The Innovation Hub

for Affordable Heating and Cooling

i-Hub DCH 5 Milestone Report #M7

i-Hub DCH5 - Development and experimental implementation of Transactive Demand Response Management System through Open ADR-approach for institutional Buildings

Project: i-Hub DCH5

Sub-Project Report Number: DCH5 - MR7

27th May, 2021

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.
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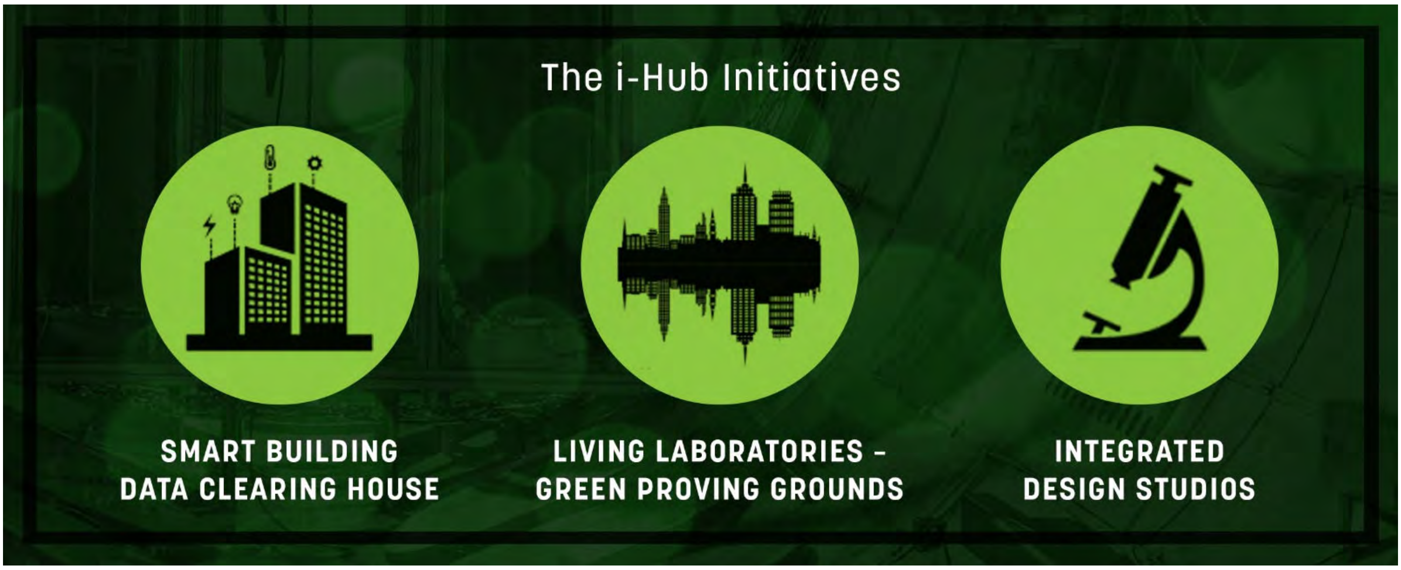
Primary Project Partner



i-Hub DCH5 - Development and experimental implementation of Transactive Demand Response Management System through Open ADR-approach for institutional Buildings

The technical and operational challenges caused by the higher ingestion of DER in the electricity grid can be addressed using demand response. In this regard, efficient scheduling of flexible loads can play a pivotal role. In this context, a fully operational open ADR based DR model, emphasizing the HVAC systems in two commercial-buildings at Swinburne University, is proposed. A multi-agent-based open transactive demand response (open-TDR) model is proposed to improve the efficiency of HVAC and onsite renewables. The core component of the model is the multifactor optimization of energy usage based upon activity type, weather conditions, and the occupancy rate.

Lead organisation

Swinburne University of Technology

Project commencement date

26th February 2021

Completion date

30th May 2022

Date published

27 th May 2022

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Project website

http://www.ihub.org.au/dch5-development-and-experimental-implementation-of-transactive-demand-response-management-system-through-open-adr-approach-for-institutional-buildings/

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 M7 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 M6, and in milestone M7 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 M7. 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 Final technical report. Also, the Individual manual links for the different components of the project are added as the appendix to this document which gives an overview of the individual components of the project.

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1 DCH5 Overview

1.1 i-Hub DCH5

Swinburne University of Technology presents DCH5: Development and experimental implementation of the 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 Demand 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 with the circumstances of the power supply, improving the dependability of the power system and its ability 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. In addition, it will provide better energy use, which will reduce energy expenses for the buildings participating 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 analytic, form the basis of this intelligence. This system offers energy providers a form of money 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 Swinburne 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.

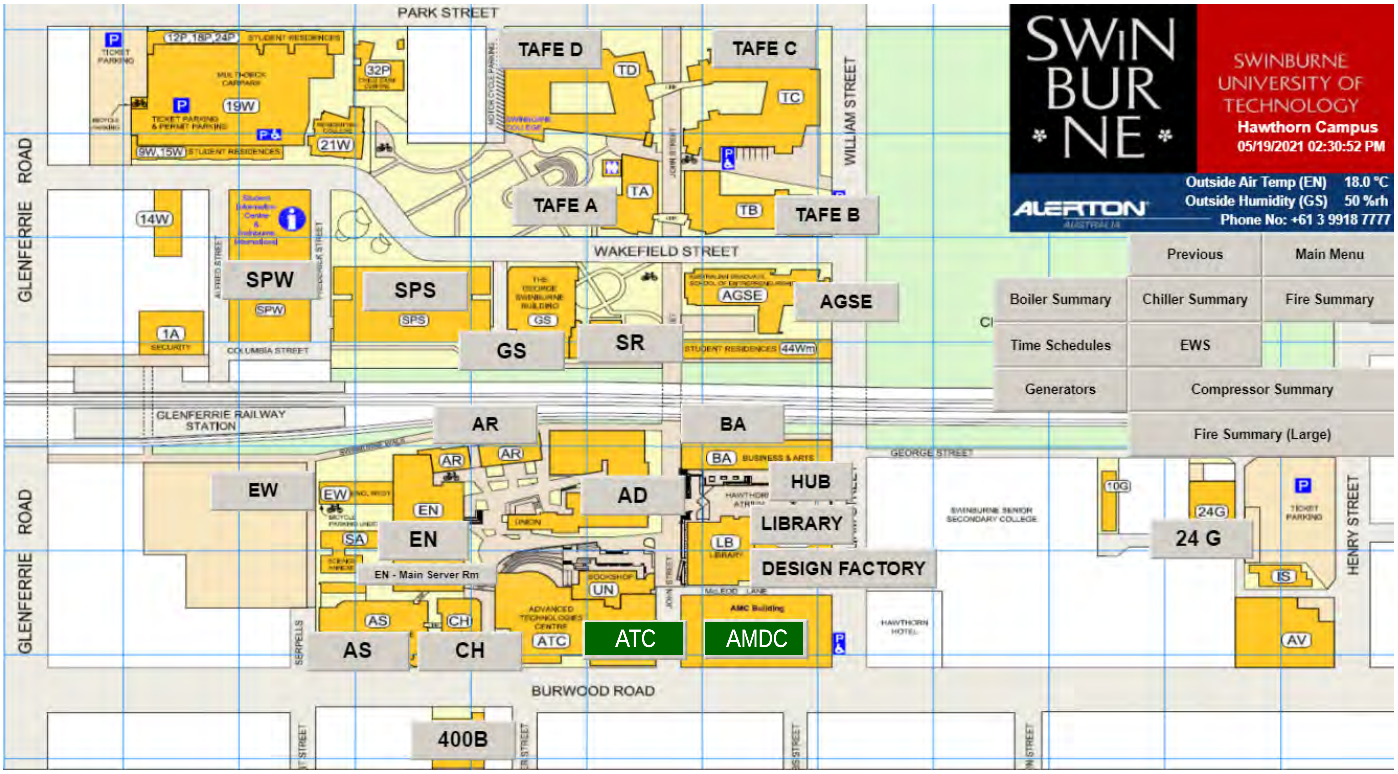

Figure 1: Aerial view of the buildings in Swinburne Hawthorn Campus

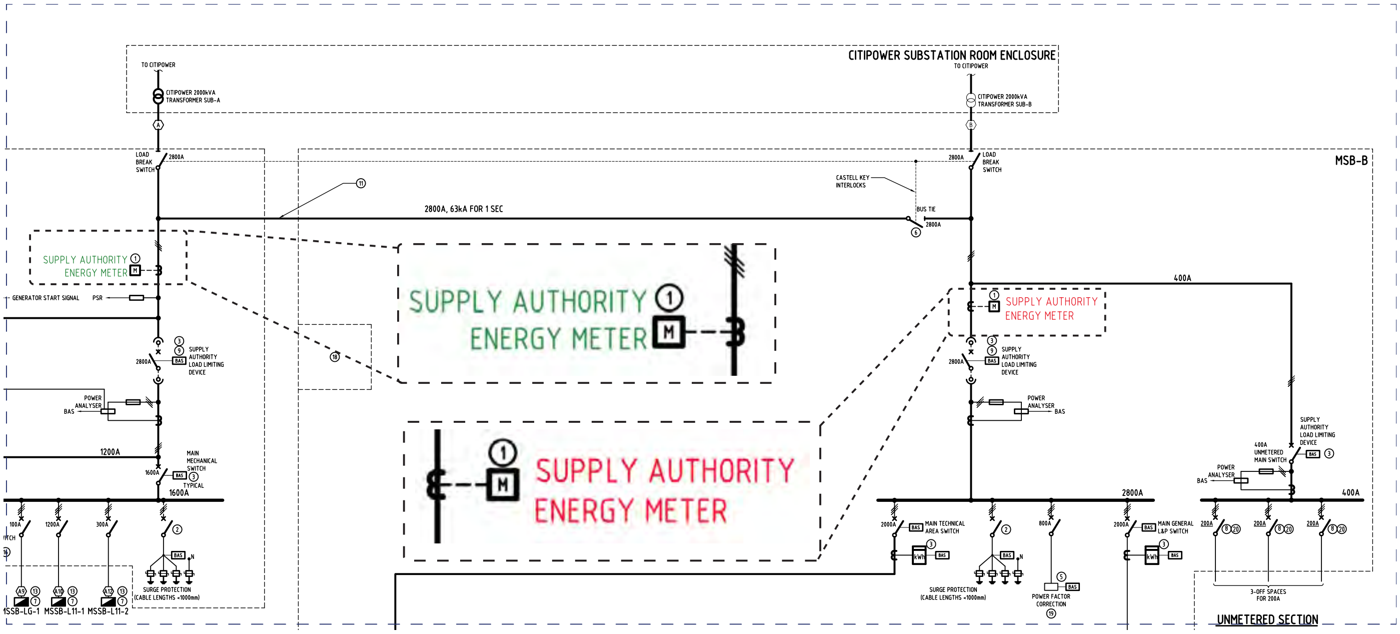

Figure 2: Electrical wiring diagram of ATC Building indicating the two Utility connections

Figure 3: Installed PV system in the ATC roof top

1.5 About this report

The purpose of this report is to provide an overview of the OpenTDR framework used for the transactive demand response and to illustrate the different components of the projects along with the experimental results obtained in the project.

2 DER system integration with controls

2.1 Solar-PV and storage system

The architecture of the solar PV storage systems is partitioned in such a way that the response to transactive demand between two entities of the community microgrid can be studied. The design, installation, and compliance of the PV system and its components are governed by all state "codes and standards" and Australian "codes and standards", including but not limited to the following:

- AS 1170.2:2002 – STRUCTURAL DESIGN ACTIONS-WIND ACTIONS
- AS 4777.1- GRID CONNECTION OF ENERGY SYSTEMS VIA INVERTERS INSTALLATION REQUIREMENTS
- AS 4777.2 - GRID CONNECTION OF ENERGY SYSTEMS VIA INVERTERS INVERTER REQUIREMENTS
- AS 5033 - INSTALLATION AND SAFETY REQUIREMENTS FOR PHOTOVOLTAIC (PV) ARRAY

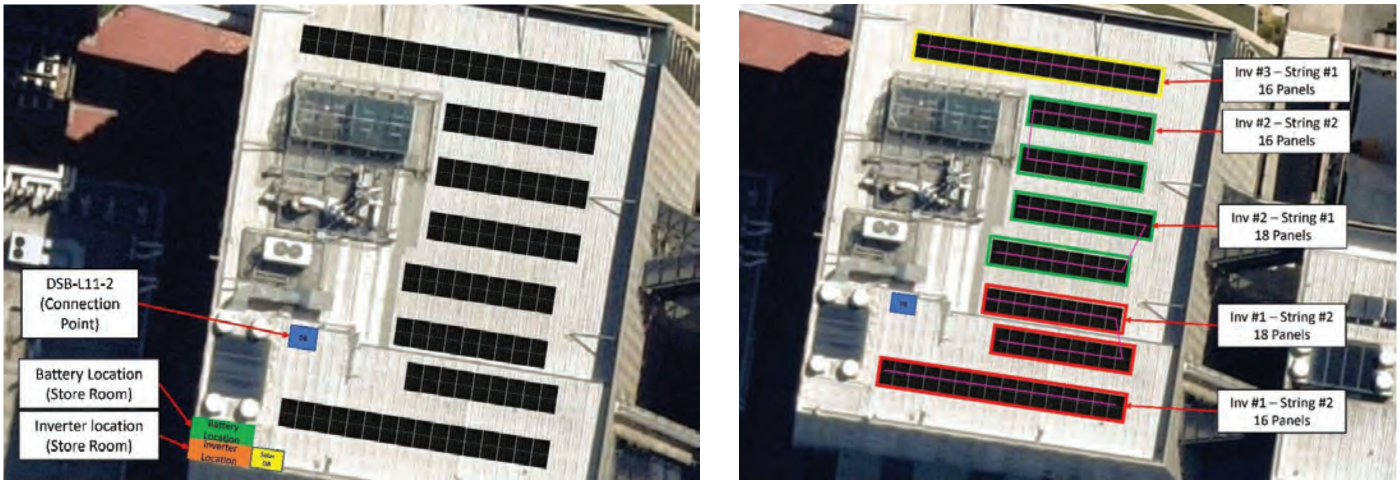

Figure 4: Site plan of the installed solar-PV system on the West Wing Roof of the ATC building

Figure 5: Inverter Room with 3 SH10RT inverters and Batteries

Table 1: Solar-PV and storage system Summary

System Details			
Panel Capacity (W)	390	No. of Panels:	84
Panel Make:	Trina	Panel Model No	TSM-390-DE09.08
Inverter Capacity (kVA)	10kVA (30kVA total)	No. of Inverters	3
Inverter Make:	Sungrow	Inverter Model	SH10RT Hybrid
Battery Capacity	10.2 kWh	No. of Battery	3
Battery Make	BYD	Battery Model	HVS10.2

– AS 3000 – ELECTRICAL INSTALLATIONS
– AS 3008 - ELECTRICAL INSTALLATIONS - SELECTION OF CABLES

As illustrated in Fig. 3, 84 x Trina Vertex 390W Solar Panels are mounted on the roof. Table 1 contains the system summary. The DC wires are routed through the main cable tray beneath the panels to the inverter. A space of 1,250mm between rows of PV panels is considered to avoid self-shading and to allow access for maintenance. To eliminate partial shadowing and maximize efficiency, the panels are angled at a 15-degree angle. The installed solar PV system is located at the top of the ATC Building (West wing), 427-451 Burwood Road, Hawthorn VIC 3122. Fig. 4 shows the position of the solar system installation on the roof.

In addition to the solar PV system, the DER also includes three solar inverters (SH10RT) and three BYD battery storage systems (HVS10.2). The main reason for studying the above mentioned system is to emulate the behavior of a community microgrid while simultaneously evaluating the various transactive demand response scenarios. The three inverters reflect the onsite generation from the two buildings (ATC and AMDC), as well as a shared community storage system. The installed location of the inverters and batteries are shown in Figure 5.

2.2 Performance Estimation of Solar-PV system

In order to evaluate the performance of the installed solar PV system, a detailed analysis of the installed PV system was carried out using PVsyst and the results of the analysis are clearly indicated below. The basic configurations and the shading results are attached to the Appendix for further reference. The importance of this assessment was mainly to evaluate the shading created by a structure on the roof where the PV systems were installed. The simulation results indicated that the distribution of the generation from the installed solar-PV system will be as indicated in the Figure 6.

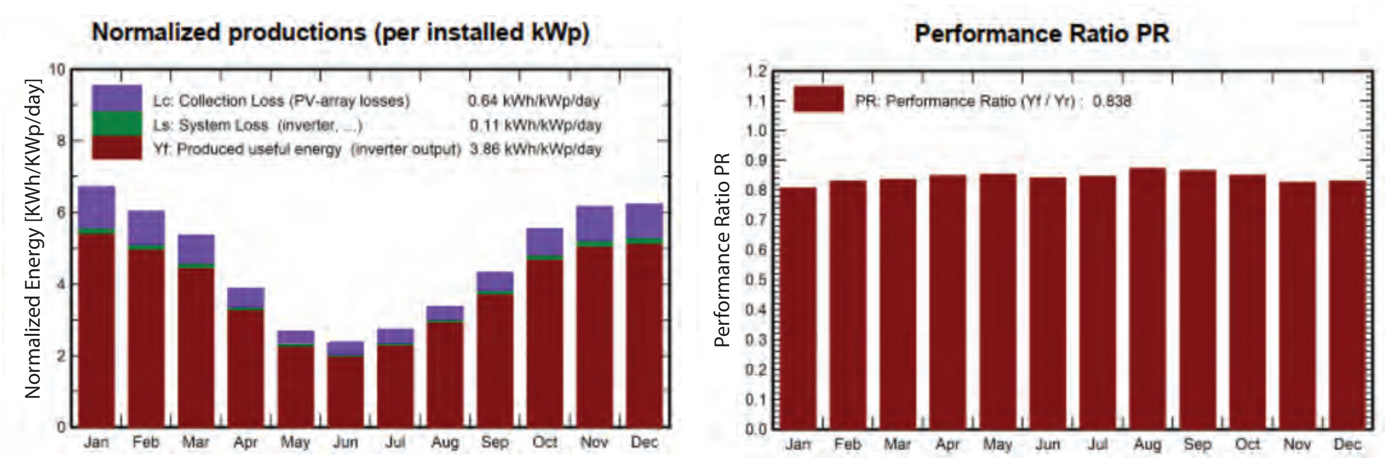

Figure 6: Estimated generation graph

3 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.

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.

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

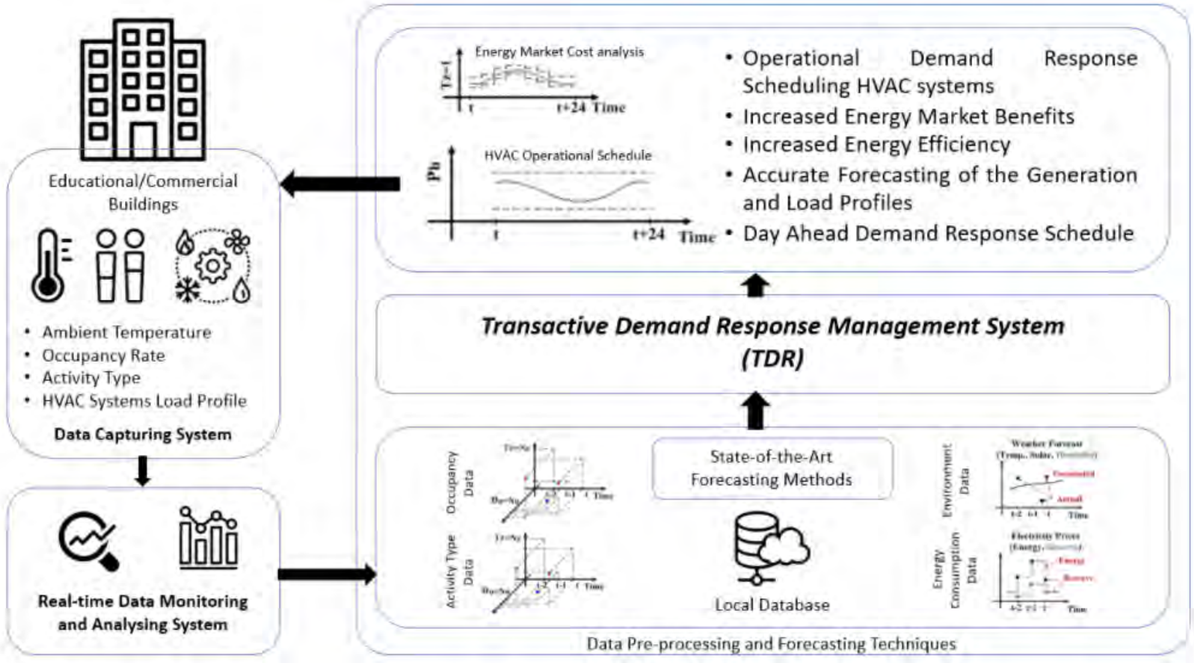

Figure 7: Overview of the proposed Open transactive demand response (OpenTDR) framework.

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. 8 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.

The openTDR framework is designed to simulate the whole community microgrid energy system. It also allows commercial buildings to adjust their usage patterns in response to the requests of market players. Demand Response (DR) services are traditionally sold to building owners by aggregates who profit from the program. To respond wisely to DR occurrences, building owners and market players must work closely together. While ideas and techniques for managing a transactive market around buildings exist, there is no evidence of their implementation. Thus, this study proposes a strong framework for implementing demand response using HVAC systems in commercial buildings. Typical business and office energy usage and expenditures are attributed to HVAC systems. Controlling HVAC system performance within their flexibility margins would greatly effect total building energy efficiency, especially in commercial and institutional sizes. Fig. 7 depicts the proposed openTDR architecture in general. Fig. 8 show the proposed OpenTDR framework's operational flow chart. A prototype that emulates the operational phenomena of Community microgrid energy sharing is constructed to empirically test the provided framework in a limited setting. This prototype uses TPlink smart switches to monitor and manage power flow. TPlink controllable lamps

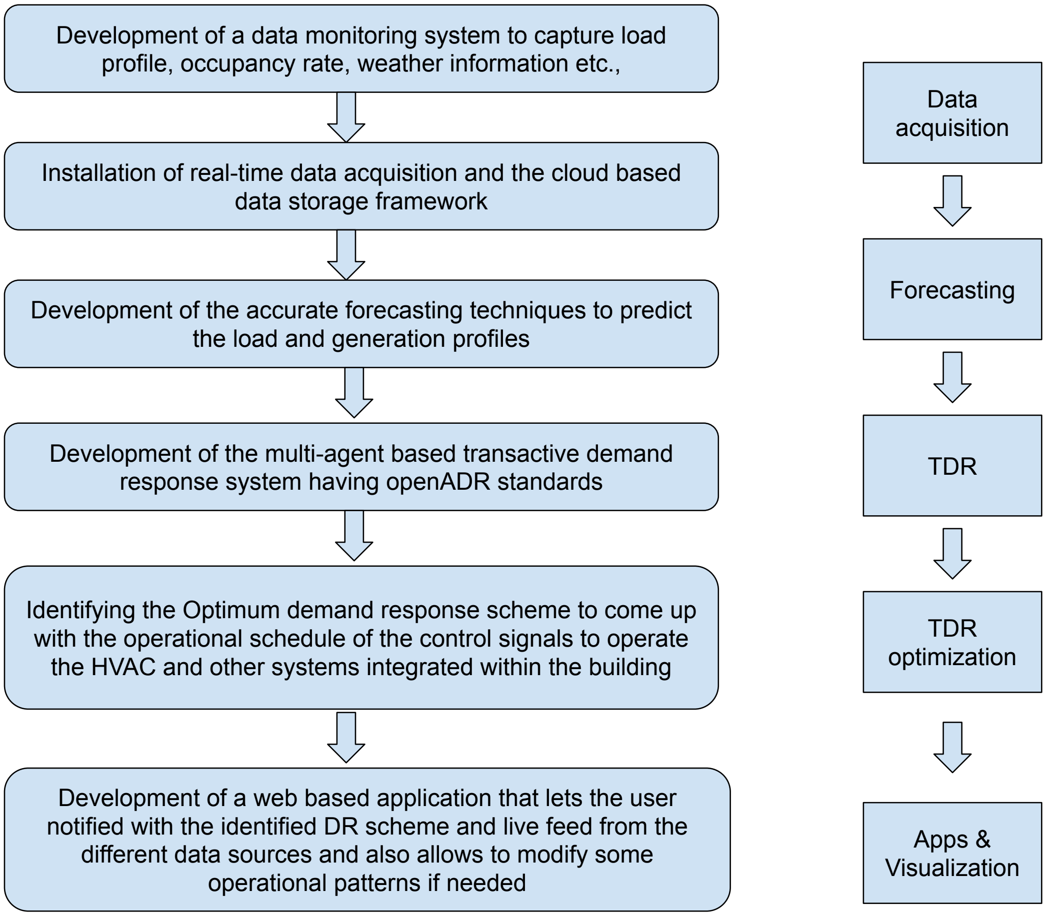

Figure 8: Operational flow chart of the proposed OpenTDR framework

indicate flexible loads. A demand response system will be implemented in the soft layer to replicate actual circumstances and to evaluate the openTDR framework using the prototype is previously reported in milestone report M5.

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 the data from the sensor nodes may be mapped to their relevant locations and control schemes. The project's output will be an unique energy management system that aids in orchestrating the flow of energy depending on market trends. With the significant penetration of renewable energy into the electrical network, the suggested system would offer a suitable power balance between supply and demand. Using a defined DR technique, the suggested solution increases the contribution of onsite RE and ESS resources in meeting energy needs for key loads such as HVAC systems. Controlling the operation of onsite generating and HVAC systems using multi-agent techniques is achieved as a part of this

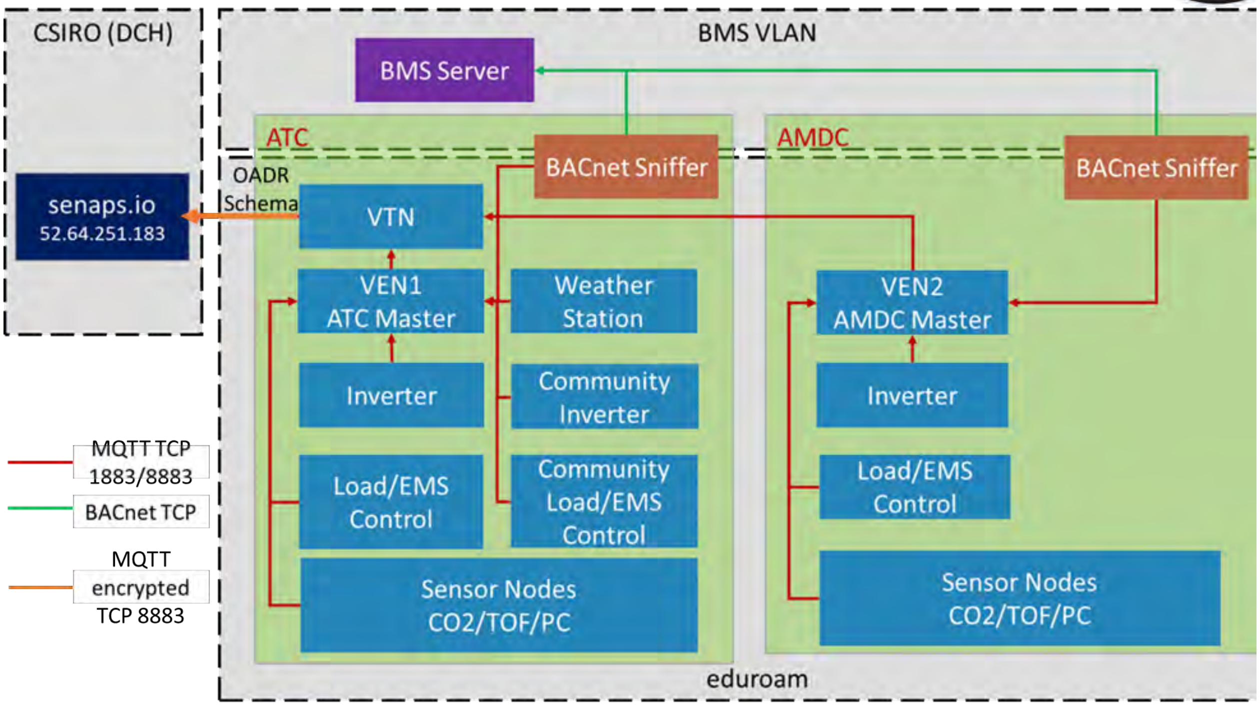

Figure 9: Network Architecture of the proposed oTDR system

project.

3.1 Proposed Network architecture

The network architecture of the proposed OpenTDR system implemented on the Swinburne campus is shown in the following Figure 11. The corresponding firewall rules and port setting have been configured with the help of the Swinburne IT team for data monitoring and HVAC control implementation. The list of entities that are considered different nodes in the project is illustrated in Figure 10.

The proposed OpenTDR framework will be used as a intermediate layer that connects the buildings with the DCH platform via the MQTT broker setup. In the proposed OpenTDR system the use of Web-Socket based MQTT broker for establishing communication with the VEN's and VTNs within the system is being developed.

Also, the openADR schema will be used as a baseline for structuring the schema of data that is communicated from one entity to another. When sending the information from the OpenTDR to DCH, the conversion of the OpenADR standardized payload msgs to building JSON format is to be developed in the upcoming milestones and the OTDR_M agent (top) of the OpenTDR framework is responsible for implementation of this conversion.

All the data which is collected is formatted into a Brick schema and then transmitted to the DCH platform and this data could be accessed by the Local energy management algorithms and the forecasting agents. It can also be used in many data analysis components. The following picture explains about the DCH data ingestion more in detail and the code used to ingest data into the DCH

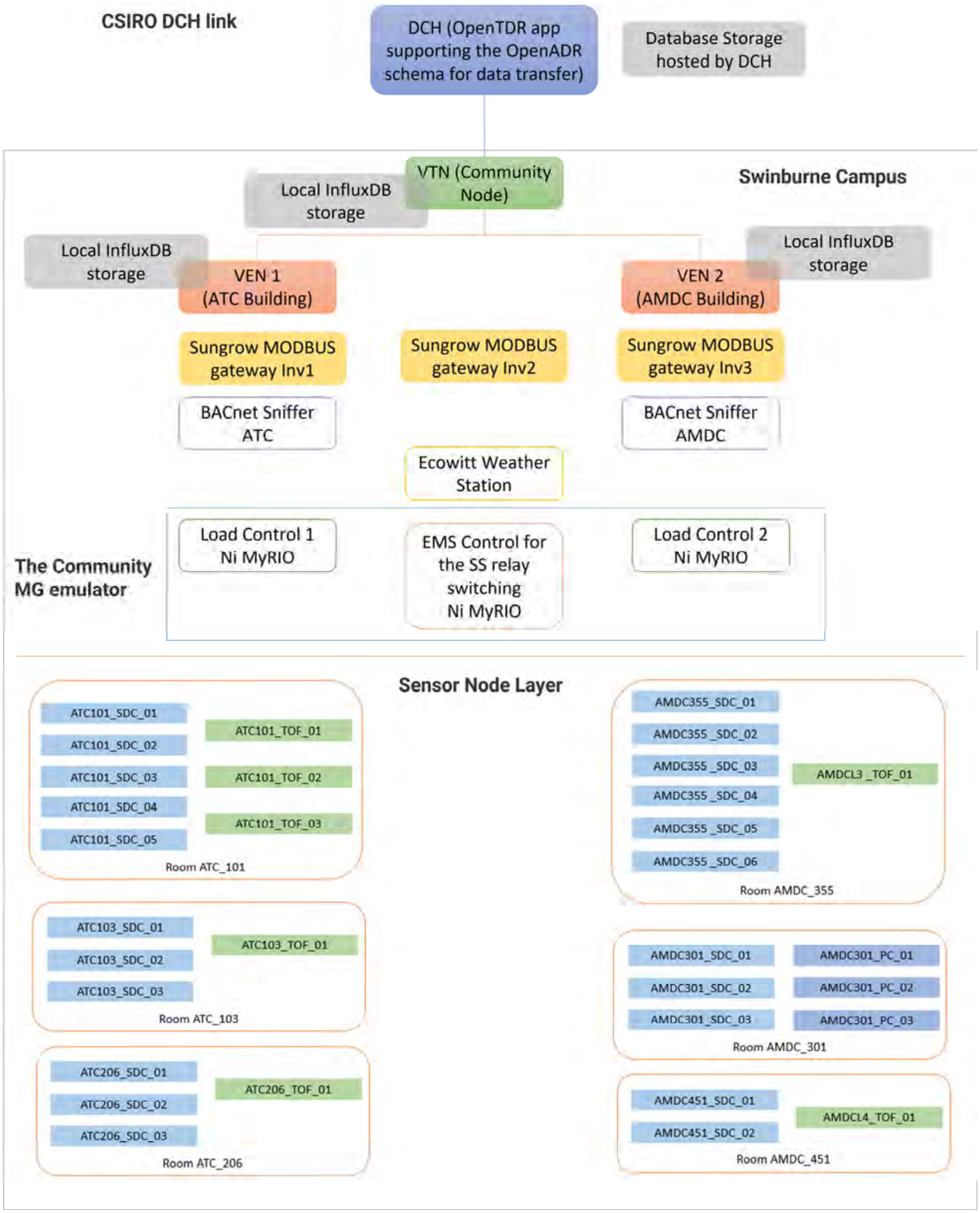

Figure 10: Hierarchical structure of different nodes

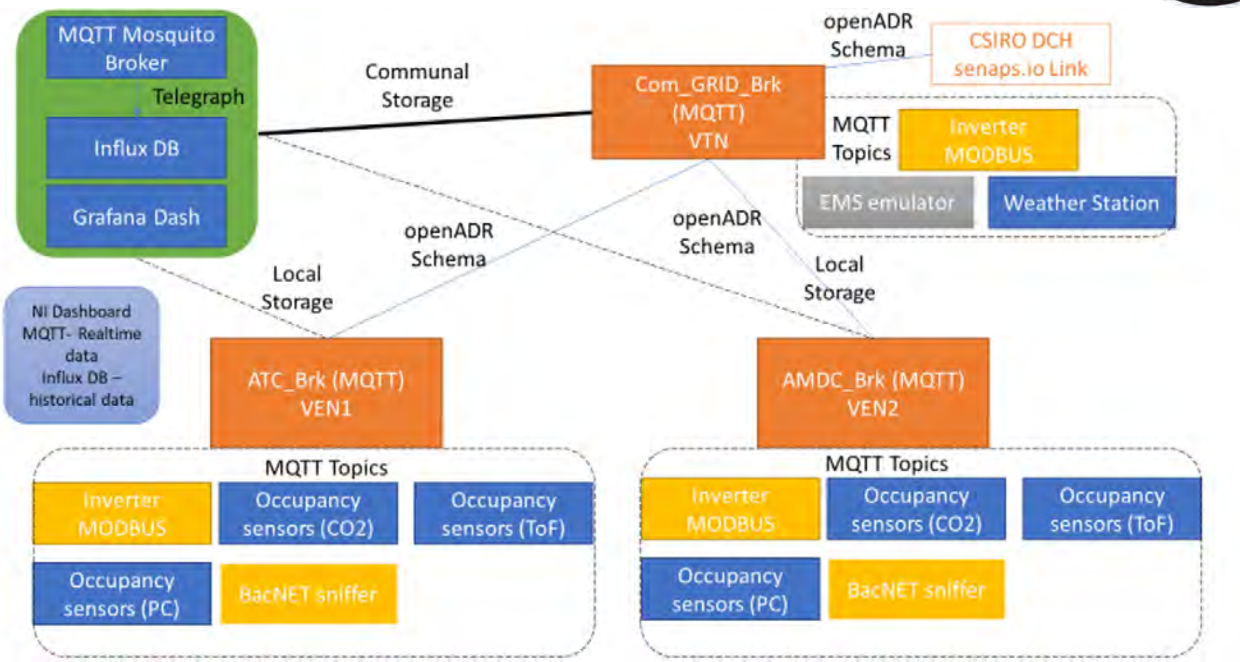

Figure 11: An overview of the data communication link

platform is tested and the mass data ingestion is in progress. An overview of the DCH integration is explained in the Fig. 12. The implementation of the bulk and realtime DCH data integration is completed during this milestone and the proposed OpenTDR framework and the algorithm will be tested and evaluated.

The OpenTDR framework follows the openADR standard to implement the data communication across different entities like the sensor node and the VEN to VTN. Figues 13 and 14 explain the manner in which the communication across the sensor nodes, VEN and the VTN happens. The entities following the openADR schema using the JSON schema for each communication and the VTN use the Update-Report schema alone to communicate to the DCH senaps.io server. In future, Swinburne research team along with the DCH-CSIRO research will be focused on developing the support to the entire OpenADR schema with DCH to assist in dynamic semantic building model creation. At the current stage, DCH 5 has enabled support for sending the data using the update Report schema and the support for the update Report schema has been integrated in the DCH end to accept the data using the OpenADR based OpenTDR schema.

4 Baseline data gathering, cleaning and preparation

The implementation of the semantic building model integrated into the OpenTDR framework uses the Brick schema-based metadata information. In collaboration with the DCH team from CSIRO, researchers in Swinburne are involved in the process of formulating a semantic building model for the two identified commercial buildings that are machine-readable, easy to read, and easy to query.

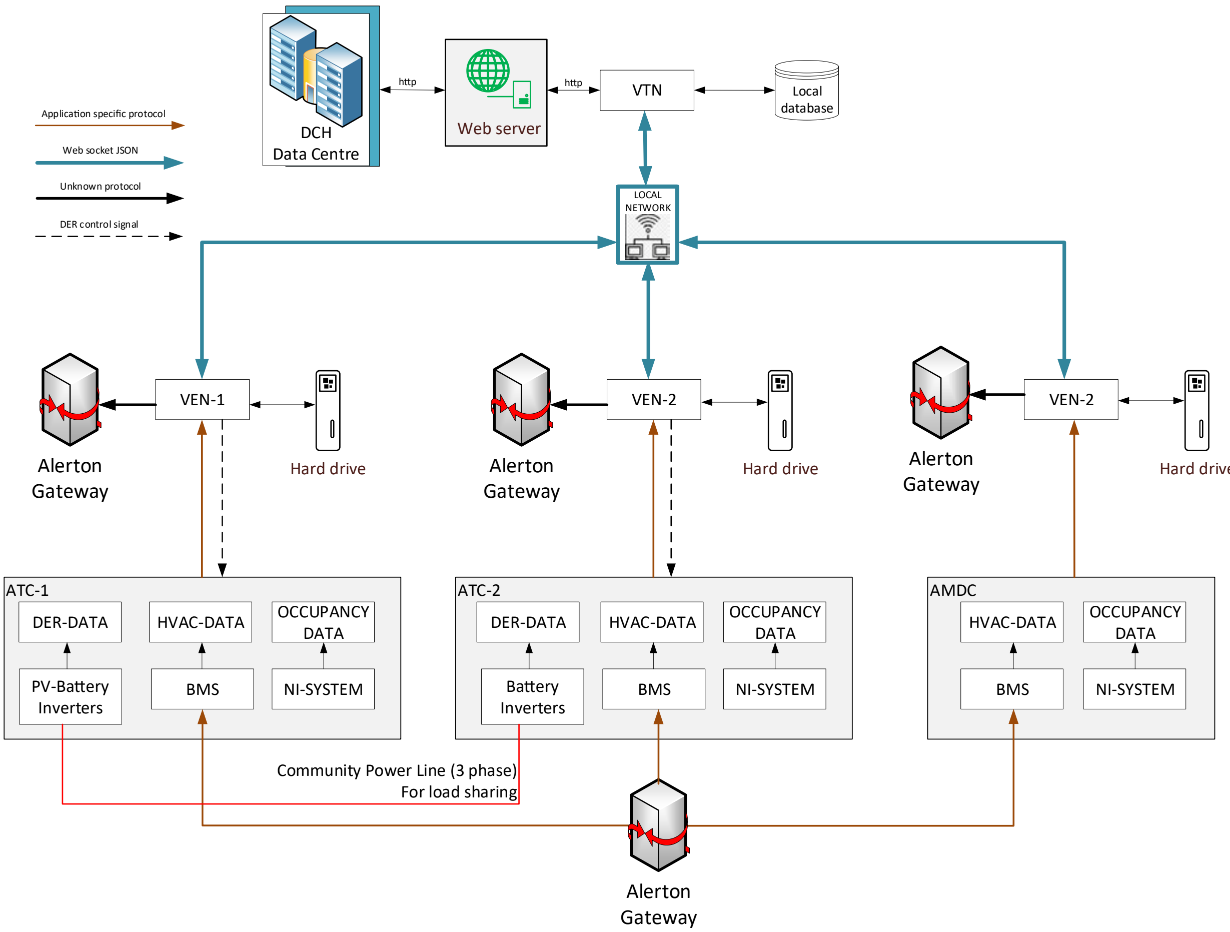

Figure 12: High level system architecture (Data communication and Control)

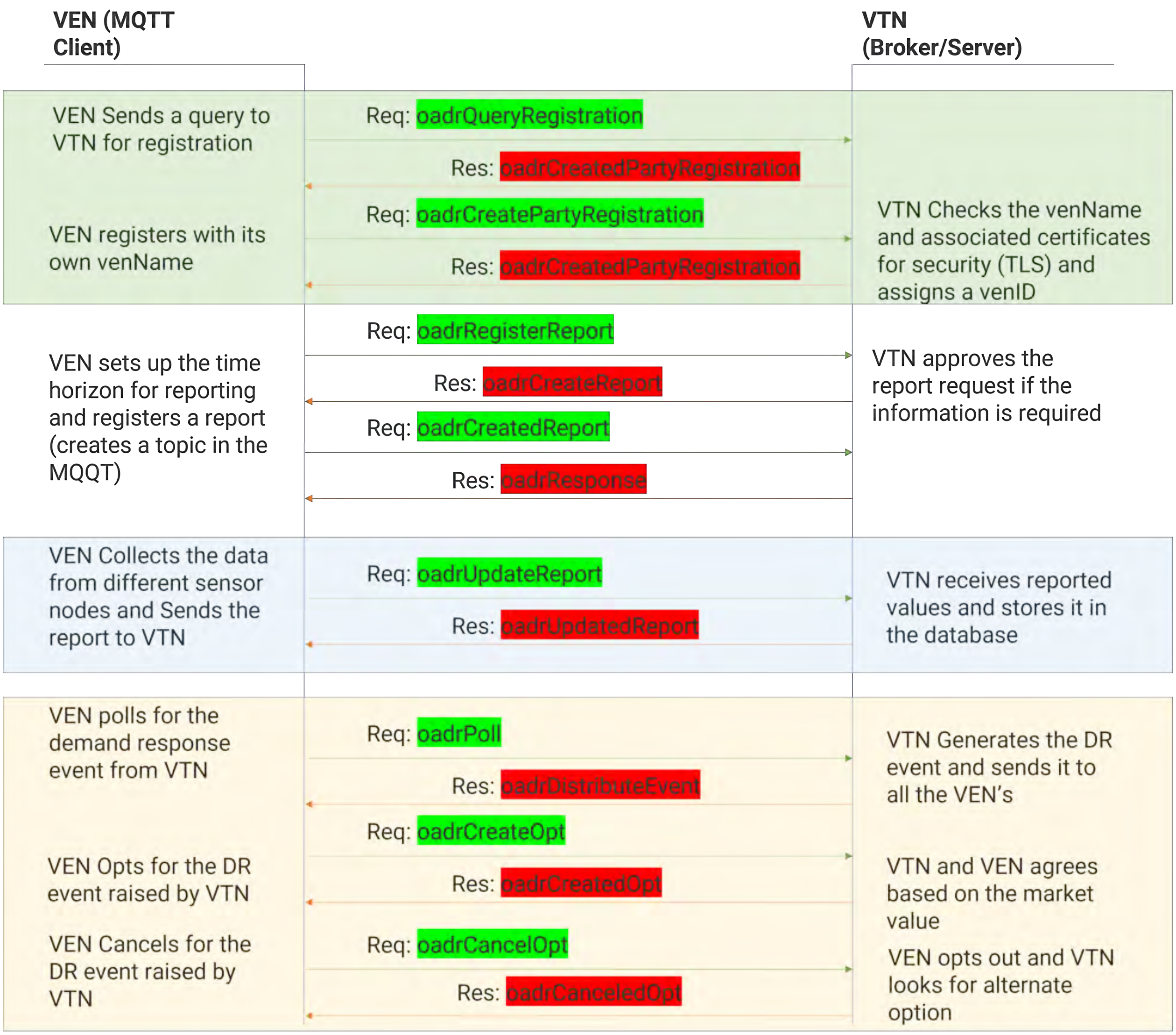

Figure 13: Communication pattern of VEN-VTN using the custom JSON schema

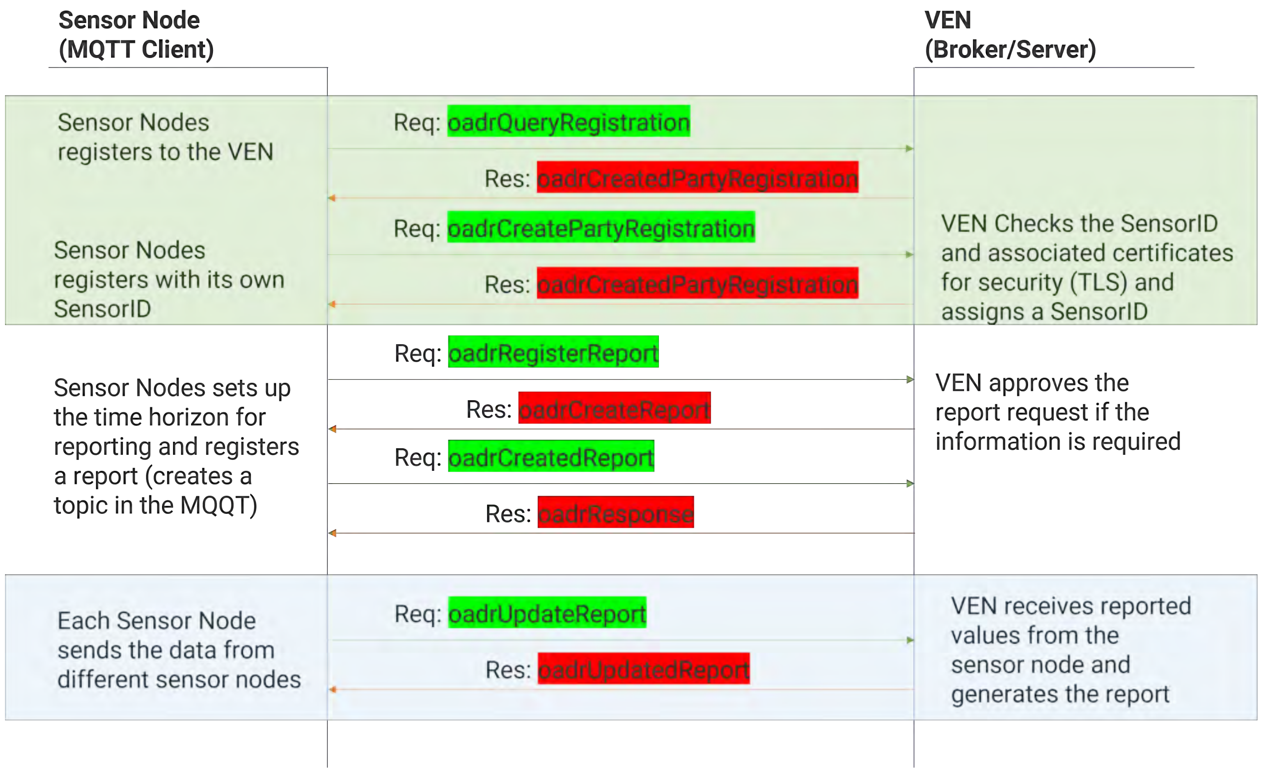

Figure 14: Communication pattern of VEN-VTN using the custom JSON schema

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. 15 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 extracted from the BACnet sniffer, which 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 buildings Brick model explaining the complete room-wise temperature set point is spit up of the HVAC system range etc.,

Based on the information extracted from the BMS BACnet sniffer, the Brick Schema-based semantic building model is being prepared by the CSIRO and researchers in Swinburne University of Technology. In addition, the research team here in Swinburne is planning to implement some additional data monitoring devices to read occupancy data and zone-wise CO2 / HR / Temp data. The newly added sensor systems are focused specifically on regions with dynamic population and potential regions in which zone-wise control can be implemented. Therefore, to achieve this, the sensor modules explained in the following are installed at the identified location. These additional sensors assist the proposed energy management algorithm in implementing the secondary level of occupancy control, and this is a key player contributing to the adjustable energy of each building that participates in transactive demand response events.

The following are the different type of systems that are considered as a part of the implemented oTDR system specifically targeting potential areas with dynamic population control and zone-wise

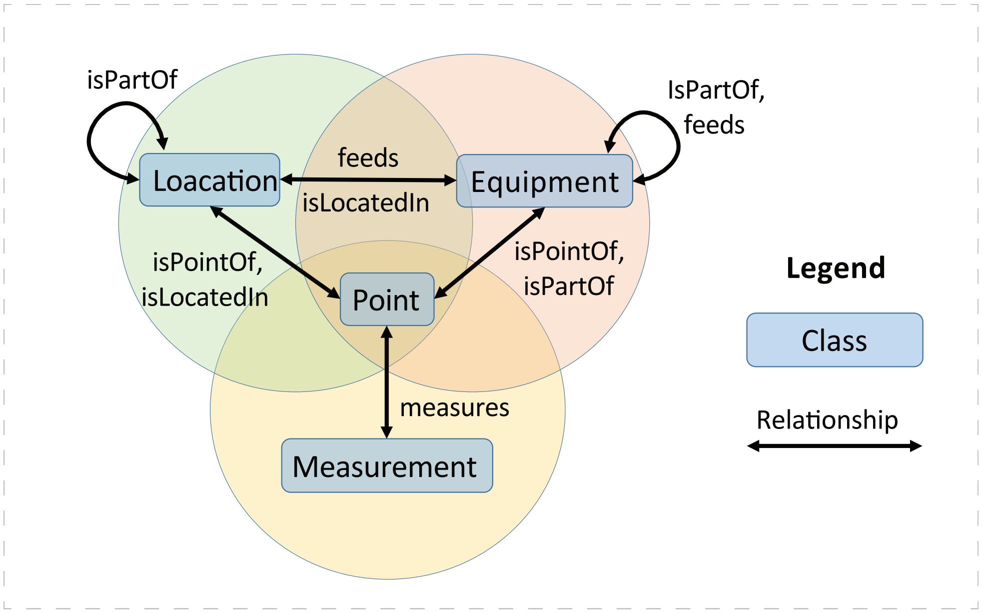

Figure 15: Brick Schema overview

temperature control.

- ToF based Occupancy Monitoring system
- Zone wise air quality (CO2 /Relative-Humidity/ Temperature) monitoring system
- External Weather Monitoring System
- BMS Data access via the BACnet gateway
- Inverter/Battery Data access via the MODBUS gateway

A more detailed insight on the proposed solutions for each data point is explained in the section below, and the locations identified with respect to the floor plans can be found in the respective figures 16,17, 18, 19, and 20. 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 Swinburne campus, Hawthorn (ATC101, ATC103, ATC206, AMDC355, AMDC301, AMDC303 and AMDC451) were unique in terms of dynamic occupancy rates. The identified locations consisted mainly of large lecture theaters and private study areas. Although the use of the lecture theaters was based on a booking system, the number of people using the spaces was dynamic because one of these lecture theaters was also used as an exhibition space for public activities. In contrast to these lecture theaters, the use of private study areas has been completely stochastic and determining the number of occupants in the area was a challenging task. This dynamic nature of the occupancy had a greater influence on encouraging researchers to work to identify the relationship between the HVAC set points/ usage and the occupancy.

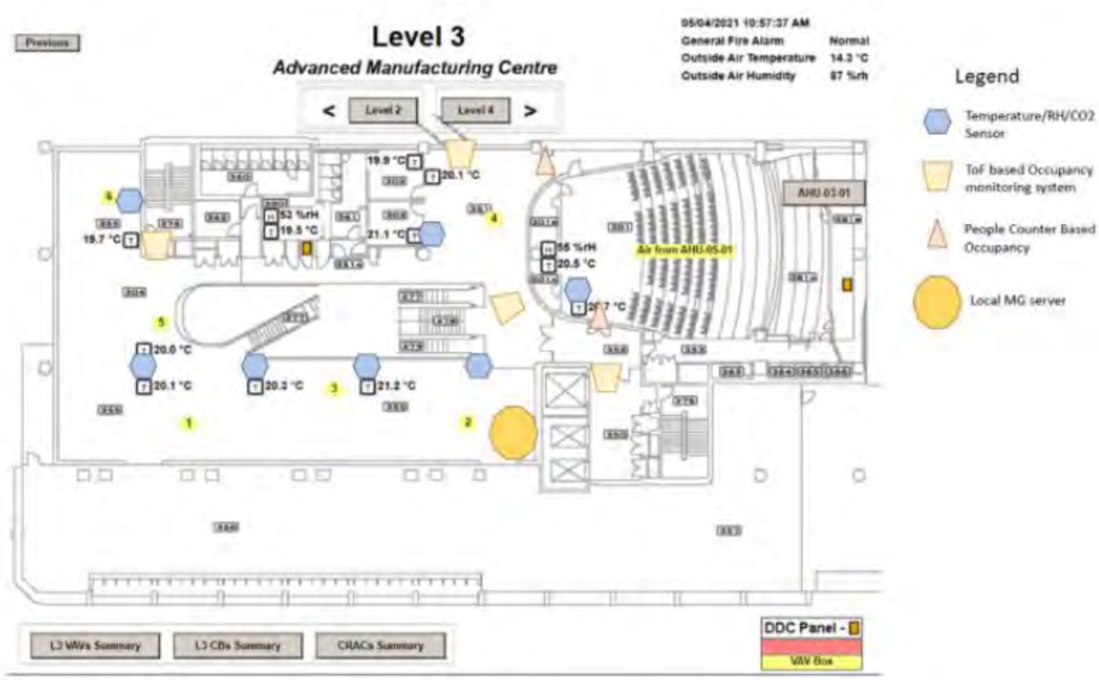

Figure 16: Level-3 AMDC floor plan with added sensor modules

Figure 17: Level-4 AMDC floor plan with added sensor modules

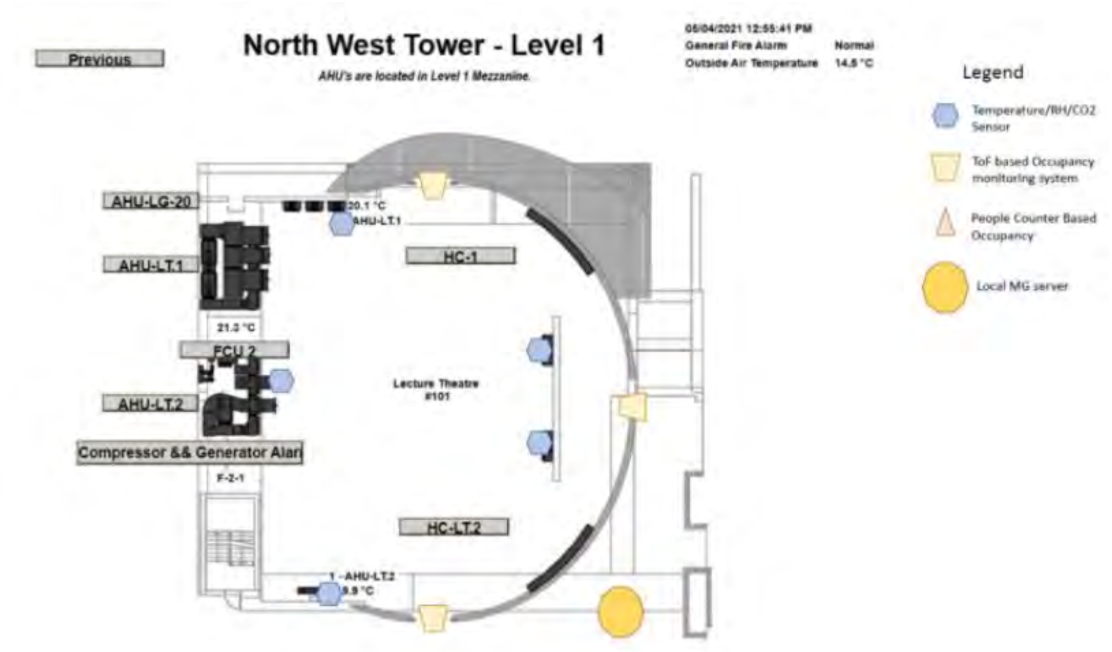

Figure 18: North West Tower Level-1 ATC floor plan with added sensor modules

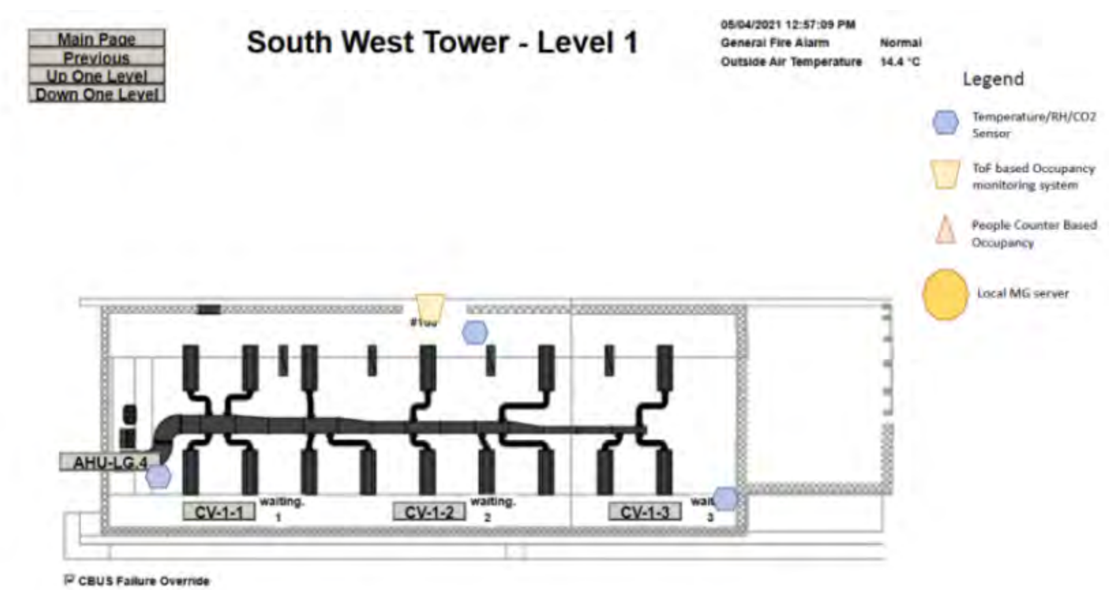

Figure 19: South West Tower Level-1 ATC floor plan with added sensor modules

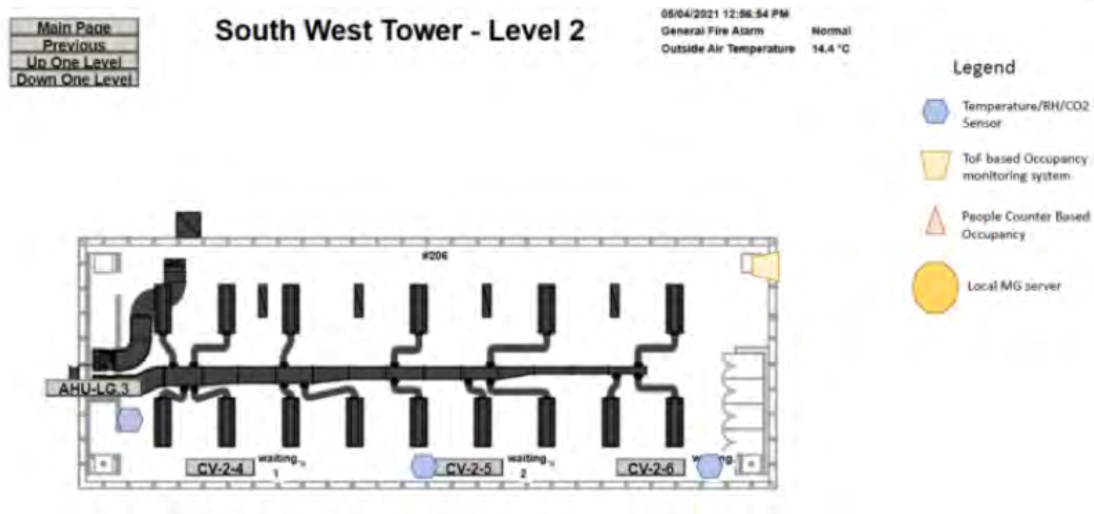

Figure 20: South West Tower Level-1 ATC floor plan with added sensor modules

4.1 ToF based Occupancy Monitoring system

The occupancy data was initially planned that the occupancy data would be installed using the IP cameras already installed, 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 researchers at the 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. However, the use of the thermal camera-based solution to detect occupancy would have created 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. The location for installation was identified, and installation of these sensor units in the locations depicted in the pictures above is in progress. The algorithm is being developed to identify the number of people entering and existing in the area, and the testing of this algorithm is in progress. The Terabee3D TOF camera-based solution was fabricated with a custom casing, and the finally fabricated solution is shown in Fig. 21. A more detailed explanation on the development and installation on the system is given in the attached appendix.

4.2 Zone wise air quality (CO2 /Relative-Humidity/ Temperature) monitoring system

The other important aspect of the newly added data points in the semantic model is that they will assist with 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

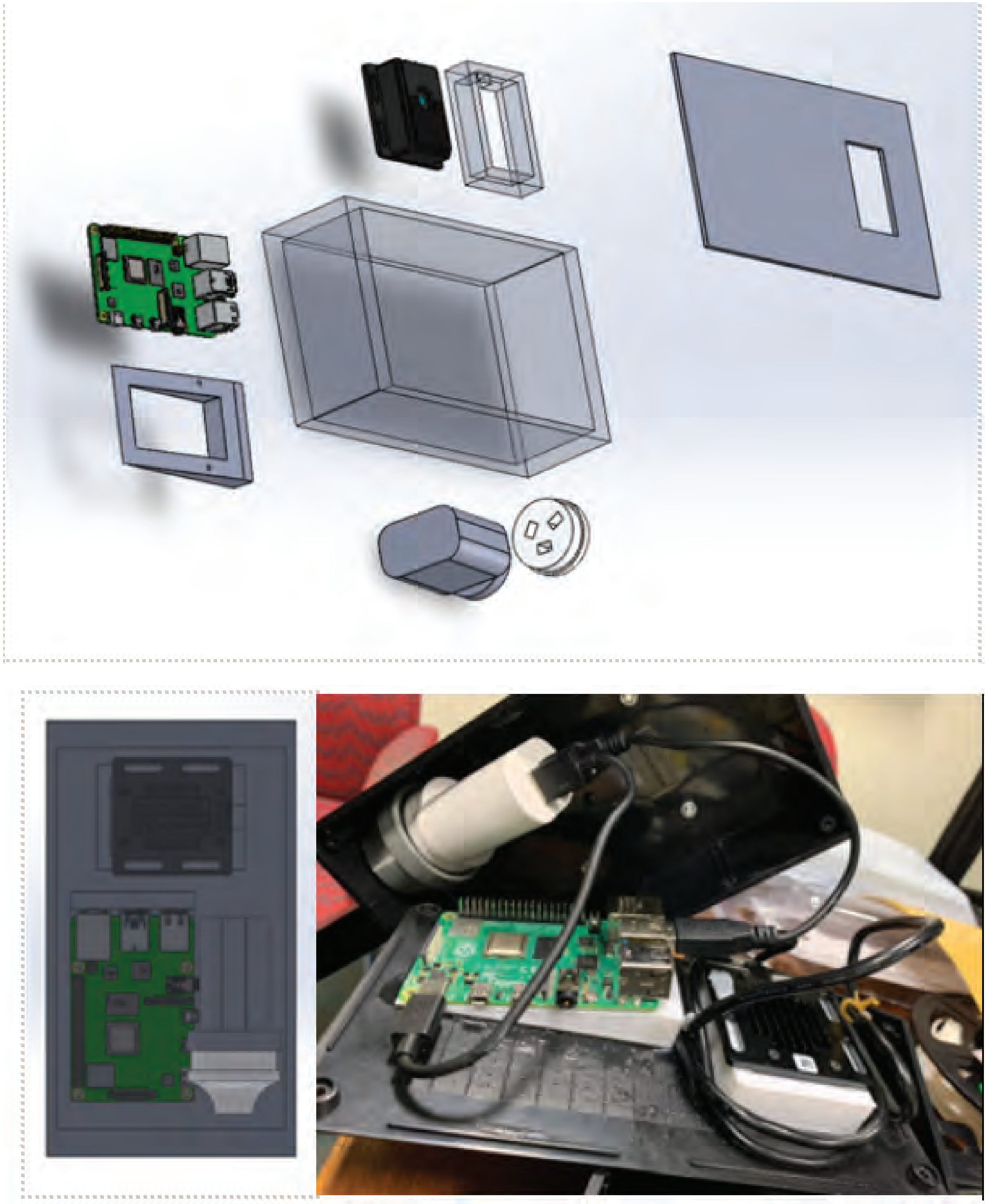

Figure 21: Custom ToF based Occupancy monitoring system developed in house by researchers from Swinburne

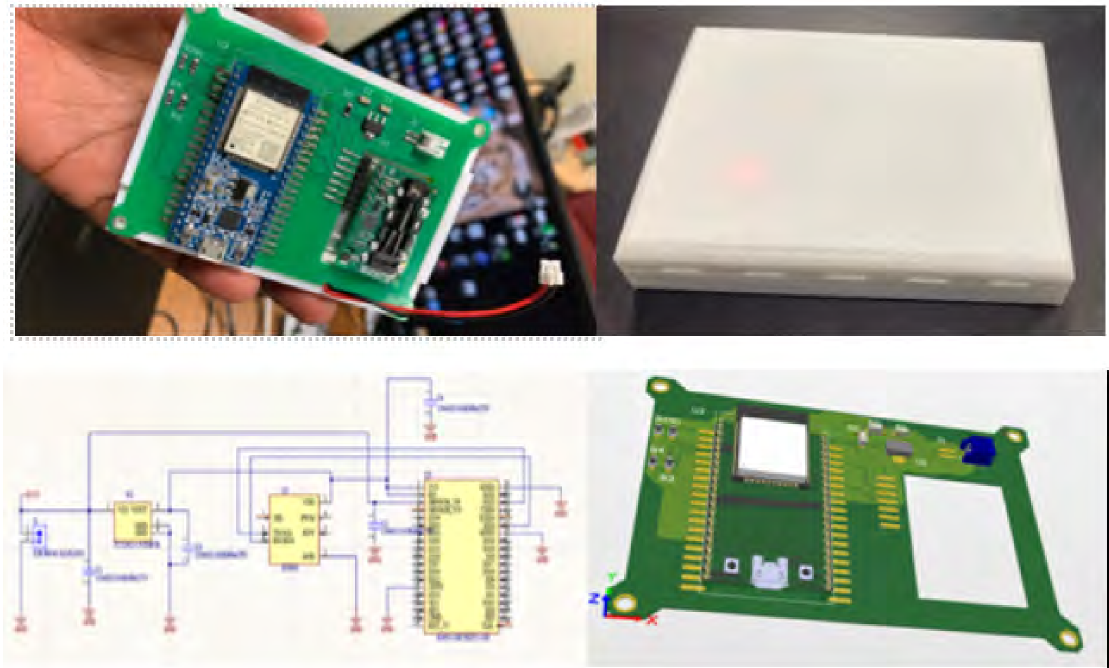

Figure 22: Custom Zone wise CO2/RH/Temp sensor module developed in house by researchers from Swinburne

and these sensor modules are very essential to determine this value. The sensor consists of an ESP32 board and an SCD30 sensor module which is mounted on the custom casing illustrated in Fig. 22. The zone-wise CO2 / RH / Temp sensor modules are battery operated, and they send the MQTT data once in every 15 min to the local server, which will receive all the information relevant to the local MG and send it to the central community or OpenTDR agent. A more detailed explanation on the development and installation on the system is given in the attached appendix.

4.3 External Weather Monitoring System

In order to obtain more realistic external weather data to implement weather-based control points of the HVAC set, an ECOWITT HP25110 weather station is installed on the roof of ATC South West Wing and basic data extraction was performed from the custom server setup using the ECOWITT weather station. 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.

4.4 BMS Data access via the BACnet gateway

One of the other data monitoring systems that was integrated into the OpenTDR system is the BMS system. Initially, a Web crawler-based sniffer was developed to access the historical data, and this is now used to extract the historical data and send it to the DCH Senaps.io platform. In addition, a BACnet sniffer is also developed in-house to extract BMS data in real time. The BMS system consists of a weather station and many other monitoring devices that are accessed through the BACnet sniffer. It can facilitate real-time data communication by providing access to BACnet points in the network and also help to configure the HVAC control signals to the BMS system. A more detailed explanation of the development and installation on the system is given in the attached appendix.

4.5 Inverter/Battery Data access via the MODBUS gateway

In addition to the above mentioned systems, the Inverter and Battery systems also provide data and this could be accessed from the iSolar cloud APIs. These modules provide information about the generation capacity, state of the charge, and the load connected to the terminal. Based on the load connected to the smart meters, it will correlate with the actual energy consumption and simulate the behavior of transactive demand response and also observe the impact of the TDR in more detail. A more detailed explanation of the development and installation on the system is given in the attached appendix.

4.6 Community Microgrid emulator

The openTDR algorithm will be experimentally evaluated on the platform created by the proposed Ni-based Community Microgrid emulator. This platform is synchronized with the MODBUS and BACnet gateway inputs and outputs. It is equipped with a collection of ACDC converters that are connected to a fixed resistance and function as programmable loads to simulate variable loads in buildings, and are modified to increase the use of on-site renewable generation.

The dynamic nature of the Community MG emulator to operate based on the MQTT topics makes this system a novel platform for us to perform various community energy sharing simulations like the oTDR application. This emulator is considered in the scope of the project mainly due to inadequate on-site generation compared to building loads. As such, it would not be a feasible option to share energy inbetween them.

The Community Microgrid emulator also includes a solid-state relay (SS relay), which coordinates with the load and changes the inverter connection in such a way that the load from one entity may be obtained from two inverters. This is meant to reflect the energy sharing between different buildings.

Figure 23 shows a glimpse on the built Community MG setup and in the appendix included, a supplementary narrative that elucidates the creation of the system as well as its implementation in more depth.

5 Multi-agent Model of the OpenTDR framework

The proposed multi-agent OpenTDR framework uses the hierarchical agent-based model shown in the Fig. 24image below. The OpenTDR framework consists of different levels of hierarchy consisting

Figure 23: Ni-Based State-of-the-art Community MG emulator

of sensor level agents as the baseline of the hierarchy, and this level consists of different sensor nodes that include the energy meters, BMS data points (thermostat for each room) and the lighting system gateway and the corresponding occupancy detection system. However, these lower-level sensors are all committed to reading their associated data points and updating the values to the higher-level agents. Low-level sensor nodes are linked to high-level smart sensor agents inside the sensor-level agent. In this study, high-level sensor agents are divided into three levels as shown describe below. Figure-(24).

BMS Gateway agent: The BMS Gateway agent is responsible for reading all data points from the low-level sensor nodes that are part of the BMS system installed in the building location. The BMS Gateway agent is part of the existing BMS system, and it is the central server for the BACnet devices connected in the BMS network, and this gateway agent does not have connection to the external network.

CO2/RH/Temp sensor Agent The CO2/RH/Temperature sensor agent is a project-specific sensor module. The main goal of this agent is to keep the local energy management agent informed of the current condition and help determine the adjustable load based on the temperature feedback and air quality. The CO2/RH/Temp sensor is a custom-built sensor module containing an SCD30 sensor and an ESP32 board. Every 15 minutes, data from this sensor module will be sent to the local network suggested for each building. The 15 minute interval constraint is mentioned in the Sensor module part in general and might be changed if the battery-based approach is changed in the future.

ToF-based OMS agent: This is another sensor agent that is used to count the number of people in a room or a floor. The Terabee 3D ToF camera feeds the OMS agent's input. Sensor location and configuration information are included in the data collection section. The agent must analyze the ToF camera's picture and execute a proprietary algorithm to identify the number of people entering and exiting the defined location.

The second level of hierarchy in the multi-level multi-agent framework is the agent level. This level of hierarchy is referred to as the Agent level since it is relevant to the framework, it has an added level of intelligence, and all the agents take part in the first level of the game that happens within the microgrid to address the overall TDR-based EMS. The agent level of the OpenTDR framework consists of the following agents:

Local Forecasting Agent: The proposed OpenTDR architecture includes a local forecasting agent that has access to the encrypted historical database within local CMG servers. The local server reads the sensor's historical data, and pre-built forecasting algorithms are trained and stored for usage at this agent level. (Once every 3 months) The stored model is used with real-time data to forecast the future timestamp. The anticipated values are then sent to the local energy management system through an MQTT channel, where the EMS modifies the predetermined market price and the potential generating capacities of the other entities.

As highlighted in the milestone (M5) there are few forecasting algorithms developed and tested using the external data sets from BOM and AEC data sets. A detailed overview of the different forecasting algorithms is explained in the section highlighted in the previous milestone report M5. During the milestone M6 , baseline models, such as the SVR model, are developed and tested with the real data extracted from the BMS system. The following image indicates the performance of the SVR algorithm in predicting external irradiation (W / m2) extracted from the BMS database. From

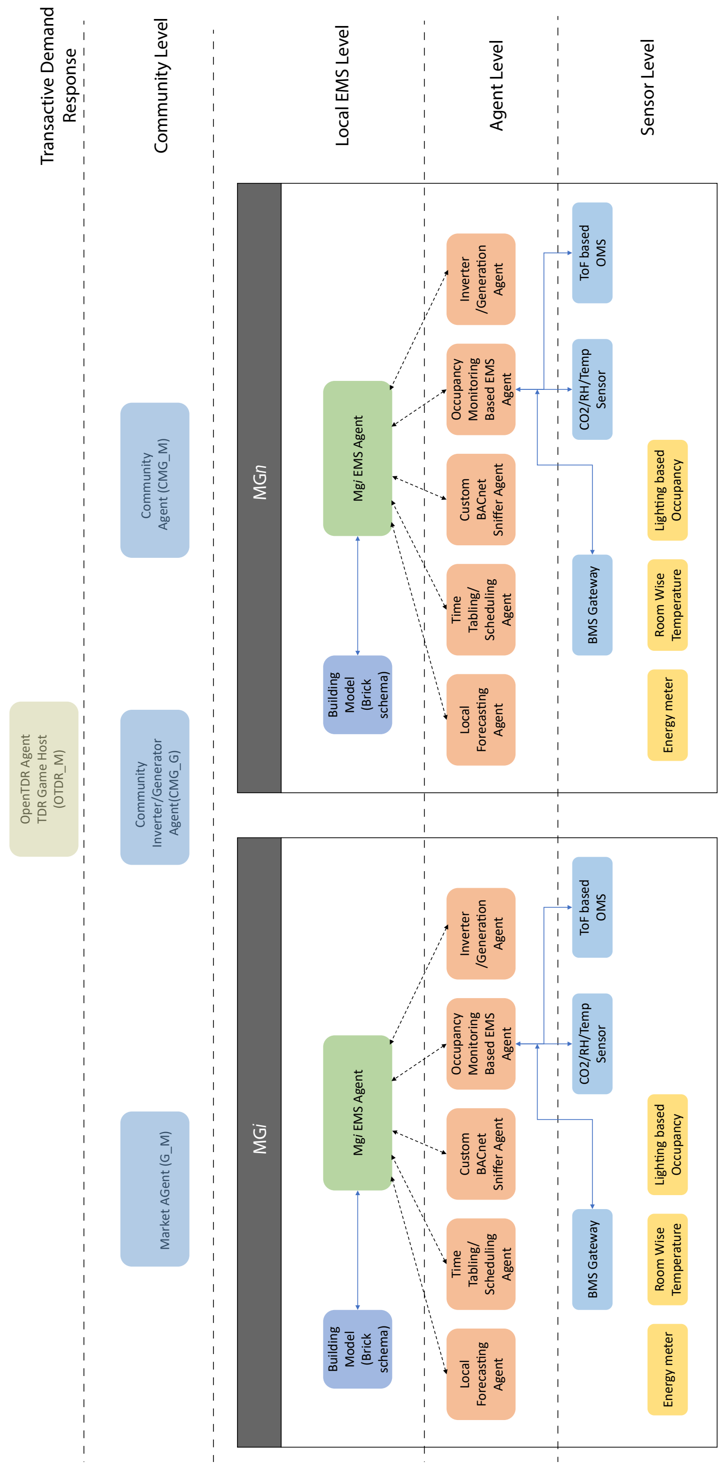

Figure 24: Hierarchical Multi-level multi-agent based OpenTDR Framework

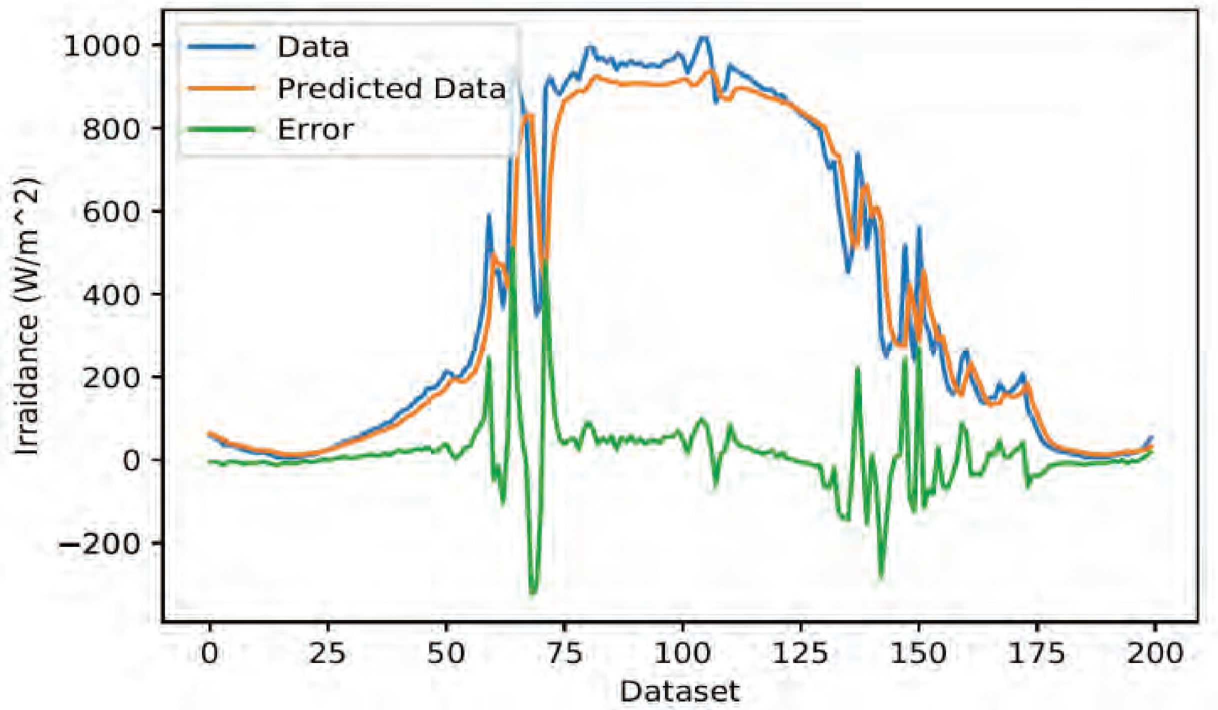

Figure 25: Forecasting evaluation of the SVR model. Blue line represent data from BMS and the orange line is its forecast.

Fig. 25 it can be seen that the forecast value matched well with the original BMS data. The RMSE of this prediction interval is around 98.15 (W/m2).

In addition to this, during this milestone there has been few more algorithms that has been developed and tested for estimating the weather parameters using the improved LSTM, XG boost and hybrid RNN-GRU model. There are a few publications that are to be submitted in the upcoming months illustrating the results obtained from the forecasting models developed as the part of the project.

Timetabling/ Scheduling Agent: The Timetabling or scheduling agent is the preliminary or the first stage of the energy management algorithm proposed that is considered in the game-theoretic TDR algorithm considered in this project. The Timetabling/ Scheduling information is obtained from the IT via an HTTP request through APIs and the booking information for each room is then later identified by processing the information obtained. Based on the Timetabling data that were obtained, the corresponding HVAC units are updated with the control signal for the operational schedule, and this is passed on to the BACnet sniffer agent. A simple implementation of the time tabling based control is implemented, and this was done for the room ATC101, and results are as in figure-(26).

In this analysis, the energy data and the timetabling data were not considered from the same location because of the limitation we have on the measurement devices and an infrastructure change request has been raised, and these identified metering devices are to be installed before the start of December 2021. The results indicated that with this type of control a possible 40% of energy

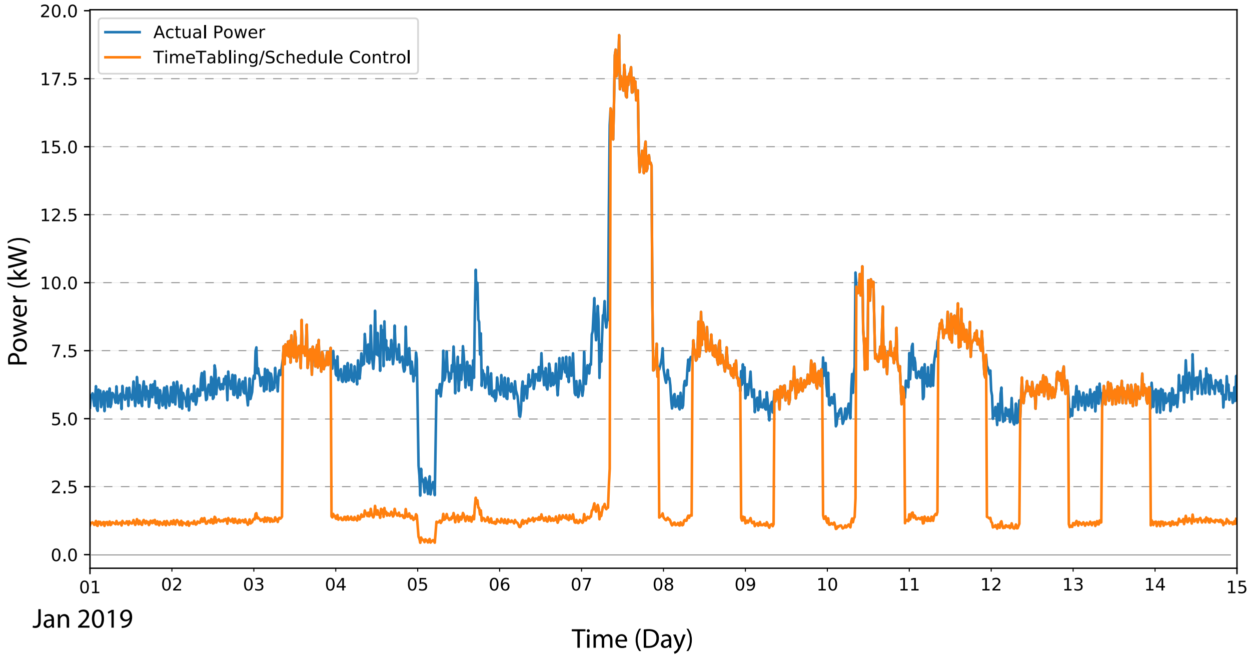

Figure 26: Timetabling/ Scheduling based control.

reduction will occur in specific regions such as lecture theaters, etc. that are considered as part of the study. This is a basic item, and therefore it is not considered as a part of the adjustable load in the transactive demand response model.

Custom BACnet sniffer agent: The BACnet sniffer agent is used to establish a connection with the BMS gateway agent and to send control signals to the HVAC system regarding the temperature set points, the VSD speeds, and the position of the value. In general, the BMS gateway agent acts as an interface to the BMS system network and will provide a bridge to the local network within the microgrid and the network corresponding to the BMS. BMS systems are, in general, maintained on a separate network to ensure that there are no cyber-security issues. At the current stage, this BMS gateway agent is a simplified Python-based BACnet sniffer that is added to the local BMS network within the campus and connected to the separate local network corresponding to the buildings that will provide the information to the EMS agents for implementing the TDR events. In Milestone M6, a python based BACnet sniffer tested on a raspberry pi was developed, and this will be replaced by a NI based device that will read the BACnet information and keep the local EMS and the CMG agent via an MQQT message. The MQQT message will then be translated by the OpenTDR agent following the OpenADR standards and then sent to the DCH (Senaps.io Platform).

Occupancy monitoring based EMS Agent: The Occupancy monitoring based EMS agent has two main functionalities to implement. The potential rooms in the building that do not have the lighting module synchronized control were initially identified and the primary occupant monitoring-based EMS is implemented and this also falls under the first stage of local energy management that happens in each entity. In order to implement that, the agent gets the inputs from the master local

Energy management agent that looks into the building model of each building and interprets the data read via the BACnet sniffer agent and then implements the control of the HVAC systems based on the feedback obtained from the Lighting CBUS interface. The second occupancy-based EMS operation is the critical component of the proposed transactive demand response, as it looks at the occupancy data of the identified zones with random occupancy rate and reduces the HVAC load operation whenever there is a request for the transactive demand response. The request for the transactive demand response will come from the OpenTDR agent, which is in the topmost hierarchy of the proposed OpenTDR framework.

Inverter/Generation Agent: The Inverter/Generation Agent is present in the Agent layer and its main purpose is to read the data from the available generation capacity and the state of the charge and to inform the local energy management agent of the available capacity, and this information is then be used together by the forecasting agent to predict the capacity of the next time step. In addition, this agent is used as the interface to control the flow of energy sharing simulation along with the local energy management agent.

The third level of hierarchy that exists in the EMS is the local EMS level and this consists of the different EMS agents from all the microgrids connected to the community microgrid, and this agent is responsible of determining the price for buying and selling the surplus and shortage energy. The agent is a player in the auction and then, based on the biding he/she proposes, the OpenTDR agent that runs the Energy market game is determine the proposed deal and ask for the approval of the local EMS agent, and once it is approved, it is implemented by collaborating with the low-level agent, and then it keeps the OpenTDR agent informed on successful completion of the TDR event in the Microgrid/building.

Above the local EMS agent comes the market agent, the community generation agent (this agent is like the generator/inverter agent), and finally the community MG_market agent. The roles and responsibility of the Market agents is to coordinate with the traditional grid and obtain the cost for the Grid sell and Grid buy and for the simulation explained further in this section a fixed cost model was considered, and this is replaced by the dynamic costing or TOU costing model, and these scenarios is evaluated using the CMG emulator setup. The community MG_market agent determines the price at which the community generator/ storage is shared within the community, and the following constraint are considered of ensuring that the buy_sell cost of the community resource is always cheaper than the Grid at all time instances. This agent consists of a forecasting tool and this helps in estimating the price of the energy sold within the community.

Then the OpenTDR agent is the final and highest level in the hierarchy of agents, and this orchestrates the game and receives the information from the agents like the market agent, the CMG_market agent and the local EMS agent to determine the optimal condition of the energy sharing that will produce profit for the community. For now, the benefit for community is considered as the prime focus of the OTDR_M agent is implemented in this milestone. The competitive nature of the agents participating in the auction targeting towards their personal benefit will be researched as the future scope of work.

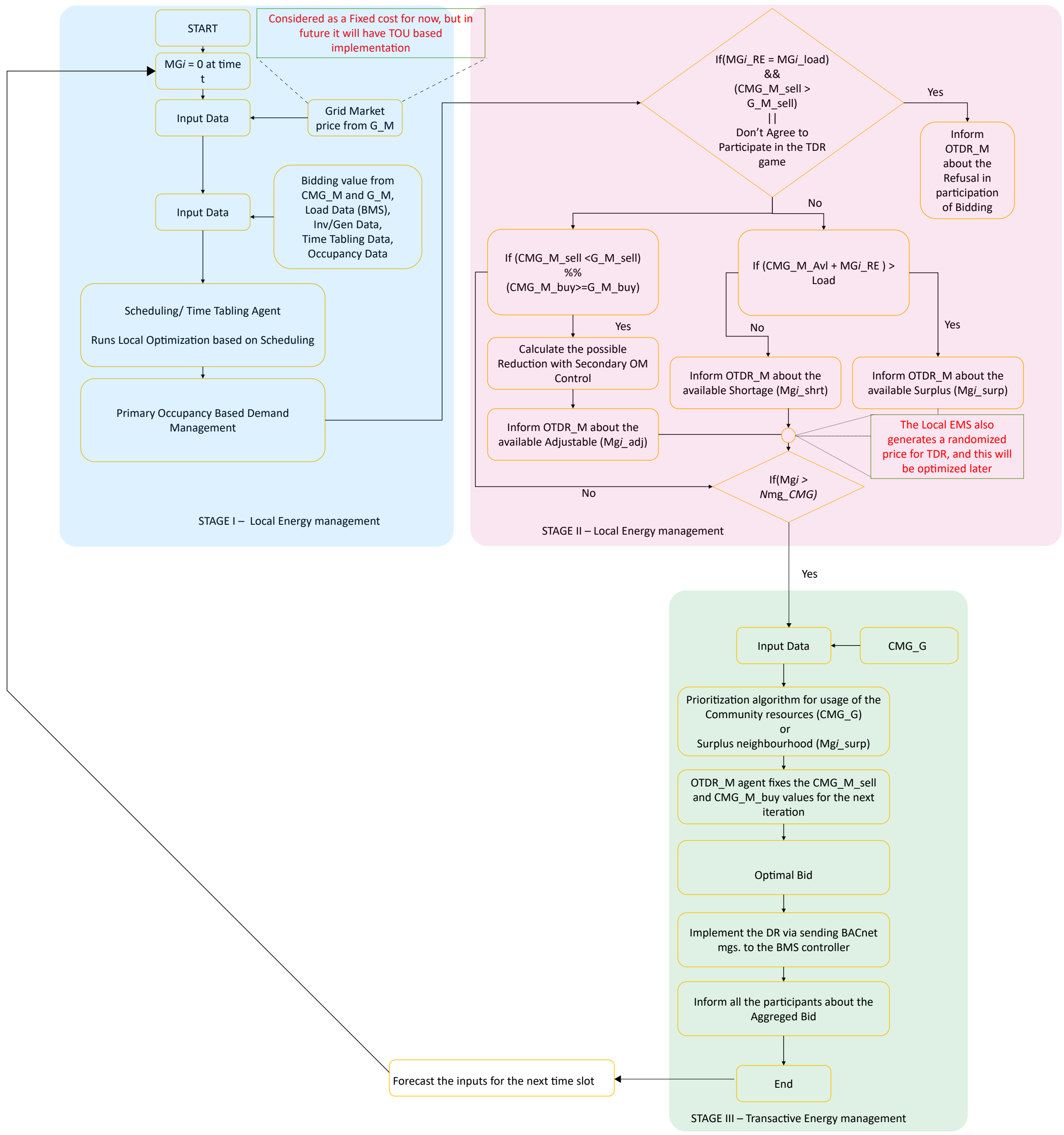

Figure 27: Flow chart of the proposed algorithm

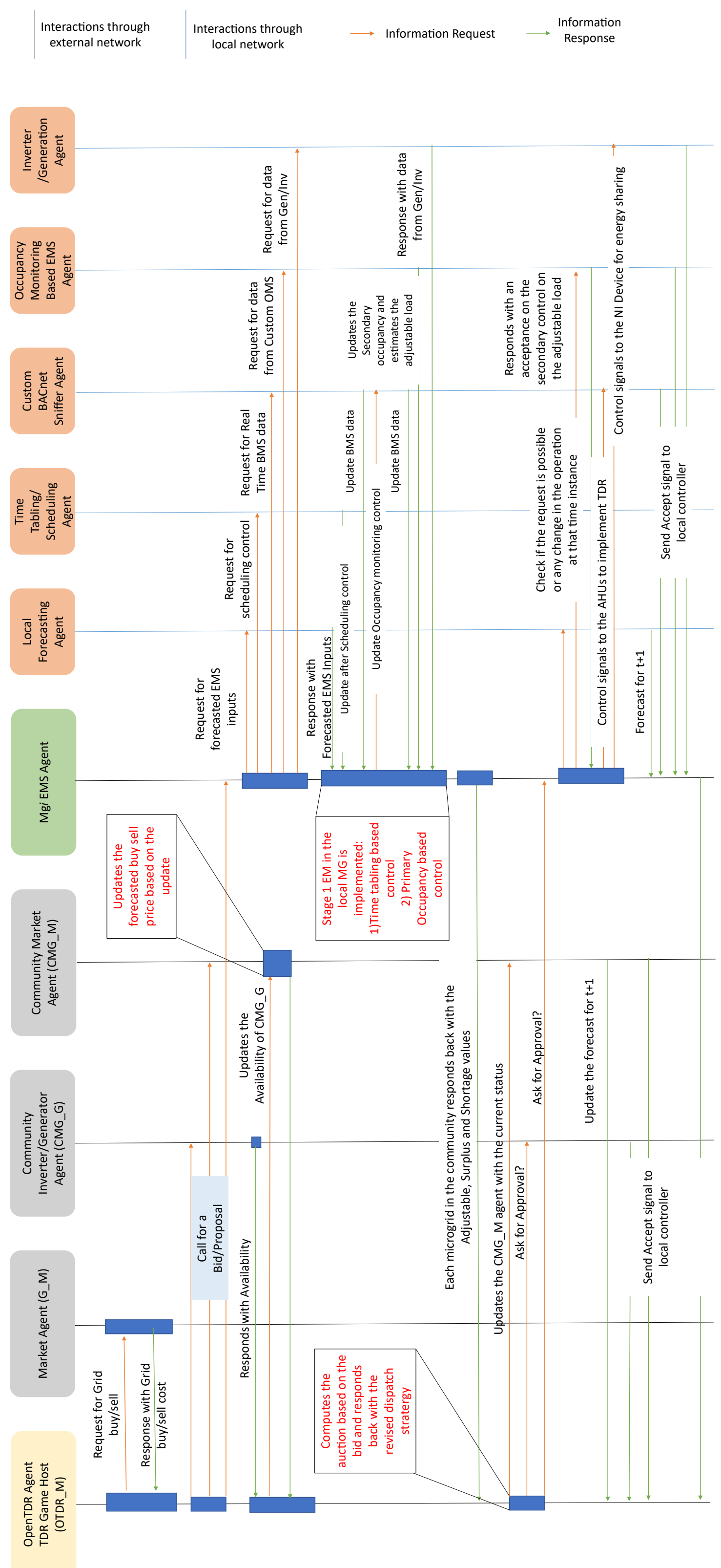

Figure 28: Interactions within agents when the OpenTDR EMS algorithm works

6 Game theoretic EMS algorithm

The figure 27 represents the flow chart of the proposed game-theoretic algorithm and consists mainly of three-stage energy management, and the first mainly includes the Timetabling / Scheduler agent and the control algorithm based on primary occupancy monitoring based on lighting feedback. Once this preliminary EMS is completed, the agents communicate with each other with the available price at which each agent would like to sell the surplus and buy the shortage, and based on the logic illustrated in the second stage of EMS indicated in the figure, the local EMS agent determines the surplus, shortage and the available adjustable load. The adjustable load calculation is based on the secondary occupancy control that is calculated based on the inputs obtained from the CO2/RH/Temp agent and the ToF OMS agent.

Once the local energy management is complete and the calculated bid cost and all input parameters are shared between the agents in the community microgrids, then the game starts and listens to the bids raised by every agent, and determines the most optimal solution and attempts to reach Nash equilibrium. The interactions that occur during this phase are clearly explained in Figure 28 As indicated, the OTDR_M agent starts the TDR game and sends a request to the traditional grid market agent, and the market agent responds with the current feed-in and demand tariff. Following that the OTDR_M agent call for a bid or proposal from all the agents, and once the Local Microgrid agent receives this request, then broadcasts a call for messages to all the low-level agents and undertakes the preliminary energy management and then keeps the OTDR agent informed about the adjustable, surplus, and shortage values. Similarly, the CMG_M and CMG_gen/Inv agent measures or forecasts the available resources and keeps the Game controller agent informed about everyone's state. Once every agent's information is obtained, an auction is run within the game to determine the demand response strategy and then the OTDR_M agent check if all the agents agree to the TDR event and if agreed upon the TDR event is triggered and the orchestration of the load (HVAC control) is implemented.

7 Results and Discussion

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 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 29. 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 29 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 shown below.

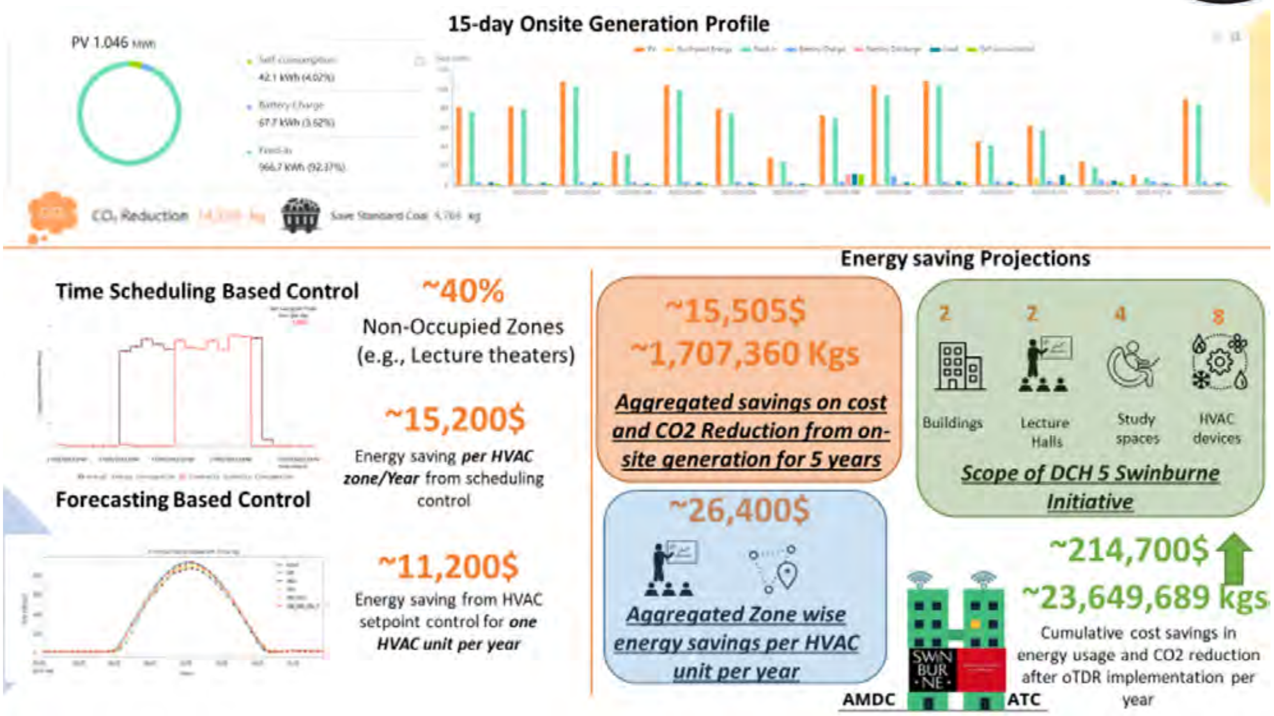

Figure 29: Overview of the results obtained from the initial case studies

7.1 Case study on Optimised onsite generation utilization

In addition to this, the impact of the installed solar generation systems is studied and a predictive analysis is carried out to understand the generation capacity of the installed Solar PV systems in Swinburne university of Technology, Hawthorn Campus. The live data monitoring system developed as part of this project uses the custom-developed OpenADR schema to communicate between the different entities in the project.

As indicated in Section 2.1 a total capacity of 32kWp Solar PV system and a 30kWh battery storage system is installed on the ATC roof top. Inverter generation data has been observed over the last two months and results are indicated in the figures shown below.

As indicated in Figure 30 and Figure 31 for the month of April and May, a total photovoltaic generation of 1.73 MWh and 1.473 MWh (to 26 May) energy has been fed into the community setup as a whole. This refers to the fact that approximately 97.77% of the generated on-site generation has been fed into the building load and this has contributed to a CO2 reduction of 14,814 Kg in total. A low-level control logic has been implemented as part of the project that uses the MODBUS gateway explained in the previous sections of the reports that optimizes the usage of the battery resource, ensuring that the building is using the full potential of onsite generation.

The MODBUS gateway is incorporated with logic to increase the utilization of the onsite generation by optimally changing the charging and discharging sequence. As the actual building load does not connect the inverters directly, the optimization implemented using the MODBUS gateway encourages the battery to discharge until 20% of backup, and this is also fed into the grid to increase the profit of the inverters.

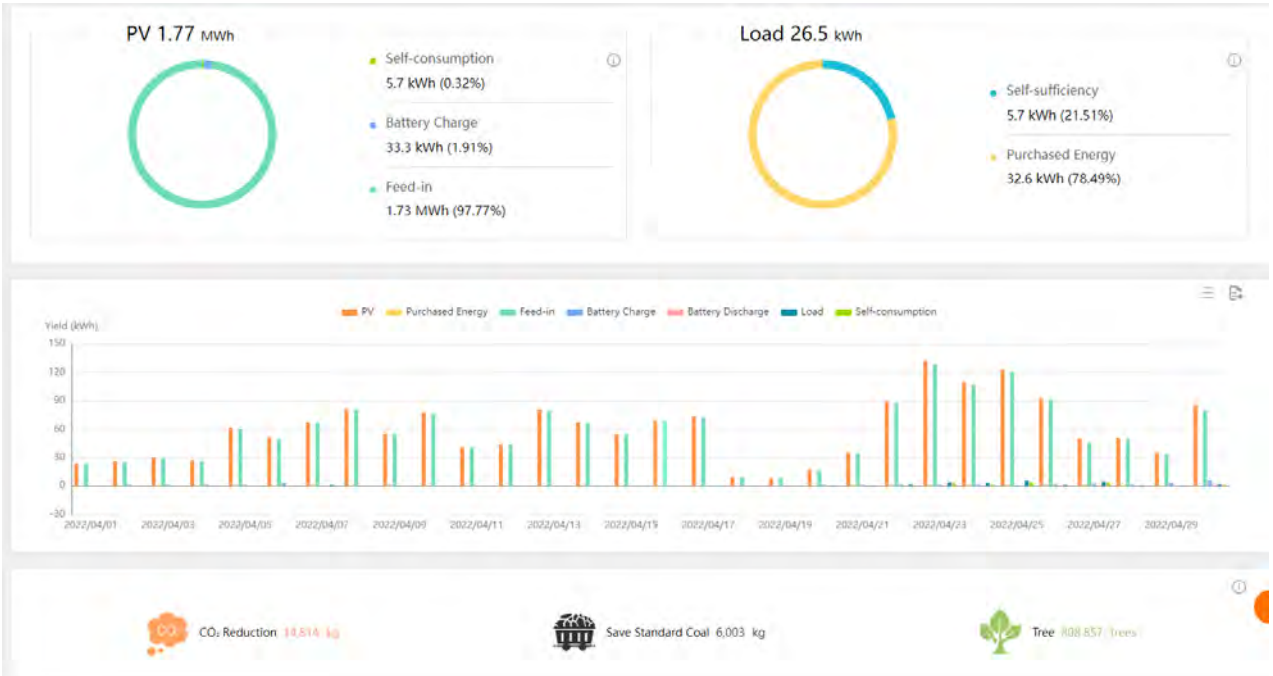

Figure 30: Onsite generation for the month of April

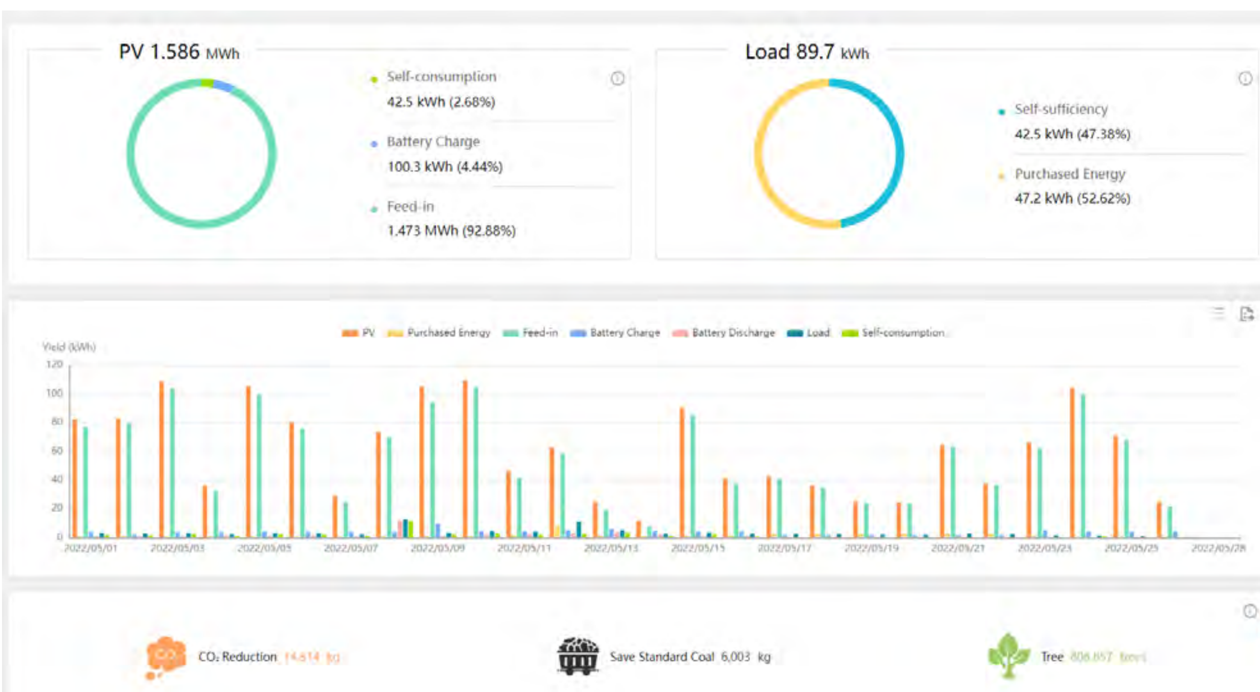

Figure 31: Onsite generation for the month of May

This MODBUS control signal is sent from the VEN such that the onsite generation is used to greater potential. When openTDR emulation is performed using the NI-based community microgrid emulator setup. the MODBUS gateways works in sync with the programmable load and dynamically adapts to the operation of the inverter in a manner in which the excess energy from one resource in the community is shared across to the other with a market benefit. More information about this experimental evaluation is presented in one of the journal articles that will be submitted by the end of June 2022.

7.2 Case study for Dynamic HVAC control using the Timetable scheduling and Set point optimization

Building HVAC systems in academic buildings are equipped with adjustable / curtailable loads and modern controls that can allow one to take advantage of this potential for demand response, load leveling, and energy savings. This potential is compounded for connected buildings as in this case study, where collaboration between multiple buildings can considerably increase the associated advantages. The designed system consists of ground-, middle-, and upper-level functionalities. The ground level includes the sensor network in the IoT framework, the middle level includes software to forecast and manage bookings, and the high level layer is the decision-making layer. Sensors are embedded in specific areas, including lecture theaters, halls, and corridors. The case study is a local multi-building microgrid embedded with a multi-agent network to manage the system. The microgrid is equipped with 84 solar modules that produce 33 kWp of energy that spans an area of 167 m2 on top of the ATC building. The system is equipped with 3 laptops (1 virtual top node and 2 virtual end nodes). These computing machines serve a higher purpose of responding to live transactive demand. The equipment of the rooms in the university building can be controlled through a building management system and the C-Bus network. The multi-agent provides a stream of information from a range of sensors to a computing machine which runs a heuristic routine to relay on/off commands through BMS. A general blockage representation of the proposed system is shown in Figure 32.

The case study covers five levels of information extraction, processing, and management. This study focuses only on the first-level energy management protocol. First-layer energy management involves the curtailment of load through the heuristic processing of live occupancy data and timetable-based scheduling. BACnet and C-Bus enable the system to perform live load control HVAC and lighting. A framework of services and levels is illustrated in Figure 33.

Managing room energy consumption is always a difficult task due to the complexity of modeling occupant behavior. These behaviors are random and difficult to predict for certain rooms. The University classrooms are often pre-scheduled to be used by an average number of students at a particular date and time. In this study, classrooms are booked online and booking information is made available to the building management system. One of the most frequent techniques to limit peak electricity demand is the Direct Load Control (DLC) strategy. An EMS/BMS can use DLC algorithms to remotely shut down or adjust intensity or cycle high-demand electrical equipment (air conditioners, water heaters, pool pumps, etc.). Duty cycle restriction and temperature setback are two common DLC AC control approaches. Duty cycle limiting entails turning on and off the AC compressor at pre-defined times. The thermostat setting is kept under this programming, but the AC compressor is only allowed to run for a certain time even if the set point is not met and then

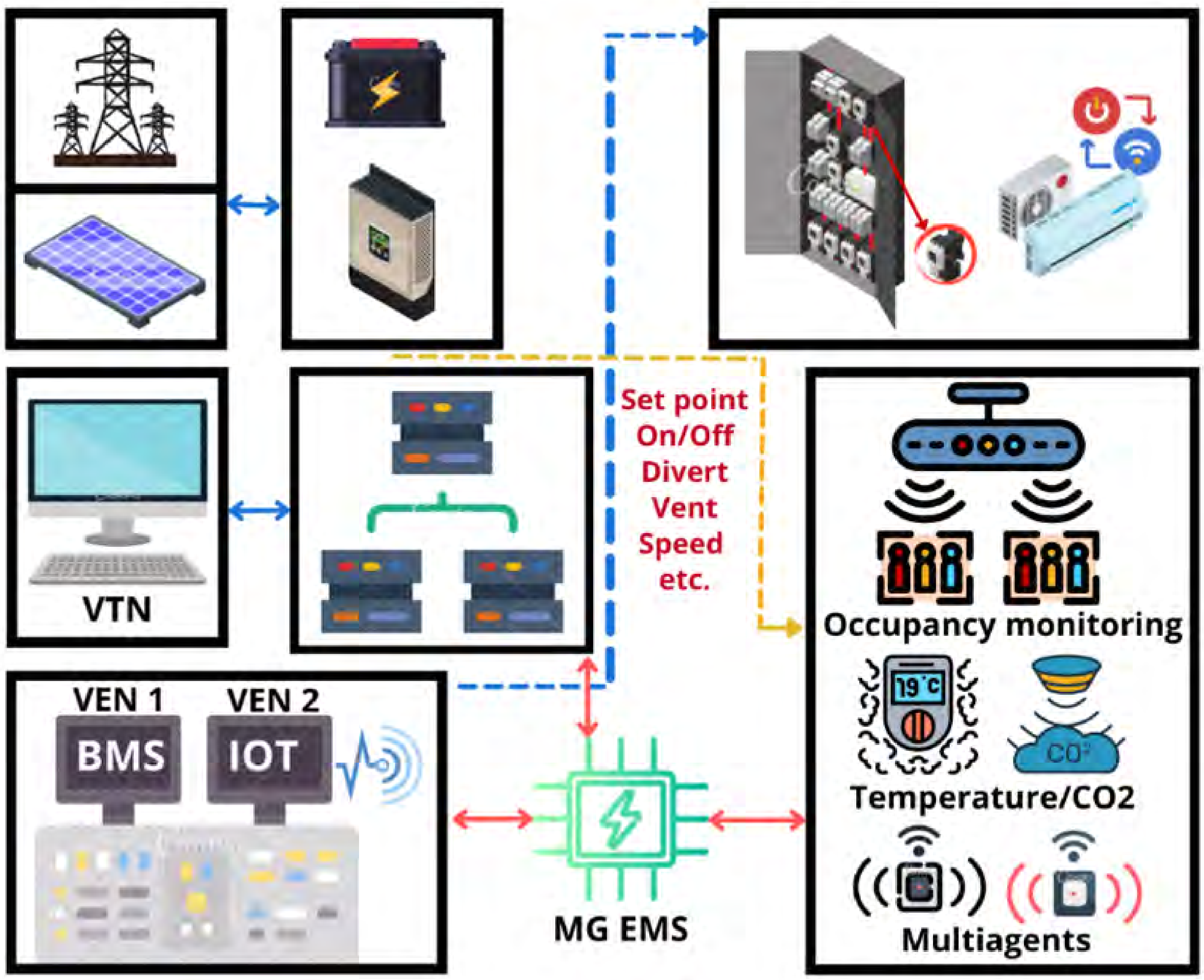

Figure 32: Architecture of the proposed multi-building connected microgrid

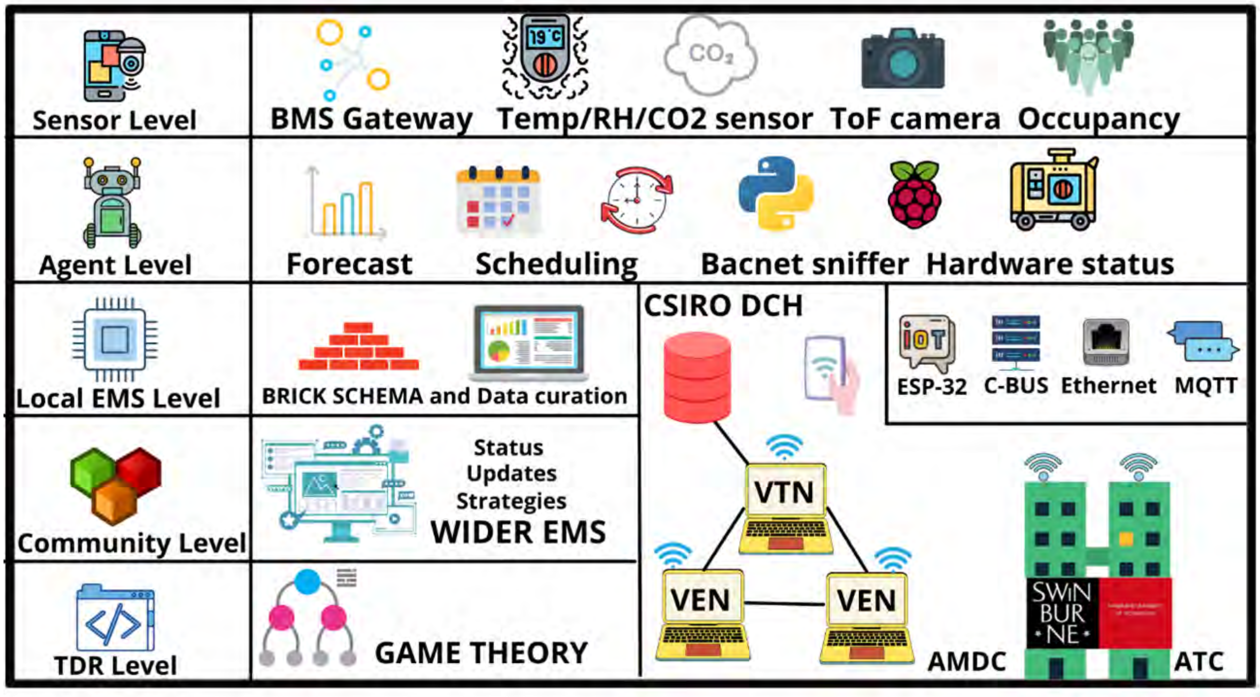

Figure 33: Framework for proposed multi-building connected microgrid

switched off (with the fan on) for a predetermined period. The time it takes for the AC compressor to be off during an activation period is called the off-cycle fraction. According to the discussions of a detailed study by Fan Zhang and Richard D, the goal is to form a judicial direct load control algorithm specific for the building and zone under study. The duo also advised to keep cycling periods shorter, which would eventually have fewer adverse impacts on thermal comfort. Depending on the specific recent DLC studies, the most frequently implemented cycling schemes are a 50% off-cycle fraction and a 0.5 hour cycling period. Other off-cycle fractions, such as 25%, 30%, 33%, 65%, 75%, and 100%, as well as different cycling intervals, such as 1 hour, have also been used. Two levels of cooling set-point temperatures, 22C and 26C, were evaluated, which reflects the theoretical comfort temperature for sedentary occupants dressed in summer clothing. Ventilation rates were investigated at multiple different levels. The minimum external airflow rate for schools serving students over the age of 16 years who do not have an air cleaning device is 10 L / s / person, according to the Australian Standard 1668.2-1991 A context block diagram is shown in Fig. and the general outlook of an office room is illustrated in Figure 34

In the experimental context, we consider the presentation of observations of the case study in two forms. 1) the impact of the time table scheduling analysis carried out for a day with the time table extracted from the booking system, giving a threshold of the hours with a 15-minute interval and switching on and off the HVAC devices using the BACnet gateway. A more detailed perspective of the BACnet gateway is given in the manual attached in the appendix. Figure 35 and Figure 36 represent the results of the timetable scheduling and the recommended set points for the HVAC zones. Due to the limitation we had on the timing of the milestone and other impact caused by COVID, we anticipate presenting the results in the upcoming journal submission by the end of June

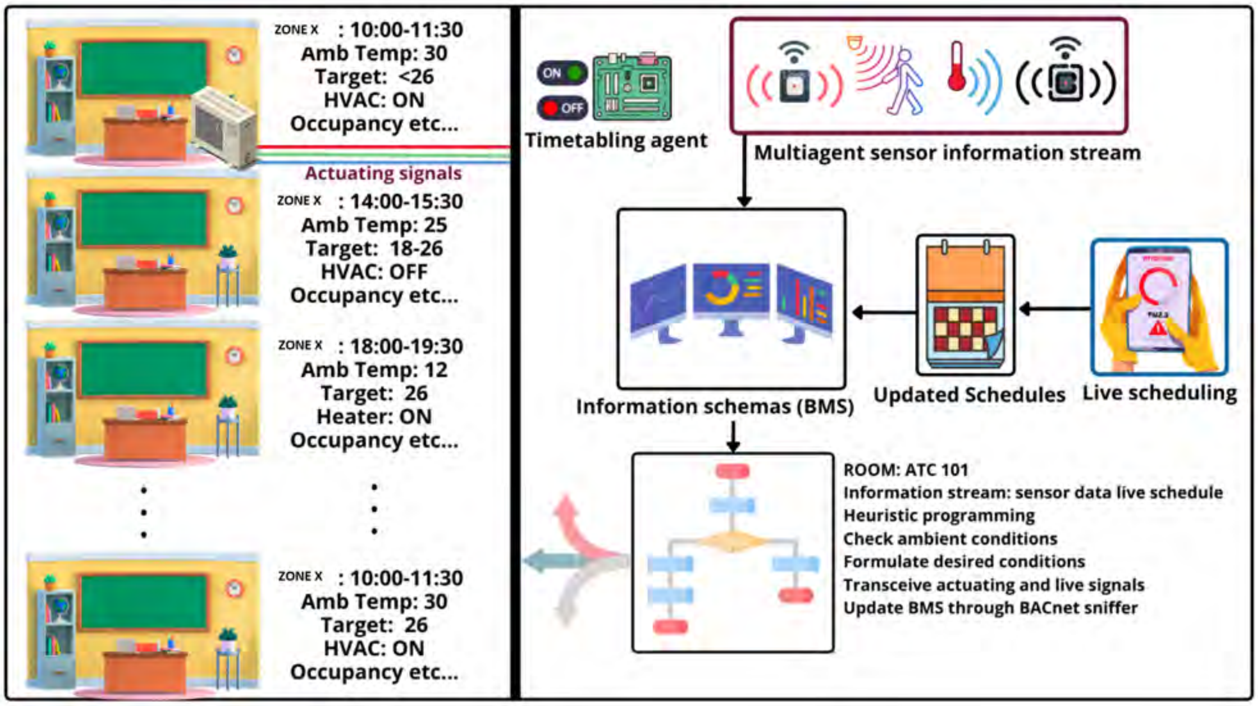

Figure 34: Block diagram for proposed multi-building connected microgrid

2022.

7.3 Case study using the Community Microgrid emulator setup

The OpenTDR framework consists of three modes of operation, which allow the user to model, simulate / emulate, and experimentally implement the OpenTDR energy management algorithm. To emulate the behavior of the transactive demand response, it is initially required to model the community microgrid with energy sharing capabilities. Two approaches are commonly used to generate the load profile data used in the simulation of OpenTDR energy management algorithms. The OpenTDR framework is incorporated with a mathematical modeling tool, which receives information from the user about the configuration of the microgrid and calculates the output of each individual component in the microgrid. The output from the modeling tool is a simplified JSON data that indicates the 24-hour ahead load/generation profile of each microgrid entity. Later, the generated load profile is passed on to the energy management algorithm, which implements an optimization technique to increase the contribution of the generated energy on site through seamless synchronization of demand response and load scheduling events in relation to the microgrid generation profile. The implementation of the local EMS in the individual MG considers the fixed and flexible load, and the optimization is done using a basic MILP algorithm and an advanced q-learning approach that prioritize the use of onsite generation and battery before sharing the energy with the other MG in the community in the output figures indicated below. The forecasting algorithms developed will later be used as part of the energy management system to further optimize the performance of the energy

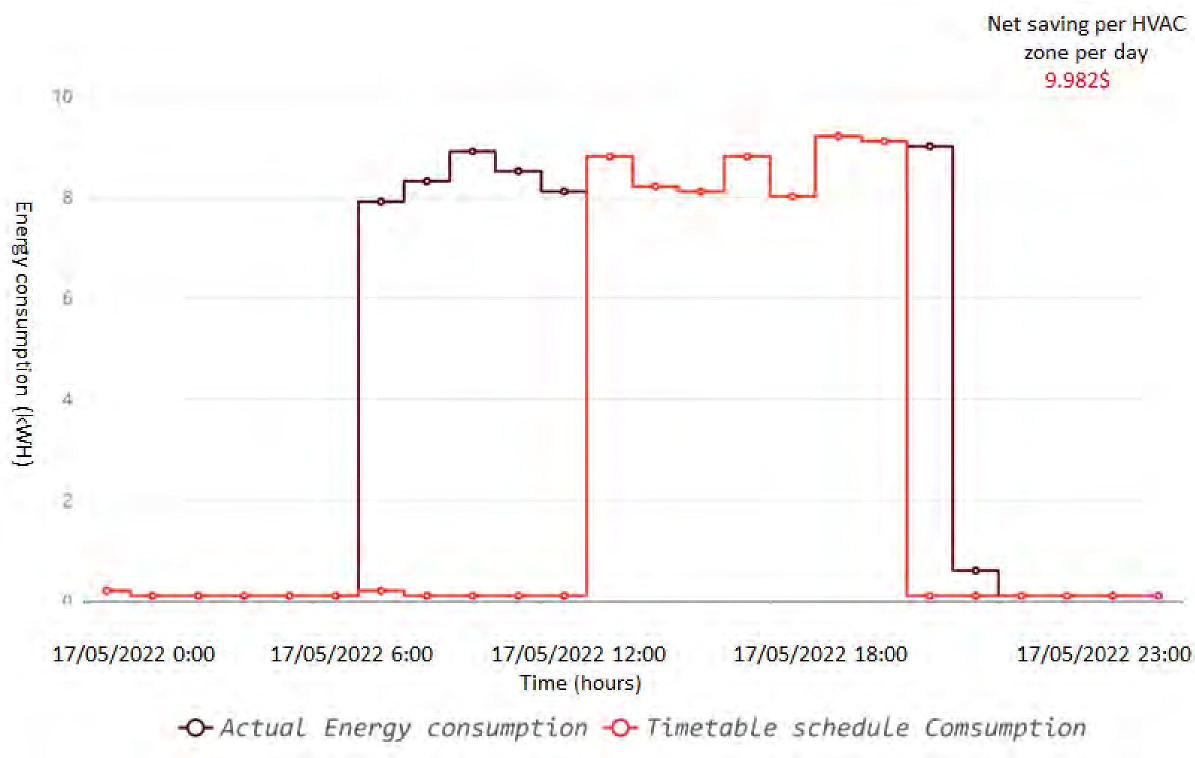

Figure 35: Results from the Time table scheduling case study for One HVAC zone on 17th May

Figure 36: Comparison of the recommended set points with the actual temperature for case study for One HVAC zone on 17th May

Table 2 (cont...): Results and considerations of different market scenario simulations

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Grid_sell_only (AUD/day)	Grid_buy_only (AUD/day)	CMG_sell_prioritised (AUD/day)	CMG_buy_prioritised (AUD/day)	CMG_sell_Auction (AUD/day)	CMG_buy_Auction (AUD/day)	CMG_sell_Auction (AUD/day)	CMG_buy_Auction (AUD/day)
Adjustable Load	--		--		--		10%	
Surplus Sold to	Grid		Community		Community		Community	
Method sell	--		Fixed price		Auction		Auction	
Price	0.07$		0.11$		--		--	
CMG	89.39	0	140.47	0	150.34	0	150.34	0
ATC(MG1)	44.87	409.92	70.51	404.64	83.24	385.75	83.24	347.175
AMDC(MG2)	0	761.74	0	709.48	0	701.5	0	631.35
Total	134.26	1171.66	210.98	1114.12	233.58	1087.25	233.58	978.525
% Reduction in Expense	NA		4.9% Reduction		7.2% Reduction		16.4 % Reduction	

management algorithm. For now, all the simulations explained in the following section are using the synthetically generated data, and this will be later replaced by the data obtained from the data acquisition systems.

Furthermore, the simulation of the proposed OpenTDR framework, with a game-theoretic model, was later simulated to understand the impact of various market transaction scenarios: The 24-hour profile of the different microgrids was considered as the input to the simulation results indicated in Table 2:

Scenario 1: Surplus energy from all resources is only sold back to the grid, and the feed-in tariff is considered 0.07

Scenario 2: In this scenario, the prioritization of sharing energy within the community was considered and the community feed at a price is assumed to be 0.11.

Scenario 3: The Scenario 3 considers an auction to happen within the participating agents where they tend to set a price based on the constraint that the community feed in tariff is less than the grid tariff, but all agents will be trying to maximize their corresponding profit.

Scenario 4: The same Scenario 3 was then considered to have 10% of the shortage load to have adjustable load based on occupancy and CO2/RH/Temp feedback and the reduction observed was simulated to reach a saving of 16.4% In this milestone, the experimental verification of this algorithm was tested, using the community microgrid emulator to check the openTDR system facilitates the impact of energy sharing and corresponding MODBUS and BACnet control steps being executed in the actual hardware.

```
C:\Users\netla\OneDrive - Swinburne University\Gokul\Job\iHub_AIRAH\CodeRepo\
    Demo>python Demo_MGsim.py
connecting to broker
C:\Users\netla\AppData\Local\Packages\PythonSoftwareFoundation.Python.3.10
    _qbz5n2kfra8p0\LocalCache\local-packages\Python310\site-packages\pymgrid\
    MicrogridGenerator.py:612: FutureWarning:
```

Table 2: Results and consideration of different market scenario sumulations

Time	ATC shrt	AMDC shr	CMG_M_shrt	AMD_surp	ATC_surp	CMG_M_surp
1	95	100	0	0	0	0
2	65	110	0	0	0	0
3	75	124	0	0	0	0
4	80	134	0	0	0	0
5	86	110	0	0	0	0
6	195	225	0	0	0	0
7	298	320	0	0	0	218
8	347	420	0	0	0	134
9	0	321	0	0	125	111
10	0	325	0	0	132	110
11	0	225	0	0	152	68
12	0	187	0	0	215	53
13	0	326	0	0	12	242
14	0	245	0	0	5	60
15	70	256	0	0	0	77
16	103	89	0	0	0	67
17	68	173	0	0	0	56
18	48	70	0	0	0	31
19	203	103	0	0	0	4
20	307	306	0	0	0	14
21	503	205	0	0	0	32
22	200	661	0	0	0	0
23	10	220	0	0	0	0
24	85	186	0	0	0	0

```
The frame.append method is deprecated and will be removed from pandas in a
    future version. Use pandas.concat instead.

    load  cost_loss_load  cost_overgeneration  cost_co2  PV_rated_power  \
0    960              10                    1       0.1          969.60
1  60363              10                    1       0.1        30785.13
2  43725              10                    1       0.1        54219.00

   battery_soc_0  battery_power_charge  battery_power_discharge  \
0            0.2                   430                      430
1            0.2                 26992                    26992
2            0.2                 19552                    19552

   battery_capacity  battery_efficiency  battery_soc_min  battery_soc_max  \
0              1718                 0.9              0.2                1
1            107965                 0.9              0.2                1
2             78207                 0.9              0.2                1

   battery_cost_cycle  grid_weak  grid_power_import  grid_power_export  \
0                0.02        0.0             1920.0             1920.0
1                0.02        1.0           120726.0           120726.0
2                0.02        NaN                NaN                NaN

   Comgen_polynom_order  Comgen_polynom_0  Comgen_polynom_1  Comgen_polynom_2  \
0                   NaN               NaN               NaN               NaN
1                   3.0          1.635550          0.435848          0.045227
2                   3.0          6.681807          0.895812          0.005779

   Comgen_rated_power  Comgen_pmin  Comgen_pmax  fuel_cost  Comgen_co2
0                 NaN          NaN          NaN        NaN         NaN
1             67070.0         0.05          0.9        0.4         2.0
2             48584.0         0.05          0.9        0.4         2.0
<pymgrid.Microgrid.Microgrid object at 0x00000274444EE110>
<pymgrid.Microgrid.Microgrid object at 0x00000274445764A0>
<pymgrid.Microgrid.Microgrid object at 0x00000274444EFB20>
MG0-Com_grid Microgrid VTN: architecture: {'PV': 1, 'battery': 1, 'Comgen': 0, '
    grid': 1}
MG1-ATC Microgrid VEN1: architecture: {'PV': 1, 'battery': 1, 'Comgen': 1, 'grid
    ': 0}
MG2-AMDC Microgrid VEN2: architecture: {'PV': 1, 'battery': 1, 'Comgen': 1, '
    grid': 1}
Microgrid 0 :
In Progress 100%
Rules Based Calculation Finished
length of MPCOutput cost is 8735, not 8736, may be invalid
Cost of the last 8735 steps (100 percent of all steps) using rule-based control:
     1077760.52
Microgrid 1 :
In Progress 100%
Rules Based Calculation Finished
length of MPCOutput cost is 8735, not 8736, may be invalid
```

```
Cost of the last 8735 steps (100 percent of all steps) using rule-based control:
     45257715.59
Microgrid 2 :
In Progress 100%
Rules Based Calculation Finished
length of MPCOutput cost is 8735, not 8736, may be invalid
Cost of the last 8735 steps (100 percent of all steps) using rule-based control:
     94285308.38
Microgrid grid status
Microgrid parameters
   load  cost_loss_load  cost_overgeneration  cost_co2  PV_rated_power  \
0   960              10                    1       0.1           969.6

   battery_soc_0  battery_power_charge  battery_power_discharge  \
0            0.2                   430                      430

   battery_capacity  battery_efficiency  battery_soc_min  battery_soc_max  \
0              1718                 0.9              0.2                1

   battery_cost_cycle  grid_weak  grid_power_import  grid_power_export
0                0.02          0               1920               1920
Architecture:
{'PV': 1, 'battery': 1, 'Comgen': 0, 'grid': 1}
Actions:
dict_keys(['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
    battery_discharge', 'grid_import', 'grid_export'])
Control dictionnary:
['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
    battery_discharge', 'grid_import', 'grid_export']
Status:
dict_keys(['load', 'hour', 'pv', 'battery_soc', 'capa_to_charge', '
    capa_to_discharge', 'grid_status', 'grid_co2', 'grid_price_import', '
    grid_price_export'])
Has run mpc baseline:
False
Has run rule based baseline:
False
None
Microgrid parameters
    load  cost_loss_load  cost_overgeneration  cost_co2  PV_rated_power  \
0  60363              10                    1       0.1        30785.13

   battery_soc_0  battery_power_charge  battery_power_discharge  \
0            0.2                 26992                    26992

   battery_capacity  battery_efficiency  battery_soc_min  battery_soc_max  \
0            107965                 0.9              0.2                1

   battery_cost_cycle  grid_weak  grid_power_import  grid_power_export  \
0                0.02          1             120726             120726

   Comgen_polynom_order  Comgen_polynom_0  Comgen_polynom_1  Comgen_polynom_2  \
```

```
0                         3             1.63555          0.435848            0.045227

   Comgen_rated_power   Comgen_pmin   Comgen_pmax   fuel_cost   Comgen_co2
0                67070          0.05           0.9         0.4            2
Architecture:
{'PV': 1, 'battery': 1, 'Comgen': 1, 'grid': 1}
Actions:
dict_keys(['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
   battery_discharge', 'grid_import', 'grid_export', 'Comgen'])
Control dictionnary:
['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
   battery_discharge', 'grid_import', 'grid_export', 'Comgen']
Status:
dict_keys(['load', 'hour', 'pv', 'battery_soc', 'capa_to_charge', '
   capa_to_discharge', 'grid_status', 'grid_co2', 'grid_price_import', '
   grid_price_export'])
Has run mpc baseline:
False
Has run rule based baseline:
False
None
Microgrid parameters
    load  cost_loss_load  cost_overgeneration  cost_co2  PV_rated_power  \
0  43725              10                    1       0.1         54219.0

   battery_soc_0  battery_power_charge  battery_power_discharge  \
0            0.2                 19552                    19552

   battery_capacity  battery_efficiency  battery_soc_min  battery_soc_max  \
0             78207                 0.9              0.2                1

   battery_cost_cycle  Comgen_polynom_order  Comgen_polynom_0  \
0                0.02                     3          6.681807

   Comgen_polynom_1  Comgen_polynom_2  Comgen_rated_power  Comgen_pmin  \
0          0.895812          0.005779               48584         0.05

   Comgen_pmax  fuel_cost  Comgen_co2
0          0.9        0.4           2
Architecture:
{'PV': 1, 'battery': 1, 'Comgen': 1, 'grid': 0}
Actions:
dict_keys(['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
   battery_discharge', 'Comgen'])
Control dictionnary:
['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
   battery_discharge', 'Comgen']
Status:
dict_keys(['load', 'hour', 'pv', 'battery_soc', 'capa_to_charge', '
   capa_to_discharge'])
Has run mpc baseline:
False
```

```
Has run rule based baseline:
False
None
Penetration PV Com_grid : 101.0 %
Penetration PV ATC: 124.0 %
Penetration PV AMDC: 51.0 %
My current Community net_load is equal to 299.2 kWh and the current battery
    capacity of the communal storage is 1718
My current ATC net_load is equal to 1.363e+04 kWh and the current battery
    capacity of the Building 1 storage is 78207
My current AMDC net_load is equal to 1.881e+04 kWh and the current battery
    capacity of the Building 2 storage is 107965
['load', 'pv_consummed', 'pv_curtailed', 'pv', 'battery_charge', '
    battery_discharge', 'grid_import', 'grid_export']
-----------------------------------
|         WELCOME TO OpenTDR for Community Node VTN        |
-----------------------------------


Training Progressing ... Episode 100/100t -      STATE   -  ACTION - COST
================================
discharge
0   - (299, 0.2) discharge 71.2 AUD
discharge
1   - (300, 0.2) discharge 142.7 AUD
discharge
2   - (264, 0.2) discharge 205.9 AUD
discharge
3   - (264, 0.2) discharge 269.0 AUD
imort
4   - (281, 0.2) import 335.5 AUD
imort
5   - (311, 0.2) import 408.5 AUD
discharge
6   - (518, 0.2) discharge 529.7 AUD
imort
7   - (643, 0.2) import 680.4 AUD
discharge
8   - (609, 0.2) discharge 864.7 AUD
imort
9   - (376, 0.2) import 978.5 AUD
imort
10 - (177, 0.2) import 1032.0 AUD
discharge
11 - (132, 0.2) discharge 1071.9 AUD
imort
12 - (143, 0.2) import 1157.7 AUD
discharge
13 - (125, 0.2) discharge 1232.8 AUD
discharge
14 - (174, 0.2) discharge 1337.6 AUD
imort
```

```
15 - (289, 0.2) import 1512.8 AUD
discharge
16 - (506, 0.2) discharge 1818.9 AUD
discharge
17 - (548, 0.2) discharge 2150.2 AUD
discharge
18 - (689, 0.2) discharge 2360.2 AUD
discharge
19 - (720, 0.2) discharge 2579.3 AUD
discharge
20 - (775, 0.2) discharge 2815.7 AUD
discharge
21 - (718, 0.2) discharge 2985.1 AUD
discharge
22 - (600, 0.2) discharge 3127.2 AUD
imort
23 - (434, 0.2) import 3229.8 AUD
```

The code snippet of the execution of the community MG emulation with synchronized MQTT messages controlling the inverter and the operation of the SS relays in the inverter is embedded with the test case emulated, and the working demonstrates the importance of driving legislative rules to support energy sharing across building within the community with a standardized approach.

8 Conclusion

Despite the impact of COVID-19, the project has made significant progress during the final milestone period (M7) and is very close to completion of the project. As a result of the proactive implementation of the COVID-19 plan, which includes a timely schedule for managing data identification and collection, work collaboratively with Swinburne's facility management team to establish COVID-safe installation and commissioning working procedures and careful identification of potential scheduling risks. Also, the major mile stone of OpenADR support for the DCH data link and also development of the Community microgrid emulator, BACnet gateway for HVAC interface, MODBUS gateway for low level inverter control and the implementation of the time tabling and set point forecast control are to be considered as major accomplishments of this milestone. Since the data monitoring system was fully functional only a week ago. Data with a clear representation of the actual savings will be reported in the planned journal submission planned for the coming month of June 2022. As a whole, a comprehensive overview of the observed results is presented in this report and a more detailed perspective of the results and the forecasting models will be presented in the journal submission targeted in the month of June as highlighted above.

Table 3 summarizes the project deliverables and their current status. It can be concluded that the majority of deliverables are nearing completion, and given the project's lag time, the progress of the project is on track to meet our targets. According to the technical analysis and modeling conducted by the team at Swinburne University of Technology and other project members, while there are some technical challenges identified, there are no significant barriers or roadblocks preventing the team from delivering on milestones or posing a threat to the project's objectives and goals leading to a successful completion of the project by the end of June 2022. Additionally, KIG, GHGP, Bramec,

Table 3: Progress on the project deliverable to date

Deliverable	Progress status
Baseline data gathering, data cleaning, preparation for model implementation	100%
Implement generation and consumption forecasting models	100%
Customisation of TDR model to the project use case	90%
Design of the occupancy monitoring systems	100%
TDR model evaluation for various generation and consumption scenarios	100%
Design of the local weather monitoring station.	100%
Implement HVAC DR using TDR model	100%
Development of the forecasting techniques using external data sets.	100%
Design and development of the openTDR emulator prototype.	100%
Initial design of the semantic building models.	100%
Performance Evaluation and Verification	80%

CSIRO and Swinburne believe that the technical issues encountered are within the realm of what is considered 'typical' for such infrastructure projects. As part of knowledge sharing initiatives of the project, we are aiming toward having a live demonstration of the project for the Open Day 2022 in Swinburne.

9 Appendix

9.1 Appendix: A

PVsyst Analysis The initial PVsyst analysis carried out for identifying of the most optimal location and the optimal sizing of the solar PV system to be installed in the roof top of ATC Building at Swinburne University of Technology, Hawthorn Campus as the part of the DCH5 Project. PVsyst Analysis Report: https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EagqG-As04RDgMBqvBVk6YoBgHAtSt-xqmiDpE0PXZB6sg?e=dWdTQN

9.2 Appendix: B

NI based MQTT GUI

Software manual for the NI based MQTT /Influx DB GUI developed as a part of the DCH 5 project. This GUI allows the user to have a dashboard for live monitoring of the individual Building data and as a whole community.

The GUI also allows the user to compare the impact of various data points and understand the relationships between them like the set point temperature and the corresponding energy consumption profile.

The MQTT GUI also incorporates the feature of accessing the historic data by looking into the influx DB database hosted locally and provides the data for the openTDR instance running in each VEN.

The MQTT GUI is developed using the DQMH framework making it more robust and customizable one for future implementations as this can be used for the dash boarding applications of the

MQTT GUI Manual : https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavu
swin_edu_au/EbLMXuX_sT9MjHkuEC7eKHMBPTazsUuK0aTdi5y1klS3zw?e=UuC06X

9.3 Appendix: C

MQTT GUI DQMH Documentation

Demonstration GUI for DCH 5 project VTN and VEN brokers that can subscribe to the list of topics and provide a platform for comparing and analysing the impact of various parameters with the energy consumption profile.

MQTT GUI DQMH Documentation:https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EeN4-k5fx0xBner-X0jpfRsB3MVG_hUAX5AM-JfWrTnmFQ?e=xIy2a8

9.4 Appendix: D

ToF based occupancy monitoring system Manual

The manual explaining the development and integration of the ToF based occupancy monitoring system is presented.

ToF based occupancy monitoring system Manual: https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EWBTSlN2-UdIsZo6MauEBnEBJFnyLSLjCspyS-S3hW
e=KBa090

9.5 Appendix: E

ToF based People counter system Manual

The manual explaining the development and integration of the ToF based People counter system is presented.

ToF based People counter system Manual: https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EQkrpSiBeKVAovcUqwb1x-4Bvr7ScEMWmrfH6lDsCJ5sJw?
e=Qrv3gZ

9.6 Appendix: F

SCD based real time Air quality monitoring system Manual

The manual explaining the development and integration of the SCD based real time Air quality monitoring system is presented.

SCD based real time Air quality monitoring system Manual: https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EbmIYI2akcdIooDViFpuvAUBI5EQKeU
e=DyqZBZ

9.7 Appendix: G

BACnet Gateway Manual

The manual explaining the development and integration of the BACnet Gateway is presented.

BACnet Gateway Manual:https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EfJpB2DnG2pPm3-6LSRCNz4BFxWrg31o6UqT7pd2fsEXZA?e=2MC5Uq

9.8 Appendix: H

MODBUS Gateway Manual

The manual explaining the development and integration of the MODBUS Gateway is presented. MODBUS Gateway Manual:https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/EVxx4E6b6NBJkZi2tBr4gmwBXVB1s52ltN8kCmwl4IMX-Q?e=vGdK3b

9.9 Appendix: I

Community Microgrid Emulator Manual

The manual explaining the development and integration of the Community Microgrid Emulator is presented.

Community Microgrid Emulator Manual: https://liveswinburneeduau-my.sharepoint.com/:b:/g/personal/gthirunavukkarasu_swin_edu_au/Edn5cYRQnlxHsNeXtfO2-ygBaPcA64qOTVqZ5nncJNTPYA?e=q3gHgG