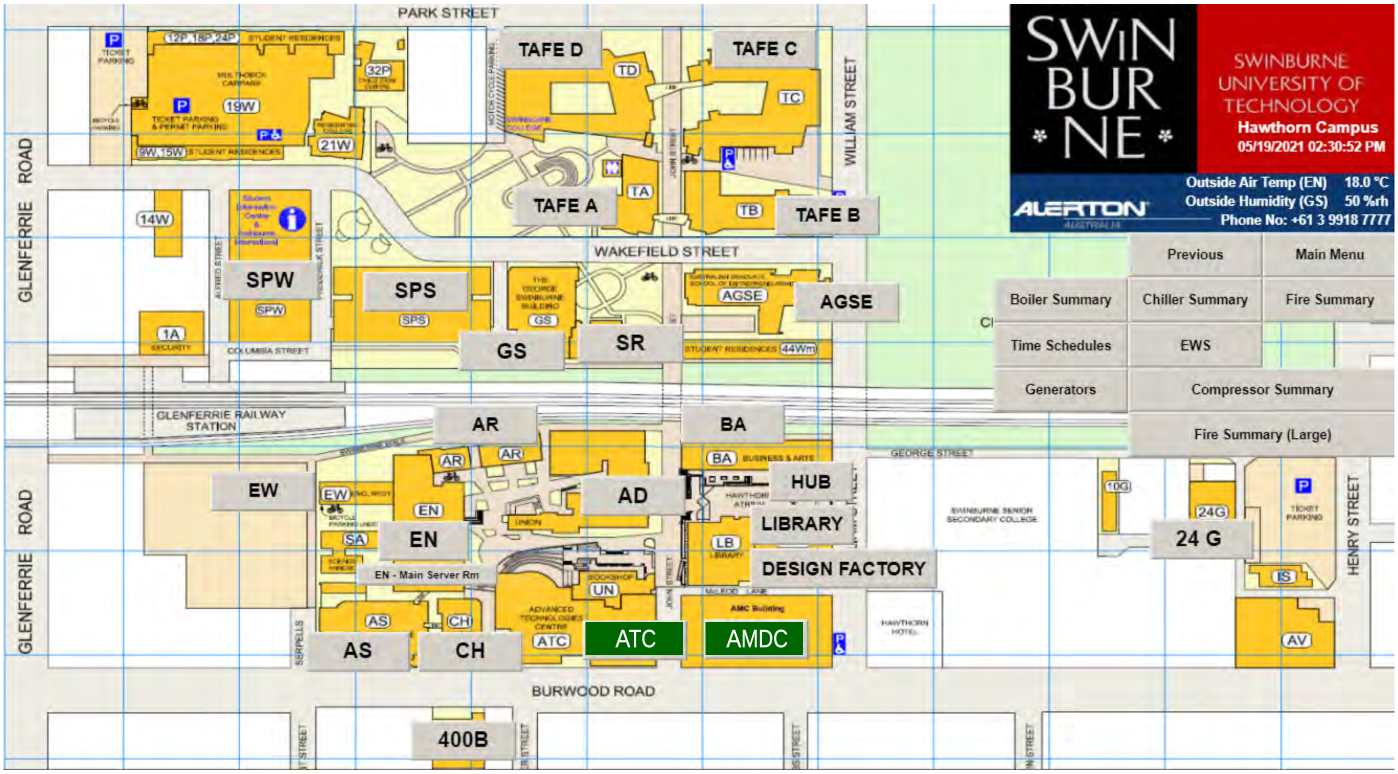

Figure 1: Aerial view of the buildings in Swinburne Hawthorn Campus

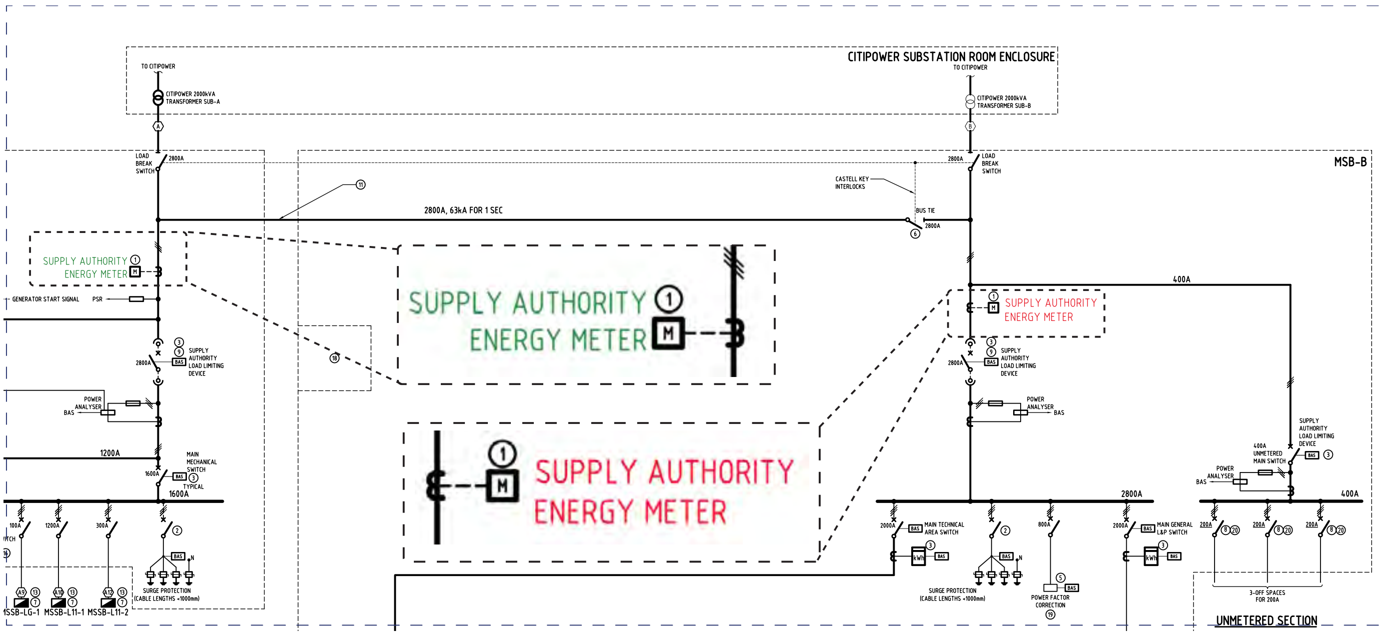

Figure 2: Electrical wiring diagram of ATC Building indicating the two Utility connections

1.5 About this report

The purpose of this report is to make the findings and conclusions of the project, as well as the technical material and the lessons learned, more widely known to the public.

This report provides an overview of the OpenTDR framework used for the transactive demand response and illustrates the system configurations of the experimental validation set-up. Detailed insight on the multi-agent-based game-theoretic OpenTDR energy management algorithm is provided in this report. The detailed explanation on the custom data monitoring devices developed for occupancy and CO2 / RH / Temp monitoring is then provided.

2 CHALLENGES

2.1 Challenge Encountered

Complexity

A further layer of complexity is added by the several types of data that the building outputs, as well as the format of those data, the resolution and the various standards and protocols necessary to communicate with the various buildings systems. Most people underestimate how hard it will be to combine all these different types of data into a single standard that lets end users access the data and use them in different ways. A further layer of complexity is added due to the various types of data extracted from the BMS and other custom-made solutions. For example, the data parser developed by CSIRO supported only integer values, and we had some Boolean values in the OpenADR schema.

Designing, Building, and Testing Hardware and Software

To determine the hardware, software, network and server configurations necessary to run the TDR service, a significant amount of effort (months worth) was required, as with any other self-managed service. To move into the development phase, this often required the recruitment of new staff members and/or the redefinition of the roles of current staff members. In addition to this, the infrastructure for the creation, deployment and testing of IoT devices, as well as hardware management, needed to be provided. To make it easy for new devices to connect, this step requires building a network and developing strategies for connectivity and redundancy.

IoT Sensors and Networking Complexity

The vast majority of the sensors that were deployed for this project did not have the ability to interact with each other or connect to the Internet. Because of this, managing it requires middleware that establishes gateway connections between sensors and the application layer of the system to which they are attached. To do this, the middleware must first be integrated and then undergo measurement and maintenance. As a direct consequence of this, we are required to analyze massive volumes of data in parallel, including sensitive information in certain cases.

The Security/Privacy Issue

There are several security problems with custom-made IoT devices. On the most basic level, we need to build a service that protects the device connection, the DCH connection, and anything else that connects to the Swinburen IoT device network. It is also not a one-time setup; it requires a secure streaming system capable of keeping up with monitoring, detection, access control, and other security requirements. This requires not just top-tier encryption skills, but also domain-specific firmware built by domain specialists. These requirements are always changing, necessitating the ability to upgrade both software and firmware.

2.2 Overcoming These Challenges

The research team at Swinburne has sufficient prior knowledge with the IoT platform to address the issues outlined above. Most of the challenges that were faced were ultimately overcome by the research team as a result of their ongoing conversations and efforts to collaborate with other project partners and subject matter specialists. To accomplish the aims of the project under circumstances in which the preexisting solutions are either inapplicable or constrained, custom solutions are produced. As a direct result of this effort, a number of tailor-made solutions have been created. Two of these solutions are the TOF-based occupancy monitoring system and the low-power real-time air quality monitoring system. Furthermore, before implementing any new devices, the designs are validated by the internal management team and also consulted with industry professionals to assist in developing the business case. This program also included training, documentation, and consultation with subject matter experts who answer any questions users may have in order to make the technology as easy to use as possible.

3 SUMMARY OF LESSONS LEARNED

3.1 Commercial- Difficulty in building data ingestion

We should not have assumed that today's buildings are smart, connected, and digital, capable of providing superb data on demand. The IT team has BMS, BACnet, Modbus, and open or IP-connected systems. They have, but they lack the data quality needed for a meaningful return on investment. The acceptance of the setpoint by the BMS supplier was also a concern. The setpoints alter depending on the building's mechanical architecture, which was not considered early on.

Sensor retrofitting for BMS data integration is sometimes unnecessary. Getting permission to incorporate them is a lengthy and bureaucratic process that is hard to complete on time. The building operations crew has been working on the same assets for years. Introducing a new package that saves money and energy, improves comfort, or minimizes maintenance is sometimes perceived as a threat by present staff, who believe that such technology may show how poorly they have been doing.

3.2 Logistical- Asset management team are reluctant to share some critical data

Swinburne University's authorities, logistics, and asset management team supported the project throughout. However, not all of their building information/data may be shared with our project. Our lesson. We felt that CC-CAM could provide occupancy data. This camera can provide occupancy statistics for specific building regions. We contacted Swinburne for this information. The authorities refused to give access, citing privacy concerns. We told them that we do not need the video footage, only the number of people tallied (built-in function of the CC-CAM). After many attempts to contact them, we were told that a separate company maintains the security cameras and cannot give us the information we require.

3.3 Difficulty of sharing energy within the neighborhood

We are aware that the potential to share surplus energy within the community, which would increase the market returns of energy on site in response to transactive demand, is not legally possible until the current Australian regulation is revised. This is despite the fact that doing so would increase the market returns of the onsite energy.

3.4 Logistical- Difficulty to get IT support on demand

This project involves the integration of new devices, data, platforms, and IoT applications with current IT assets. This involves minimal to moderate network changes, firewall upgrades, and network expansion. This required open communication with IT personnel. Getting the IT staff to understand the project demands was difficult. When someone replaces the person in control for an unavoidable cause, such as sick leave, the procedure must start over. Retrofitting a simple network expansion requires approval and a third-party supplier to install the necessary equipment and cabling, increasing time and cost. Unexpectedly, we spent a lot of time dealing with Swinburne's IT provider.

4 SUMMARY OF TECHNICAL CONTRIBUTION

4.1 OpenTDR framework for Community Micro-grid Emulation

Buildings account for more than 25% of Australia's greenhouse emissions. On-site renewable and storage enable buildings to manage and minimize their energy demand. Inadequately managed renewables may have a negative impact on grid stability and cause unwelcome outages. Adjusting the energy consumption operation schedule of the building and integrating renewable energy and storage systems reduces the burden on the electrical grid during peak times, enabling buildings to function as distributed energy assets and thus can significantly reduce their operating costs. Controlling building loads during peak and low peak periods reduces dependence on grid-supplied energy and improves the contributions of renewable energy. Thus, building owners can successfully leverage flexible demand to engage in the energy market while promoting system modernization and increasing grid resilience, dependability, and energy affordability. To this end, OpenTDR is a low voltage microgrid platform that allows the participation of distributed energy resources (DER) in the market and demand response mechanisms applied to commercial and institutional buildings.

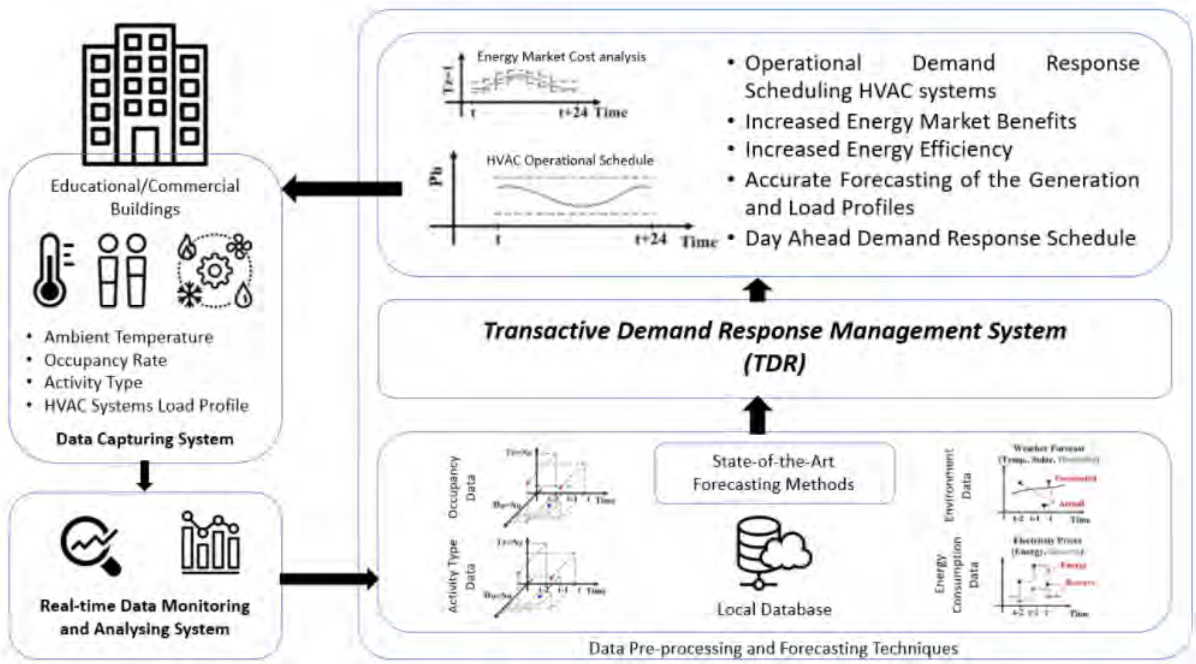

Figure 3: Overview of the proposed Open transactive demand response (OpenTDR) framework.

As stated previously, the unique issue of this project is to develop a community microgrid so that an entity (building) can share extra renewable energy on site with its neighbors instead of feeding back to the grid to meet demand collaboratively. The concept of sharing energy from the community microgrid allows advanced game theory algorithms to examine energy market scenarios, ultimately addressing community energy needs using the OpenTDR framework. A detailed overview on the progress of implementing the game-theoretic model is explained in the later sections.

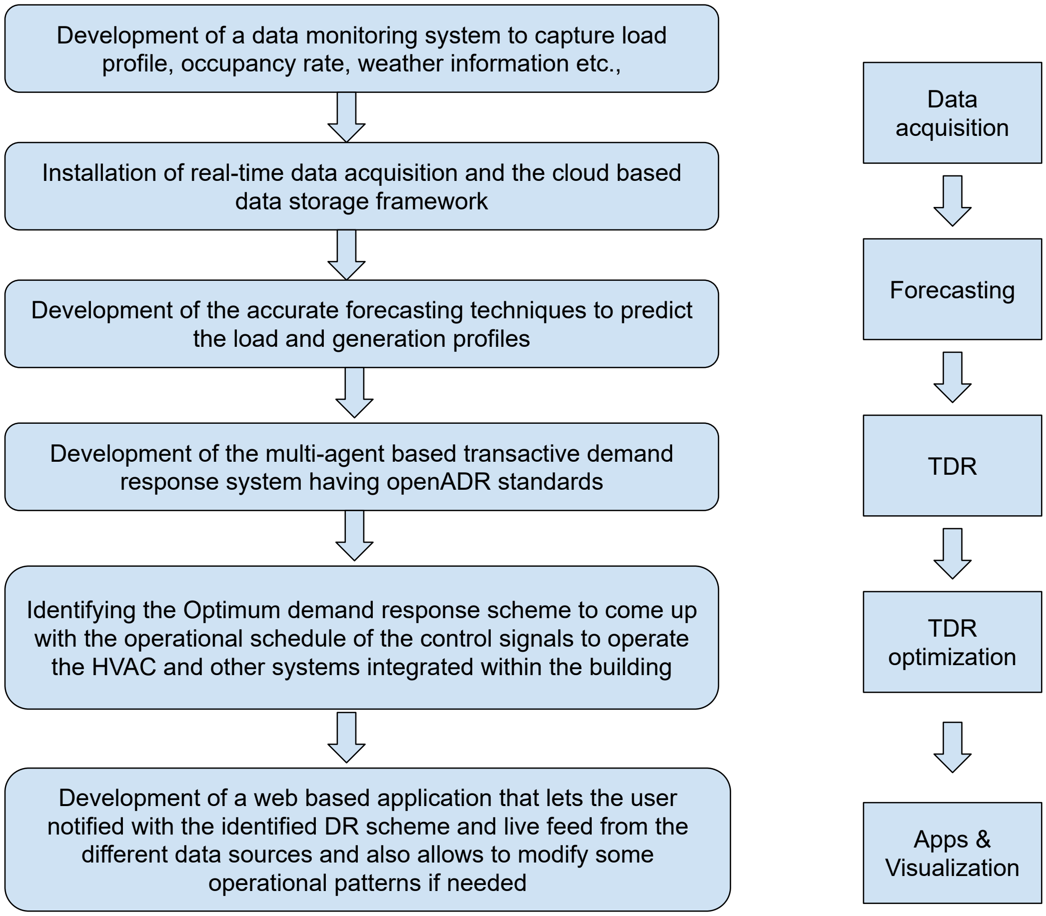

Figure 4: Operational flow chart of the proposed OpenTDR framework

To respond wisely to DR events, building owners and market players must work closely together. Although there are ideas and techniques for managing a transactive market around buildings, there is no evidence of their implementation. Therefore, this study proposes a strong framework to implement demand response using HVAC systems in commercial buildings. Typical energy usage and expenses in business and office are attributed to HVAC systems. Controlling the performance of the HVAC system within its flexibility margins would greatly affect the energy efficiency of the entire building, especially in commercial and institutional sizes. Fig. 4 shows the operational flow chart of the proposed OpenTDR framework.

This project also develops an innovative OpenTDR energy management algorithm and implements the OpenADR schema for real-time data transfer and interaction amongst CMG components. The OpenTDR framework also stores the building model information so that sensor node data can be mapped to their relevant locations and control schemes. This energy management system is tailored to orchestrate the flow of energy according to market trends.

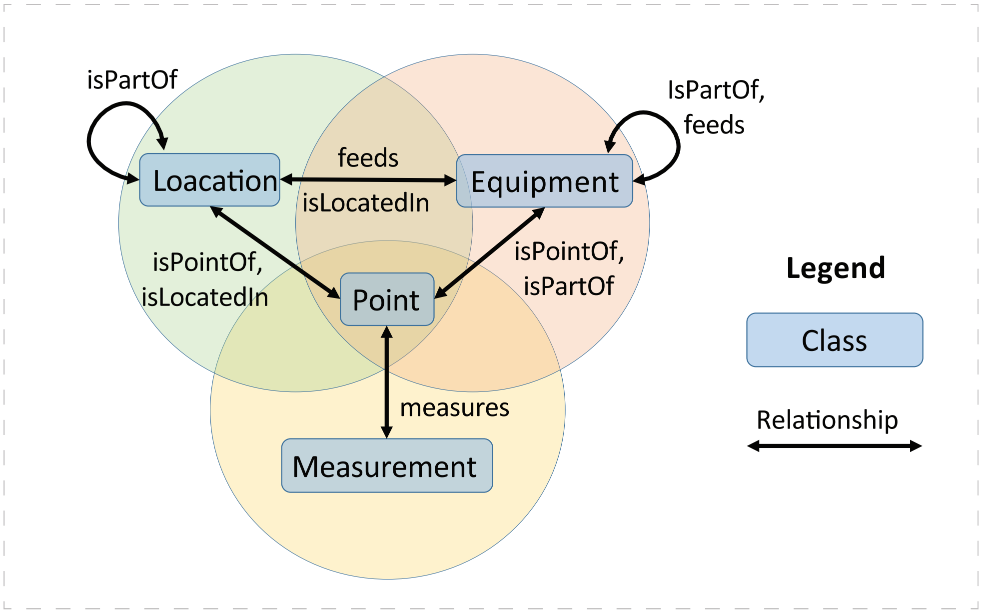

Figure 5: Brick Schema overview

4.2 Baseline data gathering, cleaning and preparation of baseline data

Implementing the semantic building model integrated into the OpenTDR framework uses the meta-data information based on Brick schema. In collaboration with the CSIRO DCH team, the Swinburne researchers team developed a semantic building model for the two identified commercial buildings that are machine readable, easy to read and easy to query. The brick schema comprehensively describes the structure of the building and the various types of data input streams along with the detailed architecture of the mechanical systems integrated within the building. Fig. 5 indicates the relationship of the measurement points of the data with the mechanical equipment and the location of the building.

The building model is generated based on the inputs that can be extracted from the BACnet sniffer, which can talk to the BMS gateway and access the required information in real-time. The implementation of the BACnet sniffer to access the BMS data allows us to create the entire brick model of the building.

The following data points are added to the system specifically targeting potential areas with dynamic population control and zone-wise temperature control.

- Occupancy Data
- Zone-wise Temperature/Relative-Humidity/CO2 Data
- External Weather Data
- BMS data
- Inverter/Battery Data

More detailed information on the proposed solutions for each data point is explained in the following sub-section.

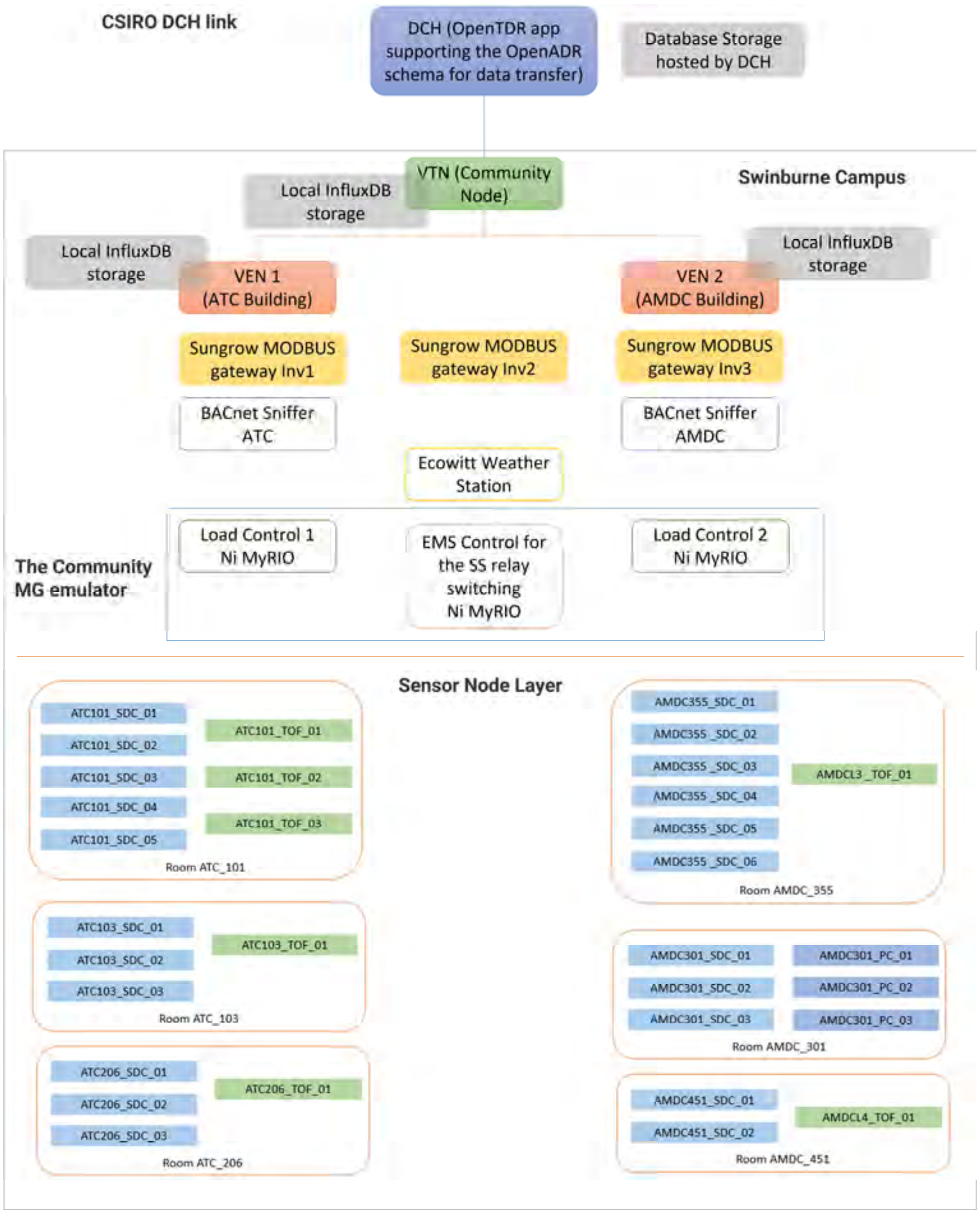

Figure 6: Hierarchical structure of different nodes

It is worth mentioning that each building consists of a local sever commonly called a VEN and it is talking to a VTN that is the Community Microgrid energy management system. The identified locations in two commercial buildings located on the campus of Swinburne, Hawthorn (ATC101, ATC103, ATC206, AMDC355, AMDC301, AMDC303 and AMDC451) as shown in Fig. 6 were unique in terms of dynamic occupancy rates. This dynamic nature of the occupancy had a greater influence on encouraging the researchers to work on identifying the relationship between the HVAC set points/ usage and the occupancy.

Occupancy Data

The occupancy data was planned to be installed using the already installed IP cameras, but due to the risk of privacy breach, an alternative solution was sought. Therefore, a custom TOF camera based solution was developed in house by the researchers in Swinburne University of Technology. The use of thermal camera imaging to process occupancy was an alternative option considered by the researchers, but this solution was ruled out due to financial limitations. But the use of the thermal camera-based solution to detect occupancy would have brought about a new spectrum of thermal comfort assessment, which could be a future consideration in this project. The occupancy monitoring solution developed using the Terabee3D TOF camera consisted of a raspberry pi that reads the depth steam obtained from the entry points of the rooms and processes them to identify the number of people entering and exiting the room. Further details of this custom solution can be found in the user manual in a separate submission along with the report.

Zone wise CO2 /Relative-Humidity/ Temperature Data

The other important aspect of the newly added data points in the semantic model is that they assist in zone-wise HVAC control, which is part of the proposed Transactive Demand Response. Based on the information received from the ToF-based occupancy sensor and the CO2 / RH / Temp sensor module, the local energy management algorithm determines the adjustable load available. The sensor consists of an ESP32 board and an SCD30 sensor module. Further details of this custom solution can be found in the user manual in a separate submission along with the report.

External Weather Data

In order to get a more realistic external weather data and implement weather-based HVAC set point controls, an ECOWITT HP25110 weather station is installed on the roof of ATC South West wing and the basic data extraction was carried out from the custom server setup using the ECOWITT weather station. Sample weather data obtained from the weather station installed on the top of the ATC building. The different weather parameters that are extracted from the weather station are indicated in the dashboard shown in Fig. 7 and a weekly plot of the data is shown in Fig. 8. [h]

The data from the weather station can be stored on external servers like the Weather Underground or ECOWITT server and accessed via APIs, but, in order to ease the process of data extraction, a local server is set up and a script is written to extract the data directly from the weather station.

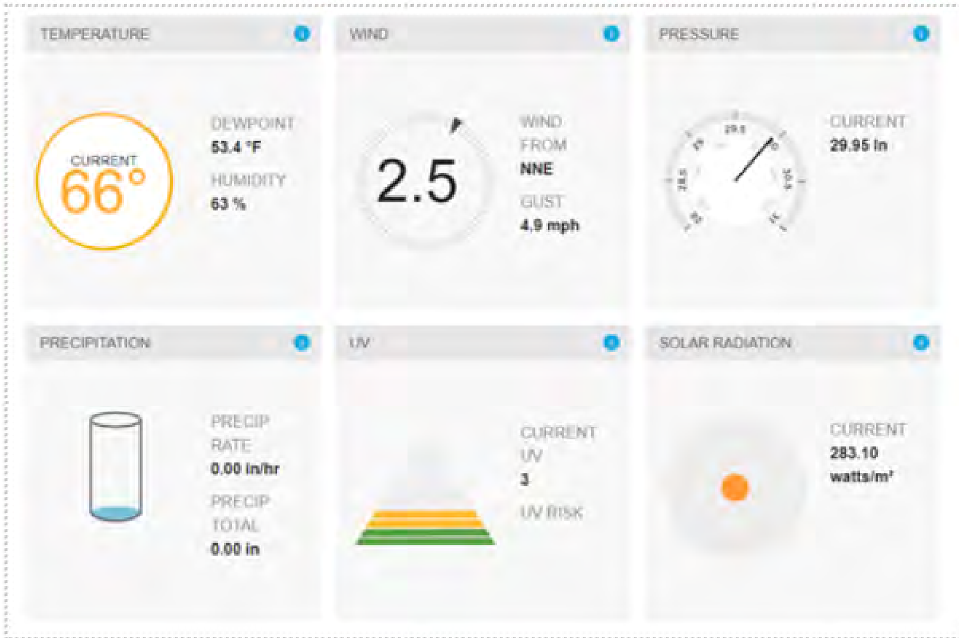

Figure 7: Dashboard of the different data points extracted from the weather station server

BMS Data

A BACnet sniffer was explored for each building in this project to replicate the data communication side of a community MG. However, the sniffer may be a single BACnet device. As part of the project, we collaborated with the ALETRON team, an external BMS supplier. We designed a Python-based gateway using the BAC0 library and custom code to read the list of recognized BACnet points. In addition to reading data, the BACnet gateway also listens to MQTT topics and manages HVAC devices in terms of operating schedule and set point management.

As part of our study, we created a BACnet gateway based on NI LabVIEW that performs the same function in terms of reading the points and updating the server with the MQTT topics as one part, listening to certain specified MQTT topics, and delivering control inputs for HVAC devices. Further details of this custom solution can be found in the user manual in a separate submission along with the report.

Inverter/Battery Data

In order to mimic the data communication side of a community MG, this research considered the possibility of using a unique MODBUS gateway for each inverter. However, the sniffer can be implemented as a standalone system for the entire campus. As part of the project, we collaborated with the SunGrow team, the inverter manufacturer, to create a customized MODBUS gateway that supports MQTT messages in order to perform low-level controls. Aside from the capability of reading data, the MODBUS gateway also listens to certain MQTT topics, controls the low-level operation of the inverters to carry out charging and discharging operations, and varies the dynamic feed-in power to carry out illustrations of the community's participation in the sharing of energy.

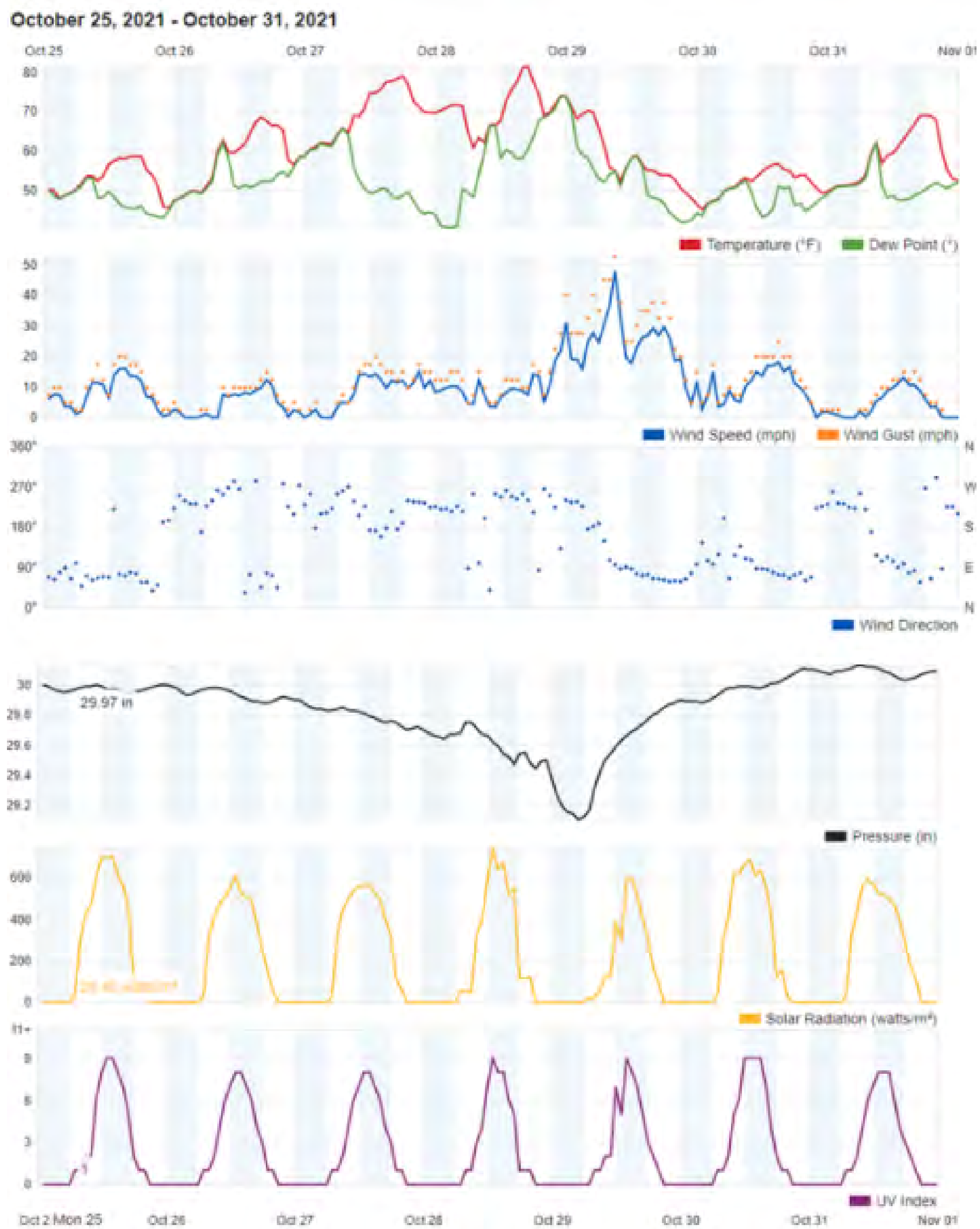

Figure 8: Sample data of a week extracted from the weather underground server

The MODBUS gateway is a Python script that reads MODBUS messages via the native TCP port. As a part of this research, we have also developed an NI LabVIEW-based MODBUS gateway, which does the same task in terms of reading the points and updating the server with the MQTT topics as one part, listening to some specific MQTT topics, and sending control inputs for the inverter low level control. Further details of this custom solution can be found in the user manual in a separate submission along with the report.

4.3 Results

In this section, a detailed overview of the results obtained as part of the DCH5 project initiative is discussed. It is observed that the main objective of the DCH5 initiative was to evaluate the impact of the transactive demand response across multiple entities within a community in this case, a university campus. The main advantage of evaluating transactive demand response schemes in university buildings is that it comprises diversified building zones, and the usage pattern of these spaces had greater potential with demand response involving flexible load. The close proximity of the buildings within a campus environment also allowed us to experiment with complex market transactions within the community. As a part of the experimental setup, it was essential to consider that the two buildings were able to host on-site generation resources and equip functionality for controlling the flexible loads (HVAC).

The Two buildings ATC and AMDC at Swinburne University of Technology, Hawthorn campus was considered for this case study to evaluate the transactive demand response. The Australian grid code had a limitation with the sharing of energy between buildings, along with some other logistic and legislative restrictions, the university campus had the project team decide to install the solar PV system on the roof of the ATC, as deliberately mentioned in Section 2.1. Second, we needed to monitor and analyze the BMS data to understand the impact of flexible load on energy consumption. A BACnet gateway was developed in house to assist in real-time data monitoring of the BMS data and also to have supervisory control over the BACnet devices of the specific targeted zones in the buildings. Two types of control have been implemented and tested, which include the time table scheduling and the forecasted set-point based control enabling the optimal usage of the flexible loads within the zones. In the context of the openTDR framework explained in Section 3. These specific demand response approaches are triggered during an occurrence of an openTDR event based on the market transactions analysis carried out by the game-theoretic model. The simulation results of the above-mentioned models have been presented in the previous sections of this report.

Due to the limitation that we have on the size of the load and the generation capacity of the buildings, it was a critical task to illustrate the energy sharing and the phenomenon of the response to transactive demand using the openTDR framework as an objective of the project. This is the reason why the Swinburne research team has collaboratively worked with Bramec on developing the state-of-the-art Ni-based community microgrid emulation system to test energy sharing and transactive demand response events. This emulator would act as a resource that will orchestrate further studies based on community energy sharing in a hardware-in-the-loop simulation setup. The results of this experimental analysis are presented in a journal article that is due in a month. The results are subjected to publication and therefore we are just demonstrating the execution of

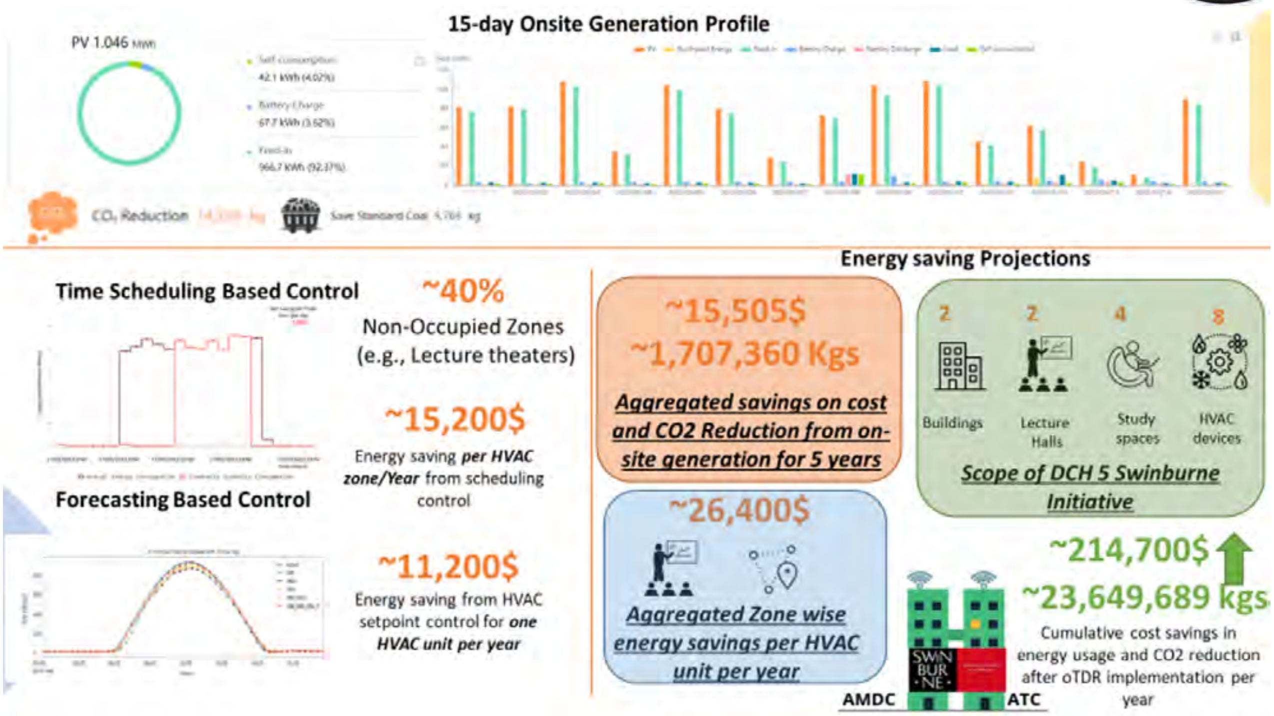

Figure 9: Overview of the results obtained from the initial case studies

the above-mentioned simulated case study using the hardware setup. In the context of the actual experimentation, the two specific control strategies have been tested individually and the results are presented in the following sections.

An overview of the results observed from the various case studies is presented in the figure 9. As mentioned in the previous section, time table scheduling is the most preferred way to reduce the load on the academic building mainly because it compromises many unused zones. From an initial case study conducted, it is evident that on average around 40% of the spaces are unused but the HVAC system is running without stopping during the operational time or 7am to 11pm. Therefore, by implementing a time-scheduling-based control, we can minimize usage by 40%. This is why in the large lecture theaters considered in the scope of the project, we tested running the time table scheduling method and observed that per HVAC device we will have a savings of about 15,200 AUD per year. Similarly to that, the set point control has been implemented considering the forecasted temperature and also the dynamic occupancy in the zones which is predicted to have a saving of 11,200 AUD in zones like the private study areas per year. The figure 9 give an overview of the projected energy savings per year for each HVAC load and also on-site generation.

As we know, with the impact of COVID and limited accessibility to campus, we were able to observe savings in the selected zones and in the future the research team will focus on implementing it on a large scale throughout the building and campus. A more detailed perspective of the results is given in the technical report shared along with the submission.

4.4 Publication

One of the deliverables of the DCH5 project is to publish several journal publications from the project outcome. In this regard, three papers are accepted for publication in the conference. The details of the conference papers are given below.

- Modified support vector regression model for very short-term solar irradiance forecasting - International Conference On Science Technology And Management (ICSTM-22) 11th January 2022,Istanbul, Turkey
- Very Short-Term Solar Irradiance Forecasting Using Multilayered Long Short-Term Memory (LSTM) - SPLITECH2022 7th International Conference on Smart and Sustainable Technologies, Split and Bol, Croatia (July 5-8 2022) - Accepted for publication
- Design, Development and Implementation of Transactive Demand Response System using OpenADR standards for Commercial Buildings - SPLITECH2022 7th International Conference on Smart and Sustainable Technologies, Split and Bol, Croatia (July 5-8 2022) - Accepted for publication

A review paper accepted for publication in the Energy stratergy reviews. In addition, four journal articles are to be submitted that include the results in the coming months. The details of these journal publications are given below.

- Role of optimization techniques in microgrid energy management systems – A review - Energy strategies Review [published]
- Case study on Live HVAC control through real time scheduling in building management system [to be published]
- Game theory based transactive energy sharing in twin building microgrid [to be published]
- Design of Transactive Demand Response Management System through OpenADR [to be published]
- Short-term Forecasting of Global Solar Irradiance using a hybrid RNN-GRU method with a XG boost ensemble [to be published]
- Short-term Forecasting of Global Horizontal Irradiance using Extreme Gradient Boosting Technique [to be published]

5 CONCLUSION AND FUTURE WORK

The objective of the DCH5 program is to examine the viability of a commercial building's participation in a DR event by integrating the building model with a cloud service provider. In addition, it aims to standardize a platform so that distributed resources can be effortlessly integrated into a system in which they can actively participate in the energy market. Although COVID limitation and supply chain shortage DCH5 is delivered on schedule. This report is designed to disseminate the information gained during the project for use in future projects.

5.1 DCH 5 future commercial prospect

Swinburne Research, in conjunction with its key stakeholders, is now working on the commercialization process of the findings and will continue to do so over the next several months. The scope of the work that was illustrated in the DCH5 project serves as a good reference for future studies in interconnected buildings and also in the low-level control process for inverters and HVAC devices.