Optimal Strategies for Occupant Satisfaction in Microgrid Environment

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Utsav Sharma
218528291
COURSE - Bachelors of Software Engineering Honours(S464)

Supervised by: Dr. Alessio Bonti, Prof, Mohamed Abdelrazek

Abstract

Electricity is the future energy and we need to conserve this energy for the future. A Microgrid is a vital technology, which has been able to achieve large scale application of distributed energy generation. This paper investigates on how a Microgrid Environment can operate a University classroom and keep its occupants satisfied. Among the statistical models, we have used regression analysis as its shown reasonable accuracy and has a relatively simple implementation. Research has shown that human's tend to have their optimal thermal comfort in cooler conditions and to achieve our goal, we have taken various factors such as HVAC System, Indoor Illuminance, Number of Occupants etc., to determine the classroom's energy consumption and energy cost. The remaining factors and their correlations have been discussed in extent. We have tried to generate electricity from a sustainable source and simulated the complete system by using digital twin technique and additionally made a small microgrid environment simulation on Node Red. Our main goal is to keep the classroom's occupants satisfied by maintaining an ideal temperature in the classroom and not exceed the energy consumption and energy cost limit. The graphs and results generated in this paper were performed on hourly and daily data of a classroom. The results indicate that as the number of occupants in a room increases, the room temperature and relative humidity increases as well. The best way to decrease the temperature is by using the installed Air Conditioners, which consumes a lot of energy.

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1 Nomenclature

Table 1: Nomenclature

Node Red	Flow based development tool for visual programming
Simulation	Imitation of a real-world operation
DC	Direct current is the unidirectional flow of electric charge
AC	Alternating current periodically reverses directions and changes it's magnitude continuously
Photovoltaic cells	An electric device to convert light energy into electricity
Solar energy	Provides electrical power through Solar Panels
Wind energy	Provides mechanical power through wind turbines
Jupyter Notebook	Helps in developing open-source software, standards and services
Energy Efficiency	The portion of energy in the form of light that can be used to convert sunlight into electricity
Irradiance	It is the sunlight absorbed by solar panels with a particular area and it is measured in W/m^2
Dataset	A group of files or data associated with one part of study
Python	High level coding language for expressing operations to be performed by a system or computer
Script	Is a file that include a number of lines of code to perform operation on a machine(computer)
Load Demand	Is the consumer who will be using the energy produced

2 Introduction

With the increase of energy demand and rising global emissions of greenhouse gases, the current centralised generation system is challenged. Today's world depends on fossil fuels for energy generation which releases harmful gases on burning and polluting our environment. Moving to more sustainable ways of producing electricity involves converting Renewable Energy Sources into energy. The future electricity distribution system will be integrated, intelligent and better known as Microgrid or even a smart grid, which includes advanced digital metres, distribution automation, communication systems and distributed energy resources. The desired smart grid functionalities include self-healing, optimising asset utilisation and minimising operations and maintenance expenses.

Improving occupant behavior is one of the best strategies to reduce building energy consumption. Students spend up to one-third of their day inside classrooms and the significance of providing thermal comfort environments for learning is an evidently proven fact. Extensive studies prove that the thermal environment in the classroom has substantial effects on students' performance. Furthermore, educational buildings occupy a large portion of building stock, and are responsible for high energy consumption within a country's non-industrial energy use. Suitable design thermal environment parameters for educational buildings, assessment and monitoring of the building performance both in terms of energy and thermal comfort are essential for students to achieve satisfactory levels of comfort with minimum energy consumption. Therefore, there is an urgent need to identify the indoor thermal requirements of students. [6]

2.1 Overview

A Microgrid is a localized group of electricity sources that under normal circumstances connect to a traditional electrical grid or main grid. Microgrids are smaller versions of a centralized electricity system. They are constructed to achieve local goals of the community being served. Local goals can include reliability and carbon emission reduction. Microgrids generate energy with the help of Renewable Energy Sources (RES) such as Solar Energy, Wind Energy, Hydro Power and many more. Renewable energy has is very beneficial as it provides clean and non-pollutant energy but has a major shortcoming i.e. its intermittent nature. Microgrid has the ability to disconnect itself from the main grid and to operate in islanded mode and function autonomously. This comes in handy in multiple situations as it can function properly in power outages. [13]

Micrograms generate power, distribute, and regulate the flow of electricity on a local scale. Smart microgrids are a good way of integrating renewable resources at the community level and also let customers participate in the electricity business. Microgrids are one of the building blocks of the perfect power system. [16]

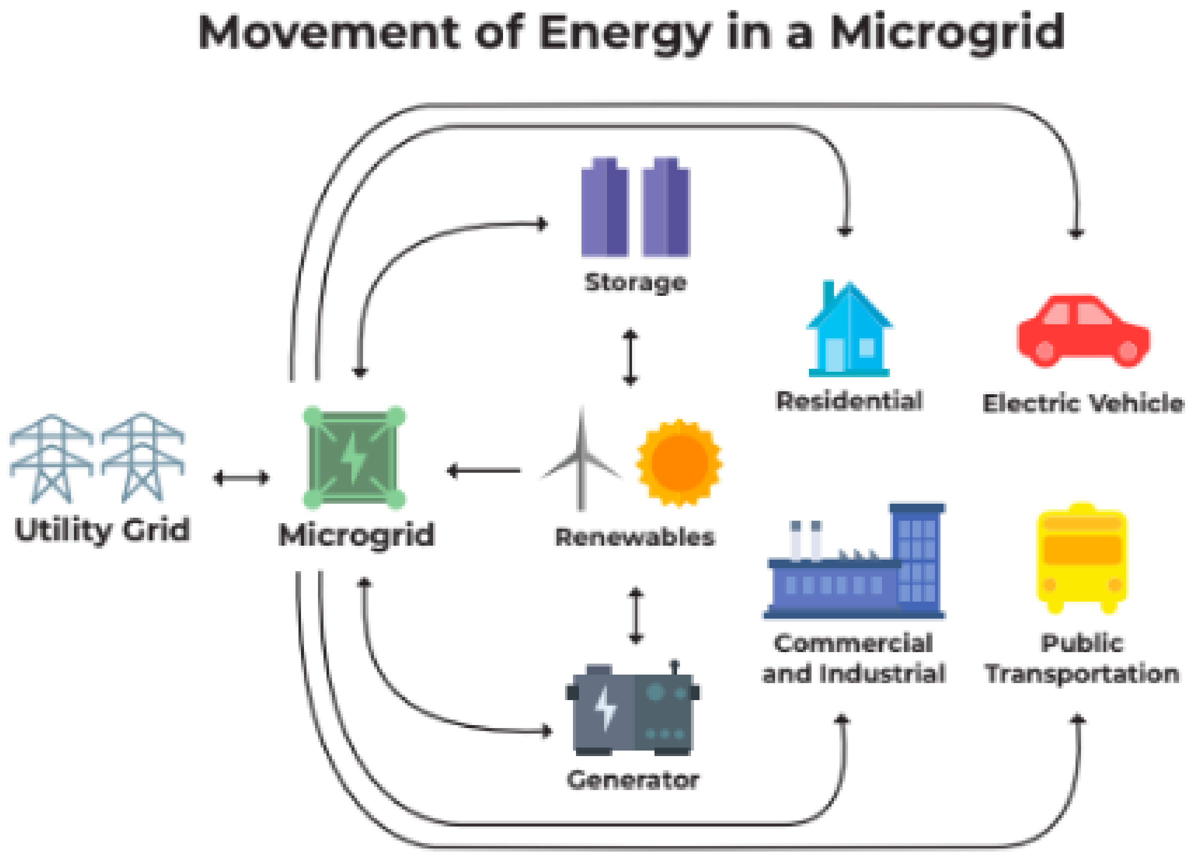


Figure 1: Microgrid Features

2.2 Aim & Objectives

A much broader aim of our thesis is to efficiently operate a classroom. We need to maintain an ideal temperature in our classroom inorder to keep our occupants satisfied and ensure our energy consumption and cost doesn't exceed its limit. The main objective of our research is to produce results in favour of ensuring that less number of occupants in a room is the optimal solution towards a green future. There are numerous factors involved in running a classroom, the size and dimension of the room, the number of students attending the class, indoor illuminance of the room and most importantly the HVAC system, which includes Air Conditioner for the classroom.

We have collected weather data, HVAC and light consumption data, solar irradiance data and accumulated them in a dataset for our regression analysis. The data was both generated as well as researched and used from existing datasets since, we weren't given access to any outside sensors. We coded Python on Jupyter Notebook for our Regression Analysis. Our results have shown that as the number of occupants increase, the room's relative humidity and its temperature increases. The HVAC system is used to cool down the room and plays the most essential part in determining the occupants satisfaction levels. Moreover, the HVAC system consumes a lot of energy and covers 70 percent of the classroom's overall energy consumption. Since our classroom is based in a microgrid environment, we have developed a small microgrid simulation for a better understanding on how a microgrid functions. Our simulation has been developed on Node Red. It basically calculates how much energy is generated at different hours of a day.

Figure 2: A sample classroom at Deakin University

2.3 Structure

The structure of the thesis is as follows:

Section 3 reviews the literature.

Section 4 presents the research design and methodology.

Section 5 describes the approach and the technical details of artefact development.

Section 6 evaluates the artefacts, on the basis of research questions (RQs) and discusses the RQs in Section 7

Section 8 discusses threats to validity

Section 9 concludes the report.

3 Literature Review

3.1 Importance of a Microgrid

Microgrids are a great, reliable backup source of power in times of need. They should be considered because they cut costs and give communities access to clean energy which is environmentally friendly. They can connect to local resources which would be too small and unreliable for an entire grid system, resources like a local waterfall or unused fields which would otherwise remain unused are great resources to power a microgrid. Power cuts annoy everyone and microgrids could be the solution to ensure an uninterrupted flow of power which would be particularly useful in hospitals and research centers. Microgrids indirectly allow for the development of undeveloped places because of the reliability of energy consumption that comes with them. [15]

3.1.1 Importance of Simulating a Microgrid Environment

The current electric power grid suffers aging in both the developing and the developed world. The results of aging grid and old infrastructures become more pronounced as the number of power outages increases. Old equipment is prone to failures, and old engineering planning and operation methods are ineffective in tackling current challenges. Recent concepts from system engineering have been adapted to upgrade the electric power and the electric grid can be treated as a complex system. A complex system is a large collection of interacting elements that act together to perform an overall task and are specifically distributed and self-organised.

A System of Systems (SoS) are large-scale integrated systems that are diverse and independent but work together towards a common goal. A Microgrid is a SoS since, its goal is to work with various RES and meet the load demand in case of power outages. Moving onto the microgrid system modelling, a microgrid uses system complex system modelling techniques and its necessary to capture the dynamic behaviour of the microgrid. The main reason behind initiating the SoS concept is to improve both economy and performance. System of Systems consist of employable heterogeneous subsystems and these subsystems can work independently with each system having the same amount of power. [18]

3.2 Background

It has been noted lately that the world's electricity systems are starting to decarbonize, decentralize and democratize. These trends are driven by the need to rein in electricity costs, replace aging infra-structure, improve resilience and reliability, reduce CO2 emissions to mitigate climate change, and provide reliable electricity to areas lacking electrical infrastructure. Microgrids have emerged as a flexible architecture for deploying distributed energy resources (DER's) that can meet the wide ranging needs of different communities from metropolitan New York to rural India. [?] In industrialized countries, microgrids features gigawatt-scale generating units, thousands or even hundreds of thousands of miles of high voltage transmission lines, minimal energy storage, and carbon-based fossil fuels as a primary energy source.

The modern grid is not a static entity,though since in the historic arc began with small-scale distributed generation, which were recognized as the DC Microgrids pioneered by Thomas Edison in the late 19th century. It underwent consolidation and centralization driven by growing demand. Starting in the late 1990s, scientists and engineers in the United States and Europe began to explore decentralized solutions that could manage the integration of tens of thousands of distributed energy resources in a way that also maximizes reliability and resilience in the face of natural disasters,physical and cyber attacks, and cascading power failures. The solution they settled on was a grid architecture that could manage electricity generation and demand locally in sub-sections of the grid that could be automatically isolated from the larger grid to provide critical services even when the grid at large fails. This approach was given the name "Microgrid". [5] [25]

3.3 Microgrid Motivation

The factors driving microgrid development and deployment in locations with existing electrical grid infrastructure fall into three broad categories: Energy Security, Economic Benefits, and Clean Energy Integration. The main driver of microgrid development has been the potential to improve the resiliency and reliability of "critical facilities" such as transportation, communications, waste treatment, health care, food, and emergency response infrastructure. One major area of activity where microgrids doesn't have a strong foothold on is the aging infrastructure and frequent severe weather events have led to billions of dollars of losses in recent years. As a result, scientists have

Figure 3: Modern day Microgrid in Chicago

been exploring the feasibility of extending microgrids beyond critical facilities to serve whole communities. For instance in the U.S, they are looking for microgrids to replace retiring generation capacity and to relieve congestion points in the transmission and distribution system. [7]

Many of the energy resources scaling up to fill this gap are decentralized, intermittent, and non-dispatchable, making them a challenge to integrate into a grid designed for a one-way flow of electricity from centralized generating plants to customer load demands. Deploying intermittent renewable sources in with co-located flexible loads and storage technologies in microgrids allows for local balancing of supply and demand makes widespread distributed renewable deployment more manageable. Rather than having to track and coordinate thousands or millions of individual distributed energy resources, each microgrid appears to the distribution utility as a small source or consumer of electricity with the ability to modify the net load profile in ways that benefit the main grid. Extensive research is now underway to design microgrids using advanced analytical approaches in order to maximize these benefits across a broad range of criteria, including land use, water use, employment, CO2 emissions, investment costs and cost of electricity, among others. [12]

3.4 Thermal Comfort and Occupant Satisfaction

Thermal comfort and occupant thermal satisfaction are considered as critical aspects in the assessment of indoor environment quality and have received considerable attention by designers and building occupants. Improper indoor temperature not only decreases the level of occupant thermal satisfaction, but also has serious health related consequences. It is also seen that thermal comfort and in particular temperature set, have a significant impact on building energy consumption level. Various factors contribute to thermal comfort and satisfaction and among those factors, temperature plays a critical role in occupants' perception.

Studies have shown that having personal control on indoor environmental conditions significantly increases the level of occupant satisfaction. In recent decades, environmental problems, especially greenhouse gas (GHG) emissions and global warming, have enforced designers to estimate the level of environmental emission of their design and reduce their environmental contribution. Moreover, customer expectations regarding the project budget imposes higher pressure on designers and decision makers to reduce the project costs.[11] When people are dissatisfied with their thermal environment, not only is it a potential health hazard, it also impacts on their ability to function effectively. Thermal comfort is the condition of mind which expresses satisfaction with the thermal environment. It is a personal experience dependent on a great number of criteria and can be different from one person to another within the same space. Its very difficult to understand how a human body operates and the preferable room temperature will keep changing as human behaviour isn't constant. The energy consumption in buildings is mainly used to create and maintain comfort conditions in the indoor environment, which also affect health of the residents. Overheating problems occurring during a warm period may cause dissatisfaction of the occupants and have a direct impact on the energy consumption of buildings for air-conditioning purposes.

It is proven fact that the occupants thermal comfort is during cooler conditions. Occupants satisfaction in confined spaces or simply within a room is associated with indoor environmental quality which consists of thermal, visual, acoustic environment and air quality. Various studies have focused only on the impact of indoor environmental quality on building occupants satisfaction and found that thermal, visual, and acoustic environment and air quality contributed to building occupants satisfaction. The importance of different indoor environmental parameters for building occupants satisfaction varied slightly among numerous studies, but the importance of the thermal environment for building occupants satisfaction was generally ranked slightly higher than the importance of air quality and acoustic environment and much higher than the importance of visual environment. [4] [25]

3.5 Regression Analysis

Regression analysis is a methodology that allows finding a functional relationship (model or equation) among dependent variables and predictor or independent variables. When dealing only with one independent variable, the regression analysis is called univariate regression, while when dealing with two or more independent variables, the regression is called multivariate regression. For complex systems, such as the energy consumption in buildings, the regression analysis should be viewed as an iterative process, i.e. a process in which the outputs are used to diagnose, validate, criticize, and possibly modify the inputs.

Our solution attempts Linear regression analysis to model the relationship among variables by fitting a linear equation to the data. It should be understood that a relationship among a independent variable and a dependent variable does not necessarily imply that the dependent variable causes the independent variable, but that there is some significant association between the two variables. There are two main types of regression analysis techniques that are used accordingly with the complexity of the relationship among variables, the simple linear regression and the multiple linear regression. Its equation is in the form y = mx + c, where y is the predicted independent variable, x is dependent variable and m and c are the co-efficient values. [23] [1]

3.6 Challenges

Although microgrids offer a spectrum of advantages, its implementation and various features are still associated with multiple shortcomings. They can be listed as-

- Bidirectional power flow- Microgrid includes distributed generators of low capacity, which cause power to flow in both direction which can lead to complexity in protection coordination and undesirable power flow pattern.
- Power quality issues in ac/dc microgrid

- Low Inertia- Microgrids have low inertia in order to maintain its power electronic interfaced DG's, which improve the systems dynamic performance. But when in isolated mode, the low inertia causes high rate of frequency deviations.
- Islanded mode of operation- Microgrid shifts from grid connected to islanded mode due to faults or voltage drops. In this situation, the power flow, voltage and frequency control become a major challenge for reliable and efficient operation.
- Coordinated control of Multiple DG's- Microgrid consists of multiple distributed generators and proper coordination control of these DG's is a matter of great concern.
- Energy Storage Options- The Renewable Energy Sources are very intermittent in nature and which leads difficulties in continuation of power supply. Energy storage systems not only stabilise load and generation imbalance but, also help in safe and reliable operation of microgrid.
- Economical and Reliable Operation
- Technology and Cybersecurity- Availability of low cost technology for safe, reliable operation along with need of proper control and technology for integration of renewable sources is a key challenge. [26] [10]

3.7 Systematic Review of Relevant Literature Artefacts

Some of the existing literature's in the area of Microgrids can be found in [8]. In this paper the authors discussed about system failures and curtailment reduction and proposed a model that aimed to reduce Curtailment Loads by efficiently scheduling available resources to the microgrid when the energy supply from the main grid is halted. The model comes up with an optimization method consisting of algorithms for capturing the uncertainties such as Weather forecast uncertainties and the main grid supply interruption. Resiliency Considerations and Operational Flexibility methods were also used.

The authors in [27] formulated two case studies to investigate the parameters involving occupant satisfaction. These case studies were ran for a four week period and examined that an occupant's thermal comfort can occur outside the preferred temperature limits. Adaptive comfort models can predict thermal sensation of the occupants better than models with a fixed limit to their indoor temperature. Lastly, the occupants control of indoor climate can strongly influence their satisfaction levels both in Summer and Winter.

In another development [28], the optimisation scheme to tackle the problems of fluctuating Power Demand and Supply Management in microgrids are discussed. Power Demand and Supply Management in a microgrid are used to maintain a good match between power generation and consumption at a minimum cost. Firstly, to tackle the randomness nature of Renewable Energy a reference distribution is introduced, and a distribution uncertainty set is defined according to past observations to confine the uncertainty. This model allows convenient handling of fluctuating renewable generation as long as the generation isn't drastically different from the past observations and empirical knowledge.

Secondly, an optimization problem is formulated to determine the optimal power consumption and generation scheduling for minimizing the fuel cost. A robust approach for handling the load balance is proposed. Lastly, the proposed algorithm can be used in cases where the real-time adjustment is of big concern. The numerical results of the proposed algorithms indicated that the energy management scheme can significantly cut down energy expenses. Factors such as reference distribution, fault tolerant limit, types and number of uninterruptible loads and user elasticity are each carefully evaluated.

[22] performed an extensive thermal comfort study of a building during the summer season in Athens. The residential building had a natural ventilated and mechanical ventilated system. It was found that building's occupants were comfortable at temperatures between 27 degrees to 28 degrees. The occupants were unhappy with the indoor thermal conditions and wanted to have more air circulation in their rooms. The ventilation system ensured that the rooms in the building had air circulation and the residents/occupants will enjoy natural air.

The model-driven approach is an approach for developing a product where the system and product can interact together in a software environment through simulations.Control functions developed within the controller can be tested in the simulation and can be transferred to a hardware to realize the microgrid controller. The second aspect of model-driven approach is, the control functions modelled in the simulation, which are supposed to be deployed in the hardware are aware of the properties and connectivity of the system and can be utilized to minimize the complexity of settings required to describe system data. The third aspect of model-driven approach allows the use of predictive simulation to enhance and achieve certain required control functionality. A paper [30] discusses the characteristics, key technologies and challenges faced during the development of a Microgrid.

These research paper's played a huge part in formulating our thesis since, these are very similar and analyse properties and entities of a microgrid and occupant satisfaction, we are trying to solve.

4 Research Design & Methodology

Research designs are plans and the procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis [2].

We have gone through an extensive literature review by reading several research papers on Microgrids, which has helped us to understand the importance of solar power utilization and its implementation. We have learnt about how solar panels operate and convert solar radiations into energy. We researched and established on what equipment's are installed on a microgrid site and developed a simple microgrid simulation on Node Red. We then shifted our focus on Thermal Comfort and occupancy satisfaction. We got acquainted with the energy consumption and cost for different appliances and their sufficient capacities for operating a classroom. Our data collection contains real-time weather data and researched data of a room since, we weren't given access to any sensors for our work.

As per our evaluations, we carried out qualitative and quantitative analysis of the complete system. We had discussions with individuals who are experts in the field of microgrid and hold expertise in the electric field. We have discussed different approaches and opinions regarding our project and it's been shared in the upcoming chapters.

4.1 Methodological Approach

Data Collection is a vital cog for our simulation and regression analysis. We carried out two major data collection procedures and ended up with two datasets for our artefacts. We collected quantitative data to ensure our microgrid and regression analysis worked efficiently. Our Microgrid Simulation dataset contains Outside Temperature, Solar Irradiance and Weather Description and ENergy Consumption values for a week. Our Regression Analysis dataset contains Outside Temperature, Room Temperature, Relative Humidity Solar Irradiance, Energy Consumption and HVAC and Light Fixture Consumption values.

We firstly created a dataset for our weather forecast prediction, which contains temperature, weather description and solar irradiance data of Waurn Ponds for over a week. We followed primary data procedure and collected information through first hand research. For our weather temperature data, we used OpenWeatherMap API to collect collect the data. During Phase I of this project, we designed a web page and used the OpenWeatherMap's Current Weather forecast API, to ensure our data procedure was reliable. Moving on, for our Solar Irradiance data we used the services of Solcast API toolkit. Solar Irradiance is the output of the sun's light energy and is calculated in Watt per meter square and is directly proportional to the energy generation.

Date	Time	Outside Te	Room Ten	Relative H	Solar Irrad	Number o	Energy Co	Light Cons	HVAC Con	Additiona	Energy Cost($)
1/08/2021	8:00	21.6	23.7	46	204	5	160	30	70	2	0.0384
1/08/2021	9:00	22.9	23.5	48	376	40	330	20	250	10	0.0792
1/08/2021	10:00	22.9	23.5	47	432	35	400	20	300	7	0.096
1/08/2021	11:00	23.2	23.1	48	437	50	560	20	500	12	0.1344
1/08/2021	12:00	25.2	23	48	615	60	700	5	550	20	0.168
1/08/2021	13:00	26.7	22.5	48	700	60	800	5	650	20	0.192
1/08/2021	14:00	25.4	22.5	49	515	70	1010	30	750	25	0.2424
1/08/2021	15:00	24.6	22.1	47	440	40	560	30	450	12	0.1344
1/08/2021	16:00	23.8	22	47	358	40	500	30	480	13	0.12
1/08/2021	17:00	24	22.2	47	294	50	500	50	500	15	0.12
1/08/2021	18:00	22.7	22.4	47	236	60	620	60	500	20	0.1488
1/08/2021	19:00	22.5	22	46	81	40	500	60	500	12	0.12
1/08/2021	20:00	22	20.6	41	0	10	260	60	180	1	0.0624
2/08/2021	9:00	24.6	23	46	355	50	460	20	60	14	0.1104
2/08/2021	10:00	25.6	22.7	45	362	35	500	10	250	7	0.12
2/08/2021	11:00	27.6	23.1	46	761	50	650	0	500	15	0.156
2/08/2021	12:00	27.4	23.5	46	809	60	700	5	600	20	0.168
2/08/2021	13:00	28	24	47	872	70	1005	5	850	25	0.2412
2/08/2021	14:00	29	23.7	47	844	50	700	10	600	15	0.168
2/08/2021	15:00	28.5	23.5	46	760	40	630	10	550	12	0.18
2/08/2021	16:00	27.3	23.5	46	561	40	620	30	550	10	0.18
2/08/2021	17:00	27.5	23.6	47	429	50	650	50	560	15	0.156

Figure 4: Dataset for Regression Analysis

Another major part of our project is to discuss the factors that determine the energy consumption of a university classroom and most importantly, what factors can affect the occupant's behaviour. The occupant's satisfaction can be achieved by maintaining the Room Temperature. The room temperature is the indoor air temperature that ensures that the occupant is comfortable [24]. The outside weather plays a major role in manipulating the indoor temperature. Thermal insulation in the walls is a way to control indoor temperature but the best way would be by installing Fans and Air Conditioners. Our simulation has a HVAC system installed within the classroom. HVAC system is installed at the ceiling of the room and has the maximum energy consumption and also costs the most. The values of energy consumption and energy cost of the HVAC system was carried out through heavy research. The number of HVAC systems installed in the class was also determined by reading articles and tutorial videos. The indoor light system, projector, laptop and mobile charger plug loads were also considered for our data collection. Again, their load demand values were researched over the internet and calculated on hourly data.

Date	Time	Temperature (Celsius)	weather_main	weather_description	Solar Irradiance (W/m^2)
2021-03-12	0:00	8.078297	Clouds	scattered clouds	0
2021-03-12	1:00	8.498297	Clouds	broken clouds	0
2021-03-12	2:00	7.238297	Clouds	broken clouds	0
2021-03-12	3:00	7.818297	Clouds	broken clouds	0
2021-03-12	4:00	8.478297	Clouds	broken clouds	0
2021-03-12	5:00	8.068297	Clouds	scattered clouds	0
2021-03-12	6:00	7.288298	Clouds	few clouds	23
2021-03-12	7:00	6.148297	Clouds	few clouds	108
2021-03-12	8:00	6.048297	Clouds	broken clouds	204
2021-03-12	9:00	7.968297	Clouds	overcast clouds	376
2021-03-12	10:00	10.5983	Clouds	overcast clouds	432
2021-03-12	11:00	11.5183	Clouds	scattered clouds	437
2021-03-12	12:00	16.2683	Clear	sky is clear	615
2021-03-12	13:00	17.2083	Clear	sky is clear	700
2021-03-12	14:00	12.8883	Clouds	few clouds	515
2021-03-12	15:00	12.9083	Clouds	broken clouds	540
2021-03-12	16:00	12.6683	Clouds	overcast clouds	358
2021-03-12	17:00	11.3683	Clouds	overcast clouds	294
2021-03-12	18:00	8.228297	Clouds	overcast clouds	236
2021-03-12	19:00	7.418297	Clouds	overcast clouds	81
2021-03-12	20:00	6.508297	Clouds	overcast clouds	0

Figure 5: Dataset for Microgrid Simulation

4.2 Technologies Used

4.2.1 Microgrid

A microgrid is an independent energy framework that serves a discrete geographic impression, like a school and college campuses, emergency clinic complex, shopping complex, and many more. It can be defined as a concise, limited-scale localized power station that has its own storage capacity and generation units and defined boundaries. Microgrids are normally upheld by generators or inexhaustible breeze and sunlight-based energy assets and are regularly used to give reinforcement force or supplement the main supply during the high demand times. The aim of using microgrids is for the distributed, decentralized, and embedded energy production. A microgrid system is programmed very carefully and its entities are connected with each other by means of some complex programming and frameworks.

A microgrid system makes it possible to connect homes, organizations and different structures to focal force sources, which permits us to utilize machines, warming/cooling frameworks, and hardware. A microgrid has a major upgrade from its predecessor traditional grid. The traditional grids had an interconnected system with a centralized architecture. Whenever there was an issue within any of its feature, the whole grid system had to shut down. The concept of microgrid tackles this problem with its unique design. A microgrid by and large works while associated with the network, it

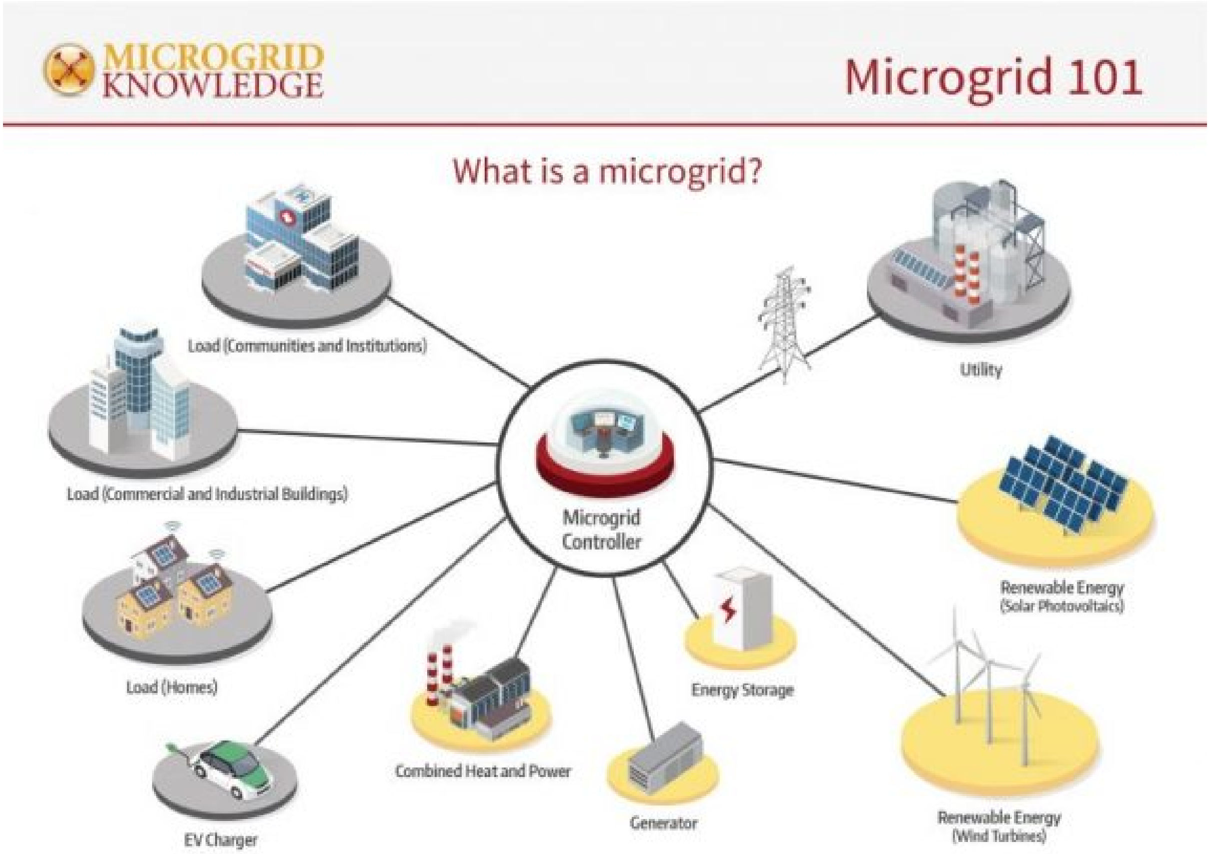


Figure 6: Microgrid distributive entities

can operate and break off by itself by making use of local energy in case of emergencies like thunder, power outage, storms, and even natural calamities. A microgrid can be fueled and engined by circulated generators, batteries, and additionally inexhaustible assets like sun-powered boards. In order to connect microgrid to grid, both are made to operate on same voltage level and a coupling is done between both to link them together. We have pointed out a few more advantages of a Microgrid,

1. Microgrids offer numerous monetary advantages. Accept sun-powered boards for instance. While they take from 7-20 years to pay for themselves, contingent upon state tax reductions or limits, they can save you a large amount every year once paid off. Sun-powered boards increase the value of your home and can be more financially stable than the energy created from petroleum products, which has not only high pricing but also a non-renewable source of energy.

2. The microgrid makes it possible to control and regulate the energy generated storage and power sources which can go a long way in controlling the power

fluctuations in renewable sources of energy and thus improves the overall quality of the power generated.

3. Microgrid is a highly dependent and reliable system. For instance, the electricity needs to cover a long distance before reaching its consumers i.e., homes and building, the chance of sudden occurrence of any natural calamity like storm, thunder is always a cause if concern that can affect the power supply. Privately created energy doesn't need to go far, so a microgrid can power up in any event, when outrageous climate takes out most electrical cables. In rare cases, your microgrid has differentiated and creates energy from numerous sources, that adds one additional degree of safety.
4. Microgrids are more modest, and can subsequently be introduced more rapidly than customary power plants. It is easy to incorporate the microgrids in the remote areas even without any power supply. Thus the microgrids makes it possible to satisfy the ever increasing power supply demand of this rapidly growing population.

4.2.2 Digital Twin

The shift towards the 4th industrial revolution and Industry 4.0 has increased the level of automation of the industrial systems and processes and connectivity between them. In this revolutionary trend, one of the focus areas is creating transparency between the physical world and the digital world (cyberspace) and this led to a new concept, called digital twin. Some related or partially overlapping conceptual terms are the digital counterparts, virtual twin, virtual object, product agent, and an avatar. A digital twin is a replica model residing in a virtual environment that includes everything that is known about an object. It is a replica of physical counterparts that change with the current environment in real-time to assist in monitor, test, treat and maintain a physical system. Digital twins are virtual imitations of actual gadgets that information researchers and IT experts can use to run recreations before directly working and operating with the actual devices. They are additionally changing how advancements like IoT, AI, and investigation are upgraded.

[3]

A digital twin is, fundamentally, a PC program that utilizes real-world and real-time information to make reproductions that can predict how a device will perform. These

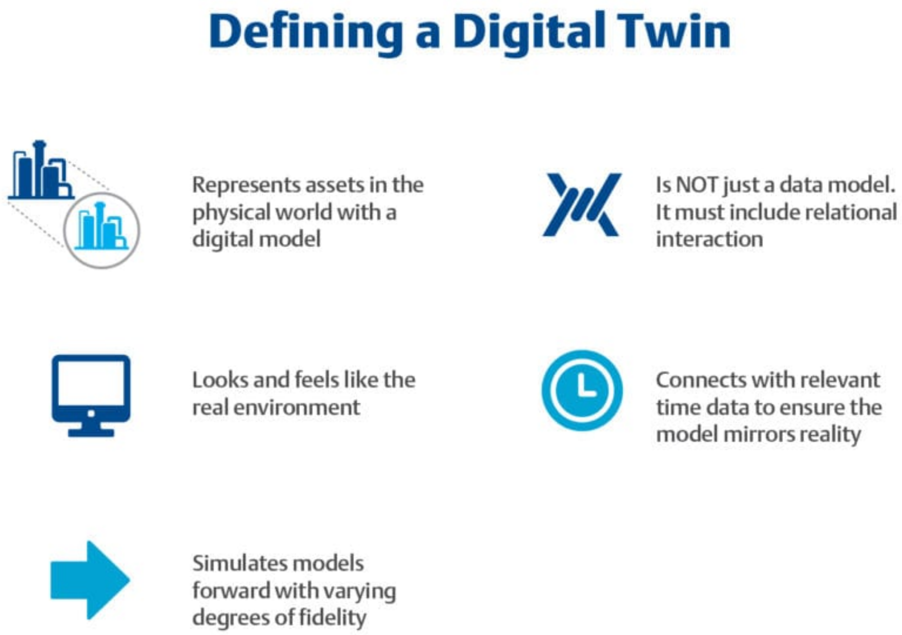


Figure 7: Digital Twin

projects can coordinate with IOT applications, computer algorithms, and human mind to improve the yield. In layman's terms, consider it as an extension between the physical and digital universes. To begin with, smarts devices and components that collects information about status, working conditions, and position of an actual device are coordinated into an digital device to make the simulation of the actual device. These parts are associated with a cloud-based framework that gets and measures all the information that the sensors screen. Then the team of analysts, analyses the simulation so formed against business and other context-oriented information. Exercises are learned and openings are found inside the virtual climate that can be applied to our real world. A Digital Twin can likewise be depicted as a virtual model of an actual device, service or a process that can be checked, investigated, and improved. The model is made utilizing computers to design and is incorporated with the IOT, AI, and ML examination.

The reported uses of a Digital Twin are-

1. Digital twin for manufacturing assets: All the manufacturing assets can be

connected and replicated in cyberspace via their digital twin.

2. Digital twin for factories: A live factory environment can also be abstracted with digital twins with its complete operational visibility and flexibility.

3. Digital twin for people: Digital twin can also represent people/workers including their data (weight, health data, activity data, and emotional status) which can aid in establishing models to better understand the well being and working conditions of humans in a factory.

4. Digital twin for production networks: By connecting manufacturing assets, people and service via digital twin, every aspect of business can be virtually represented. [17]

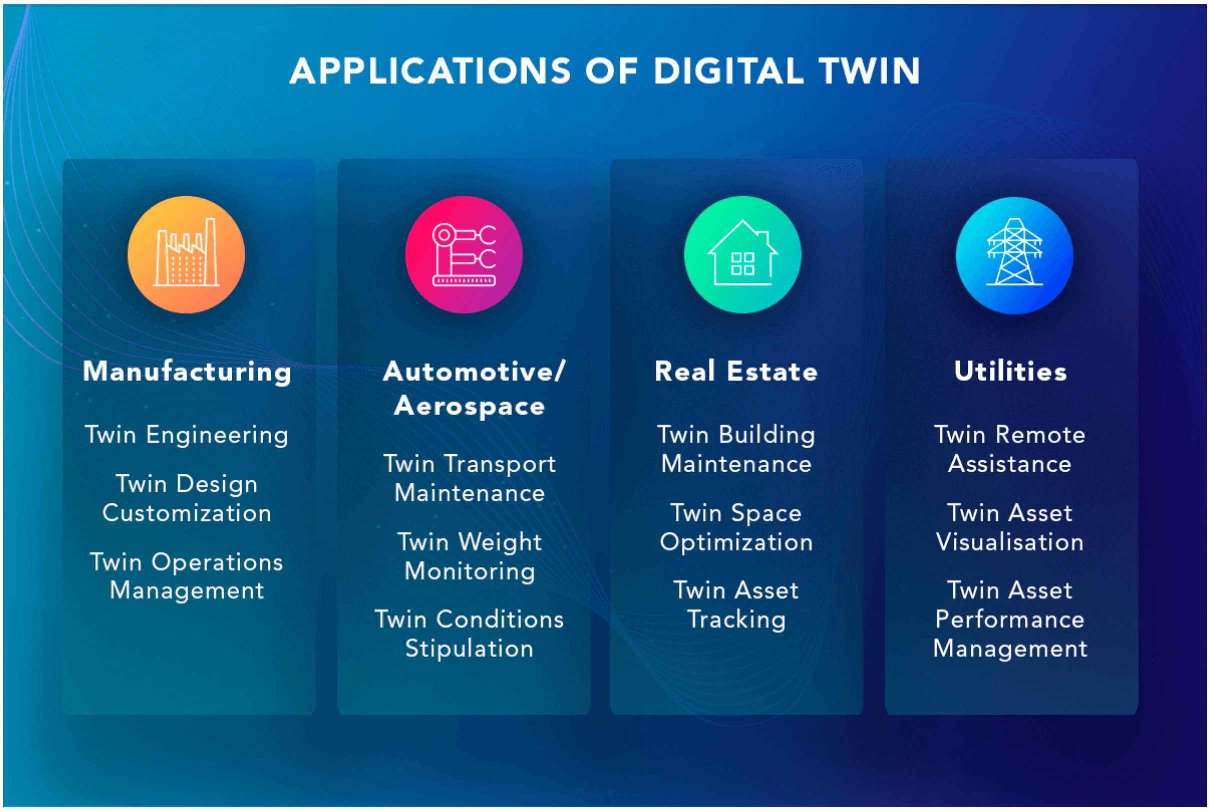


Figure 8: Uses of a Digital Twin

4.2.3 Node Red

We have developed a microgrid simulation on Node Red using its Dashboard feature. Node-RED is an open source flow-based development tool used for the integration of

IoT hardware devices, API's (Application Programming Interfaces) and online services developed by IBM Emerging Technology. Node-RED is a flexible and powerful tool that is used to create prototypes. This system allows quick creation of applications, especially applications that trigger on an event such as IoT applications. The essence of this tool is to enable engineers and technicians to simply create and configure real-time applications on end-devices. It is a free JavaScript-based tool, built on Node.Js platform, which provides a visual browser-based flow editor. The system contains nodes that are represented by appropriate icons. It can operate in two ways: drag, drop and wire up nodes, or import JavaScript code. The Node Red package can be run either on IBM Cloud or can be downloaded on our personal devices by generating the IP Address on the terminal. I've downloaded Node Red on my laptop and use it by generating its IP Address. [9]

The node provides different functions, such as to monitor the flow as the debug out the node, or to read and write with Raspberry Pi node. Created flows are stored using JSON. Node-RED enables its developers to wire up input, output and processing nodes in order to create flows for data processing, controlling things and even sending alerts. Node Red enables the connection of web services and customizes nodes to one another or to things, in order to perform functions such as sending sensor data via e-mail or to services like social media applications, easily performing complex analysis. Node-RED has three basic components in Node Panel, Flow Panel and Info and Debug Panel. [20]

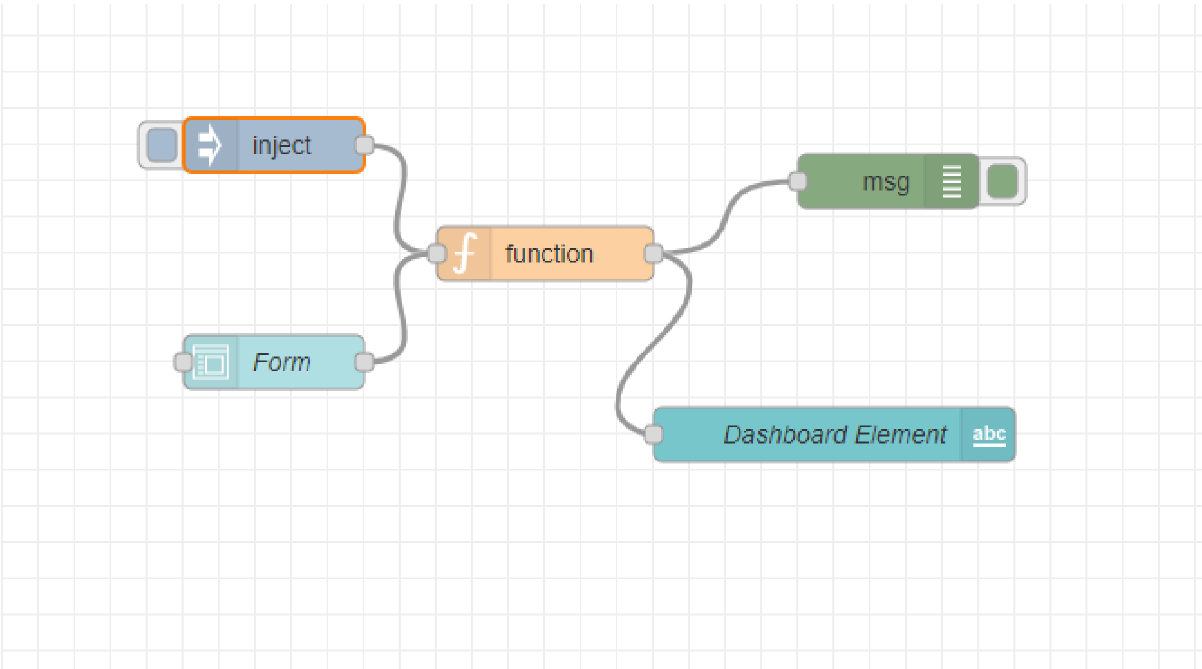


Figure 9: Basic Node Red Simulation

The Node-RED Dashboard is a module that provides a set of nodes in Node-RED to quickly create a live data dashboard. By using these nodes, we can replace inject nodes with buttons and instead of printing our results on the debug pane, we can send the data directly to a web component. Nodes from the dashboard section provide widgets that show up in the application's user interface (UI). The user interface is organized in tabs and groups and the user can have multiple display tabs. When a dashboard node is dragged onto the flow canvas, they will require a target display tab and display group. In simple words, each widget should have an associated group that determines where the widget should appear on the user interface. The Node Red Dashboard site can be easily accessible on each device with Node Red installed. The IP Address generated on the terminal must end with 'ui' to access the Dashboard UI site.

4.2.4 Jupyter Notebook

Jupyter Notebook is an open-source, browser-based tool functioning as a virtual lab notebook to support workflows, data, code and visualisations. The Jupyter Notebook is an incredibly powerful tool for interactively developing and presenting data science projects. It integrates code and its output in a single document, where us users can run code, display the output and add explanations, formulas, charts and make our work transparent. Using Jupyter notebook is a major part of the data science workflow around the globe since, it makes the work easier to communicate and share its results. It facilitates interoperability and scholarly communication. These notebooks can live in online repositories and provide connections to research objects such as datasets, code, methods documents, workflows, and publications that reside elsewhere. Jupyter notebooks are one means to make science more open. Since the notebook is open-source, its completely free-of cost and can be downloaded from the software on its own or as a part of the Anaconda toolkit. Most importantly, the best and most common language used for this Notebook is Python which will be discussed later on this paper. [21]

Jupyter Project is a spin-off project of IPython. IPython is a command shell used for interactive computing in multiple programming language, preferably in Python. In 2005, IPython's developers attempted on building a notebook system but their prototype never came to fruition. A few years later, they were able to implement a notebook-type system and incorporated and release it by late 2011. A brief research states that the developers were working on creating this notebook system at the same time Sage notebook was in progress. Sage notebook is a layout of the

In [2]:
```python
# Import packages
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import seaborn as sns
from sklearn.linear_model import LinearRegression

# Read the data
data = pd.read_csv("C:\\Users\\Utsav Sharma\\OneDrive\\Desktop\\data.csv")
data
```

Out[2]:

	Date	Time	Room Temperature	Outside Temperature	Relative Humidity	Solar Irradiance	Number of Occupants	Energy Consumption	Light Consumption	HVAC Consumption	Additional Equipment Consumption	Energy Cost($)
0	23/03/2021	8:00	23.7	21.6	46	204	5	160	30	70	2	0.0384
1	23/03/2021	9:00	23.5	22.9	48	376	40	330	20	250	10	0.0792
2	23/03/2021	10:00	23.5	22.9	47	432	35	400	20	300	7	0.0960
3	23/03/2021	11:00	23.1	23.2	48	437	50	560	20	500	12	0.1344
4	23/03/2021	12:00	23.0	25.2	48	615	60	700	5	550	20	0.1680
...	...	...	...	...	...	...	...	...	...	...	...	...
604	9/05/2021	16:00	23.5	27.3	46	561	40	620	30	550	10	0.1800
605	9/05/2021	17:00	23.6	27.5	47	429	50	650	50	560	15	0.1560
606	9/05/2021	18:00	23.6	26.0	47	235	80	1040	60	900	30	0.2496
607	9/05/2021	19:00	23.2	25.0	46	53	60	700	60	500	22	0.1680

Figure 10: Importing packages and loading our dataset in Jupyter Notebook

google notebooks. At the time, the concept of a notebook containing ordinary text, calculations and graphics was definitely not new. Moving on, IPython is now used as a Python Backend also known as a Kernel and the next generation of Jupyter Notebooks has already been introduced as Jupyter Lab. Jupyter Notebooks run with the help of Anaconda Python. The basic requirement is to have the latest Python package installed. Anaconda distribution can be used to install both these applications. Anaconda provides us users with access to over 700 packages. These packages can be downloaded easily.

5 Artefact Development Approach

In this section, we will discuss about the approaches and ideas we took for our artefacts. Our paper involves two major artefact.

5.1 Node Red Simulation

The first artefact involves the simulation of a functioning microgrid on Node Red. We have implemented a microgrid system that generates and supplies energy according to its load demand. The Load Demand or Energy Consumption data is fixed and is based on an hourly basis of 7 days. This load demand data is same throughout the simulation, but on a few occasions the demand increases with the inclusion of new devices which results in the requirement of more energy. In such cases, the battery supplies the stored energy back to the grid to ensure there's no power failures or power outages. Here we cover the most important entities found in a microgrid.

5.1.1 Microgrid Functioning

- Solar Panels- A microgrid environment has solar panels installed for energy generation. The solar panels have its own dimensions and have a specific maximum charge capacity i.e. the amount of energy it can generate at a time. These Solar Panels absorb the sun's radiations and convert it to energy with the help of its PV Cells. The Solar Irradiance and the Weather are not the same thing, since its been noticed on various occasions that the sun shines even when its raining. Thus, the solar irradiance plays a major role in determining how much energy will the solar panels produces during the day. Solar Panels is highly advantageous since solar energy is a renewable source of energy, its available everywhere. It is pollution free and reduces the dependence and usage of non-renewable sources. Moreover, they require less amount of maintenance and don't require much cleaning.
- Formulas- The next process is to convert the solar irradiance collected to solar energy for our power generation. The first formula it goes through is the Energy Efficiency Formula. This formula involves the solar panels maximum charge capacity and area and is whole divided by the 10 for its unit conversion. The next formula used is to calculate how much energy is being generated. This is

Figure 11: Solar Panels are used to convert solar radiation into energy

can also be noted as the most essential formula for our process. The Total Energy Generation formula consists of the Solar Panel's area, Solar Irradiance at that particular time and the Energy Efficiency calculated. Its important to note here, that the energy being generated is in DC Voltage Source and is converted to AC Voltage source and has a simple conversion rate. The DC to AC Voltage Conversion formula simply multiplies the energy generated previously by 95 percent.

- Energy Storage System- Once the microgrid has generated its AC Source energy, it then looks to store 20 percent of the energy in the battery. The battery also known as the Energy Storage system holds the core property in any microgrid environment. The battery has its own capacity which is sufficient for supplying energy to the consumers when its required the most. During the day there are moments when the weather won't be suitable for energy generation. It might be raining or the clouds might cover the whole sky. In such situations, the battery supplies energy to the consumers to fulfill their requirements. The battery's decision making ability to provide energy at times when needed justifies the argument of battery being the most resourceful entity in a microgrid system.
- Supplying Energy to Consumers- Once the battery stores 20 percent of the energy, the microgrid checks the consumer's energy demand and supplies the required energy. This step arises many questions, on why the consumer's demands are met after storing energy in the battery. The reason being that the main goal is to ensure that the battery is stored with energy at all times.

The microgrid environment has numerous solar panels installed throughout the campus and the microgrid ends with with surplus energy. There are very rare cases where the microgrid fails to meet the consumer's demand after energy storage. In such situations the battery or the main grid supplies energy.

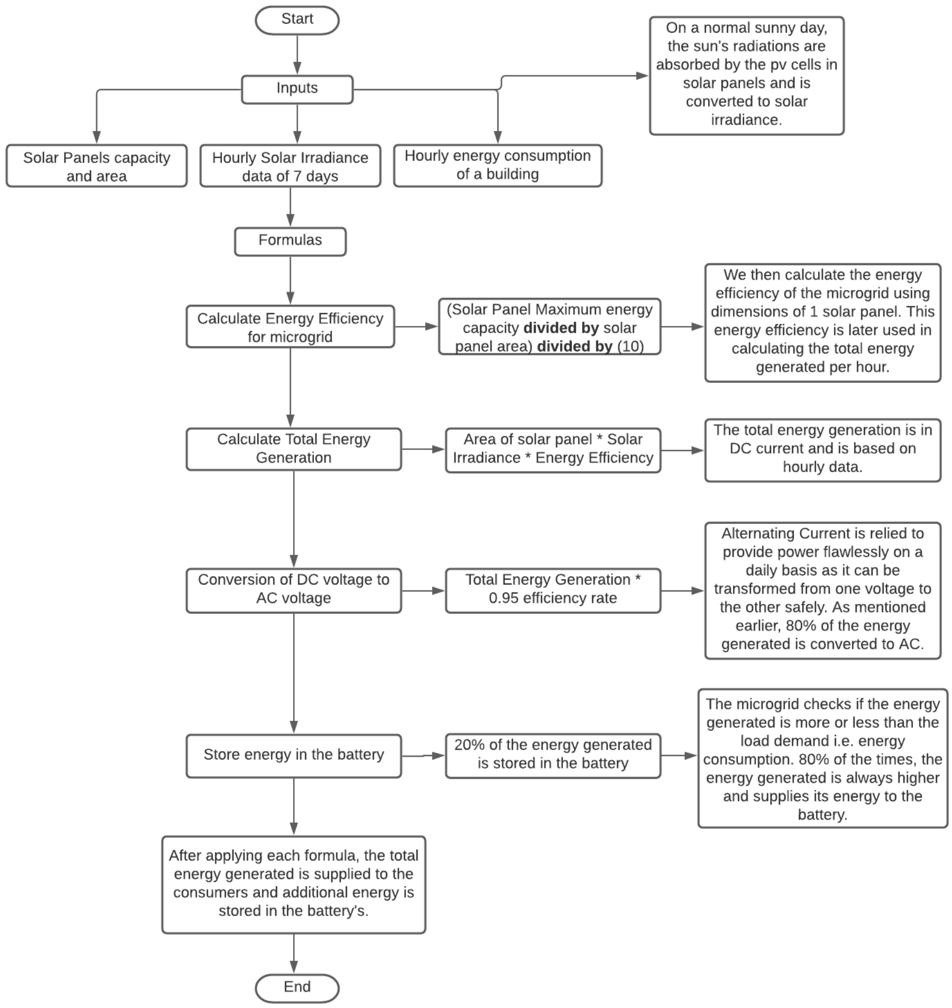


Figure 12: Microgrid Functioning

5.2 Regression Analysis of Dataset

Our second artefact involves the Regression Analysis of a classroom's data collection. Our goal is to run a classroom and keep its occupants satisfied. Our artefact further proves that as the number of occupants in a classroom increases, the thermal comfort decreases and the energy consumption and energy cost exceed their limits. Our results add on to the fact that having less number of occupants in a room is the optimal solution towards Energy Consumption for a greener future. For our results, we will calculate the energy consumption of each device and generate graphs using Regression Analysis to understand what features have the highest impact towards our goal. To begin with, we have researched on different major features that can affect the thermal comfort of the room and also determine the occupants satisfaction level. We have formulated a metrics table involving those features.

5.2.1 Features

The features can be divided into three main aspects such as Environment conditions like Room Temperature, Relative Humidity, transmitted Solar Irradiation and Indoor illuminance. Occupant-Related factors such as Presence/Absence in the space, Skin temperature and Heart Rate. Building-related factors such as supplied Air Temperature by HVAC system, Lighting Fixtures, Shading position. These features are larger terms for for the actual factors. Around half of these features have identical meanings and are coincidental. Here's a brief description on each feature-

- Room Temperature- It is an important measure in a building environment when considering the thermal comfort of the occupants. Cooler conditions in a room is highly preferred as cold temperatures decrease negative mental health outcome while high temperature increases negative mental health. Thus, the occupants tend to find their thermal comfort in cooler conditions. [14]
- Relative Humidity- It affects the thermal comfort since higher the RH, the less heat a person will lose and keep them warm. Relative Humidity is affected by the outside temperature and number of occupants in the room. To conclude, as relative humidity increases, the evaporation of sweat from an occupant's body becomes much more difficult. [29]
- Solar Irradiance- It affects the radiant field in the indoor environment and hence it has a remarkable influence on comfort conditions. If the building has solar panels installed on the roofs, then solar radiation is the best source for generating energy in a cheap and clean manner. Solar Irradiance also affects the use of light fixtures in a room since, the light fixtures are usually not used when solar irradiance is at its peak level.
- Indoor Illuminance- Indoor illuminance is used for adequacy and visual comfort. It comprises of both natural and artificial lighting. Natural lighting involves the

use of Solar irradiance and Artificial lighting involves the use of light fixtures such as Fluorescent tubes or environmentally friendly LED tubes. Light fixtures have their specific energy consumption.

- Presence/Absence in space- The presence of electrical in rooms is of upmost importance as it makes our lives easier and helps us in carrying our day-to-day activities. The on;y problem is that they consume energy and are harmful for the environment unless, they are used in a prudent manner.
- Skin Temperature- It's the temperature of the outermost part of the human body and it prefers cooler conditions. This attribute doesn't affect the room's environment but is essential to the occupant's behaviour. The human body is very unpredictable and their skin temperature ensures the use of air conditioner and other appliances.
- Heart Rate- Heart rate remains steady when the body is in thermal comfort and increases when the temperature goes up. Again, this attribute doesn't affect the room's environment but is of the highest importance in a human body.
- HVAC System- It is well known that the dynamic performance of a Heating, Ventilation and Air Conditioning(HVAC) system has great impact on power and energy consumption, as well as on indoor air quality. It's the most essential system in campus as it assists by controlling indoor climate and proper airflow and ensures we neither freeze nor sweat. It has major risks to the environment as well as energy consumption and energy cost. [29]
- Lighting Fixtures- Light Switching on or off plays a huge factor in thermal comfort of the occupant. It enables visual comfort in dark rooms or dim-lighted rooms.
- Shading Position- Shading position can help in blocking outside sunlight from entering the room in case when the outside sunlight is causing discrepancies with the visual comfort. Moreover, they lead to the use of light fixtures which consume energy.

5.2.2 Metrics Table

This table describes each feature on the basis of its importance within a room as well as the occupant. The table gives each feature a rating value between 1 and 10.

Feature	Impact	Rating (1-10)
Room Temperature	Very High Impact	10
Relative Humidity	High Impact	8
Solar Radiation	Decent Impact	7
Indoor Illuminance	High Impact	8
Presence/Absence in space	High Impact	8
Skin Temperature	High Impact	8
Heart Rate	Very High Impact	10
HVAC System	Very High Impact	10
Light Fixture	High Impact	9
Shading Position	Decent Impact	7

Table 2: Metrics Table

The rating for each each feature is based on thermal comfort and occupant satisfaction. The HVAC System and Heart Rate are rated as 10 even though one runs on energy and the other is a part of the human body. Some extra factors affecting the room temperature can be the classroom's size, since larger the area and occupant population, the higher the air conditioner capacity required. Insulation in the walls and ceiling of the room can also lower the air conditioner capacity required. Having a larger window size in a room may mean a larger capacity system due to the higher solar gains into the space.

6 Empirical Evaluation

In this section, we will discuss the evaluation plan for our artefacts, there are a total of two major artefacts discussed in paper.

6.1 Node Red Simulation

The simulation developed starts with the inject node and ends with the debug node. It simply consists of a Form, Function and Text input nodes.

6.1.1 Inject Node

The inject node is used to manually trigger a flow by clicking the node's button with the editor. In our simulation, the inject node contains all the important variables required to calculate the total energy generation for a microgrid. We have assigned values to each variable which will be displayed in the Debug Node. This doesn't hold much importance with regards to our final simulation since the Dashboard UI requires data to be entered in real-time.

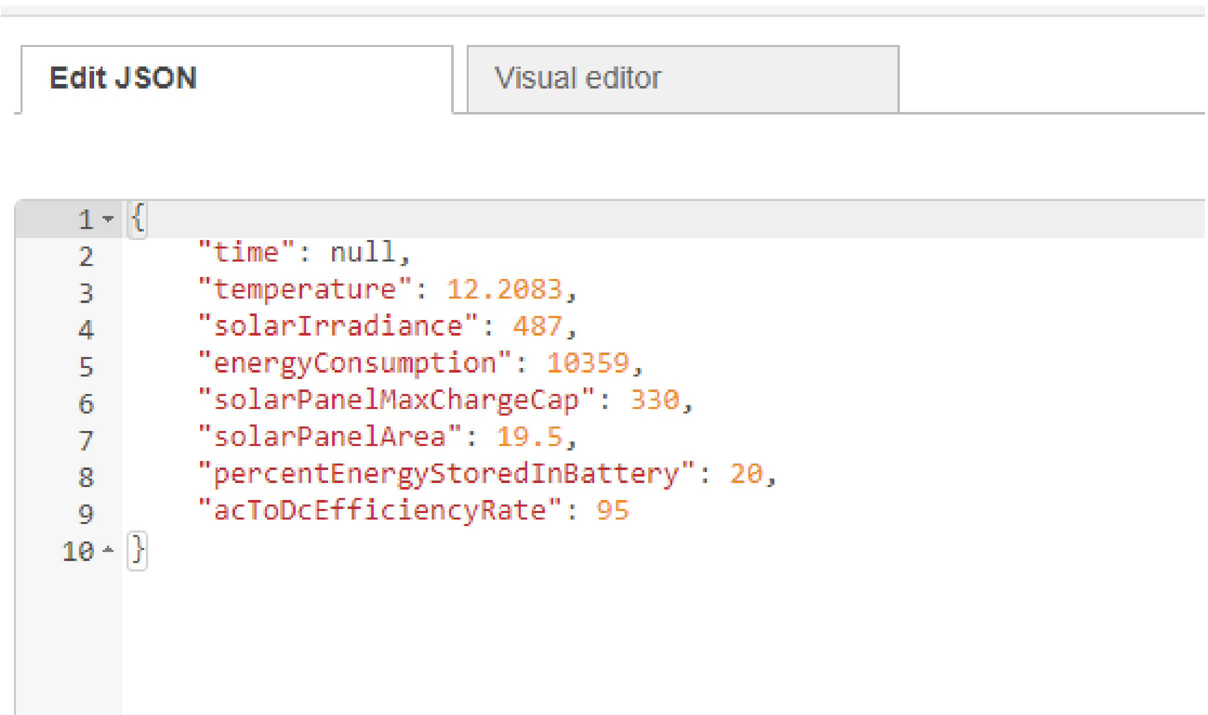


Figure 13: Inject Node

6.1.2 Form Node

The form nodes offers the ability to create a simple static collection of inputs. This flow defines the form inputs and then applies additional parameters. Additionally, we have assigned their 'type' as well for instance, Temperature is of type Number.

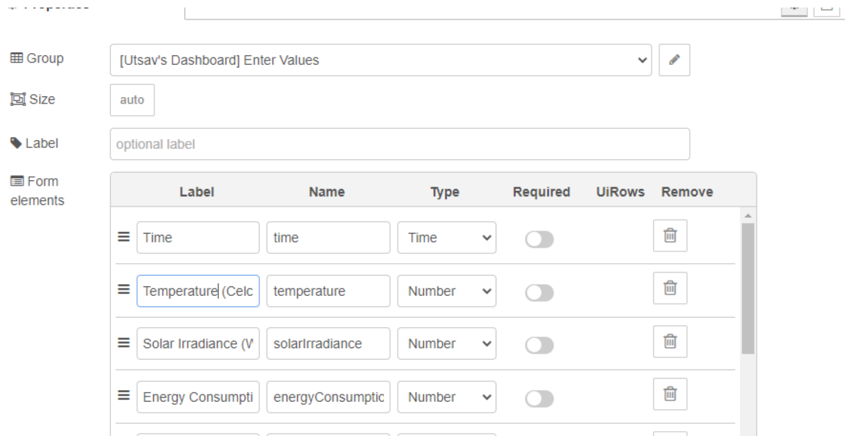


Figure 14: Form Node is used for determining the inputs

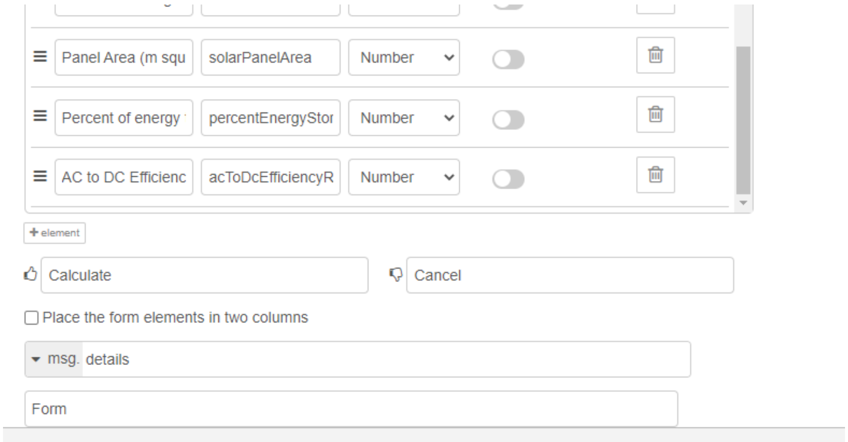


Figure 15: Form Node is used for determining the inputs

6.1.3 Function Node

The next node is the Function Node. It is of immense significance as its used to run javascript code against the msg object. In short, we have entered our formulas used for calculating the energy generated in a microgrid. The formulas used can be found at the end of this section.

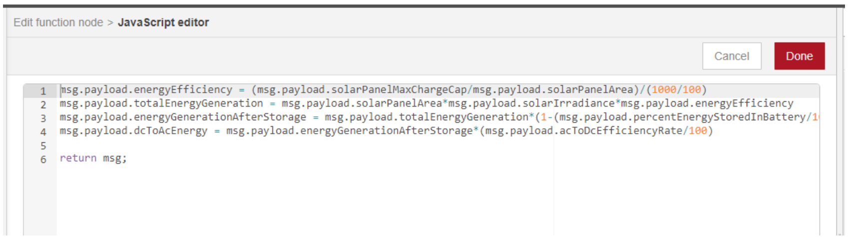


Figure 16: The function node contains the formulas used in calculating total energy generation

6.1.4 Text Input Board

The text node provides the ability to display a single value on the Dashboard. Our simulation contains three of these input boards as we calculate three distinct results. Each board has a similar board size and font size and the font colour used is black. The outputs produced by these boards are ”Total Energy Generated”, ”AC Converted Energy in Watts” and ”Energy left after battery storage”. We have named the board as ”Dashboard Element” to avoid any confusions.

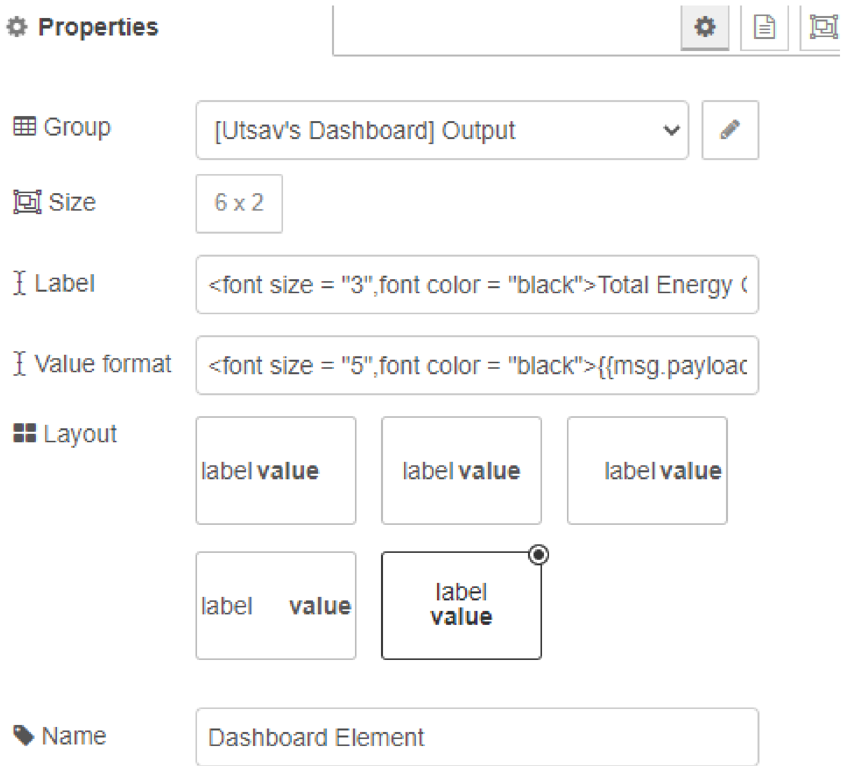


Figure 17: The text input node helps in displaying our results on the Dashboard UI page

6.1.5 Debug Node

The debug node displays the output of variables stored in the inject node. Each node red simulation ends with the debug node but our simulation with dashboard elements and this debug node doesn't hold much importance for our final work.

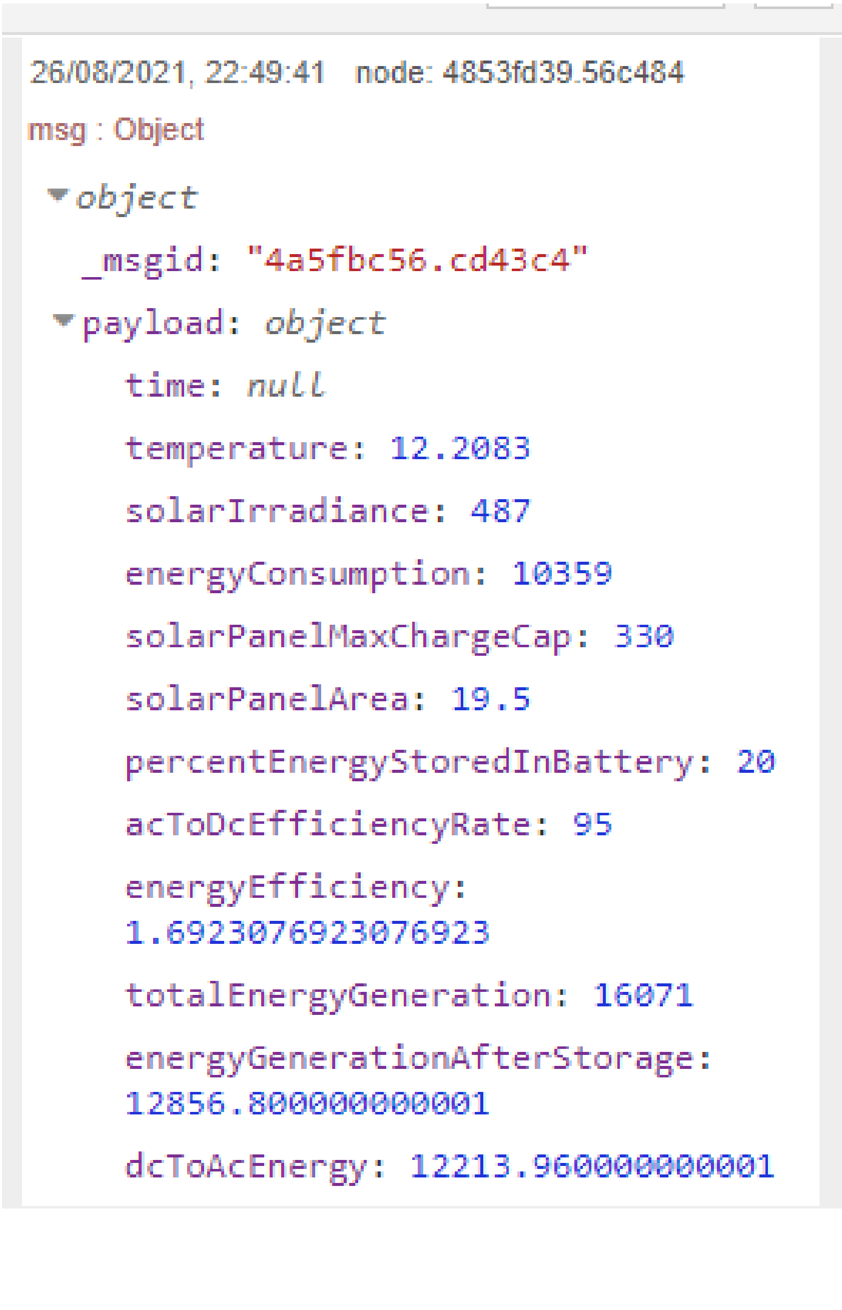


Figure 18: The variables and values entered in the inject node are displayed here

6.1.6 Dashboard Groups and Dashboard UI Page

As mentioned in the Node Red Research Design Section, its important to assign groups and tabs for each widget when working with Node Red Dashboard. We have created just a single tab named Utsav's Dashboard. The Form Node and Text Input Nodes are the two most important nodes in our simulation and are a part of Dashboard nodes. Since the Form Node enters the variables used for calculation, it comes under group name "[Utsav's Dashboard] Enter Values" and the Text Input node is used for displaying the results and comes under the "[Utsav's Dashboard] Output" group.

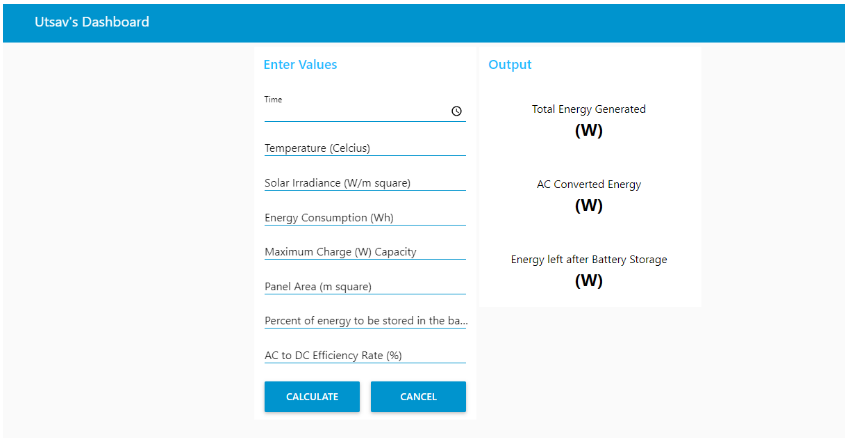


Figure 19: The Dashboard UI page is used for calculating and simulating our results

6.1.7 Formulas Used

The formulas used for our Microgrid Simulation involve the Total Energy Generation in a microgrid. Firstly, its important to know that our inputs are The Solar Panels Maximum Charge Capacity and Area, The Solar Irradiance and the The Energy requirements of the Consumer. The first formula involves calculating the

1. Energy Efficiency= [(330 / 19.5) / 1000/100]

   The maximum charge capacity for our Solar Panel is 330 Ah and the Are is 19.5 square meters. The 1000/100 value is used for converting the final result in its correct unit value. The energy efficiency value is always 1.6923 .

2. Total Energy Generation = Solar Panel Area * Energy Efficiency * Solar Irradiance

   The solar irradiance value varies throughout the day. This energy generated is DC Source and is converted to AC source.

3. AC Source Conversion = Total Energy Generation * 95/100
4. Battery Storage = AC Source Conversion * 20/100

6.2 Regression Analysis of Dataset

In the previous section, we discussed about each feature involving our goal and their importance. Now we will carry a research on finding the energy consumption of using each appliance and the cost for using those appliances.

The location for our experiment is a classroom within a microgrid environment. The classroom is around the size of 2000 square feet. The preferred number of students in the classroom is 60 but can accommodate up to 80 students at a time. The ideal temperature in a classroom is between 20-24 degrees and highly depends on the number of occupants present in the room. The classes take place from 9:00 a.m. in the morning till 8:00 p.m. in the afternoon. Their might be a few students who arrive before the classes start and stay after the classes end.

As mentioned earlier, the thermal comfort of occupants is in cooler conditions. As the number of occupants increase in the room, the relative humidity of the room goes up as well. The best way to tackle this is by using the installed HVAC system, as the air conditioner will quickly cool the room. The air conditioner on the other hand consumes a lot of electricity and has a sizeable cost as well. Moreover, as we decrease the temperature of the air conditioner to strengthen its effect, the price goes up. The problem here is that there's no alternative to a HVAC system in a classroom and its the best possible way to cool down a room. Ceiling and table fans are not used nowadays and the windows are always closed. Research in the field of indoor comfort is showing that lower winter temperatures (20°C) and higher summer temperatures (up to 25°C) can maintain comfort levels acceptable to most occupants, depending on other aspects of the building, relative humidity and the occupants' tolerance levels. To conclude this section, If number of people increase –> Temperature and Humidity increases —> Use of HVAC System –> Energy consumption and cost increases.

6.2.1 Energy Consumption and Cost for Appliances

We carried out an extensive research on finding the consumption and cost per hour for each of our electric appliance present in a room. They can be listed as HVAC System, Light Fixtures, Projector, Laptops and Mobile Phone Chargers and Lecturer Desktop. The values were found online on various Air Conditioner and Light Fixture company articles.

Appliance	Energy Consumption (Wh)
HVAC System	4000
Light Fixture	30
Laptop Charger	20W
Mobile Charger	10W
Projector	35W
Desktop	20W

Table 3: Electrical Appliance Energy Consumption Table

As you can see, the HVAC system is easily way ahead of its companions in consuming and costing energy. Additionally, there around 2-3 Air Conditioner's in a class which takes the total consumption way over. The light fixtures too have a very low energy consumption of 30 Watts, but this value is just for a single light fixture most classrooms usually have around 10 to 15 light fixtures. To test our research work, we made a few scenarios with different sets of students in a class and calculated the energy consumption and cost of the class. Each appliance costs 24 cents an hour to work on an average. On the basis of our scenarios, the energy consumption with the minimum amount of occupants i.e., 10 students is about 0.35kWh. As the occupants increase, the use of air conditioners increases. By this we mean that a class with 3 air conditioners only uses one air conditioner with 10 students even though, we cannot predict the student's seating. The capacities of the air conditioner is sufficient enough to cool the whole room. As the number students increase, the classroom then uses its remaining air conditioners. To calculate the energy consumption, we took the sum of each appliance's consumption and multiplied the sum by the overall time taken divided by thousand. The energy cost was calculated by multiplying the energy consumption by 24 cents.

Energy Consumption = (Total Sum) * (Time Taken/1000).

6.2.2 Factors and Correlations

The next step towards our Regression Analysis is to determine the Factors affecting the occupants thermal comfort and the room's energy consumption and energy cost. Earlier we discussed the features that are responsible for manipulating the thermal comfort and now we will look into the actual factors concur with thermal comfort.

We can divide our goals in two categories

1. Goal 1- Maintain Ideal Room Temperature in the class.

   The factors affecting this goal are Room Temperature, Outside Temperature, Relative Humidity, Number of Occupants and HVAC System.

   Here the room temperature is the entity we need to maintain throughout each class. The ideal temperature of the class can be between 20-24 degrees depending on the number of students. The Outside Temperature is among the substantial factors in determining the temperature within the class. Next, the number of occupants determine the relative humidity level of the classroom since, with the increase in occupants leads to increase in relative humidity. The preferable Relative humidity ranges between 40 and 50 and the ideal relative humidity for an individual is at 45. As mentioned earlier, the HVAC system is used for cooling the room down and is used to maintain and achieve the ideal room temperature. The HVAC system is preferable set at 22 degrees to cool the room and decreases as the number of students increase.

2. Goal 2- Do not exceed Energy Consumption and Energy Cost Limits.

   The factors affecting this goal are HVAC System, Light Fixtures, Additional Equipment Plug Loads, Solar Irradiance.

   We need to ensure that the energy consumption doesn't cross 1 kWh for a 1 hour class. Here, the energy consumption of each factor determines our total energy consumption. The Energy cost cost 24 cents at an average for each appliance per hour. The HVAC System is switched on at all times. They are used for both cooling and heating purposes. Its important to note that heating a room is much cheaper than cooling a room but again, the thermal comfort of an individual is in cooler conditions and depends on the weather.

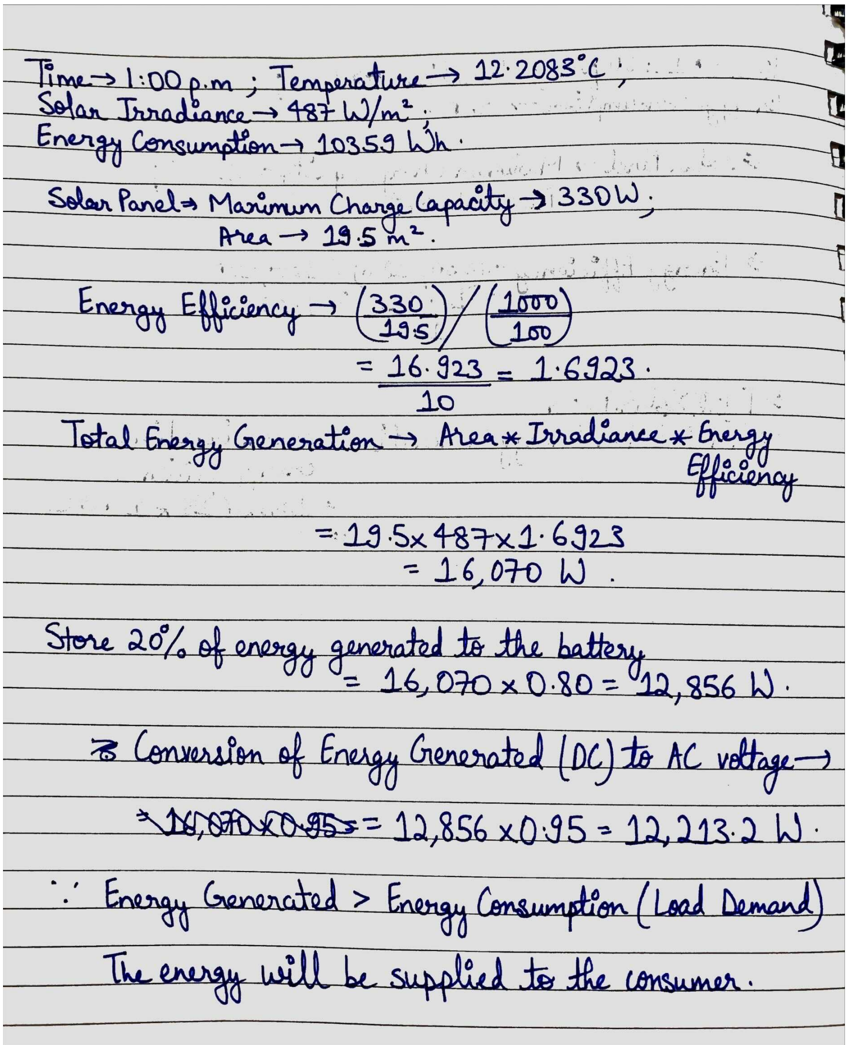
   The Additional Equipment Plug Loads refers to the combined consumption of Laptop and Mobile Chargers, Projector and Desktop energy loads. The Solar Irradiance here affects the usage of light fixtures in the room. During the day, each light fixture isn't used and only a number of light tubes are switched on. During noon time, the Solar Irradiance is at its peak and the class acquires ample amount of sunlight, which proves to be at a visual comfort level for the occupants. The Solar Irradiance however, doesn't affect the room temperature and relative humidity as the Sun's radiations do not determine the outside weather. For instance, the sun shines at occasions when its raining thus, leading to a cooler environment. Another example would be warmer and humid nights when there's no solar irradiance at all.

7 Results & Discussion

This section will discuss the results obtained throughout the trimester.

7.1 Node Red Simulation

In the previous section, we discussed the nodes we used in our simulation and how Node Red Dashboard UI looks like. Moving on, before we used our Dashboard UI for simulating and calculating energy generation, we carried a sample microgrid energy generation calculation on paper to verify our formulas and data collected were correct.


Time → 1:00 p.m ; Temperature → 12.2083°C ;
Solar Irradiance → 487 W/m² ;
Energy Consumption → 10359 Wh.

Solar Panel → Maximum Charge Capacity → 330 W ;
Area → 19.5 m².

Energy Efficiency → $\left(\frac{330}{19.5}\right) / \left(\frac{1000}{100}\right)$

$= \frac{16.923}{10} = 1.6923.$

Total Energy Generation → Area * Irradiance * Energy Efficiency

$= 19.5 \times 487 \times 1.6923$

$= 16,070$ W.

Store 20% of energy generated to the battery

$= 16,070 \times 0.80 = 12,856$ W.

Conversion of Energy Generated (DC) to AC voltage →

$\cancel{16,070 \times 0.95} = 12,856 \times 0.95 = 12,213.2$ W.

∵ Energy Generated > Energy Consumption (Load Demand)

The energy will be supplied to the consumer.

Figure 20: Sample Microgrid Energy Generation Calculation

In this sample, we have simulated the energy generation at 1:00 p.m. in the afternoon.

Our Temperature is 12.2083 Celsius, Solar Irradiance is 487 Watt per square meter and the Load Demand is 10,359 Wh for our microgrid environment. We have used our formulas to calculate the Energy Efficiency, Total Energy Generation, Energy Left after Battery Storage procedure and lastly, AC Voltage Conversion. To conclude, we were able to fulfill the consumers energy demand and our formulas and dataset is correct.

Our Node Red simulation contains the same formulas and asks the user for each distinct value to run the simulation. Node Red Dashboard UI makes the whole system more interactive and the user can manipulate and customise any value to their liking. As explained in the evaluation section, we have used Inject, Form, Function, three Text Input and Debug nodes for our simulation.

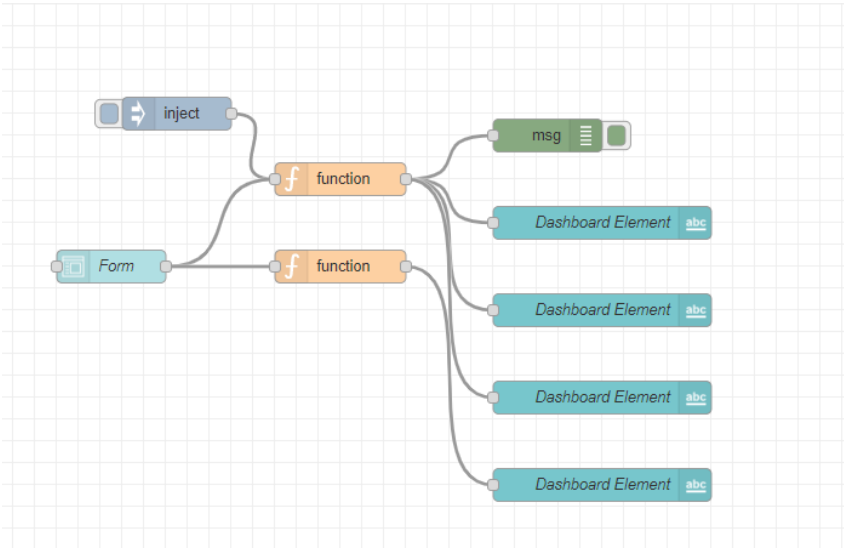


Figure 21: Node Red Simulation

Our final simulation and calculations are done on the Dashboard UI web page. The user needs to first enter the required values. once each value is entered, we can then press the Calculate button to see our results. The results are displayed on the right side of the image as depicted. For our simulation we entered time as 12:00 pm, when the solar energy is at its peak. The Solar Irradiance value is 745 Watt per square meter, Temperature is around the 15 degrees Celsius but the temperature doesn't affect our simulation. The energy consumption during 12:00 p.m. is 13567 Wh, depending on how any students are attending the campus. The maximum charge capacity and solar panel area are always the same. The percent of energy to be stored in the battery is 20 percent and the AC to DC Conversion rate is 95 percent.

On calculating these results, we get our total energy generation to be 24585.00 Wh. After storing 20 percent energy in our battery, we get 19668.00 Wh. And lastly, on

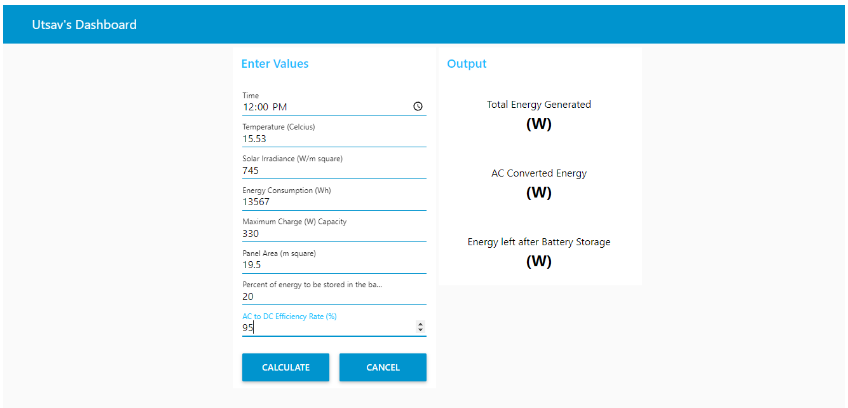


Figure 22: Entering values in Dashboard UI

converting the DC to AC Voltage we get 18684.60 Wh. Since, the AC Voltage energy generated is way more than the load demand/energy consumption, the microgrid than either stores the remaining energy back in the battery storage or sends it back to the main grid.

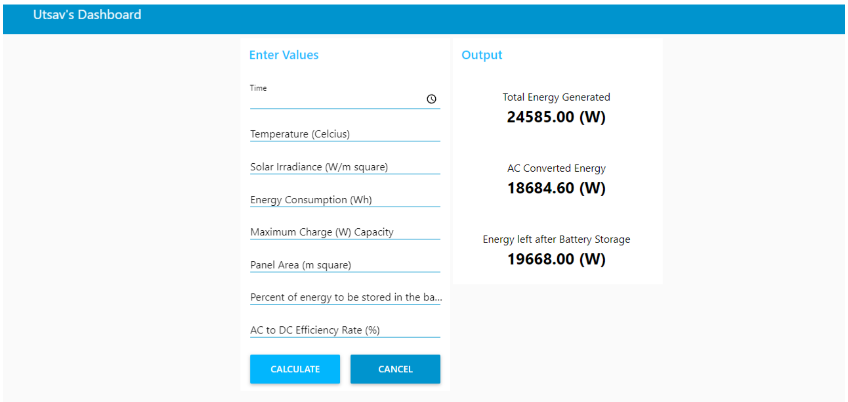


Figure 23: Final results in Dashboard UI

I've exported my simulation in a JSON file and uploaded it on Node Red. To run my simulation, you need to open Node Red and import my JSON file to check the simulation.

7.2 Regression Analysis of Dataset

In the previous sections, we discussed on what factors affect a classroom's indoor air temperature and quality, energy consumption and energy cost. We then formulated correlations between our goals and the factors having an influence on them. We will now discuss the Machine Learning method and Python code used for regression analysis and present our results and graphs for each correlation.

We have used Support Vector Machine and Linear Regression methods for our regression analysis. A Support Vector Machine (SVM) is a machine learning algorithm that is able to generalise between two different sets of classes if the set of labelled data is provided in the training set to the algorithm. The main function of the SVM is to check for the hyperplane that is able to distinguish between the two classes [19]. Support Vector Regression (SVR) uses the same principle as SVM, but is specifically used for regression related problems. Linear Regression on the other hand is used to predict the relationship between two variables i.e. the dependent variable and the independent variable.

```
# Import packages
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import seaborn as sns
from sklearn.svm import SVR
from sklearn.linear_model import LinearRegression
from sklearn.pipeline import make_pipeline
from sklearn.preprocessing import StandardScaler

# Read the data
data = pd.read_csv("C:\\Users\\Utsav Sharma\\OneDrive\\Desktop\\data.csv")
data
```

Figure 24: Importing libraries for Regression

We start of our code by importing the required libraries and packages. The numpy and pandas library is imported in Jupyter Notebook and pandas reads the csv file, which contains our dataset. Next we perform some tasks to understand our code by checking its Shape which indicates the number of rows and columns, Info to check if there are any null values in the data and lastly Describe to see if there's a huge jump or variation in the data file. Our next step is to start visualizing our data to determine the correlations between factors. We begin by generating a heatmap of the data.

As you can see, the Room Temperature seems the most correlated to the Number of Occupants. We will now present our graphs based on the goals discussed in the previous section.

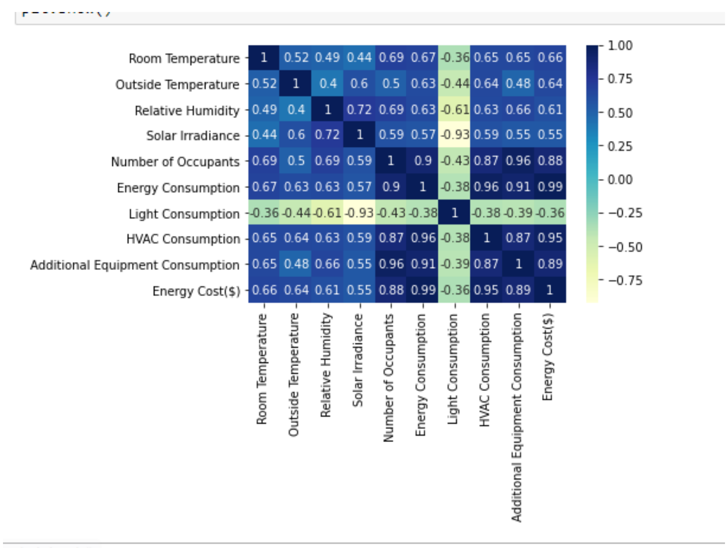


Figure 25: Heatmap of the dataset

7.2.1 Maintaining an Ideal Room Temperature

Our dependent variable is the Room Temperature and its factors are Outside Temperature, Relative Humidity, Number of Occupants and HVAC Consumption.

1. Room Temperature vs Outside Temperature

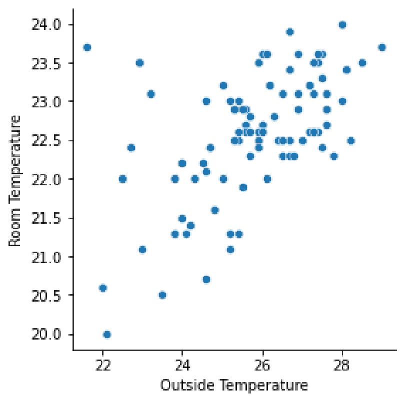


Figure 26: Room Temperature vs Outside Temperature

As the outside temperature increases the room temperature increases as well. There's always a difference of 2-4 degrees between the two but are directly proportional to each other. The only moments during the day when these two factors are almost the same is before the classes begin.

2. Room Temperature vs Relative Humidity

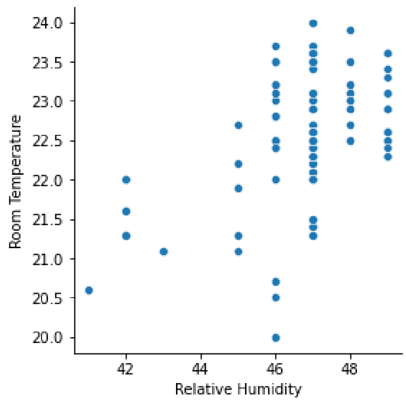


Figure 27: Room Temperature vs Relative Humidity

As the Relative Humidity of the class increases the room temperature increases as well. The relative humidity of the class depends highly on the number of occupants. As the occupants increase the relative humidity goes up and when the occupants decrease, the relative humidity reduces too.

3. Room Temperature vs Number of Occupants

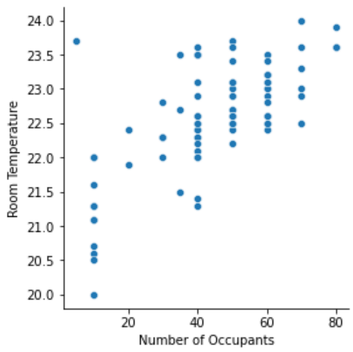


Figure 28: Room Temperature vs Number of Occupants

As explained above, the number of occupants play a huge role in increasing the relative humidity of the room hence, increasing the room temperature as well. The occupants in the room are between 10-80 during the day.

4. Room Temperature vs HVAC Consumption

The HVAC Consumption plays the predominant role in decreasing the room temperature and achieving our goal of maintaining an ideal temperature. As the graph suggests, the room temperature increases and the HVAC consumption increases as well. The HVAC works throughout the day and has a major impact in the total energy consumption as well. The use of HVAC again depends on

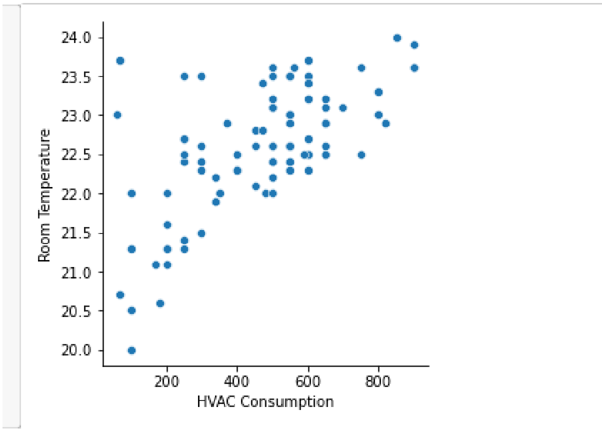


Figure 29: Room Temperature vs HVAC Consumption

the number of occupants in the room. As our occupants increase in number the HVAC consumes more power to maintain each occupant's thermal comfort level.

7.2.2 To ensure Energy Consumption and Energy Cost during a class is within limits

We will present two sets of graphs with our dependent variable being the Energy Consumption and Energy Cost. Its factors will be HVAC Consumption, Light Fixtures Consumption, Additional Equipment Consumption and Solar Irradiance.

1. Energy Consumption vs HVAC Consumption

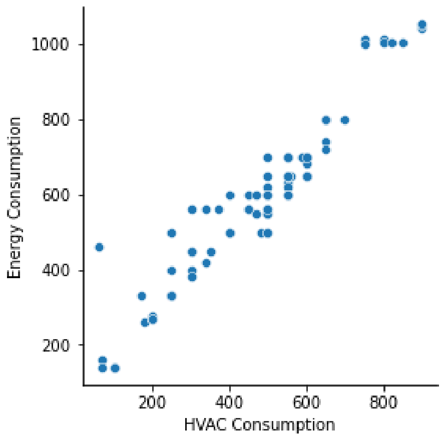


Figure 30: Energy Consumption vs HVAC Consumption

The HVAC consumes majority of the electricity available inorder to achieve the thermal comfort of our occupants. It works throughout the day and essentially determines the total energy consumption of the classroom.

2. Energy Consumption vs Light Fixtures Consumption

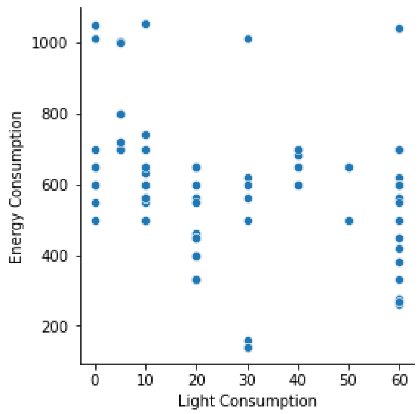


Figure 31: Energy Consumption vs Light Fixtures Consumption

The light fixtures don't have a major impact on the energy consumption of the class. As evident in the graph, there are a few instances where the high light consumption values have low energy consumption values. Light Fixtures have a much better correlation to the Solar Irradiance data.

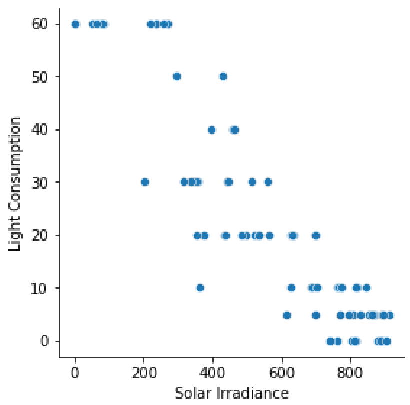


Figure 32: Light Fixtures Consumption vs Solar Irradiance

As the Solar Irradiance intensifies, the light fixtures in the class are switched off. Once the sun sets, the light fixtures are used throughout the duration of the classes for the occupants visual comfort.

3. Energy Consumption vs Additional Equipment's Consumption

The additional equipment plug loads too don't have major emphasis on the final energy consumption. However, the Consumption of these plug interestingly increases with the increase in the number of occupants in the room. As the

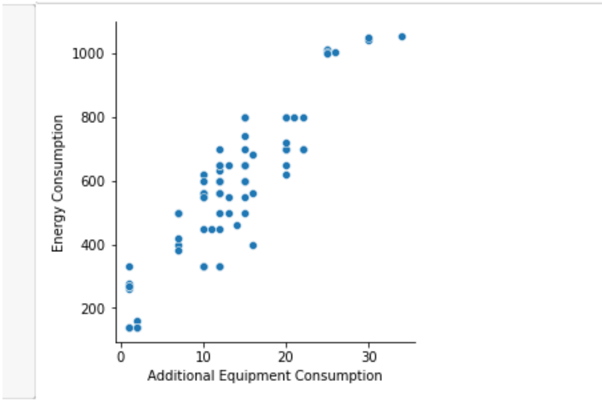


Figure 33: Energy Consumption vs Additional Equipment's Consumption

number of occupants increase, the number of devices in the room increase as well. These devices require sufficient power to run and thus, the occupants charge these devices.

4. Energy Cost vs HVAC Consumption

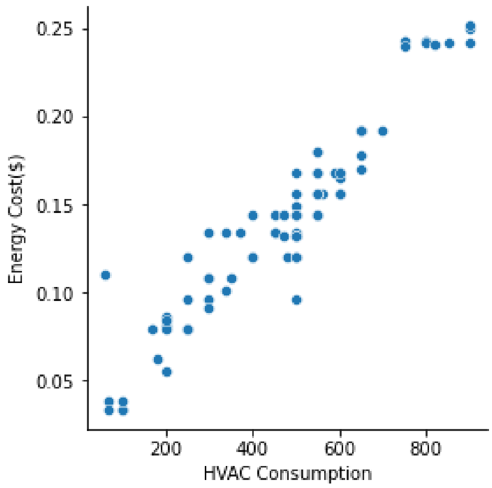


Figure 34: Energy Cost vs HVAC Consumption

The HVAC consumes majority of the electricity which leads to a heavy cost for using this system.

5. Energy Cost vs Light Fixtures Consumption

The light fixtures don't consume much and thus, don't cost much as well.

6. Energy Cost vs Additional Equipment's Consumption

The additional equipment plug loads too don't have major emphasis on the final energy cost.

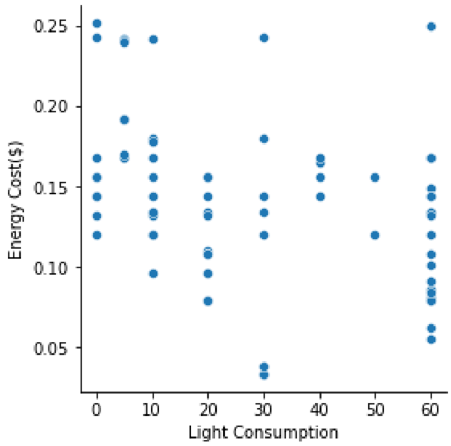


Figure 35: Energy Cost vs Light Fixtures Consumption

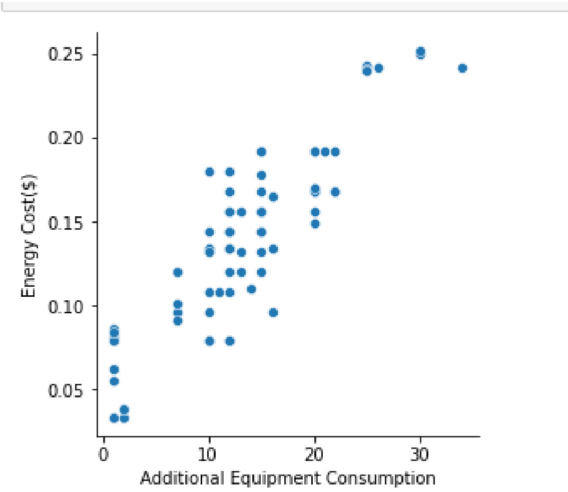


Figure 36: Energy Cost vs Additional Equipment's Consumption

7.2.3 Final Results

The graphs above indicate that HVAC Consumption is the primary source for achieving Thermal Comfort in the room but in return it consumes a lot of electricity and costs a heavy sum for its use. Our Dependent Variables throughout the whole process i.e. Room Temperature, Number of Occupants, Energy Consumption and Energy Cost are correlated to each other. After all, we are determining the Energy Consumption while trying to maintain an Ideal Room Temperature. The same goes for the energy cost and number of occupants.

Our goal is to achieve thermal comfort and not exceed energy consumption limit i.e. 1 kWh for a 1 hour class. But with the increase in occupants, it becomes difficult to achieve our goals. We have come to a conclusion that having 30 occupants for a class is ideal and helps in achieving our goals. Still we can stretch the number of students up to 60 at a time but once we allow 70 or 80 occupants in the room, we fail to achieve our goals.

1. Room Temperature vs Energy Consumption

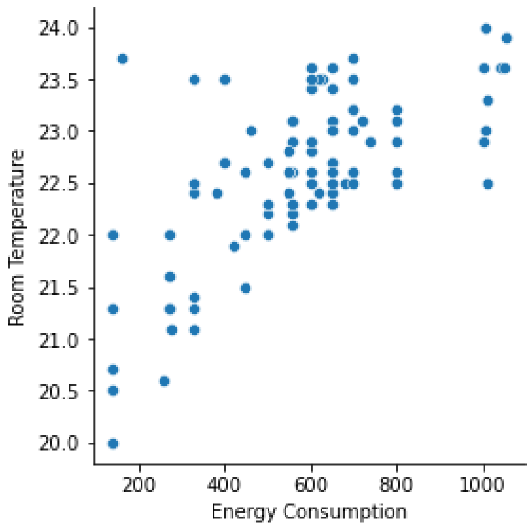


Figure 37: Room Temperature vs Energy Consumption

As the room temperature increase the energy consumption increases as well solely, because of the HVAC Consumption working in full force. Similarly, with the rise in energy consumption, the energy cost increases as well.

2. Number of Occupants vs Energy Consumption

As the number of occupants increase in the room, the room temperature goes up which leads to a higher energy consumption as well. Again, with the rise in energy consumption, the energy cost increases as well.

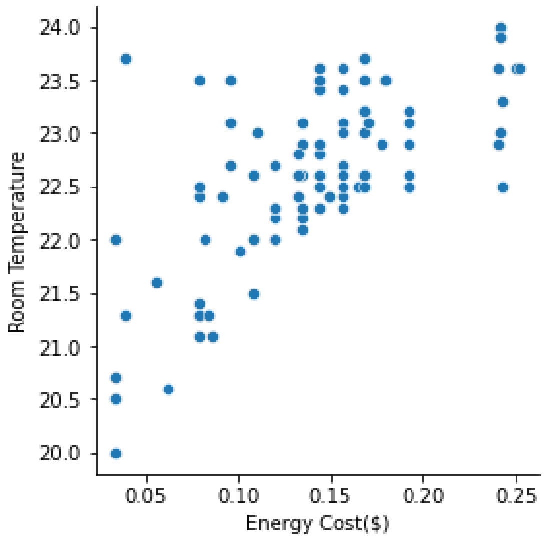


Figure 38: Room Temperature vs Energy Cost

8 Threats to Validity

1. This project is low risk as it does not require any real-life services and all the tests are carried out in a controllable environment locally. There are still a few minor risks which can cause problems in the virtual environment for instance, the database used for our simulation has been stored in an Excel file. Excel files can limit development speed and the amount of storage space. Online databases such as MySQL, MongoDB or Firebase FireStore are much faster and are better options than Excel sheets as they take minutes to do what Excel takes to do in an hour. Additionally, MongoDB or MySQL allow us to visualise data with much less effort.

2. Our microgrid simulation was done on Node Red. Node Red is a GUI system and is inclined towards giving its users an interactive experience. Its not an ideal tool for simulating a microgrid since, we cannot display solar panels and battery storage systems. Instead we can insert nodes and name them the following and enter real-time values to get the job done.

3. Regression Analysis is an elite method for determining and predicting the relationship between two variables. Our dataset at the time doesn't contain many values and even contains data from different sources. The functional relationship that is established between any two or more variables on the basis

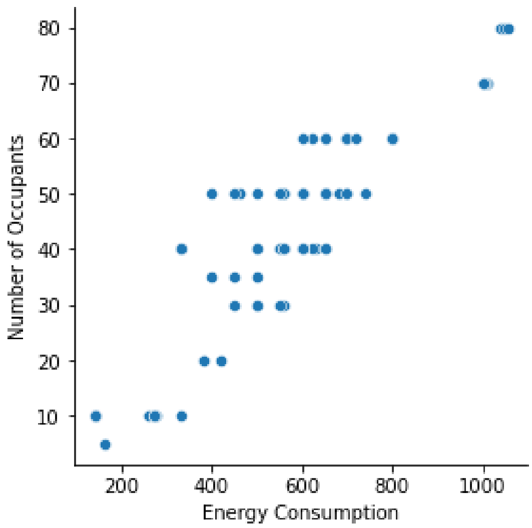


Figure 39: Number of Occupants vs Energy Consumption

of some limited data may not hold good if more and more data are taken into consideration. Additionally, regression analysis involves very lengthy and complicated procedure of calculations and analysis. Its assumed that the relationship between two variables on the basis of regression equation may lead to erroneous and misleading results.

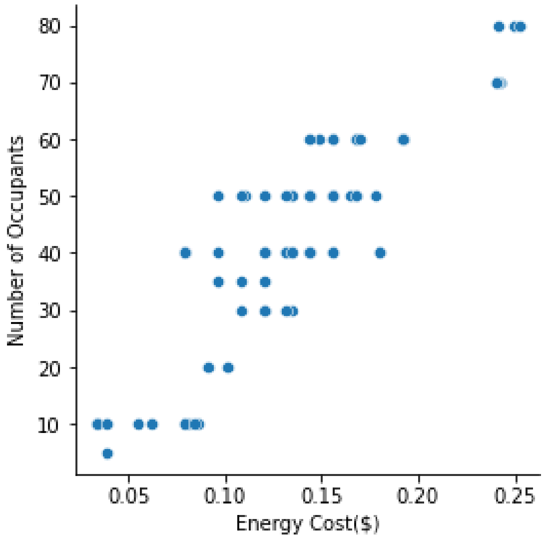


Figure 40: Number of Occupants vs Energy Cost

9 Conclusion & Future Work

9.1 Conclusion

The aim of this paper is to prove that with the increasing number of occupants in a classroom, it becomes difficult to achieve the Thermal Comfort of the room. Thermal Comfort of the room depends on the Room Temperature and individual Relative Humidity and can be achieved by using HVAC System. We used Regression Analysis for our artefact evaluation and additionally, made a microgrid simulation on Node Red since our classroom is based in a microgrid environment.

For our Regression Analysis, we firstly formulated a Metrics Table involving important factors, which have a direct impact on occupants thermal comfort. We then researched on the energy consumption and energy cost for running an effective classroom. Lastly, we identified our main goals and made a correlation between each factor. The Thermal Comfort and Energy Consumption of the classroom was heavily determined by the use of the HVAC system since, it was the primary source for achieving Thermal Comfort and keeping our occupants satisfied. For our simulation, we used Node Red's Dashboard module because of its highly interactive nature. Our simulation simply calculated the total energy generation in a microgrid system and checked if the energy generated was sufficient enough to be supplied to its consumers.

Our Regression Analysis concluded that the ideal number of occupants in a classroom is between 50 to 60 but, once we exceed these many number of occupants our energy consumption goals fail and it becomes much more difficult to maintain the ideal temperature of the classroom. The final graphs indicated that Room Temperature and Number of Occupants have a direct relation to the Energy Consumption of the room since, with the increase in occupants leads to increase in room temperature which ultimately leads to a higher energy consumption value.

9.2 Future Work

In the coming future, we would like to automate the complete system and make the system more intelligent. During our artefact process our plan was to collect real-life room temperature and relative humidity data using sensors in our University classroom. Due to the ongoing pandemic and everlasting lockdown in Melbourne, our university was closed down and we had to use dummy data in our dataset.

Our eventual plan was incorporate Machine Learning Algorithms to our Node Red simulation. The system would then be capable of making its own decisions and would have found ways to heal itself in time of crisis. Our Regression Analysis and simulation couldn't be used together due to these downfalls. In case we hadn't faced these drawbacks, our solar microgrid system simulation would've resulted and shown many interesting insights.

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