The Innovation Hub

for Affordable Heating and Cooling

i-Hub DCH 5 Milestone Report #M6

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 - MR6

19th Nov, 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.

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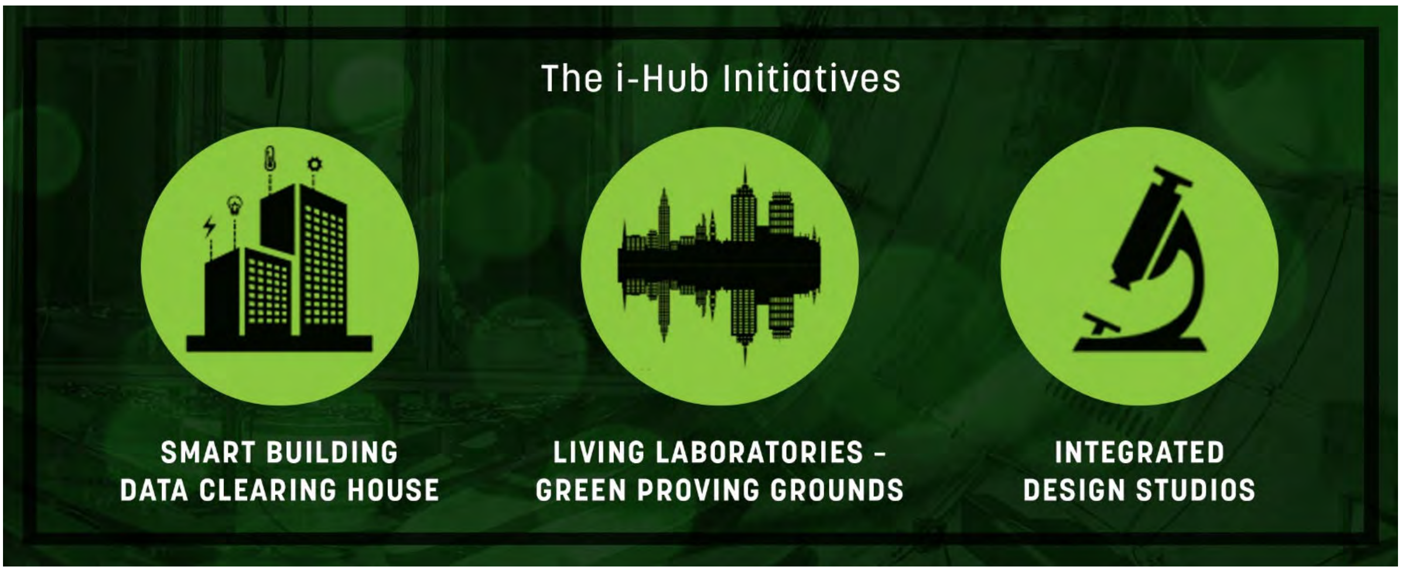
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Primary Project Partner



i-Hub DCH5 - 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

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Executive Summary

Demand Response (DR) could play a significant role in addressing the numerous technical and operational challenges due to the high level of renewable energy penetration in the electricity network. This can be done by delivering a proper power balance between the demand and supply side 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 PV-Battery storage systems and control of HVAC system in two commercial buildings located at Swinburne University Hawthorn campus. Furthermore, the system is expected to be capable of participating in DR event through a novel openTDR framework. This document outlines the activities carried out during the M6 milestone period. Identification of the potential buildings, designing and implementing an onsite renewable system, and initial design of the different data monitoring systems that include occupancy rate, weather information, and energy consumption data of the existing BMS system was carried out in M5. 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 is been developed and tested using synthetic data. In the upcoming milestone, further implementation of the proposed algorithm in the actual buildings would be tested and the data ingestion to the DVH platform would be targeted.

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 Centre (ATC) and Advance Manufacture and Design Center (AMDC) have been identified as the potential building 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 for evaluating the proposed OpenTDR framework, which is detailed in the following report. Additionally, the solar PV system along with battery storage is installed in the rooftop of ATC and the system is commisioned to operating in full potential during the phase of M6.

The concept of sharing energy between entities is critically reviewed, and the final design of the infrastructural requirements is discussed with our partners KIG and GHGP. The other component of the project is the HVAC system's control based on the feedback recieved from the OpenTDR framework. Swinburne has also allocated some additional budget to have the existing BMS providers assist with implementing a supervisory control mechanism for the HVAC unit. 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 were evaluated with the data extracted from the Local BMS in the identified buildings. Swinburne anticipates publishing the investigation's findings in a peer-reviewed academic journals by end of this year. Along with the forecasting models, Swinburne researchers also created a prototype to evaluate the operation of the OpenTDR framework which would further used in future evaluation of community microgrid simulation.

Research team in Swinburne university of technology, have developed a custom occupancy,

weather, and BMS integration tool (BACnet Sniffer) which is required for experimental verification of the openTDR framework during the Milestone M6. Additional information regarding the finalised design concepts of all the data monitoring devices and manner in which the proposed OpenTDR framework and the OpenTDR algorithm incorporated within the framework is explained more in detail in the Milestone M6 progress report presented in this document. Finally, the openTDR framework's various data monitoring and control signals would be sent to the DCH platform using an openADR to BuildingJSON parser developed in house. To ensure the proposed OpenTDR framework is standardised, all the data communication happening within the network and also the to the DCH are using the OpenADR standard schema and this implementation will be the focus of the upcoming milestones in the project along with implementing the HVAC control and evaluating the algorithms performance in real world application.

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1 Introduction

1.1 i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is a collaborative initiative between the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), CSIRO, different universities across Australia, which is financially supported by the Australian Renewable Energy Agency (ARENA). The main objective of i-hub is to accelerate the heating, ventilation, air conditioning, and refrigeration (HVAC&R) industry's to prepare for a lower emissions future.

The mission of i-Hub is to assist the larger HVAC&R sector in disseminating information, developing skills, and creating capacity. By fostering a collaborative approach to innovation, i-Hub connects Australia's best institutions, academics, consultants, building owners, and equipment makers.

1.2 i-Hub DCH5

The i-Hub consist of three focus areas or 'Initiatives' aiming for them to occur in the widespread spectrum – from the research and innovation stage to adoption and global use to assist the HVAC&R industry transition to a low-emissions future.

The priority areas include:

1. Living Laboratories (places that enable testing of new technologies under controlled conditions) and Green Proving Grounds (to accelerate market acceptance and adoption of innovative building technologies)
2. Integrated Design Studios – facilitates collaborations with building owners and the design industry
3. Smart Building Data Clearing House – creating access to data for a better understanding of current building performance and energy management.

The Smart Building Data Clearinghouse seeks to increase the quality and utility of building data by offering a data storage platform that enables accurate and comprehensive access to building data for decision- and policy-making purposes. All DCH member organisations will receive access to the clearing house's data, enabling them to work on developing smart algorithms and analytical services to enhance the energy efficiency of buildings.

Swinburne University of Technology researchers present the DCH5: Development and experimental implementation of Transactive Demand Response Management System using Open ADR-approach for Institutional Buildings, in partnership with CSIRO, AIRAH, Bramec, and KIG. In this project, demand response will be utilised to overcome the technical and operational issues generated by increased DER intake in the electrical system. In this aspect, accurate scheduling of variable loads may be critical in coordinating how onsite power is effectively employed within a community of microgrids. In this regard, an open ADR-based Demad Response (OpenTDR) platform is being developed. The primary goal of this OpenTDR framework is to improve the efficiency of onsite DER production by incorporating demand response events connected with HVAC systems. Swinburne University's Hawthorn campus is considering using two commercial buildings for the experimental installation of the OpenTDR framework and evaluating the effect of transactive demand response events. The OpenTDR framework is created with a multi-agent model that will aid in the modelling of community microgrid energy management. The goals of this framework are to increase the efficiency of HVAC operation inside each building/Microgrid and to increase the use of on-site renewables. The model's main component is the Game theory-based optimisation of energy use depending on activity type, weather conditions, and occupancy rate, which is further detailed in the following sections.

1.3 About this report

The purpose of this report is to provide an overview on the OpenTDR framework used for transactive demand response and illustrate the progress made in milestone M6 by elaborating on the system configurations of the experimental validation setup. A more detailed insight on the multi-agent based game theoretic OpenTDR energy management algorithm is provided in this report. Followed by which a detailed explanation on the custom data monitoring devices developed for occupancy and CO2/RH/Temp monitoring is provided. Finally, different market scenario simulations to evaluate the performance of the openTDR framework is explained and the plan for the integration of the OpenTDR framework data points to the DCH senaps.io platform is further explained.

2 Site Description

The Swinburne Community microgrid precinct consists of two buildings ATC and AMDC considered for evaluation of the OpenTDR framework. A detailed analysis of the buildings in Swinburne University of Technology, Hawthorn Campus was conducted 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 the existing BMS to control the HVAC system.

Taking two adjacent buildings into consideration at a time, as illustrated in the aerial view of 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 suits for the project case. As such the ATC building's west wing was identified as a good site for the solar-PV system. Furthermore, the occupancy and use patterns in the ATC and AMDC buildings are very dynamic, which supports our selection criteria. External wiring for energy sharing between the two buildings is not viable due to a restriction with the current building layout. However, based on the electrical wiring schematic, it was discovered that there are two NMI meters/utility connections within the ATC building. The two NMI

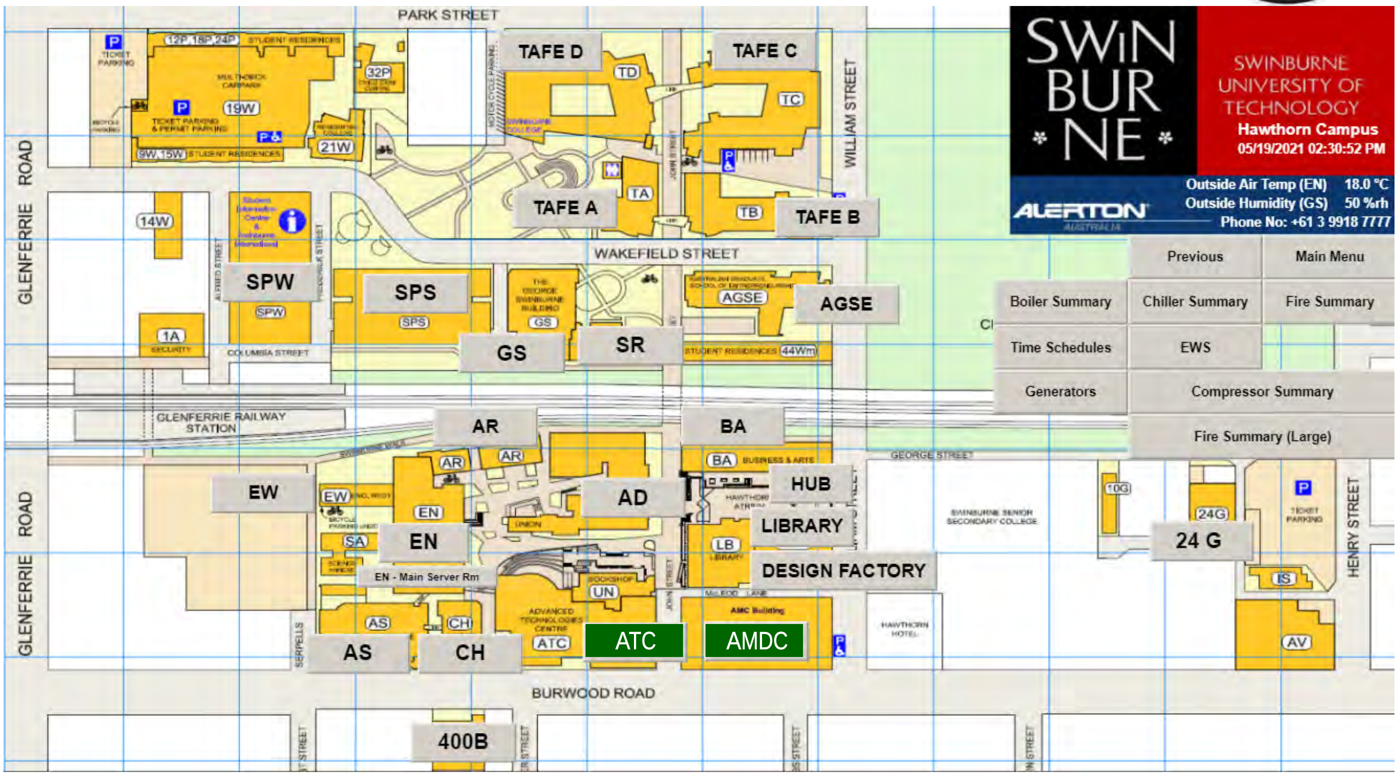


Figure 1: Aerial view of the buildings in Swinburne Hawthorn Campus

structures shown in the Fig. 2 allow us to begin energy sharing or imitate energy sharing between two community microgrid entities.

Further analysis of the system showed a legislative prohibition against connecting two connections originating from two separate transformers. As a consequence, the application to undertake energy sharing with two DSBs connected to the same electricity metre was ultimately approved. Two alternative nodes for enabling transactive energy sharing in the building are shown in Fig 3. Consequently, a transactive demand response and community energy sharing assessment are required for evaluating regulatory restrictions and their impact on interconnecting two or more microgrid entities.

3 DER system integration with controls

3.1 Solar-PV and storage system

The architecture of the solar-PV-storage systems is partitioned in such a manner that the transactive demand response between two entities of the community microgrid may be studied. Fig. 3 depicts the single line diagram (SLD) of this design. 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

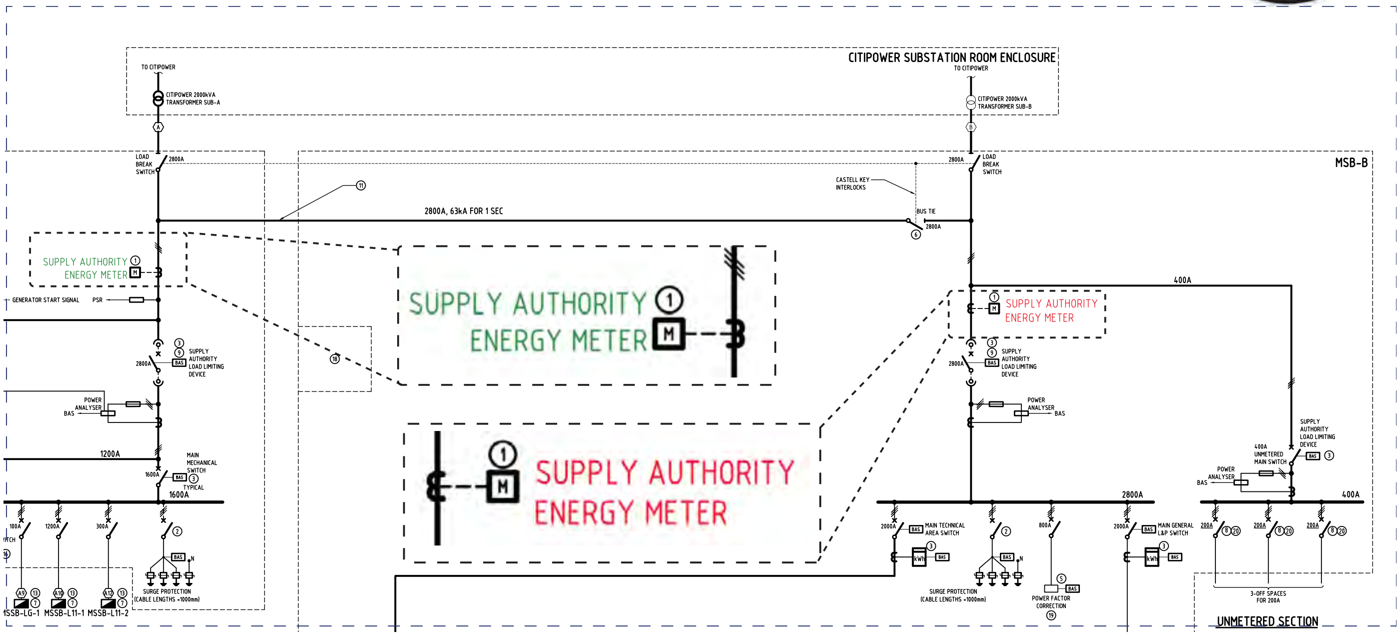


Figure 2: Electrical wiring diagram of ATC Building indicating the two Utility connections

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

As illustrated in the Fig. 4, 84 x Trina Vertex 390W Solar Panels are mounted on the roof. Table 1 contains the system summary. The DC wires are routed via the main cable tray beneath the panels to the inverter. A space of 1,250mm between rows of PV panels is regarded to avoid self-shading and to allow access for maintenance. To eliminate partial shadowing and maximise efficiency, the panels are angled at a 15-degree angle. The installed solar-PV system is positioned on the top of the ATC Building (West wing), 427-451 Burwood Rd, Hawthorn VIC 3122. Fig. 5 depicts the position of the solar system's installation on the roof.

Aside from 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 system shown in Fig. 3 is to emulate the behaviour of a community microgrid while simultaneously evaluating the various transactive demand response scenarios. The three inverters reflect onsite generating from the two buildings (ATC and AMDC), as well as a shared community storage system. The installed location of the inverters and batteries are depicted in the Figure 6.

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

Installer & Designer Details			
Installer Name	Jeremy McDonald	Installer CEC No.:	A4649938
Designer Name	Onur Kaya	Designer CEC No.:	A9736463
Electrician Na	Jeremy McDonald	Licence Number:	A45678

Installation Details	
Install Date	15/09/2021
Total DC Capacity (kWp)	32.76 kWp
Total AC Capacity (kVA)	30 kVA
Installation Company	GREEN HOME GREEN PLANET

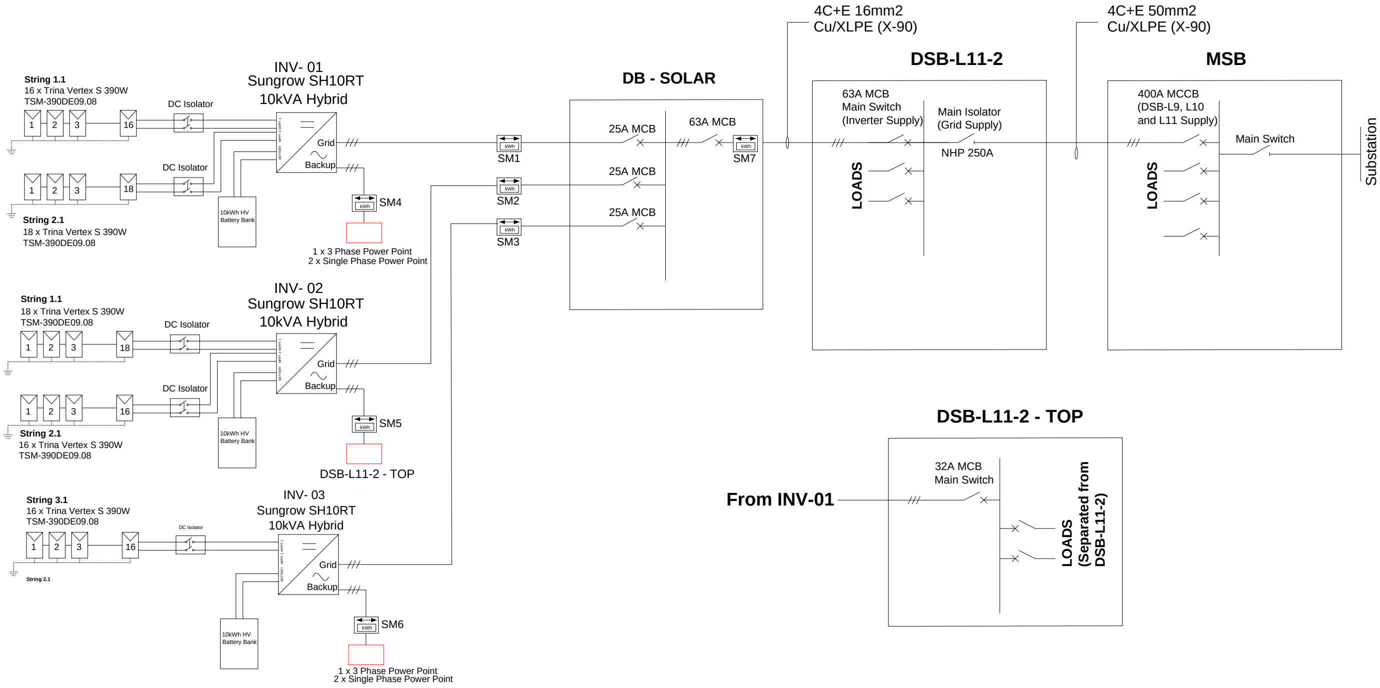


Figure 3: As-build (Single Line) diagram of installed Solar-PV and Storage system. DSB's are configured to emulate the transactive energy sharing.

3.2 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 from the analysis is 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 7.

3.3 OpenTDR framework for Community Micro-grid Emulation

Buildings account for over 25% of Australia's greenhouse emissions. Onsite renewables and storage enable buildings to manage and minimise their energy demand. Inadequately managed renewables may have a negative impact on grid stability and cause unwelcome outages. may help stabilise the grid by adopting flexible loads like air conditioning and lighting systems. Adjusting the operation schedule of building energy consumption 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 may significantly reduce their operating costs. Controlling building loads during peak and off-peak reduces the dependency on grid-supplied energy and improves renewable energy contributions. Thus, building owners may successfully leverage flexible demand to

Figure 4: Installed PV system in the ATC roof top

engage in the energy market while promoting system modernisation and boosting grid resilience, dependability, and energy affordability. To this end, OpenTDR is a low-voltage microgrid platform that allows market participation of distributed energy resources (DER) and demand response mechanisms applied to commercial and institutional buildings.

As previously stated, this project's unique issue is to develop a community micro-grid so that one entity (building) may share extra on-site renewable energy with its neighbours instead of feeding back to the grid to meet demand collaboratively. The concept of community micro-grid energy sharing will allow advanced game theoretic algorithms to examine energy market scenarios, ultimately addressing community energy needs utilising the OpenTDR framework. A detailed overview on the progress of implementing the game-theoretic model is explained in the following sections.

A prospective areas for linking the entities to test the idea of the community micro-grid was identified. As shown in Fig. 3 First two inverters represent the buildings ATC and AMDC, while the other inverter represents the common storage/generation in the CMG configuration. The NI based EMS algorithm will help orchestrate possible energy sharing between CMG nodes. An energy sharing auction will be conducted using a game-theoretic energy management method to discover the optimal bid. Because the CMG intends to deliver energy at a lower cost than the grid, the possibility of sharing energy within the neighbourhood boosts the return value. If the grid offers a cheaper price, the local EMS in the microgrid may choose to obtain the shortfall from the grid instead of the CMG. The CMG's large range of possible outcomes makes the energy management issue difficult and stochastic. This is one of the key reasons why the openTDR framework's game theoretic energy

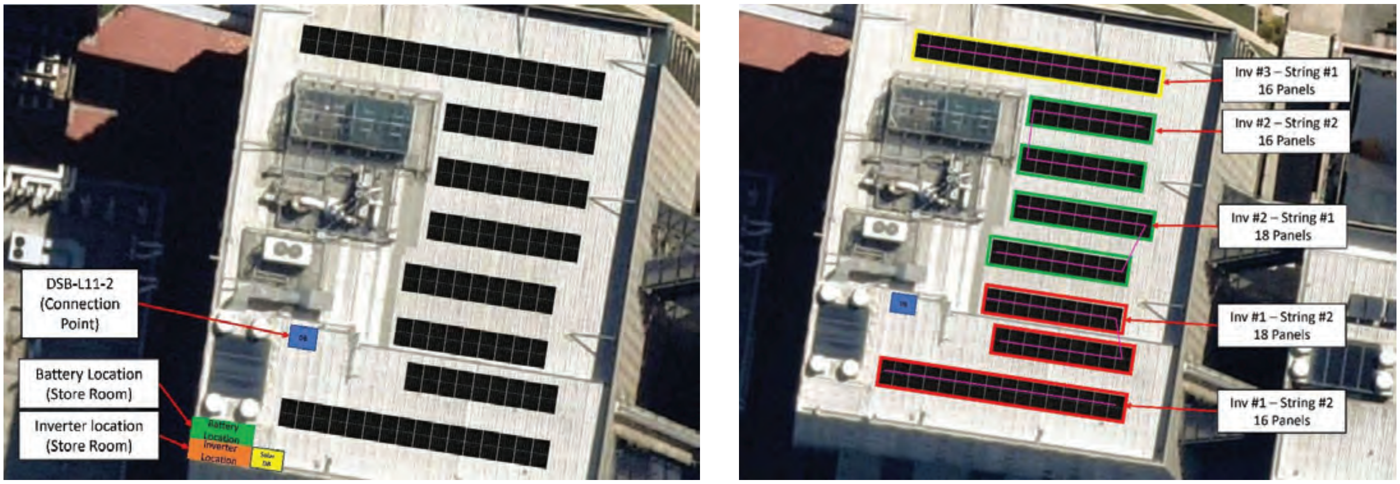


Figure 5: Site plan of the installed solar-PV system on the West Wing Roof of the ATC building

Figure 6: Inverter Room with 3 SH10RT inverters and Batteries

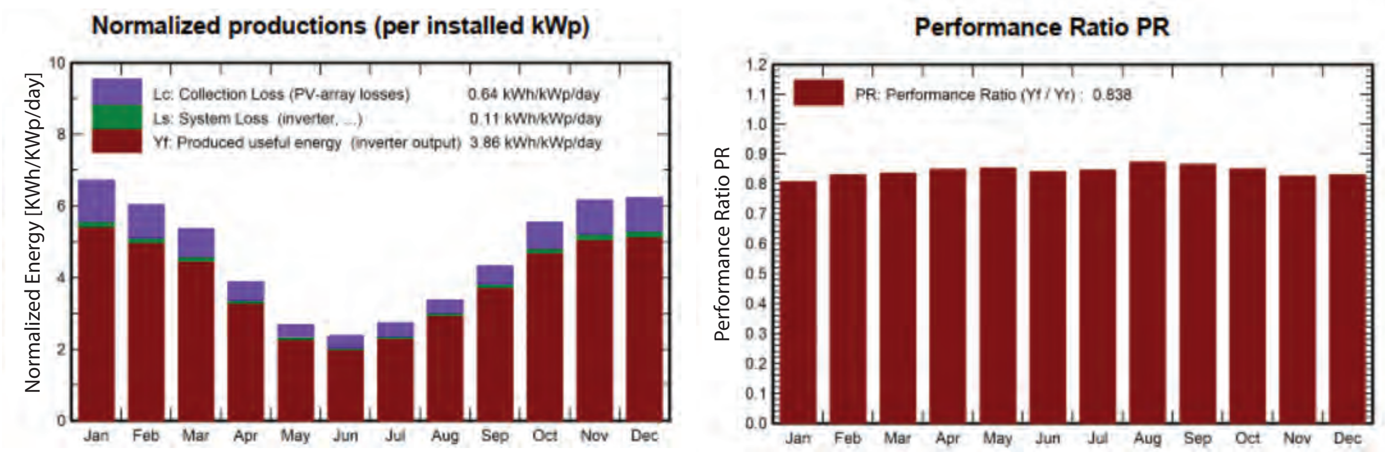


Figure 7: Estimated generation graph

management model is assessed in this project. The multi-agent model allows for energy sharing and simulation of various market conditions. The experimental setup is delayed due to COVID affecting the delivery of the NI CRIO. The onsite renewable energy production (PV + storage) is connected to the DSB-L11-2, which is the typical grid point in the CMG emulation. The BMS loads and other data points like weather, internal zone temperature, relative humidity, and CO2 values help the TDR algorithm create set points and control mechanisms for demand reduction. This report will go through the configuration of this system in depth.

The openTDR framework is intended to simulate the whole community microgrid energy system. It also allows commercial buildings to adjust their usage patterns in response to market players' requests. 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. 8 depicts the proposed openTDR architecture in general. Fig. 9 and Fig. 10 show the proposed OpenTDR framework's high-level block structure and 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 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 reported in previous 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 sen-

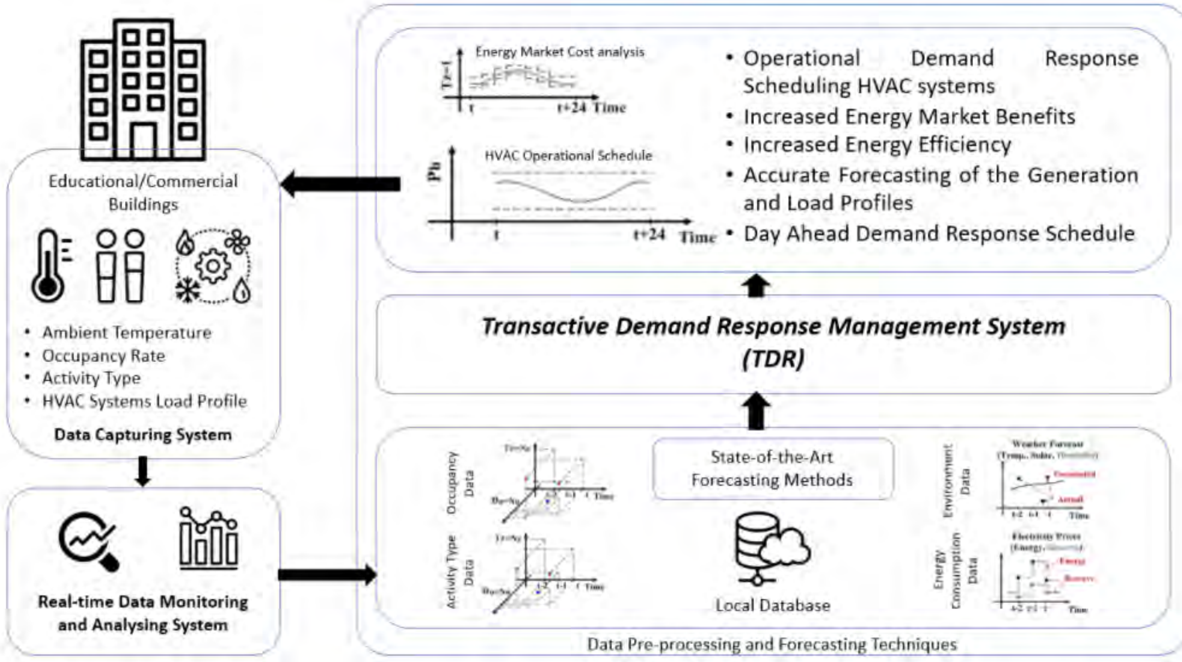


Figure 8: Overview of the proposed Open transactive demand response (OpenTDR) framework.

sor 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 the goal of the suggested method.

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 for data storage and querying. The brick schema comprehensively describes the structure of the building and the various type of data input streams along with the detailed architecture of the mechanical systems integrated within the building. Fig. 11 indicates the relationship of the data measurement points 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 buildings Brick

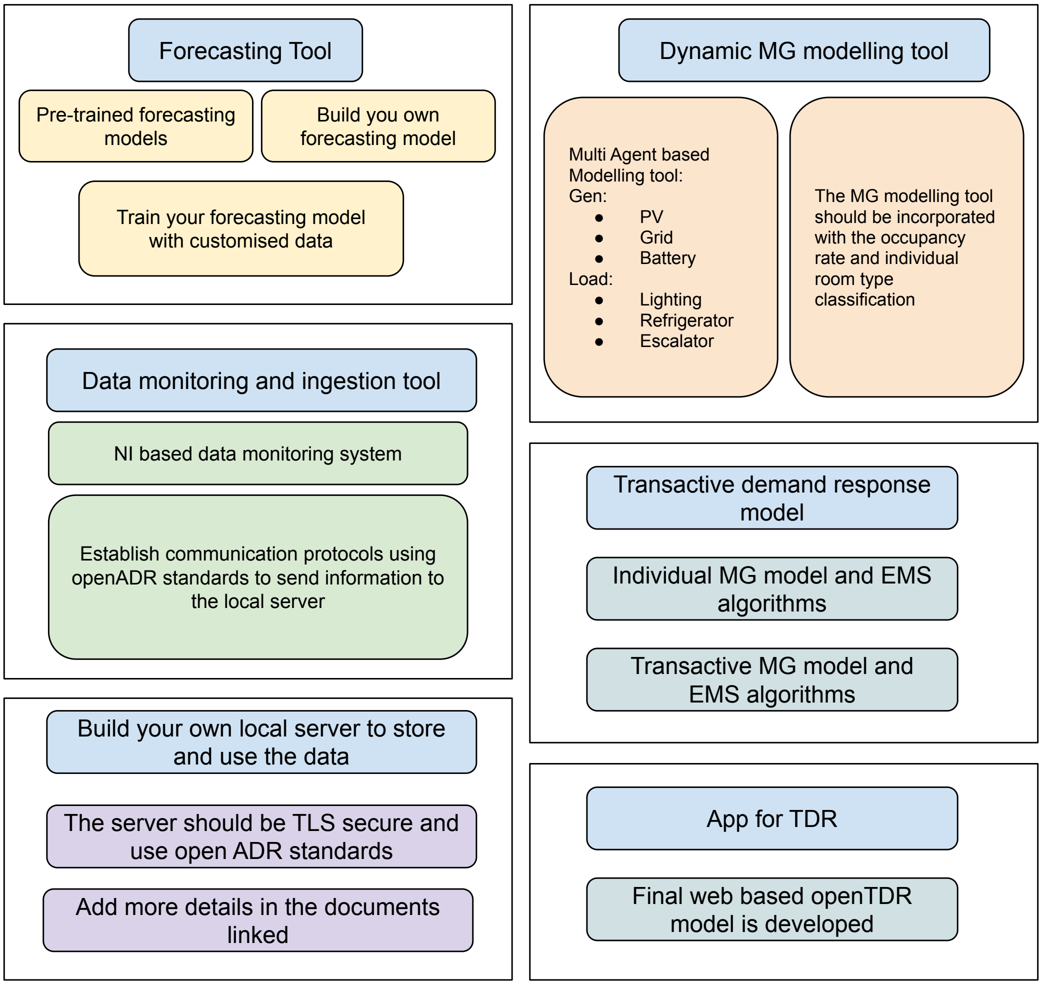


Figure 9: Block Diagram of the proposed openTDR Framework

model explaining the complete room wise 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 addition data monitoring devices to read the Occupancy data and zone wise CO2/RH/Temp data. The newly added sensor systems are focusing specifically on the regions with dynamic population and the potential region in which the zone wise control can be implemented. Therefore, in order to achieve this, the sensor modules explained below are installed in the below mentioned location. These additional sensors assist the proposed energy management algorithm to implement the secondary level of occupancy control and this is key player contributing to the adjustable energy from each building that take part in the transactive demand response events.

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

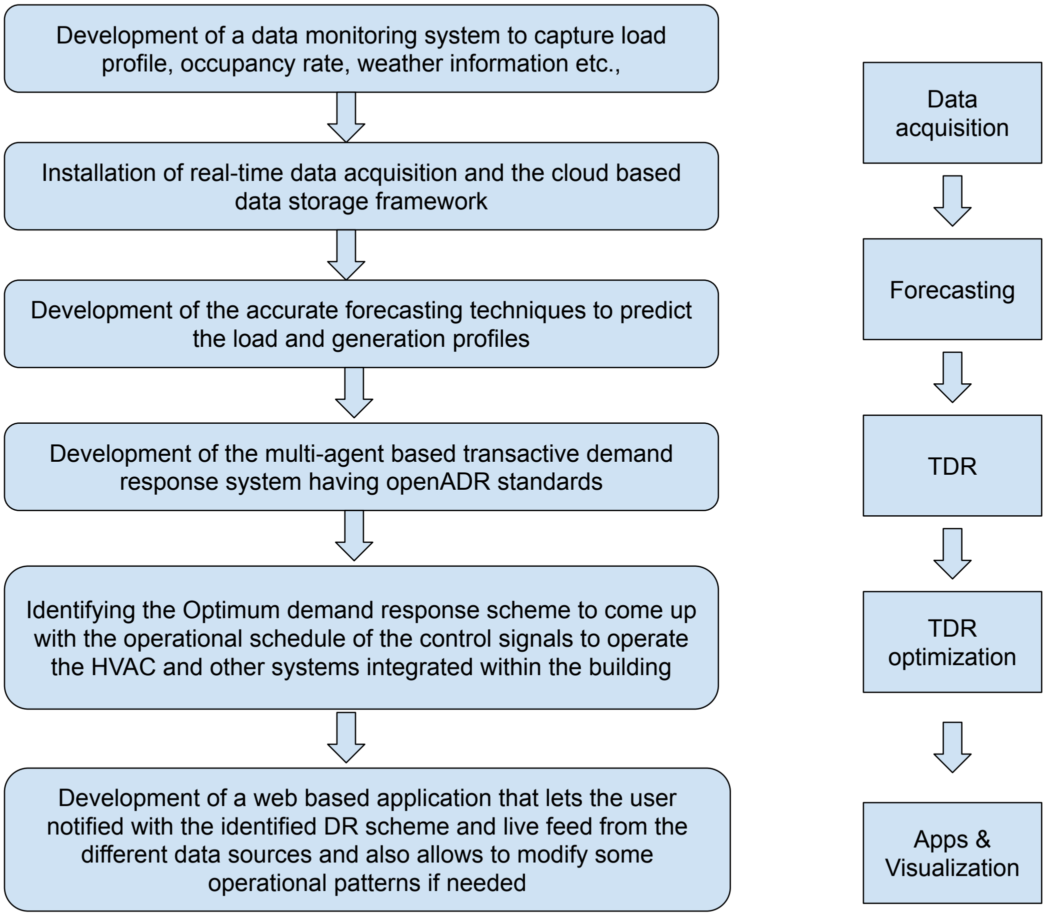


Figure 10: Operational flow chart of the proposed OpenTDR framework

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

A more detailed insight on the proposed solutions for each data point is explained in the section below and the identified locations with respect the floor plans can be found in respective figures 12,13, 14, 15, and 16. As indicated in the above-mentioned figures, the different type of sensor module is installed in the following locations. It is worth mentioning that each building consists of a local sever commonly called as a VEN and it is talking to a VTN that is the Community Microgrid energy management system. The identified locations in two commercial buildings situated at Swinburne, Hawthorn campus (ATC101, ATC103, ATC206, AMDC355, AMDC301, AMDC303, and AMDC451)

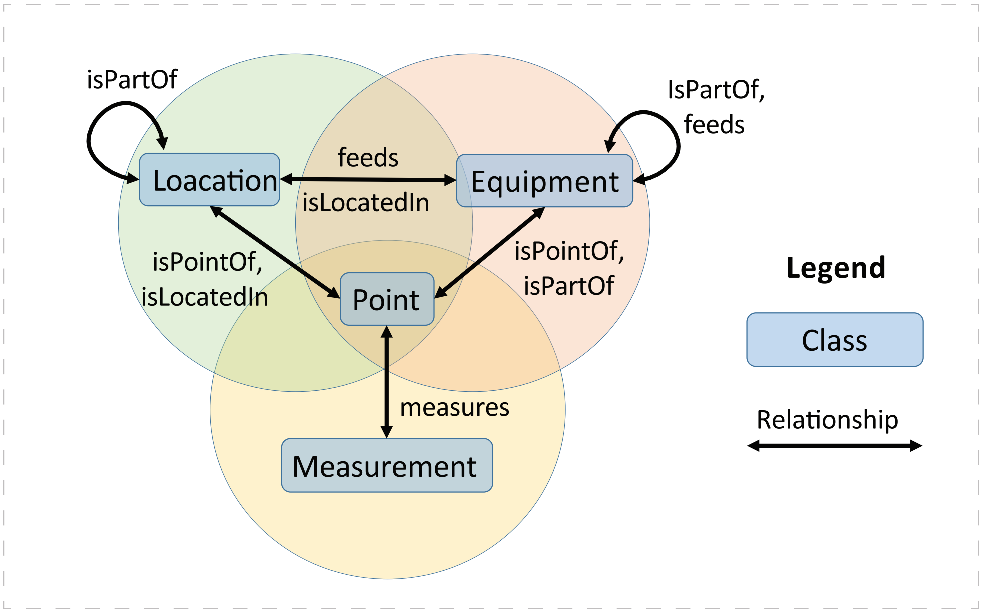


Figure 11: Brick Schema overview

were unique regarding the dynamic occupancy rates. The identified locations mainly consisted of large lecture theatres and private study areas. Although the use of the lecture theatres was based on booking system, the number of occupants utilising the spaces was dynamic because one of this lecture theatres was also used as an exhibition space for public activities. In contrast to these lecture theatres, the utilisation of the private study areas has been complete stochastic and determining the number of occupants in the area was a challenging task. This dynamic nature of the occupancy had a greater influence in encouraging the researchers to work on identifying the relationship of the HVAC set points/ usage and the occupancy.

4.1 Occupancy Data

The occupancy data was initially planned to be installed using the already installed IP cameras, but due to the risk of privacy breach, an alternate solution was sought out. Therefore, a custom TOF Camera based solution was developed in house by the researchers in Swinburne University of Technology. Usage of thermal camera imaging to process the occupancy was an alternate option considered by the researchers, but this solution was ruled out due to the financial limitations. But the use of the thermal camera-based solution for detecting the occupancy would have brought in a new spectrum of thermal comfort assessment which could be a future consideration in this project.

The occupancy monitoring solution developed using Terabee3D TOF camera consisted of a raspberry pi that reads the depth steam obtained from the entry points of the rooms and process 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 shown above are in progress. The algorithm to identify the number of occupants entering and existing the area is developed and testing of this algorithm is in progress. The Terabee3D TOF camera-based solution

Figure 12: Level-3 floor plan with added sensor modules

Figure 13: Level-4 floor plan with added sensor modules

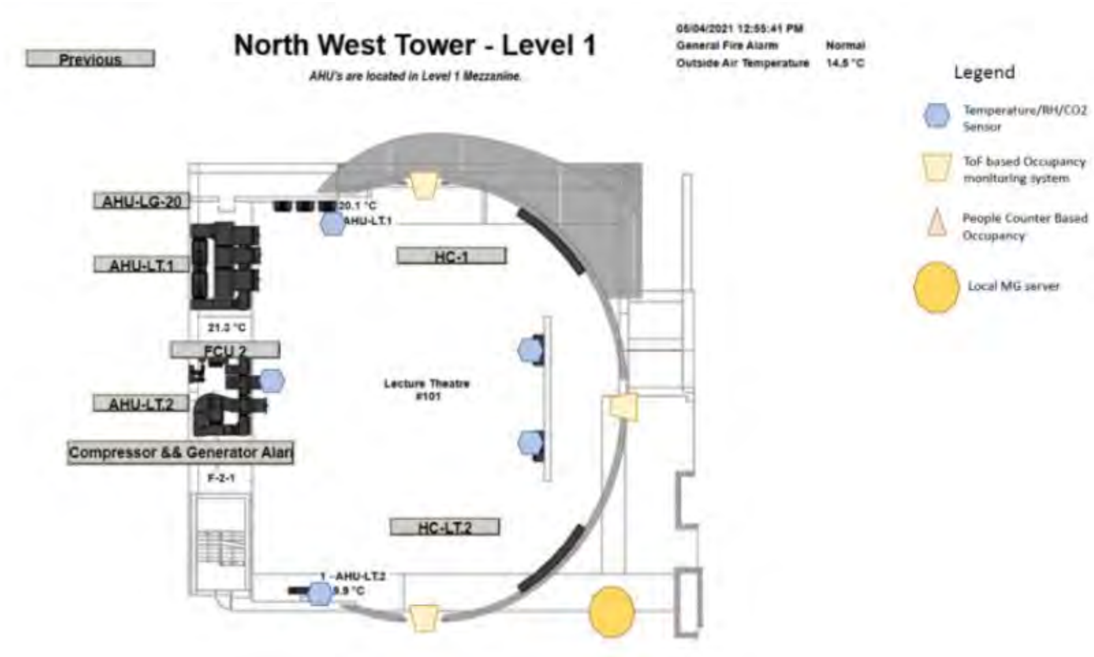


Figure 14: North West Tower Level-1 floor plan with added sensor modules

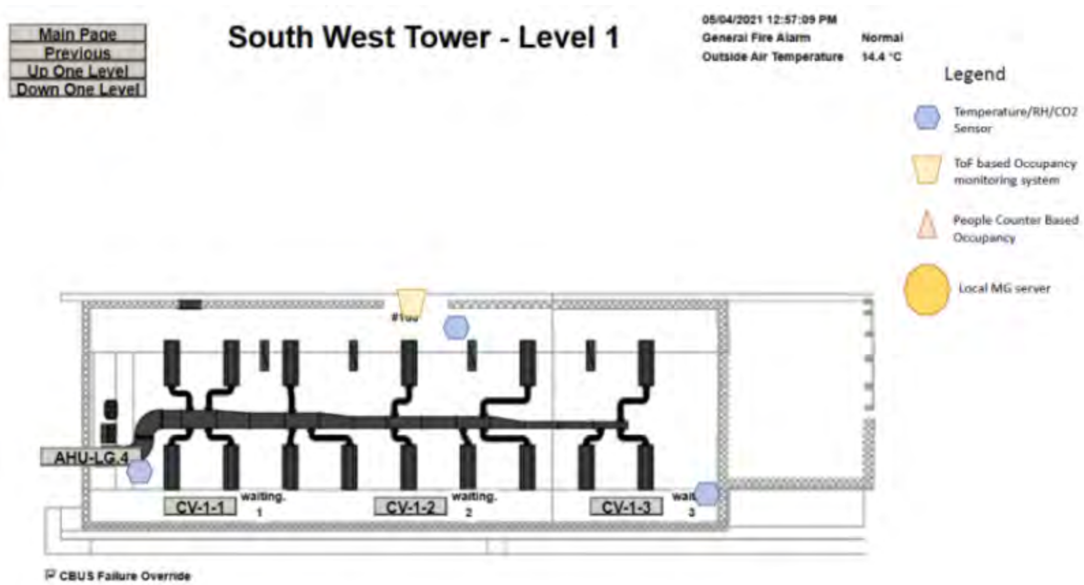


Figure 15: South West Tower Level-1 floor plan with added sensor modules

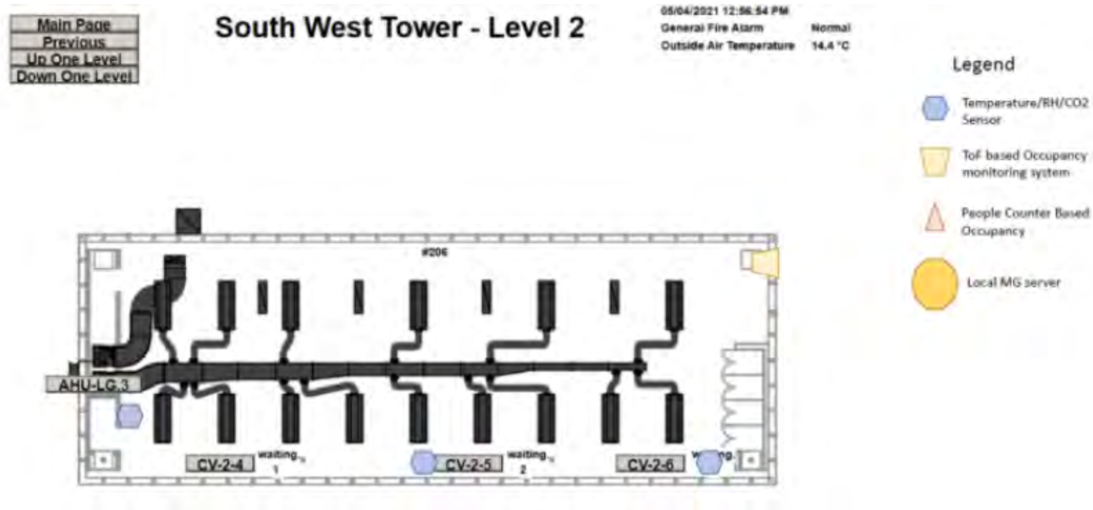


Figure 16: South West Tower Level-1 floor plan with added sensor modules

was fabricated with a custom casing and the finally fabricated solution is shown in the Fig. 17.

4.2 Zone wise CO2 /Relative-Humidity/ Temperature Data

The other important aspect of the newly added data points into the semantic model is that it will 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 available adjustable load and these sensor modules are very essential to determine this value. The Sensor consists of a ESP32 board and a SCD30 sensor module which is fit in the custom casing illustrated in the Fig. 18. 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 in relevance to the local MG and send it to the central Community or OpenTDR agent.

4.3 External Weather Data

In order to get a more realistic external weather data and implement weather-based HVAC set point controls, a ECOWITT HP25110 weather station in the roof of ATC South West wing is installed 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 in the roof top of ATC building. The different weather parameters that could be extracted from the weather station are indicated in the dashboard shown in Fig. 19 and a weekly plot of the data is shown in the Fig. 20.

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

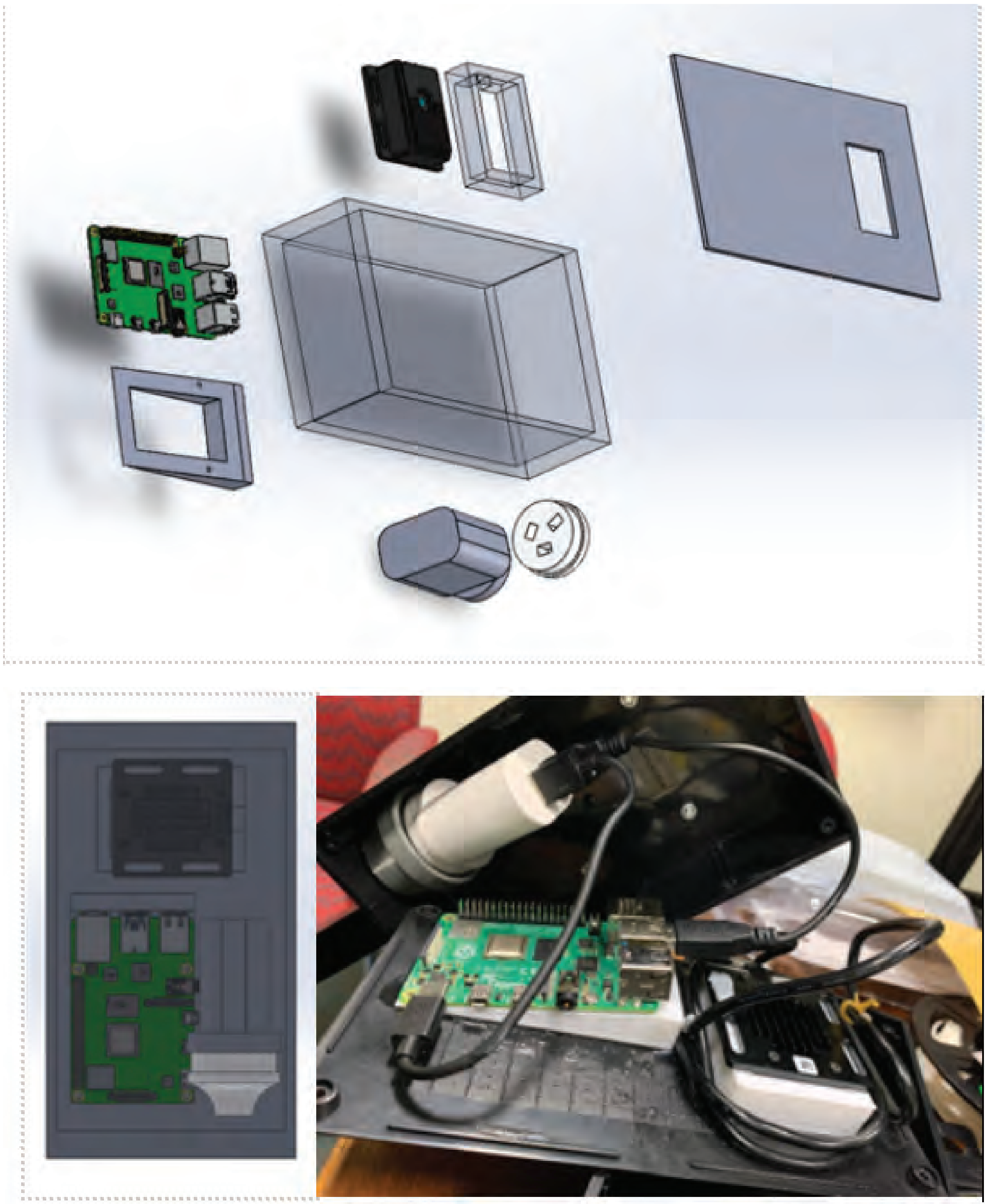


Figure 17: Custom ToF based Occupancy monitoring system developed in house by researchers from Swinburne

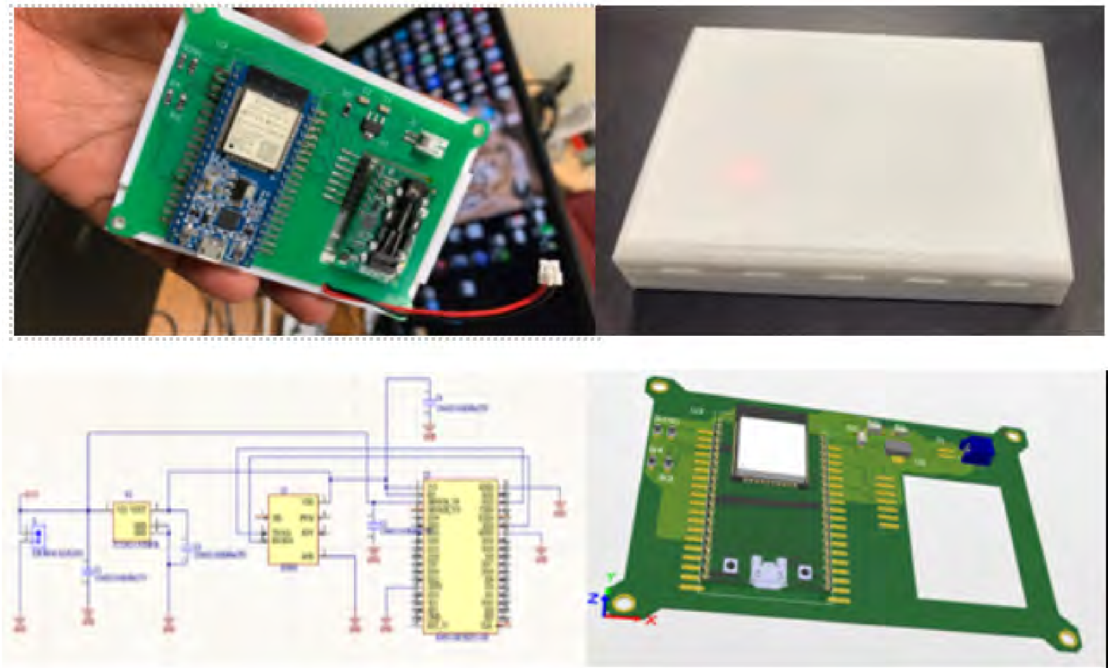


Figure 18: Custom Zone wise CO2/RH/Temp sensor module developed in house by researchers from Swinburne

4.4 BMS Data

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 historic data and send it to the DCH Senaps.io platform. In addition, a BACnet sniffer is also developed in house to extract the BMS data in real time. The BMS system consists of a weather station and many other monitoring devices that are accessed via a BACnet sniffer. A sample copy of the data extracted from this tool covering the radiations and the energy consumption of a particular meter point indicating the energy consumption of the buildings for the entire year 2019 is shown in the Fig. 21.

Data used in Fig. 22 are one of the sample copies of the different data sets which could be extracted from the BMS system. It can facilitate real time data communication providing access to the BACnet points in the network and also help in setting up the HVAC control signals to the BMS system.

4.5 Inverter/Battery Data

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 the 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 be correlate with the actual energy consumption and simulate the behaviour of transactive demand response and also observe the impact of the TDR more in

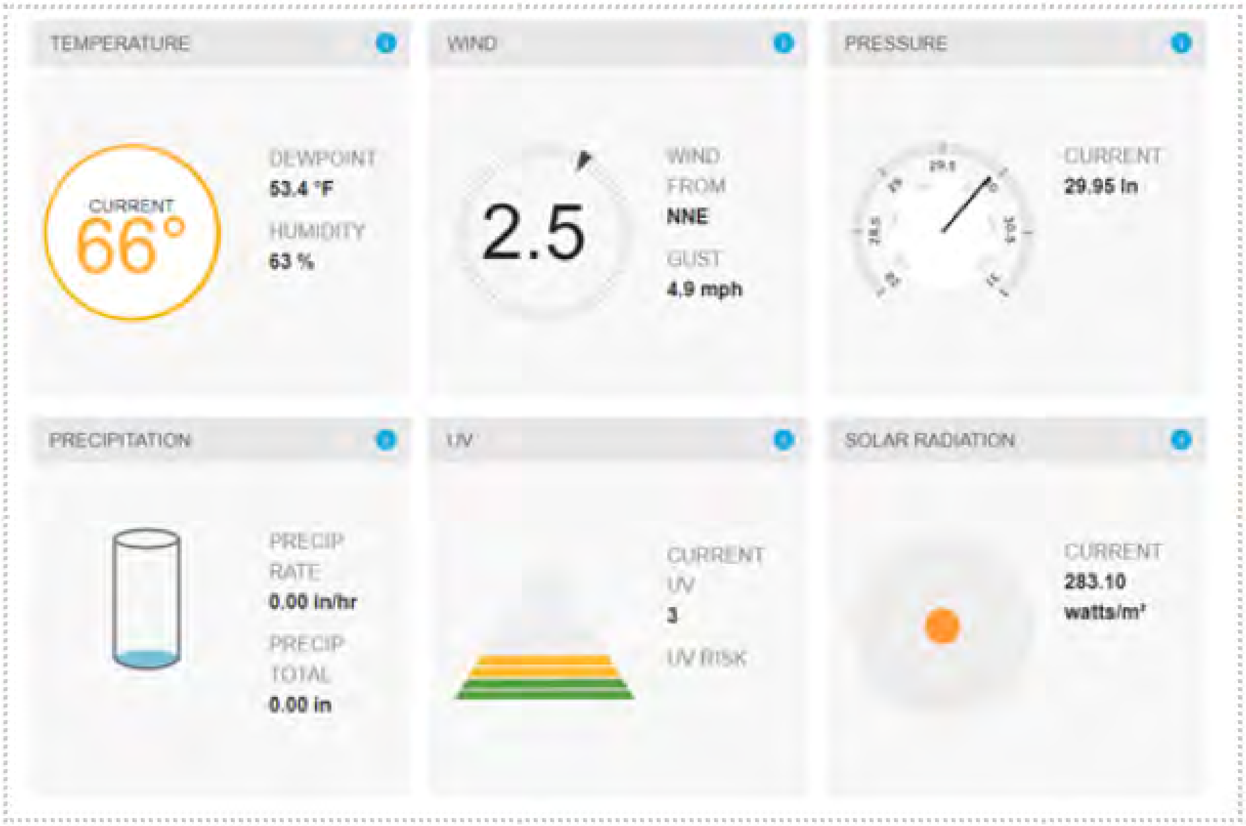


Figure 19: Dashboard of the different data points extracted from the weather station server

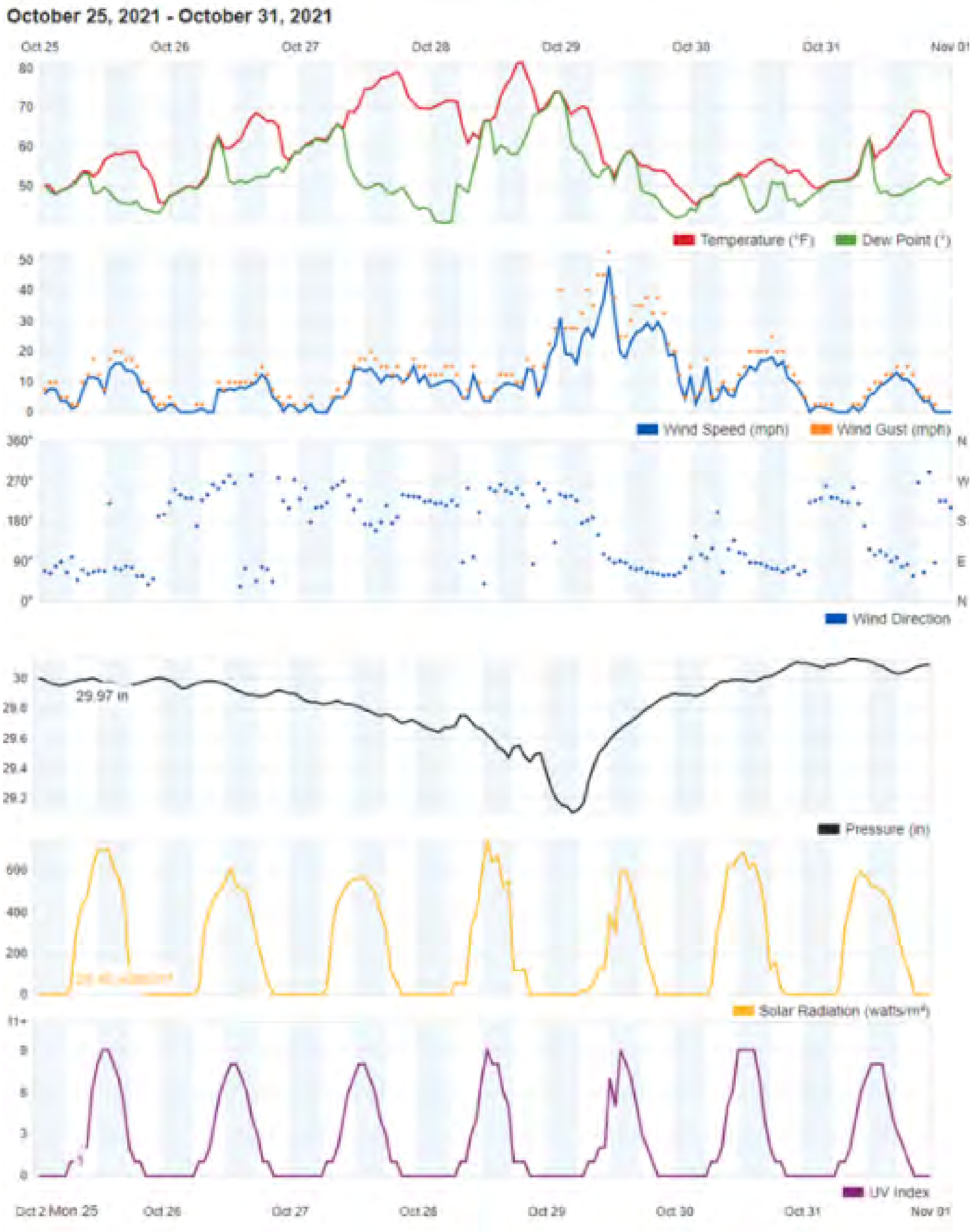


Figure 20: Sample data of a week extracted from the weather underground server

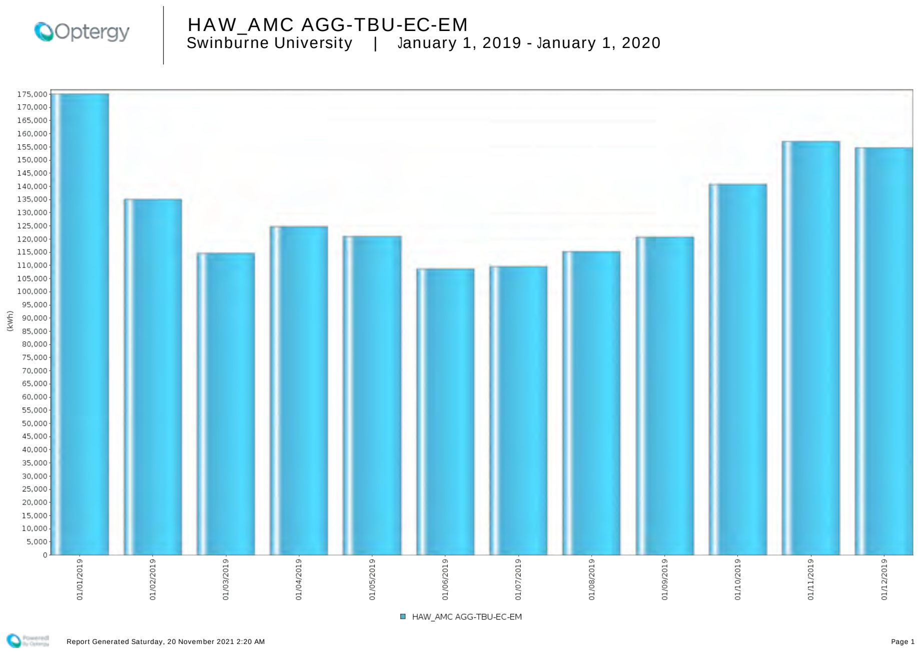


Figure 21: Sample data of AMDC energy consumption for 2019

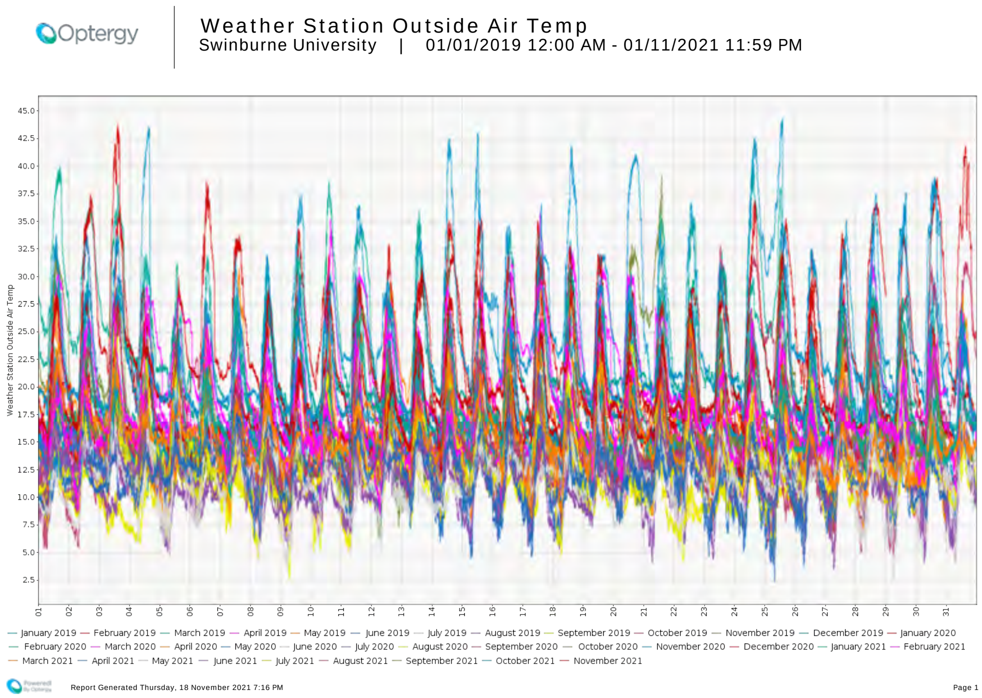


Figure 22: Monthly distribution of the Air temperature across 2019 extracted from the BMS

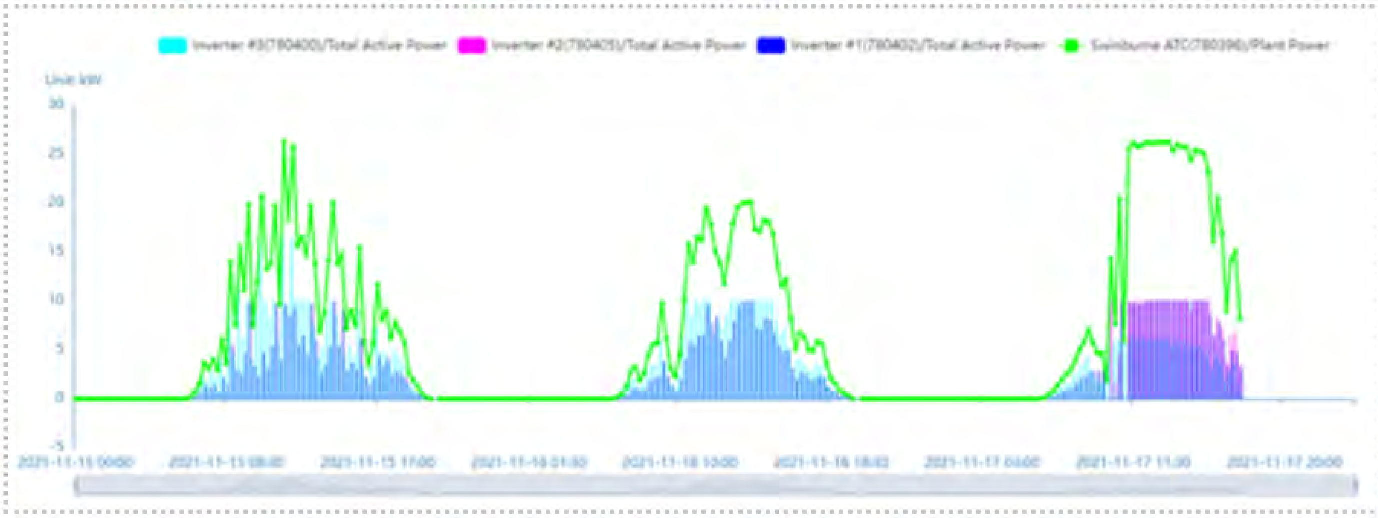


Figure 23: Sample Data extracted using the iSolarCloud APIs

detail. Fig. 23 indicates a sample copy of the data obtained from the iSolarCloud APIs and all this information will be first extracted by the Local energy management system and them formulated using a JSON schema and the data would be sent to the OTDR_M agent.

A detailed overview of the different agents and the hierarchical multi-agent based OpenTDR framework is given in the upcoming sections of the report.

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 level of hierarchy consisting of the sensor level agents as the baseline of the hierarchy and this level consist of different sensor node which include the energy meters, BMS data points (thermostat for each room, and 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. The low-level sensor nodes are linked to the smart high-level sensor agents inside the sensor level agent. In this study, high-level sensor agents are divided into three types:

BMS Gateway agent: The BMS Gateway agent is responsible for reading all the data points from the low-level sensor nodes that is part of the BMS system installed in the building locations. 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. This agent's major goal is to keep the local energy management agent informed of the present condition and help them determine the adjustable load based on temperature feedback and

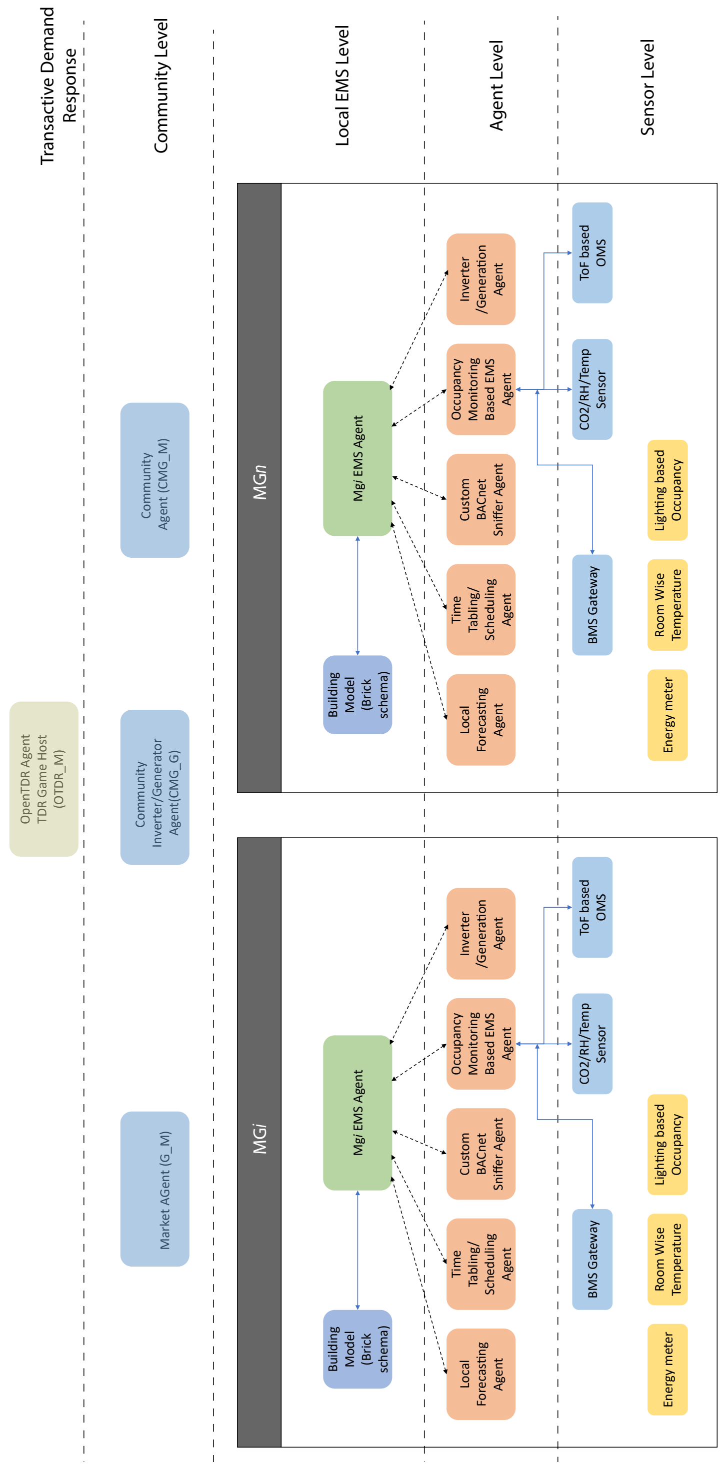


Figure 24: Hierarchical Multi-level multi-agent based OpenTDR Framework

air quality. The CO2/RH/Temp sensor is a custom-built sensor module containing a 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 used to count the number of people in a room or floor. The Terabee 3D ToF camera feeds the OMS agent's input. The sensor location and setup information is included in the data collection section. The Agent must analyse 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 historical database encrypted inside the local CMG servers. The local server reads the sensor's historical data, and prebuilt forecasting algorithms are trained and stored for usage at this agent level. (Once every 3 months) The stored model is utilised with real-time data to forecast the future timestamp. The anticipated values are then sent to the Local energy management system through a MQTT channel, where the EMS modifies the pre-determined market price and the other entities' potential generating capacities.

As highlighted in the previous 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 this milestone the baseline models like SVR model is developed and tested with the real data extracted from the BMS system. The following image indicates the performance of the SVR algorithm for prediction of external outside irradiation (W/m2) extracted from the BMS database. From the Fig. 25 it can be seen that the forecasted value well matched with the original data from the BMS. The RMSE of this prediction interval is around 98.15 (W/m2).

Timetabling/ Scheduling Agent: The Timetabling or scheduling agent is the preliminary or the first stage of the proposed energy management algorithm 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 was obtain 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 follows:

For this implementation for evaluating the control algorithm using the timetabling or scheduling

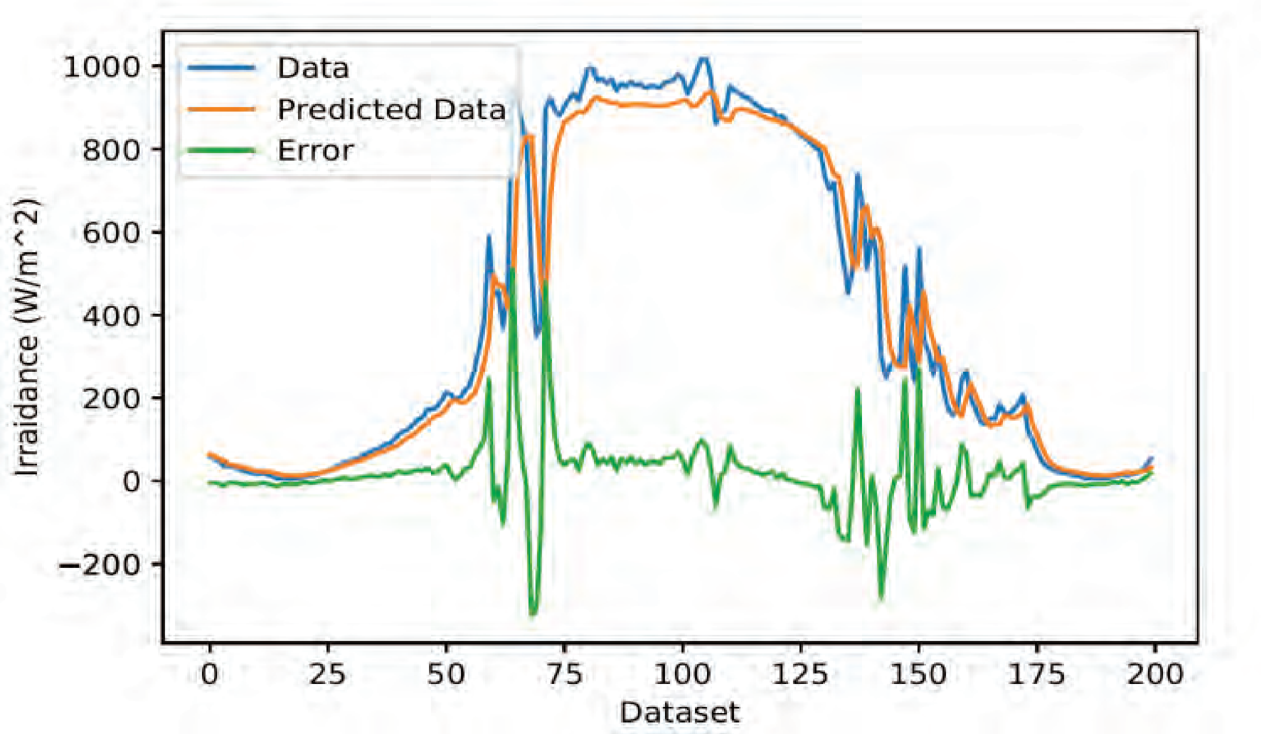


Figure 25: Forecasting evaluation of the SVR model. Blue line represent data from BMS and the orange line is its forecast.

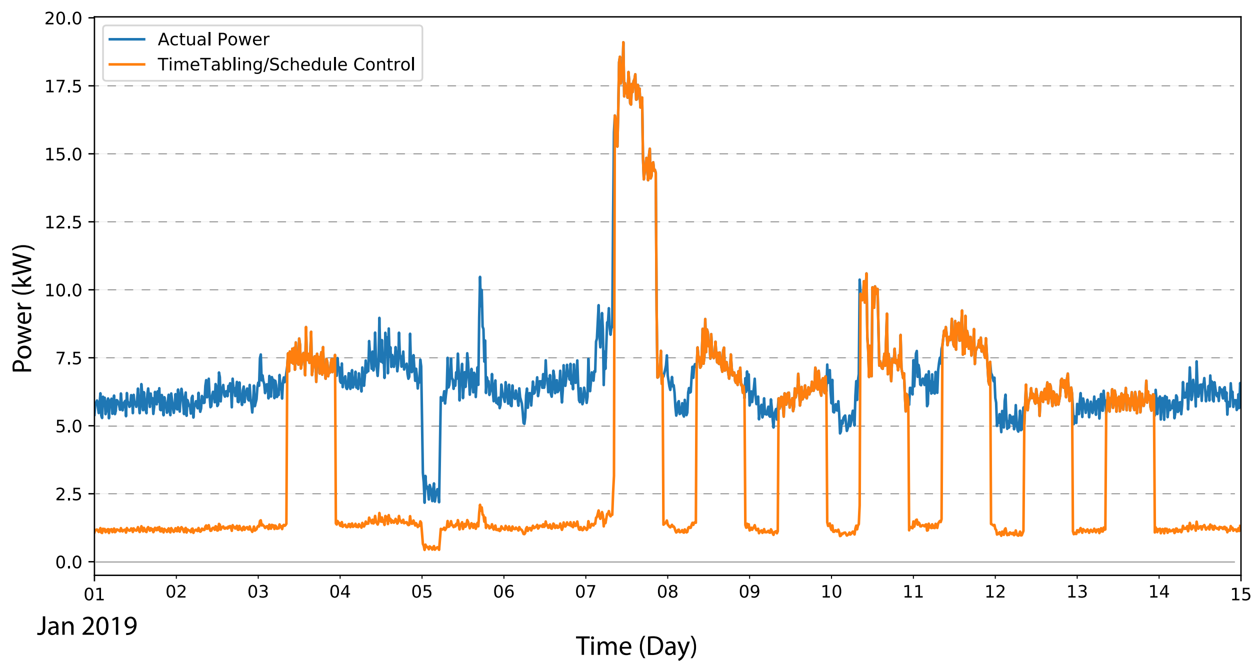


Figure 26: Timetabling/ Scheduling based control.

agent, the power consumed by one of the smart meters and used it with a schedule of a ROOM was considered.

In this analysis, the energy data and the timetabling data was not considered from the same location because of the limitation we have on the measurement devices and a 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 the with this sort of a control a possible 50% of energy reduction will happen in specific regions like the lecture theaters etc that are considered as a 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 will be used establish a connection to the BMS gateway agent and to send control signals to the HVAC system regarding the set points, VSD speeds, and value position. In general, the BMS gateway agent acts as an interface to the BMS system network, and it will provide a bridge to the local network within the microgrid and the Network corresponding to the BMS. The BMS systems are in general maintained in 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 it will be connected to the separate local network corresponding to the buildings which 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 by following the OpenADR standards and then send the information 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 doesn't have the lighting module synchronised control were initially identified and the primary Occupancy monitoring based EMS is implemented and this also falls under the first stage of Local energy management that happens in at 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 implement the control of the HVAC systems based on the feedback obtained from the Lighting CBUS interface. The second operation of the occupancy-based EMS is the critical component of the proposed Transactive demand response as this looks into the occupancy data of the identified zones with random occupancy rate and reduces the operation of the HVAC load whenever there is 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 about the available generation capacity and the state of the charge and the lets the local energy management agent informed about the available capacity and this information will then be used by the forecasting agent in conjunction to predict the capacity of the next time step. Also, this agent will used as the interface to control the flow of energy sharing simulation along with the local energy management agent which will run in a NI CRiO.

The third level of hierarchy that exist 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 of the surplus and shortage energy. The agent will be a player in the auction and then based on the biding he/she proposes, the OpenTDR agent that runs the Energy market game will determine the proposed deal and ask for the approval of the local EMS agent and once it is approved it will be implemented by collaborating with the low-level agent and then it will keep the OpenTDR agent informed on successful completion of the TDR event in the Microgrid/building.

Above the local EMS agent comes the market agent, community generation agent (this agent is like the Generator/inverter agent) and finally the community MG_market agent. The Market agents' roles and responsibility 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 will be replaced by the dynamic costing or TOU costing model and these scenarios will be 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 constrains 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 will assist in the estimation of the price the energy sold within the community.

Followed by which the OpenTDR agent will be the final and topmost level in the hierarchy of the agents, and this will orchestrate the game and it will receive the information's from the agents like the market agent, CMG_market agent and the Local EMS agent for determining the optimal condition of the energy sharing that will yield profit to the community. For now, the benefit for community is considered as the prime focus of the OTDR_M agent but in the upcoming milestone the implementation on the competitive nature of the agents participating in the auction targeting towards their personal benefit will be explored.

6 Game theoretic EMS algorithm

The figure 27 represents the flow chart of the proposed game theoretic algorithm, and it mainly comprises of 3 stage energy management and the first one mainly includes the Timetabling/Scheduling agent and Primary occupancy Monitoring based control algorithm based on the lighting feedback. Once this preliminary EMS is completed, the agents communicate across each other with the available price each agent would like to sell the surplus and buy the shortage at and based on the logic illustrated in the second stage of EMS indicated in the figure, the local EMS agent will determine 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 the input parameters are shared across the agents in community microgrids. And then the game starts and listens to the bids raised by every agent and the determines the most optimal solution and try to

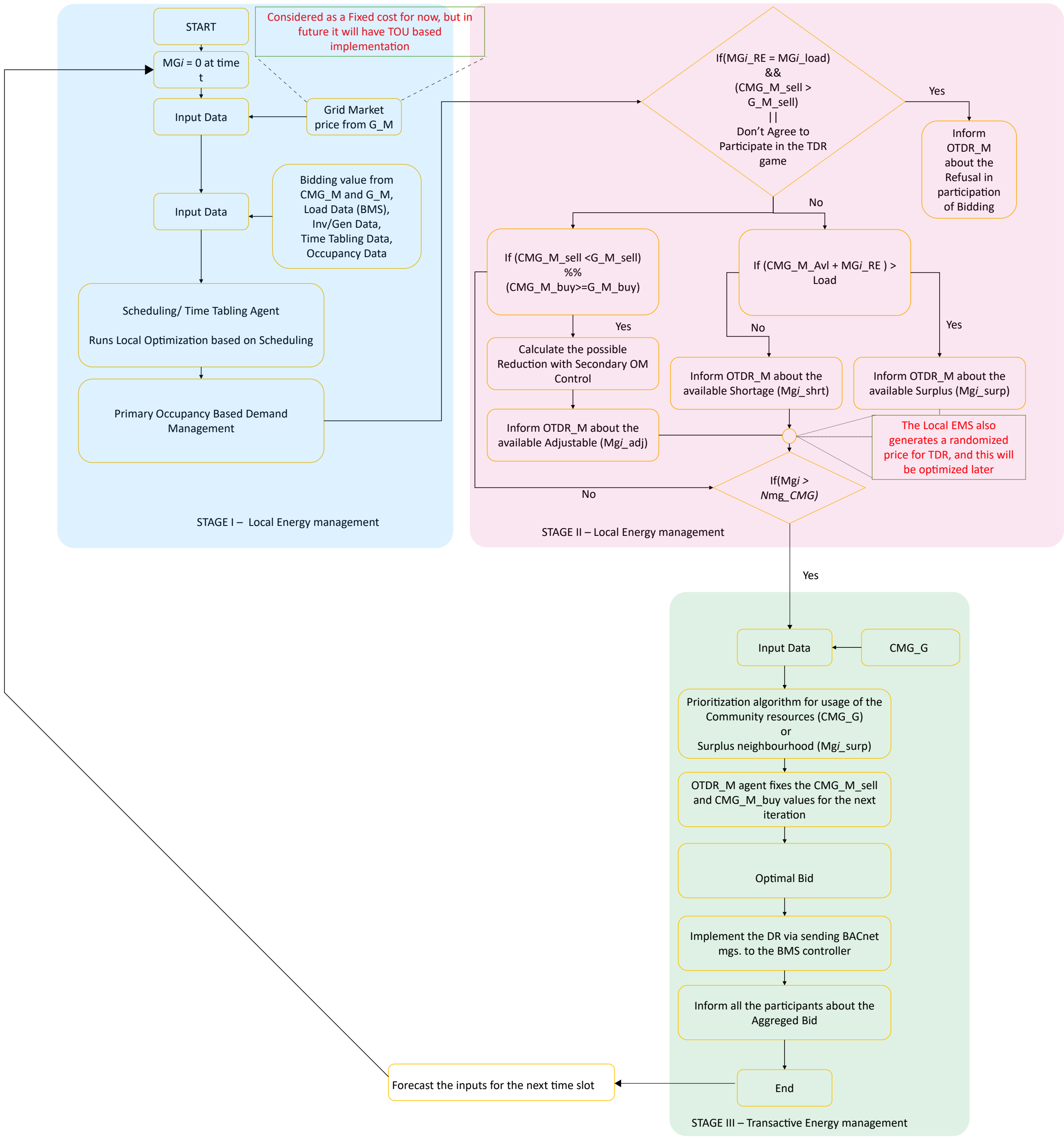


Figure 27: Flow chart of the proposed algorithm

reach Nash equilibrium. The interactions happening during this phase is clearly explained in the 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. (For the simulation highlighted below this is assumed to be constant and this will be updated in the coming milestone). Following that the OTDR_M agent call for a bid or proposal from all the agents and the once the Local Microgrid agent receive this request then broadcast 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.

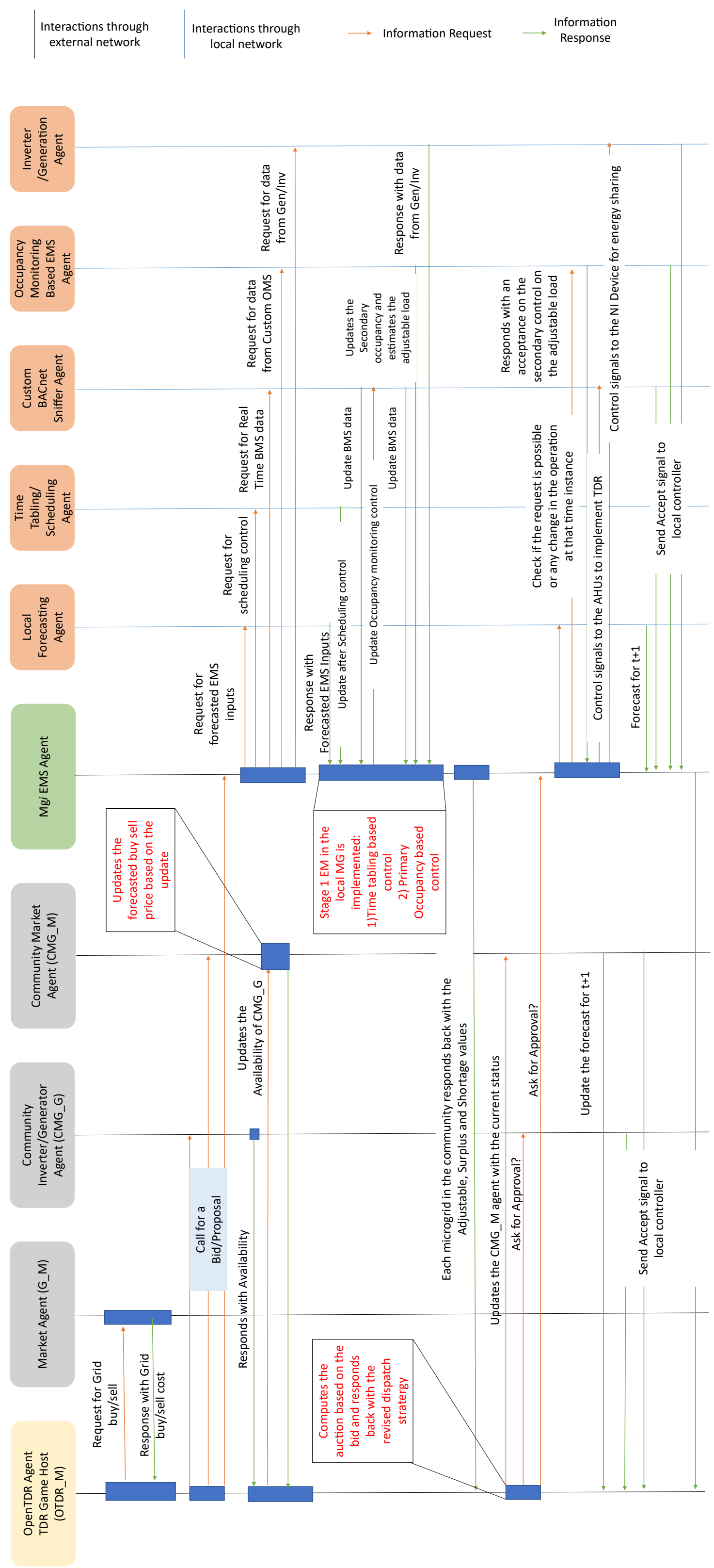


Figure 28: Interactions within agents when the OpenTDR EMS algorithm works

7 Simulation studies of the proposed algorithms

The OpenTDR framework consists of three modes of operation, which allows the user to model, simulate/emulate and to experimentally implement the OpenTDR energy management algorithm. To simulate the behaviour of transactive demand response, initially, it is required to model the Community microgrid with energy sharing capabilities. Two approaches are commonly used for generating the load profile data used in the simulation of the OpenTDR energy management algorithms. The OpenTDR framework will be incorporated with a mathematical modelling tool which will receive the information from the user about the configuration of the microgrid and calculate the output of each individual component in the microgrid. The output from the modelling 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 on-site generated energy though seamless synchronising of the demand response and load scheduling events in relation to the generation profile of the microgrid. 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 that prioritise on the use of onsite generation and battery before sharing the energy with the other MG in the in the community in the output figures indicated below. The forecasting algorithms developed will be later used as a part of the energy management system to further optimise the performance of the energy 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.

Figures 29 (a) and Figure 29 (b) represent the optimized generation/demand profile of two individual microgrids simulated with the baseline energy management algorithm. The inputs given the energy management system are generated using the mathematical modelling tool. The transactive energy sharing between the two microgrids were considered in the result expressed in Figure 29 (c).

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

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

Scenario 2: In this scenario the prioritization of sharing the energy within the community was considered and the Community feed in 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 maximise 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 the upcoming milestone the experimental verification of this algorithm will be tested, and the simulation will also be fine-tuned to have an accurate load data simulated.

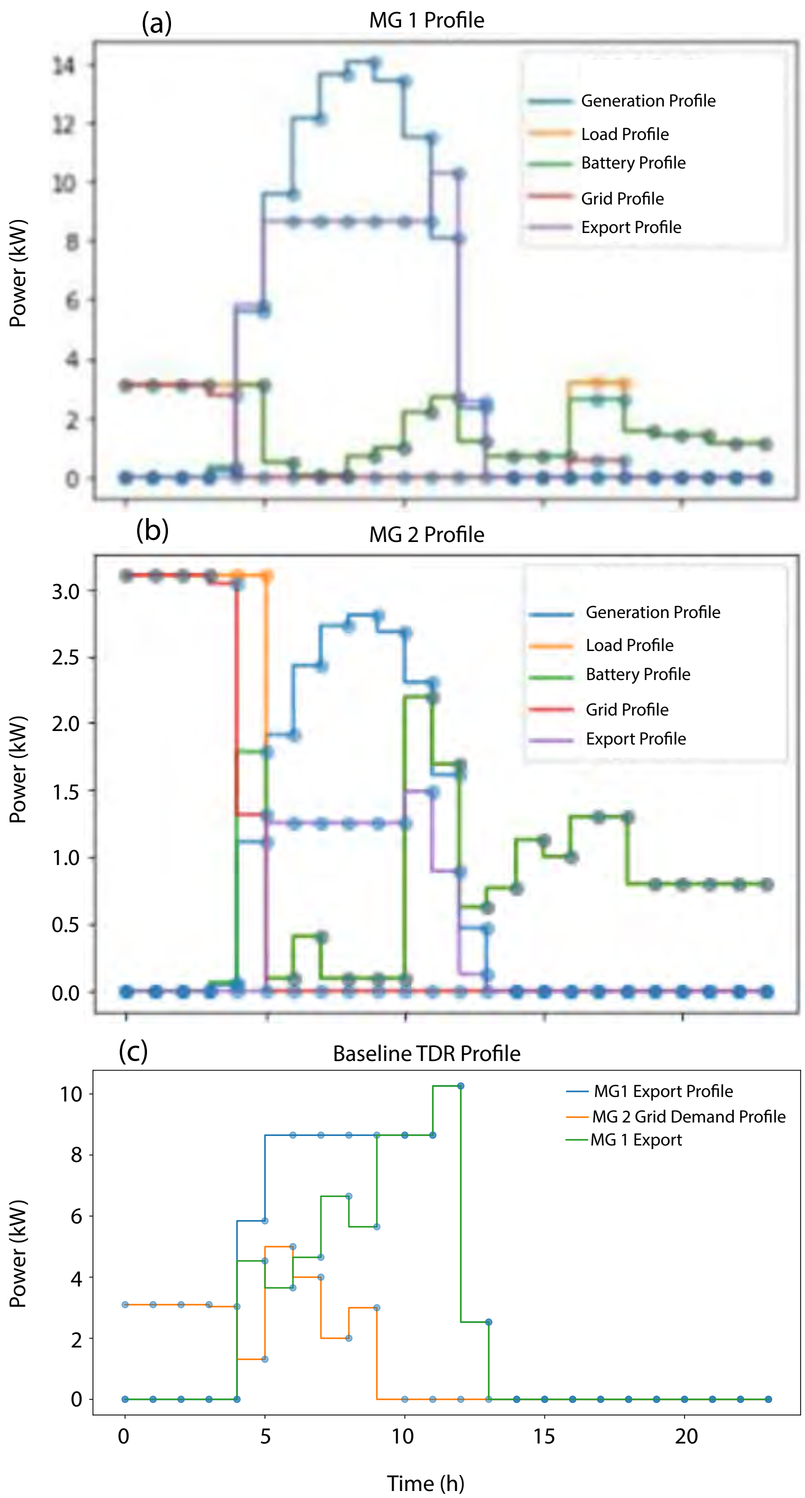


Figure 29: Microgrid profiles and the results of the baseline TDR

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

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	

8 DCH Data ingestion

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 platform is tested and the mass data ingestion is in progress.

```
#### Code snipet for sending MQTT data to the DCH platform tested ####
#import required files
import paho.mqtt.client as mqtt
import ssl
import certifi
import json
import time
#declare parameters
broker = Hostname                    #"senaps.io"
port = PortNumber                    #8883
```

```
topic = "HostName/Location/Building/generic/Datastream"
#example "dch/SwinburneCampus/ATC/generic/test-ds"
username = username
#"dsapi-subsequent-lamentable-sky:Email:address"
password = "*********"
#Create client
client = mqtt.Client("client_name0")
#swinburne-test-client
#add ssl security certification for data encryption
client.tls_set(certifi.where(), tls_version=ssl.PROTOCOL_TLSv1_2)
client.tls_insecure_set(True)
client.username_pw_set(username, password)
#establish connection
client.connect(broker, port, 60)
client.loop_start()
time.sleep(2)
#define the payload msg or the data to be sent
#for now the data format used is following the DCH building JSON schema,
this will be replaces by the schema following the OpenADR
standards in the upcoming milestones.
payload_msg = {
"$schema": "http://csiro.au/dch/bms-json/schema-draft-06.json",
"point":

     {
    "pointName": "pointB",
    "currentValue": 2,
    "parentName": "parentA"
    }
}
# For each point and parent name a corresponding datastream is created.
#send the data to the DCH host
pub_result =
     client.publish(topic, json.dumps(payload_msg), qos=1, retain=False)
print(f'Data sent {pub_result}')
client.loop_stop()
```

An overview of the DCH integration is explained in the Fig. 30. The implementation of the bulk and realtime DCH data integration will be done in the next milestone and the proposed OpenTDR framework and the algorithm will be tested and evaluated.

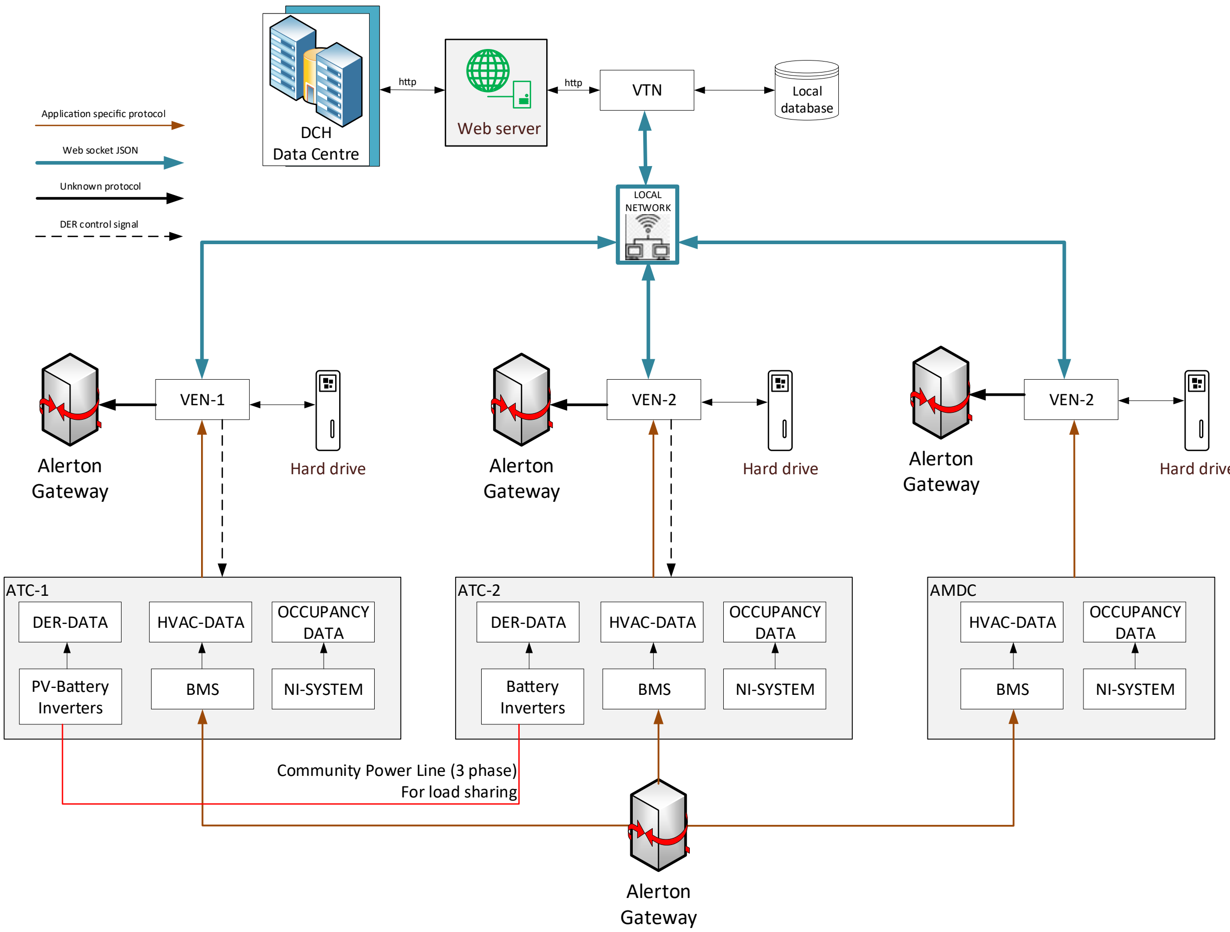


Figure 30: High level system architecture (Data communication and Control)

Table 3: Progress on the project deliverable to date

Deliverable	Progress status
Baseline data gathering, data cleaning, preparation for model implementation	80%
Implement generation and consumption forecasting models	90%
Customisation of TDR model to the project use case	70%
Design of the occupancy monitoring systems	100%
TDR model evaluation for various generation and consumption scenarios	80%
Design of the local weather monitoring station.	100%
Implement HVAC DR using TDR model	60%
Development of the forecasting techniques using external data sets.	100%
Design and development of the openTDR emulator prototype.	95%
Initial design of the semantic building models.	75%
Performance Evaluation and Verification	40%

9 Conclusion

Despite the impact of COVID-19, the project has made significant progress during the Second milestone period (M6). 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.

Table 3 summarises the project's 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 future milestones. The NI devices will be delivered by the first week of December and the installation of the sensor modules completed by the Start of December. Therefore, a fully operational DCH integration from the Swinburne is prjected to finish by mid-January. Following that, the data collected will be used to fine-tune the foretasting models in the project's next phase. Some of the results observed during the second phase of the project will be targeted to be published by the end of this year. According to the technical analysis and modelling conducted by the team at Swinburne University of Technology and other project members, while there are some technical challenges identified in the first and second milestone, 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 at this stage. Additionally, KIG, GHGP, Bramec, CSIRO and Swinburne believe that the technical issues encountered are within the realm of what is considered 'typical' for such infrastructure projects.

10 Appendix

10.1 Appendix: A

General parameters

Grid-Connected System | **Tables on a building**

PV Field Orientation

Orientation		**Sheds configuration**		**Models used**	
Fixed plane		Nb. of sheds	8 units	Transposition	Perez
Tilt/Azimuth	15 / -8 °	**Sizes**		Diffuse	Perez, Meteonorm
		Sheds spacing	3.41 m	Circumsolar	separate
		Collector width	2.00 m		
		Ground Cov. Ratio (GCR)	58.6 %		
		Shading limit angle			
		Limit profile angle	19.3 °		

Horizon	**Near Shadings**	**User's needs**
Free Horizon	Linear shadings	Unlimited load (grid)

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Trina Solar	Manufacturer	Sungrow
Model	TSM-DE14H-(II)-390	Model	SG10KTL
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	390 Wp	Unit Nom. Power	10.00 kWac
Number of PV modules	84 units	Number of inverters	3 units
Nominal (STC)	32.8 kWp	Total power	30.0 kWac

Array #1 - PV Array

Number of PV modules	18 units	Number of inverters	1 Unit
Nominal (STC)	7.02 kWp	Total power	10.0 kWac
Modules	1 String x 18 In series		
At operating cond. (50°C)		Operating voltage	250-800 V
Pmpp	6.39 kWp	Pnom ratio (DC:AC)	0.70
U mpp	666 V		
I mpp	9.6 A		

Array #2 - Sub-array #2

Number of PV modules	32 units	Number of inverters	1 Unit
Nominal (STC)	12.48 kWp	Total power	10.0 kWac
Modules	2 Strings x 16 In series		
At operating cond. (50°C)		Operating voltage	250-800 V
Pmpp	11.35 kWp	Pnom ratio (DC:AC)	1.25
U mpp	592 V		
I mpp	19 A		

Array #3 - Sub-array #3

Number of PV modules	16 units	Number of inverters	1 * MPPT 50% 0.5 units
Nominal (STC)	6.24 kWp	Total power	5.0 kWac
Modules	1 String x 16 In series		
At operating cond. (50°C)		Operating voltage	250-800 V
Pmpp	5.68 kWp	Pnom ratio (DC:AC)	1.25
U mpp	592 V		
I mpp	9.6 A		

PV Array Characteristics

Array #4 - Sub-array #4

Number of PV modules	18 units	Number of inverters	1 * MPPT 50% 0.5 units
Nominal (STC)	7.02 kWp	Total power	5.0 kWac
Modules	1 String x 18 In series		
At operating cond. (50°C)		Operating voltage	250-800 V
Pmpp	6.39 kWp	Pnom ratio (DC:AC)	1.40
U mpp	666 V		
I mpp	9.6 A		

Total PV power		**Total inverter power**	
Nominal (STC)	33 kWp	Total power	30 kWac
Total	84 modules	Nb. of inverters	3 units
Module area	167 m²	Pnom ratio	1.09
Cell area	146 m²		

Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

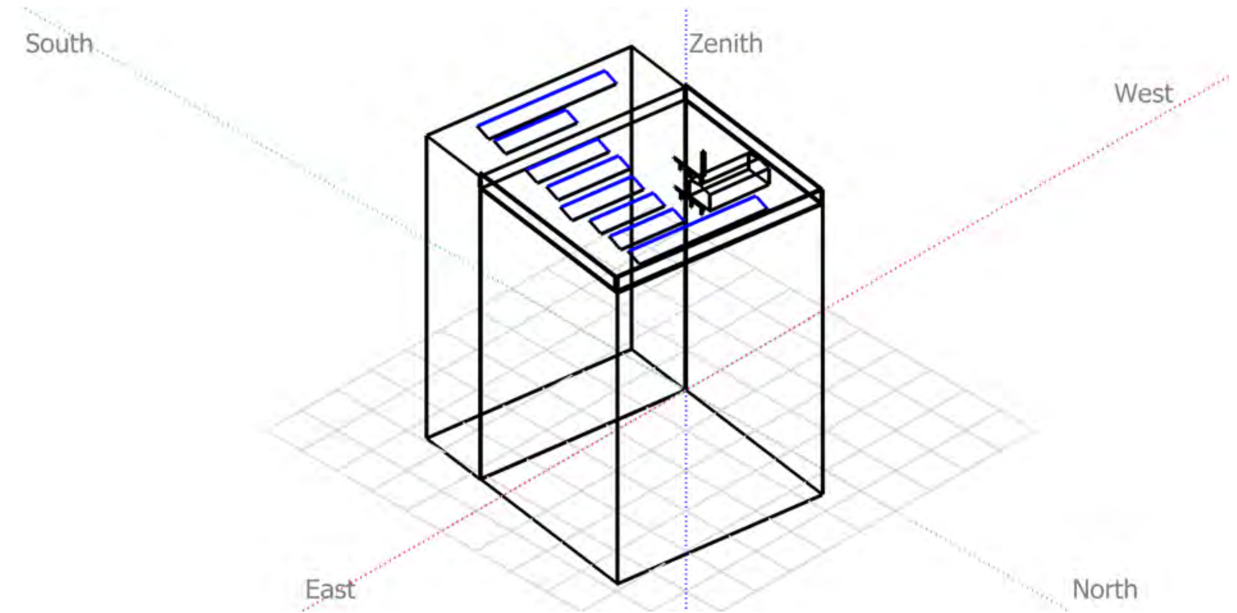
DC wiring losses

Global wiring resistance 10 mΩ
Loss Fraction 1.5 % at STC

Array #1 - PV Array		**Array #2 - Sub-array #2**	
Global array res.	1158 mΩ	Global array res.	515 mΩ
Loss Fraction	1.5 % at STC	Loss Fraction	1.5 % at STC
Array #3 - Sub-array #3		**Array #4 - Sub-array #4**	
Global array res.	1029 mΩ	Global array res.	1158 mΩ
Loss Fraction	1.5 % at STC	Loss Fraction	1.5 % at STC

Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram