ANALYZING ELECTRICITY BILL DATA TO BRING RESIDENTIAL BUILDINGS CLOSER TO NET – ZERO

BY TEAM 15 – RESIDENTIAL ENERGY EVALUATOR

FOR WIPRO CLIMATE CHALLENGE 2022

CONTENTS:

DIAGRAMS & PICTURES:

I. TEAM MEMBERS:

- Kausar De – Leader, Web Service Lead
- Moubani Sen – Analytics Lead
- Kaustav Laskar – IoT & Service Lead
- Subhajit Bag – Hardware Lead

II. PROBLEM IDENTIFIED:

- Residential buildings are responsible for a third of the world's final energy consumption, yet there is no benchmark for evaluating their energy usage
- Monthly energy consumption data for buildings exists in the form of electricity bills, but is not utilized for benchmarking or consumption analysis
- New buildings are being designed for net – zero, but if the existing building's energy consumption is not reduced, net – zero goals will not be achieved
- Older buildings are not compatible with modern smart appliances and lack a digital footprint, making it hard to track their consumption

III. TARGET MARKET DETAILS:

We are targeting middle – income, single – family households as a beachhead market. We will use this as a foundation to target high – income households and housing societies, and establish our presence in the Indian Sustainable Housing Market, valued at 20 billion USD by the World Bank.

IV. SOLUTION APPROACH:

Having previous experience in data analytics and machine learning, and coming from an engineering background, the team was in agreement that data science has some of the highest potential for accelerating the transition to net – zero infrastructure and circular economy. Seeing the lack of a benchmarking system for residential building energy consumption despite the influence that sector has on global energy consumption was alarming, and was also a hurdle to our data science approach, as we cannot say someone is efficient or inefficient if there is no baseline. So, our ideation began with finding a way to assign an Energy Performance Index (EPI) to buildings. The format for the EPI came from the Bureau of Energy Efficiency (BEE)'s Building Labelling Program. However, since building energy consumption data is not open source, the idea of pulling metrics from an existing dataset were shelved. Then, we realized that every building generates monthly consumption data in the form of electricity bills. Again, since this data is not open source, we needed users to provide it to us. That is why the web portal was ideated not only as a dashboard and interface for the user to engage with the solution, but to also serve as an onboarding and data collection point. But just collecting past consumption data would be inadequate, and asking users to repeatedly upload bill data is tedious. And thus, we decided to develop a monitoring circuit to get live consumption data and also eliminate the chance for human error. In order to actually achieve energy savings without human intervention, we also decided to pursue automatic appliance control such as light dimming and fan speed control based on sensor data. Extensive infrastructure data such as flat area, appliance data and number of occupants from the portal and live consumption metrics from the circuit can be utilized by a machine learning and statistics – based model to generate forecasts and also point out the specific reasons for a specific user's efficiency or inefficiency compared to the standard. Now, in order to accumulate users, we needed to find the right approach to communicate value to the consumer. As we are all aware, nobody has the right to force a homeowner to purchase specific appliances or run them at a specific set point, even if it is the most efficient or environmentally – friendly option. Therefore, we decided that the best way to pitch the solution to clients would be to highlight the benefits that align with their lifestyle, goals and aspirations, as seen in the upcoming section.

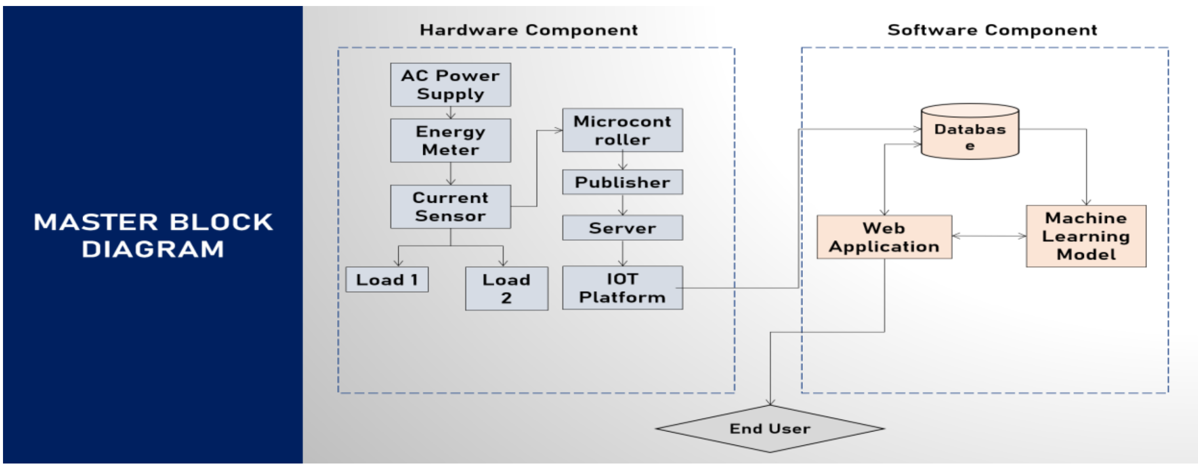

Fig. IV.I: Master Block Diagram of Solution

V. TECHNICAL DETAILS – WEB PORTAL:

The web portal has been developed using Python's Django framework, HTML, CSS, JavaScript and Bootstrap. The database is made in PostgreSQL. The website has been hosted on Heroku. The static files and the database itself have been hosted on Amazon AWS.

A. Why Django?

Django is a very powerful, versatile and scalable backend development framework that utilizes Python. It is used by industry giants such Instagram, Disqus and Wall Street Journal. The features that make it the ideal backbone for our portal are as follows:

- Model – View – Template (MVT) architecture simplifies data querying and URL pathing
- Built – in security features make website safe effortlessly
- Easy to scale up to handle large traffic
- Myriad of supported frameworks and modules to add features to website
- Active open – source community patches out exploits and improves framework regularly

These factors, along with the fact that multiple team members are well versed in Python, led us to choose Django to build the portal.

B. Website Features:

- Login & registration system where users register their properties without sharing personal data
- Email system for communicating registration, password resets and benchmark results
- Personal dashboard for each user
- Separate specialized admin dashboard
- Listing of flats on database
- Benchmarking against flats of same category as well as against past data
- Detailed data collection, including appliance data
- Benchmark page for each flat featuring past consumption, EPI and per occupant consumption metrics

C. How MVT Architecture Works:

Model refers to the table schema for collecting data from the user and saving it to the database. Models are created in the models.py file, where all the data fields are specified, including type of data accepted and default values. If models make references to each other using foreign keys, those are also coded here. In terms of database, each model is a table and all the fields within the model are the different columns of the table. Most models are user – defined, but some, such as the User model, are built – in. Each model must be registered in the admin panel before they can be interacted with, and any changes or new models must be migrated to the databases in order to update the table schemas. Fields specific to certain DBMS systems are also supported, provided the connected database supports them.

Views are simply Python functions which handle all the dynamic elements of a website. Each page in the website requires a view specific to it, and that view handles everything from rendering the website to filling in forms and querying data requested by the user from the database. URLs to each page specify the corresponding view. Views can be given additional properties, such as requiring the user to be logged in, using decorators.

Templates are the pages of the website, built using HTML, CSS and JavaScript. Templates support inheritance like classes, allowing us to program a base template, the contents of which will be present in any inheriting templates. Website components such as navbars can be programmed as separate templates, and can be included in other pages as per the programmer's discretion. If the programmer chooses to use a frontend framework such as React to develop the frontend of the website, the template system can be circumvented entirely by using REST APIs to connect the Django backend to the React frontend. Fundamentally, templates are the user – facing component that enables CRUD operations and showing the output to the user.

The following graphic helps illustrate this better:

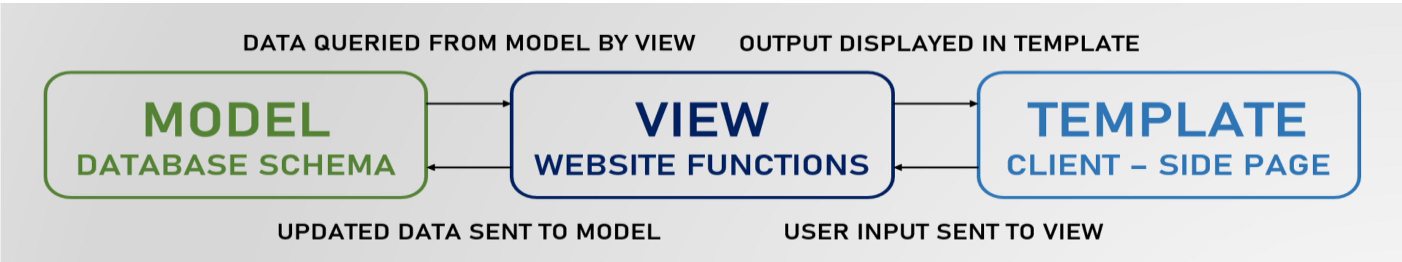

Fig. V.I: MVT Architecture Graphic

D. Model Schema UML Diagram:

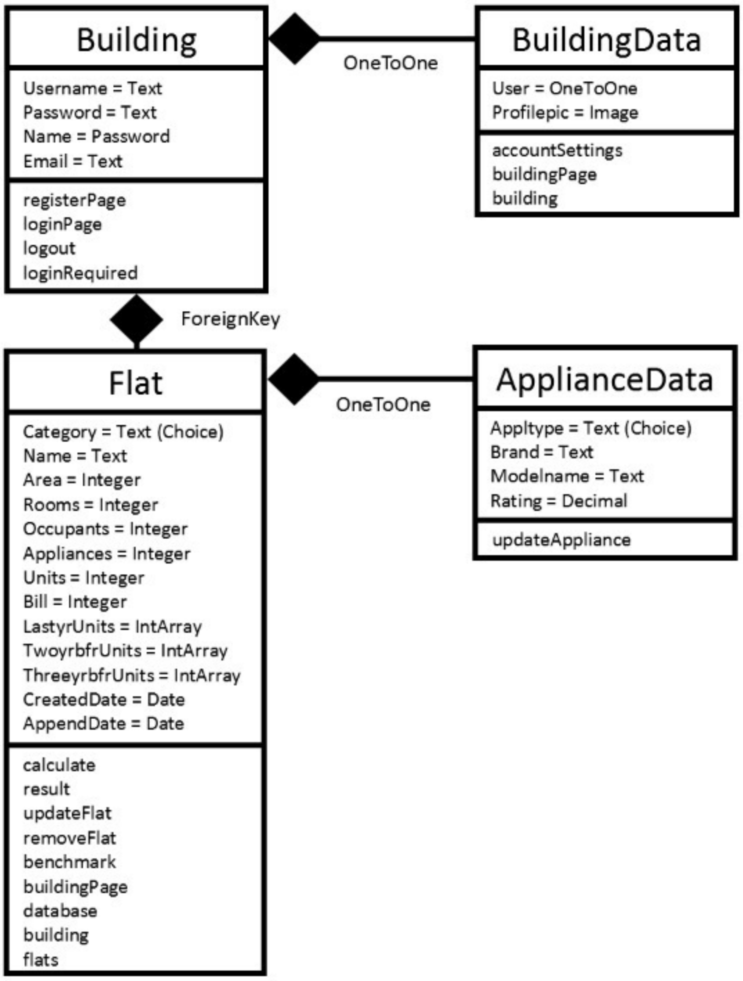

Fig. V.II: Portal UML Diagram

E. Screenshots:

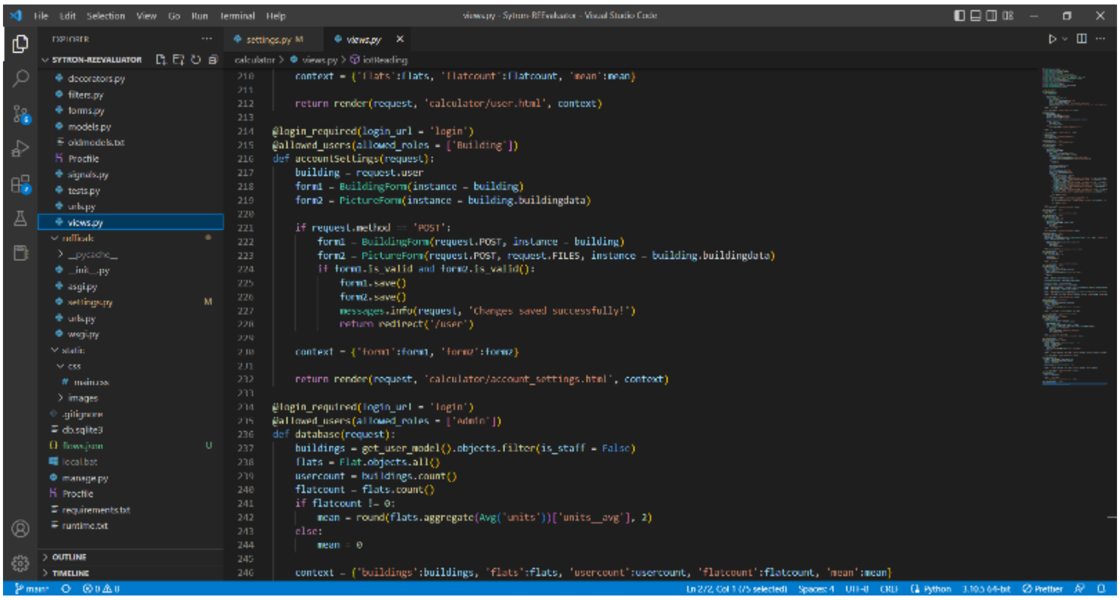

Fig. V.III: Code screenshot of views.py file

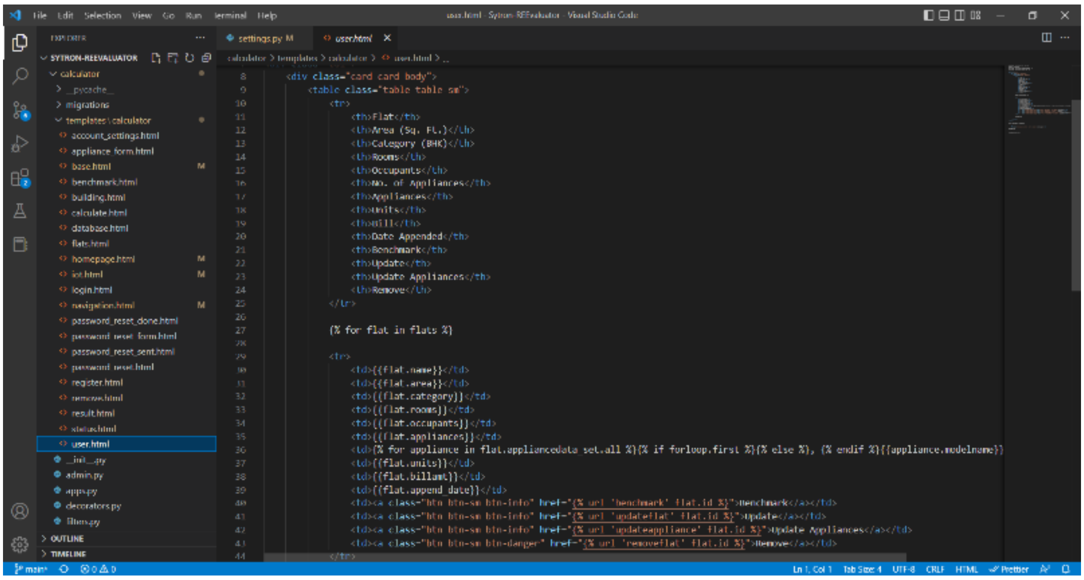

Fig. V.IV: Code screenshots of User Dashboard Template

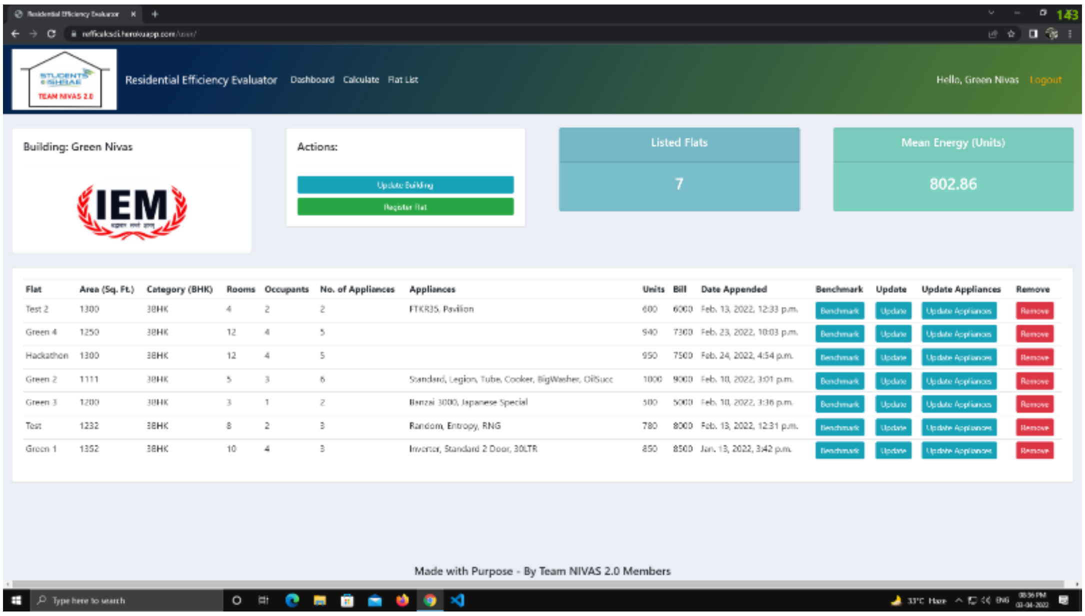

Fig.V.V : User Dashboard*

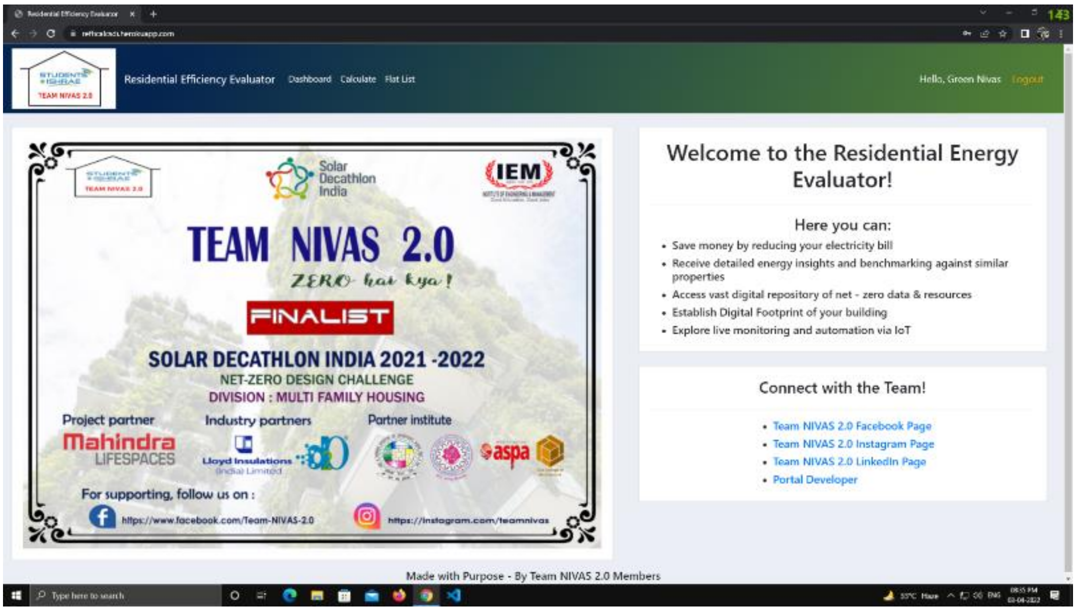

Fig. V.VI: Homepage*

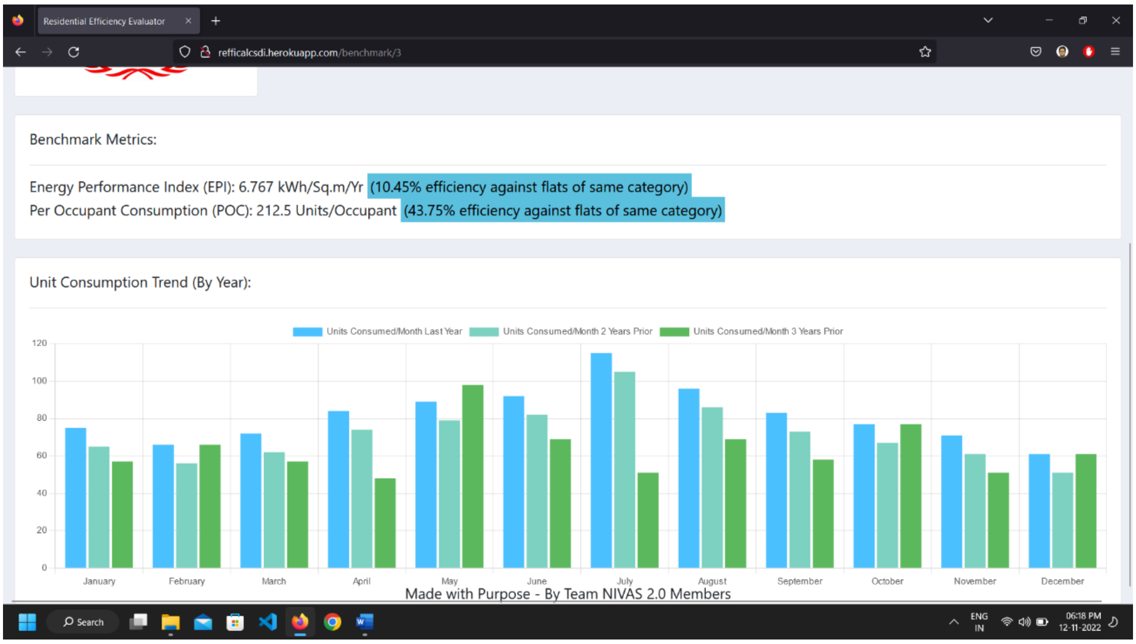

Fig. V.VII: Benchmark Results*

*Subject to change in near future

F. Important Frameworks & Modules Used:

Dj-database-url: Allows database to be accessed from URL

Django-filter: Allows filtering of search results

Django-storages: Routes static files to S3 bucket

Psycopg2: PostgreSQL adapter for Django

Pillow: Image rendering handler for python

Gunicorn & Whitenoise: Enables cloud – based hosting

Django-admin: Built – in admin panel

Smtplib: Built – in SMTP tools for emailing

VI. TECHNICAL DETAILS – MONITORING & AUTOMATION:

IoT describes the network of physical objects that are embedded with sensors, Software and other technology for the purpose of connection and exchanging data with system over internet.

A. IoT Technology and Protocol:

- Z-Wave: Z-Wave may be a low-power RF communications for IoT technology design for home automation for products such as lamp controllers and sensors among many other devices.
- Wi-Fi: Wi-Fi connectivity is one among the most popular IOT communication protocol, often a clear choice for many developers, especially given the supply of Wi-Fi within the home environment within LANs.
- Cellular: IoT application can be operated from a long distance with the help of 3G/4G/Cellular. While cellular is clearly capable of sending high quantities of knowledge especially for 4G, the value and also power consumption will be too high for many applications. But it often ideal for sensor-based low-bandwidth-data projects that will send very low amounts of data over the Internet.

B. What Does IoT Software Actually Do?

- Data Collection
- Device Integration
- Real Time Analytics

- Application & Process Extension

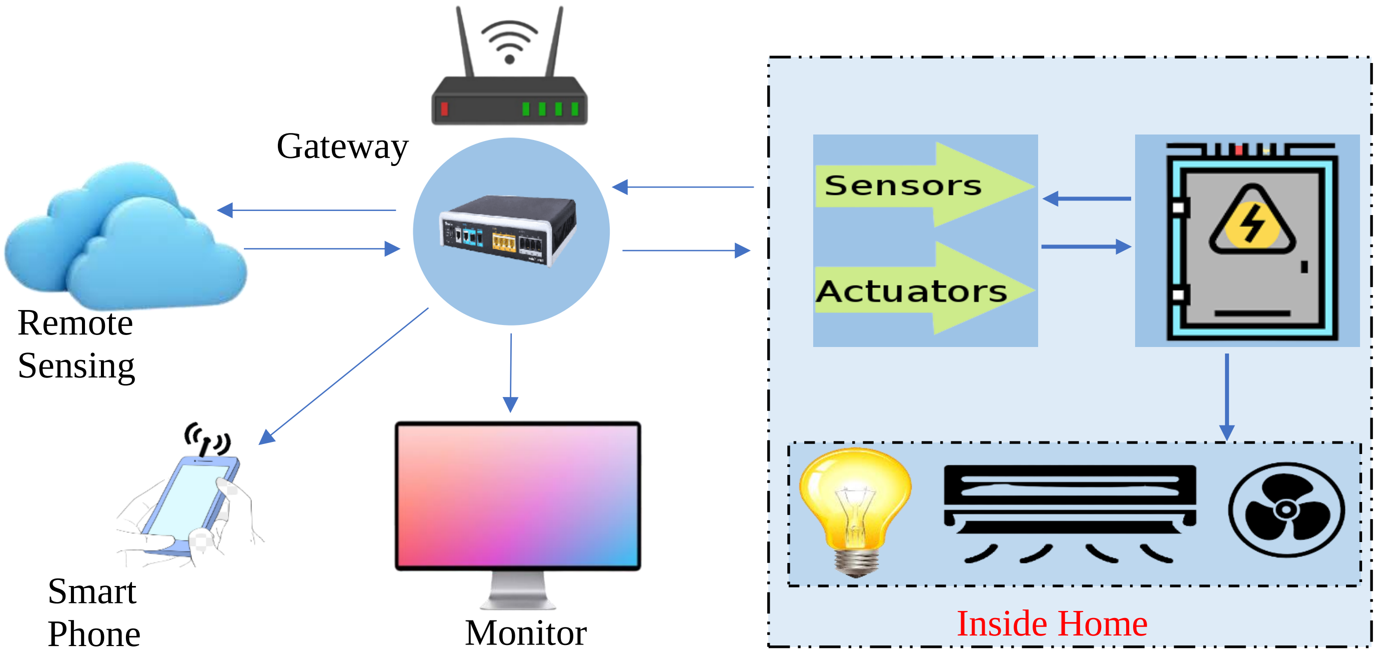

Fig. VI.I: IoT Connection Overview

C. Node MCU

Node MCU is an open – source platform based on ESP826. It includes firmware which runs on the Wi-Fi SoC from Espressif Systems. Both the firmware and prototyping board designs are open source. The firmware use Lua scripting Language. The firmware is based on eLua project and build on the Espressif Non-OS SDK for ESP8266. It uses many open – source projects such as lua-cjson and SPIFFS.

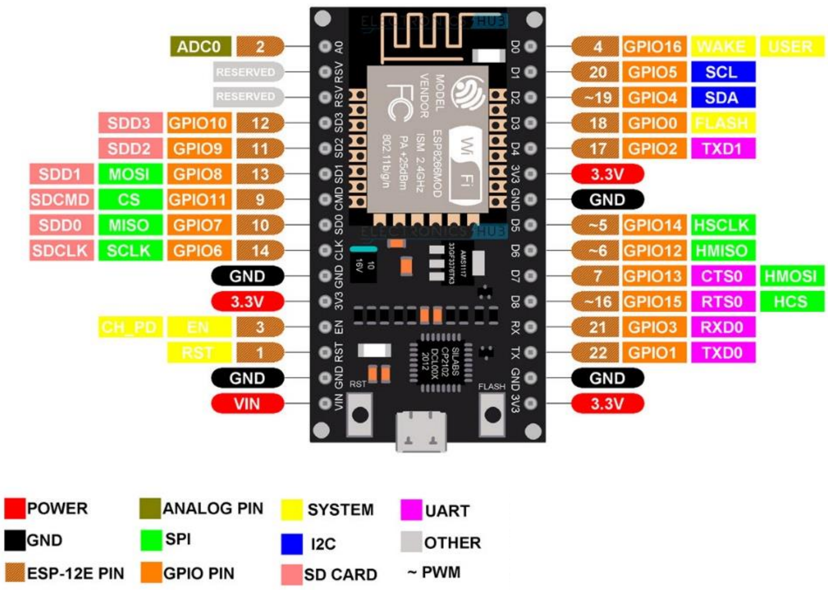

Fig. VI.II: PIN Configuration of NodeMCU

D. Our Proposed Design:

The Block Diagram gives the overall idea of the project. The MCU unit is the main controlling unit of the system. The user uses the mobile to set the functionality of the appliances. The mobile appliance interprets the command from the user in the form of voice of switch and sends the signal to MCU Board through a wireless network. The NodeMCU then finally switches appliance on/off and manipulates them through relay. There is also a display unit which display the status of appliance.

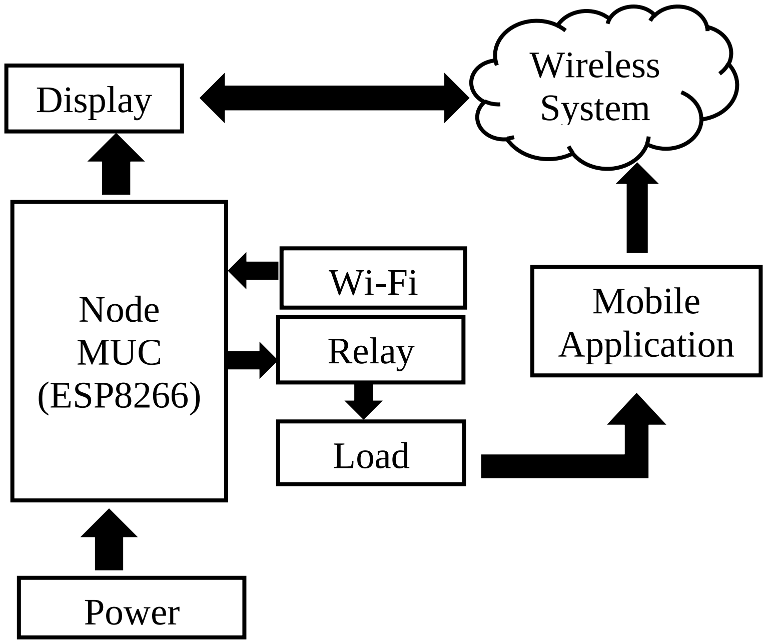

Fig.VI.III: IoT Design Block Diagram

Sensor Used:

- Temperature sensor
- Flux sensors
- Water level sensors
- Air composition sensors
- Pressure sensors
- Humidity sensors
- Infrared sensors
- Vibrations sensors
- Ultrasonic sensors

E. Main Features of the Prototype:

- The prototype establishes a wireless remote switching system of home appliances.
- The command to switch an appliance on or off can be given from radio buttons on the app from one's smartphone.
- There's also a provision developed to use voice commands on smartphone to engage with home appliances.
- Can be used with any Wi – Fi enabled device.
- Displays the status of each appliance on the app in smartphone.
- Cost effective.

F. Project Layout:

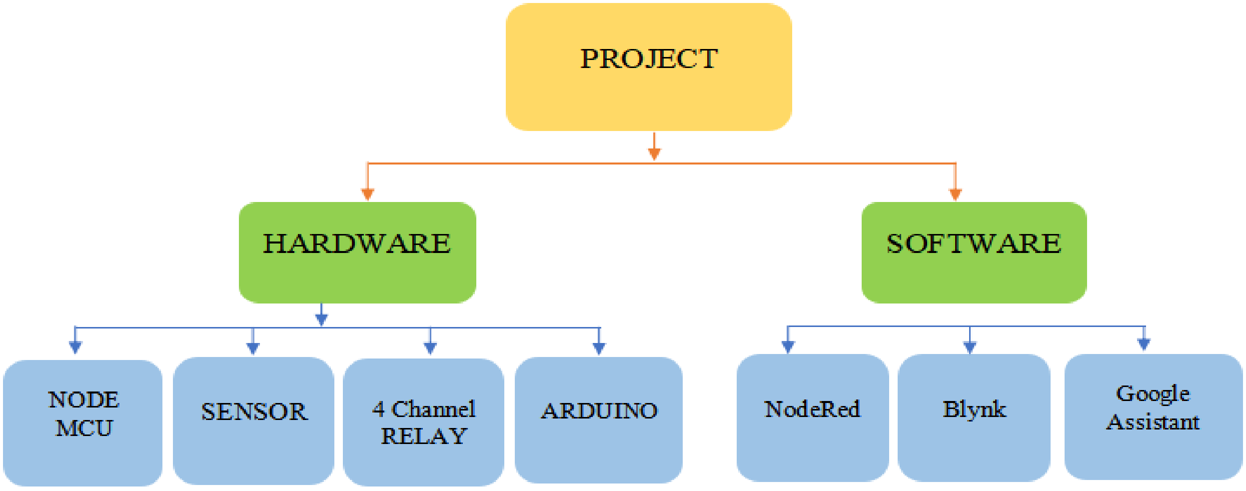

Fig. VI.IV: Hardware Project Layout

Advantages of NodeMCU:

- Low cost, the Node MCU is cheaper than any other IOT grounded device.
- Node MCU has Arduino Like I/O.
- Node MCU has fluently configurable network API.
- Reduced size of board.
- Low power consumption

Disadvantages of NodeMCU:

- Dependent on internet connection
- Requires learning a new language and a new interface.
- Reduced pinout.
- Scarce documentation.

```
/*
* Simple HTTP get webclient test
*/
#include <ESP8266WiFi.h>
const char* ssid = "handson"; // key in your own SSID
const char* password = "abc1234"; // key in your own WiFi access point password
const char* host = "www.handsontec.com";
void setup() {
 Serial.begin(115200);
 delay(100);
 // We start by connecting to a WiFi network
 Serial.println();
 Serial.println();
 Serial.print("Connecting to ");
 Serial.println(ssid);

 WiFi.begin(ssid, password);

 while (WiFi.status() != WL_CONNECTED) {
 delay(500);
 Serial.print(".");
 }
 Serial.println("");
 Serial.println("WiFi connected");
 Serial.println("IP address: ");
 Serial.println(WiFi.localIP());
}
int value = 0;
void loop() {
 delay(5000);
 ++value;
 Serial.print("connecting to ");
 Serial.println(host);

 // Use WiFiClient class to create TCP connections
 WiFiClient client;
```

```
}
int value = 0;
void loop() {
 delay(5000);
 ++value;
 Serial.print("connecting to ");
 Serial.println(host);

 // Use WiFiClient class to create TCP connections
 WiFiClient client;
 const int httpPort = 80;
 if (!client.connect(host, httpPort)) {
 Serial.println("connection failed");
 return;
 }

 // We now create a URI for the request
 String url = "/projects/index.html";
 Serial.print("Requesting URL: ");
 Serial.println(url);

 // This will send the request to the server
 client.print(String("GET ") + url + " HTTP/1.1\r\n" +
 "Host: " + host + "\r\n" +
 "Connection: close\r\n\r\n");
 delay(500);

 // Read all the lines of the reply from server and print them to Serial
 while(client.available()){
 String line = client.readStringUntil('\r');
 Serial.print(line);
 }

 Serial.println();
 Serial.println("closing connection");
}
```

Fig. VI.V& VI.VI: Code of Connection of NodeMCU

s

```
int RelayControl1 = 4; // Digital Arduino Pin used to control the motor
int RelayControl2 = 5;
int RelayControl3 = 6;
int RelayControl4 = 7;
void setup()
{
 Serial.begin(9600);
 pinMode(RelayControl1, OUTPUT);
 pinMode(RelayControl2, OUTPUT);
 pinMode(RelayControl3, OUTPUT);
 pinMode(RelayControl4, OUTPUT);
}
void loop()
{
 digitalWrite(RelayControl1,HIGH);// NO1 and COM1 Connected (LED on)
 delay(1000);
 digitalWrite(RelayControl1,LOW);// NO1 and COM1 disconnected (LED off)
 delay(1000);
 digitalWrite(RelayControl2,HIGH);
 delay(1000);
 digitalWrite(RelayControl2,LOW);
 delay(1000);
 digitalWrite(RelayControl3,HIGH);
 delay(1000);
 digitalWrite(RelayControl3,LOW);
 delay(1000);
 digitalWrite(RelayControl4,HIGH);
 delay(1000);
 digitalWrite(RelayControl4,LOW);
 delay(1000);
}
```

Fig. VI.VII: Code of Connection of Relay

G. Physical Prototype Development Update:

First Prototype (Lab Validation):

We developed and validated a prototype circuit in our EES lab that is capable of reading current data from a load bank that simulates the simultaneous load of multiple appliances in a real flat. It sent that data to a cloud platform via the IoT technology discussed above.

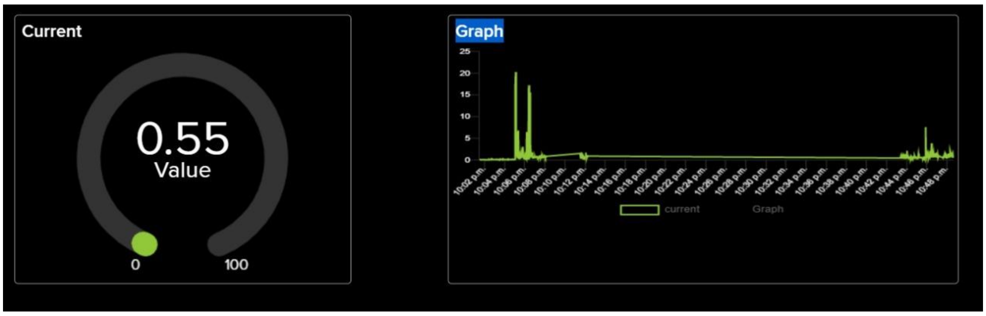

Fig. VI.VIII Current Reading on Cloud Platform

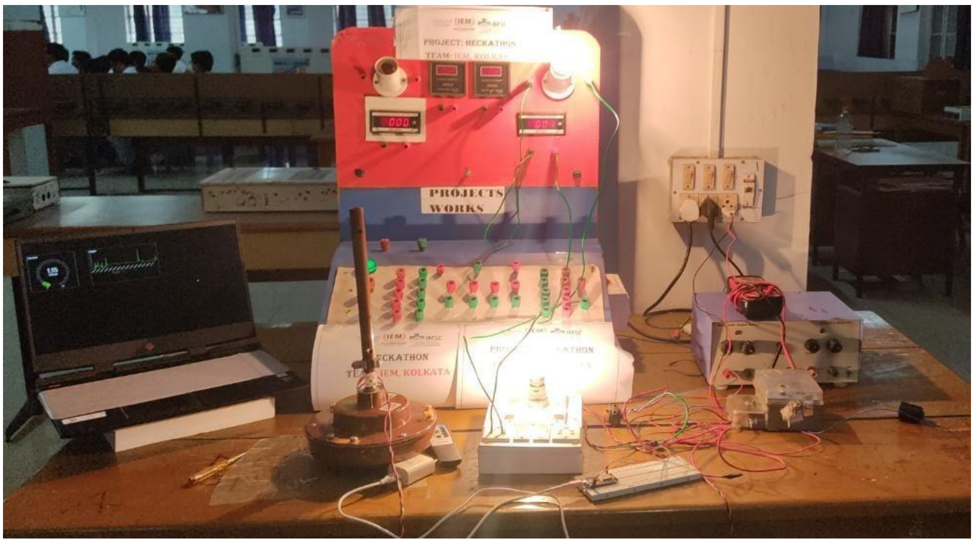

Fig. VI.IX: Lab Prototype in Action

Current Prototype (Automation Testing):

We have developed a prototype with a new load box which will serve as a base for developing automation technology, starting with dimming lights and controlling the speed of BLDC fans using sensor data.

H. Component List & Purpose:

- 0-15AMP 96*96MM Digital Ammeter – Measures load current
- 0-500V 96*96MM Digital Voltmeter – Measures load voltage
- 0-2500W 96*96MM Digital Wattmeter – Measures active power
- 0-30AMP Energy meter – Measures energy consumed
- Havells 20AMP Double Pole MCB – Protection switch
- Philips 100W Bulb, Celling Fan – Used to simulate domestic load
- 220V Red Indicating Bulb, Pritam One Way Switch – Circuit control apparatus
- PVC Angle Holder – Holds lightbulbs in load box
- 3 Pin 15AMP Pritam Socket Switch – Main connector to Load box

Fig. 6.10: New Components in Isolation

Fig. 6.11: Current Prototype for Automation Testing

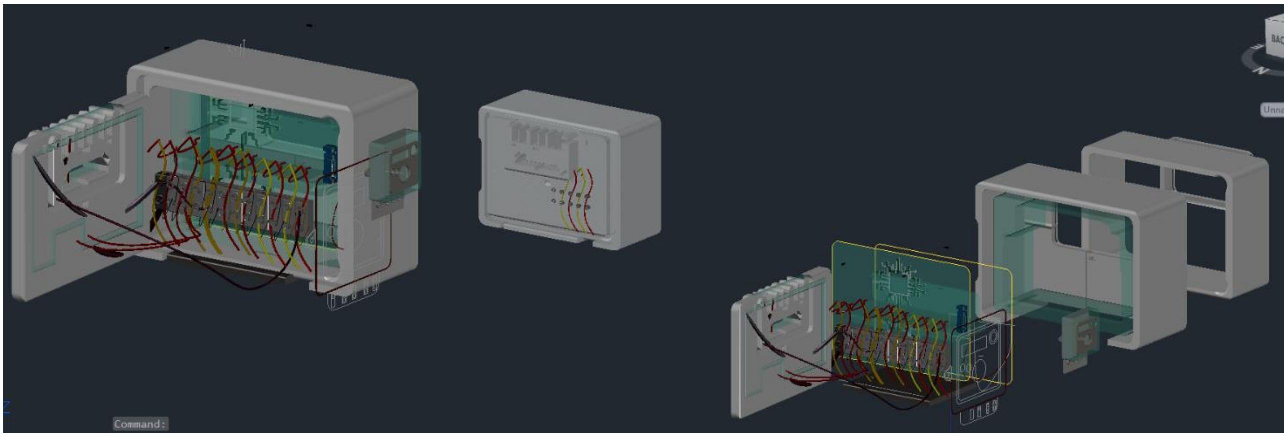

Fig. 6.12: Concept 3D Model of Commercial Kit

VII. TECHNICAL DETAILS – DATA ANALYSIS:

A. Background:

To achieve low-carbon economic development, which is a common objective of most countries, increasing energy efficiency is a crucial step. In a bid to achieve the same there has been extensive research done on the use of artificial intelligence in energy conservation already to read patterns, examine and analyze them. This project especially has used time series analysis, forecasting, machine learning techniques, and artificial intelligence to increase the efficiency of the output.

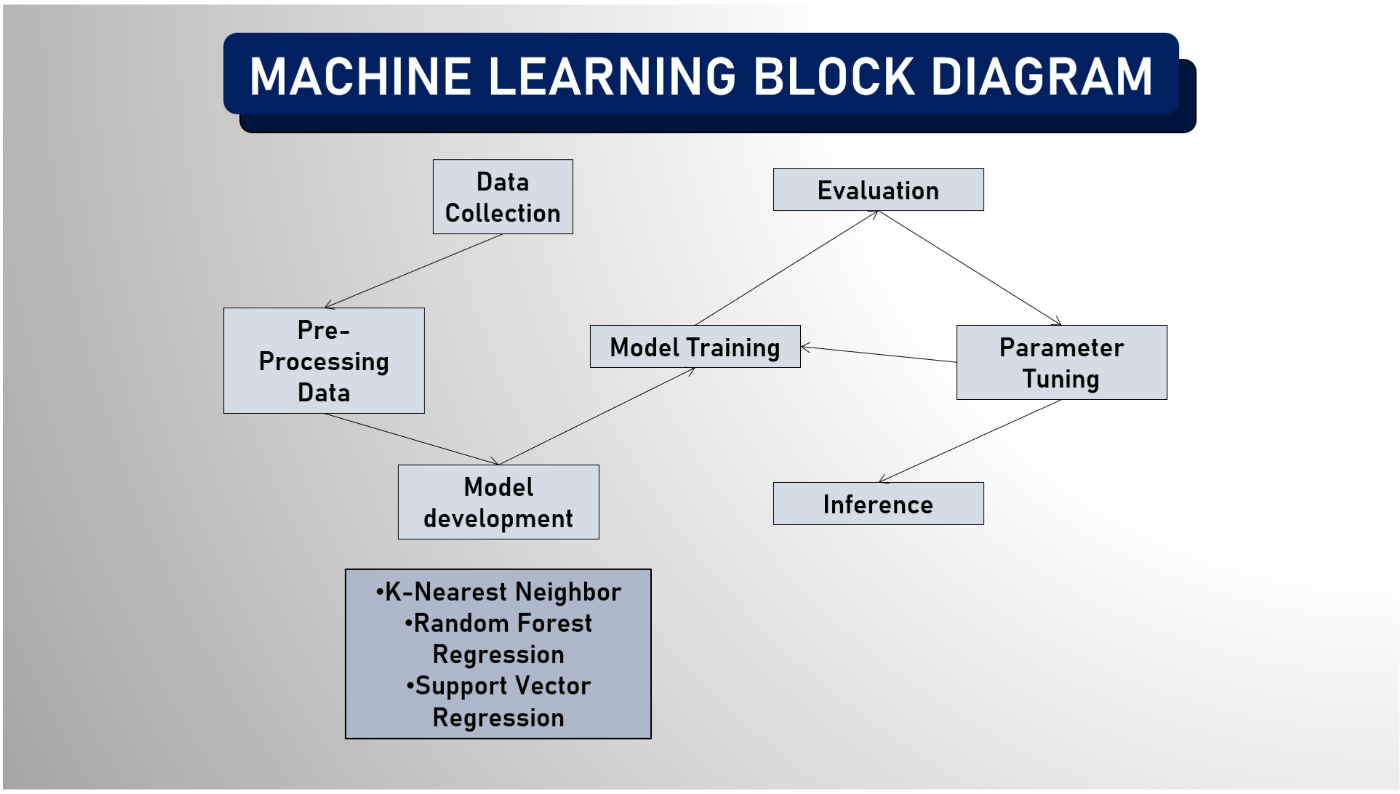

Fig. 7.1: Machine Learning Block Diagram

The first step in improving an existing home is to undertake a home energy assessment, also known as an energy audit, to learn how your home uses energy and identify the most effective strategies to reduce energy use and expenditures. While the cloud-based portal collects your information to register you and give you the relevant insights, the algorithms that have been developed aid in accurately providing those insights by learning from previously observed habits and behavior that it intercepts and identifies.

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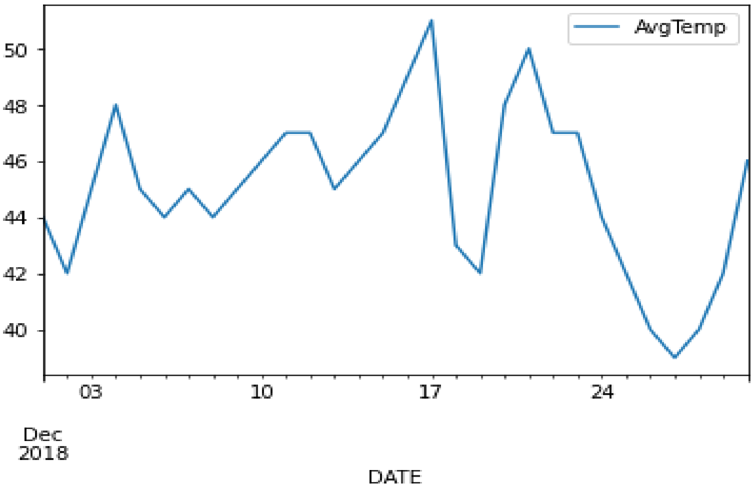

Fig. 7.2: Graph Showing Prediction of Average Temperature Over December 2018

B. Algorithms Used:

Machine learning algorithms like K nearest neighbor or KNN, random forest, and support vector were initially used to generate predictions.

To forecast the values of any new data points, the KNN algorithm uses "feature similarity". Basically, the value given to the new point depends on how much it resembles the points in the training set.

A random forest regressor is a meta predictor in which the dataset's numerous sub-samples are subjected to a number of classification decision trees and utilizes averaging to increase predicted accuracy and reduce over fitting.

The supervised learning approach called Support Vector Regression (SVR) was also employed to forecast discrete values. The Support Vector Machines (SVM) and SVR both operate on the same theory that is determining the optimum fit line.

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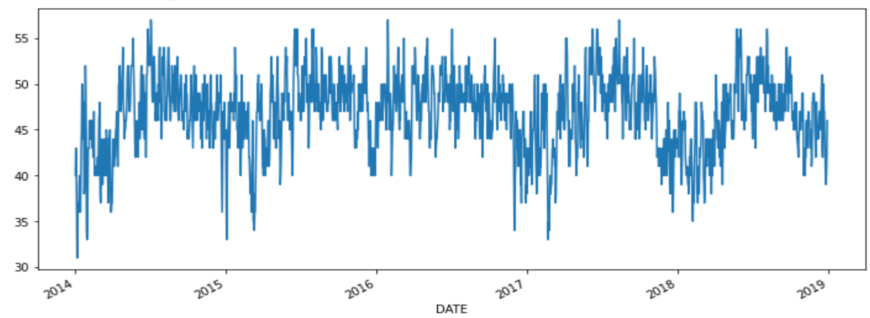

Fig. 7.3: Graph Showing Prediction of Average Temperature Over Given Years

Model Results:

After putting these 3 models to the test on real data sets, the resultant predictions' accuracy was 0.722, 0.788 and 0.766 respectively. Consequently, we determined that random forest regressor algorithm was the best.

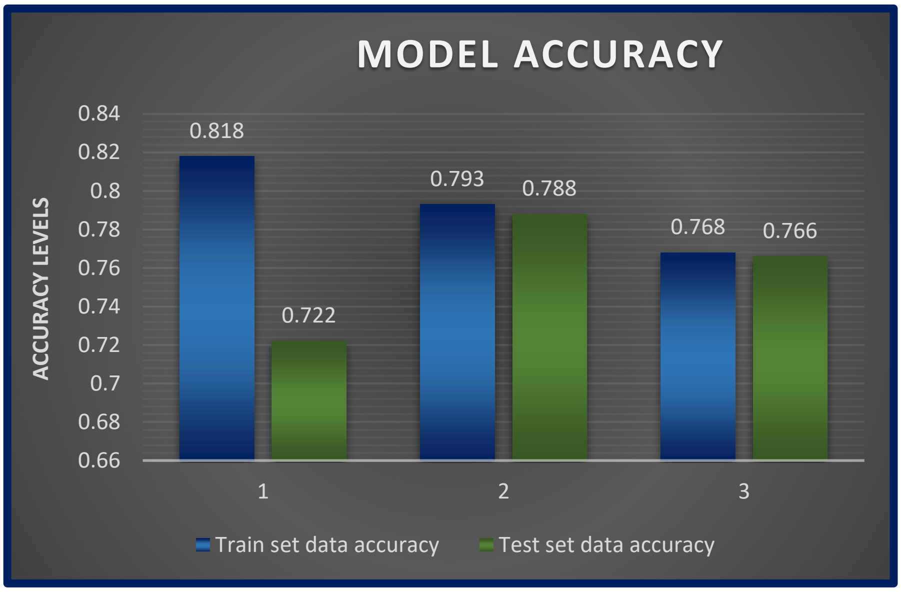

Fig. 7.4: Model Accuracy Graph

C. Statistics Component:

In the following stage, we used the ARIMA (Autoregressive Integrated Moving Average) model to further improve the accuracy of our prediction-making algorithms to improve the accuracy of our prediction-making algorithms. The model is employed to comprehend past information or forecast subsequent data in a series.

It transforms a non-stationary time series into a stationary one via differencing and then forecasts future values using historical data. In order to predict future values, these models employ "auto" correlations and moving averages over residual errors in the data. Python is the language and the platform is Google Colab used for the developing algorithms.

```
[ ] from pmdarima import auto_arima
    #import warnings
    #warnings.filterwarnings("ignore")
```

```
[ ] stepwise_fit = auto_arima(df['AvgTemp'],trace=True,
                              suppress_warnings=True)

    stepwise_fit.summary()
```

```
Performing stepwise search to minimize aic
 ARIMA(2,0,2)(0,0,0)[0] intercept   : AIC=8344.456, Time=3.66 sec
 ARIMA(0,0,0)(0,0,0)[0] intercept   : AIC=10347.755, Time=0.06 sec
 ARIMA(1,0,0)(0,0,0)[0] intercept   : AIC=8365.701, Time=0.22 sec
 ARIMA(0,0,1)(0,0,0)[0] intercept   : AIC=9136.225, Time=0.38 sec
 ARIMA(0,0,0)(0,0,0)[0]             : AIC=19192.139, Time=0.04 sec
 ARIMA(1,0,2)(0,0,0)[0] intercept   : AIC=8355.947, Time=2.19 sec
```

Fig. 7.5: Implementation of the ARIMA Model

D. Current Status:

We at the moment are modifying the NBeats wave generating model to better our forecasts and results. The model is basically made up of a series of stacks, each of which combines many blocks. The blocks use forecast and backcast links to connect feed forward networks. We are learning, comprehending, and attempting to utilize for betterment of the project.

```
 USER: XYZ
PREVIOUS MONTH CONSUMPTION: 245 units
PRESENT MONTH CONSUMPTION: 301 units
 USAGE: ↑
NEXT MONTH CONSUMPTION PREDICTION: 310 units
WARNING!!!
 TO DECREASE ENERGY CONSUMPTION FOLLOW THE RECOMMENDATIONS PROVIDED BY OBSERVING YOUR ENERGY CONSUMPTION PATTERN
 1. Switch off standby.
2.Change your light bulbs to LEDs.
3.Don't leave bathroom or kitchen ventilation fans running longer than necessary.
4.Use natural light when possible.
```

Fig. 7.6: Example of Outcome for Customers

E. Impact on Circular Economy:

A key tenet of sustainable business and industrial activities is the circular economy.

As part of the circular economy, we must account for the natural resources we take from and utilize in daily operations and, to the extent practical, restore them to their former states. This includes everything from air and water to habitats. Additionally, everything we use must have a pathway for reuse or recycling, either directly or through a process or sector that is nearby.

Therefore, with this effort, we wish to take a step and encourage others to follow suit in order to assist accomplish a broader goal, which is to minimize carbon footprint and aid in the fight against global warming.

VIII. FUTURE PLANS & IDEAS:

A. Web Portal:

- Improved user interface
- Automatic data reading from bill soft copy
- Hosting migrated to AWS fully
- Benchmarking report in PDF format

B. Hardware Kit:

- Automatic appliance control (e.g., light dimming, fan speed control)
- Current readings directly from MCB
- Compact box packaging to be sold commercially
- Alternative IoT platform to handle increased scalability

C. Data Science Model:

- Specific reasons for deviation from benchmark
- Ability to flag unique cases such as uncommon appliances
- Personalized savings recommendations
- Novel datasets for use in research and net zero policy decision making

IX. BUSINESS MODEL

A. Our Deal:

We (Residential Energy Evaluator) are selling Energy Portfolio Management and Home Automation services to single family households and housing societies for a subscription fee worth 10% of the value we help save. Our automation service requires the purchase of a hardware kit costing INR 10000.

B. Customer Profile:

Our ideal customer is a middle to high income individual living and working in a metropolitan city. They are either single or have a nuclear family. They have become a homeowner recently. They lead a very busy, fast – paced life and are very aspirational and career – driven. They are well educated and are aware of the climate crisis, and are interested in supporting initiatives and products that pave the way towards a net zero economy. Their motivations are rooted in wanting a better, sustainable life for themselves, their loved ones and their future generations.

The customer does extensive market research via online and peer recommendation methods into finding products that can save them time and money while causing minimum lifestyle disruption. They are able to afford a moderate financial commitment, provided the benefit is clearly communicated to them. They appreciate features that give a luxurious feel. The product's impact on their carbon footprint is also a major consideration.

This customer persona has been developed after surveying more than a hundred such workers living in Kolkata, Pune and other metro areas.

C. CVP:

We appeal to our customer's desire to reduce recurring costs by providing up to 40% projected electricity bill savings if they invest in our automation kit. By reducing energy consumption, our product achieves comparable carbon footprint reduction. Appliance automation saves time, achieves actual energy savings without needing human intervention and also provides a luxurious feeling, and the investment required is kept reasonable, further aligning with the customer's values and lifestyle. Our detailed consumption and benchmarking metrics also ensure that the consumer is made aware of the value they are receiving from our innovation and the improvement to their efficiency.

D. Revenue and Impact Projections:

The World Bank projects the Indian Sustainable Housing Market to be worth 20 billion US Dollars.

Therein, our beachhead market of Kolkata constitutes roughly 1,07,000 households. Assuming we are able to achieve 5% of that market share in our first year, even if we earn INR 130 profit from each customer, we are looking at a profit of over 6.5 million INR.

Assuming the same amount of market captured, we project energy consumption reduction equivalent to 32480 tonnes of CO_2, which corresponds roughly to over 3000 acres of trees.

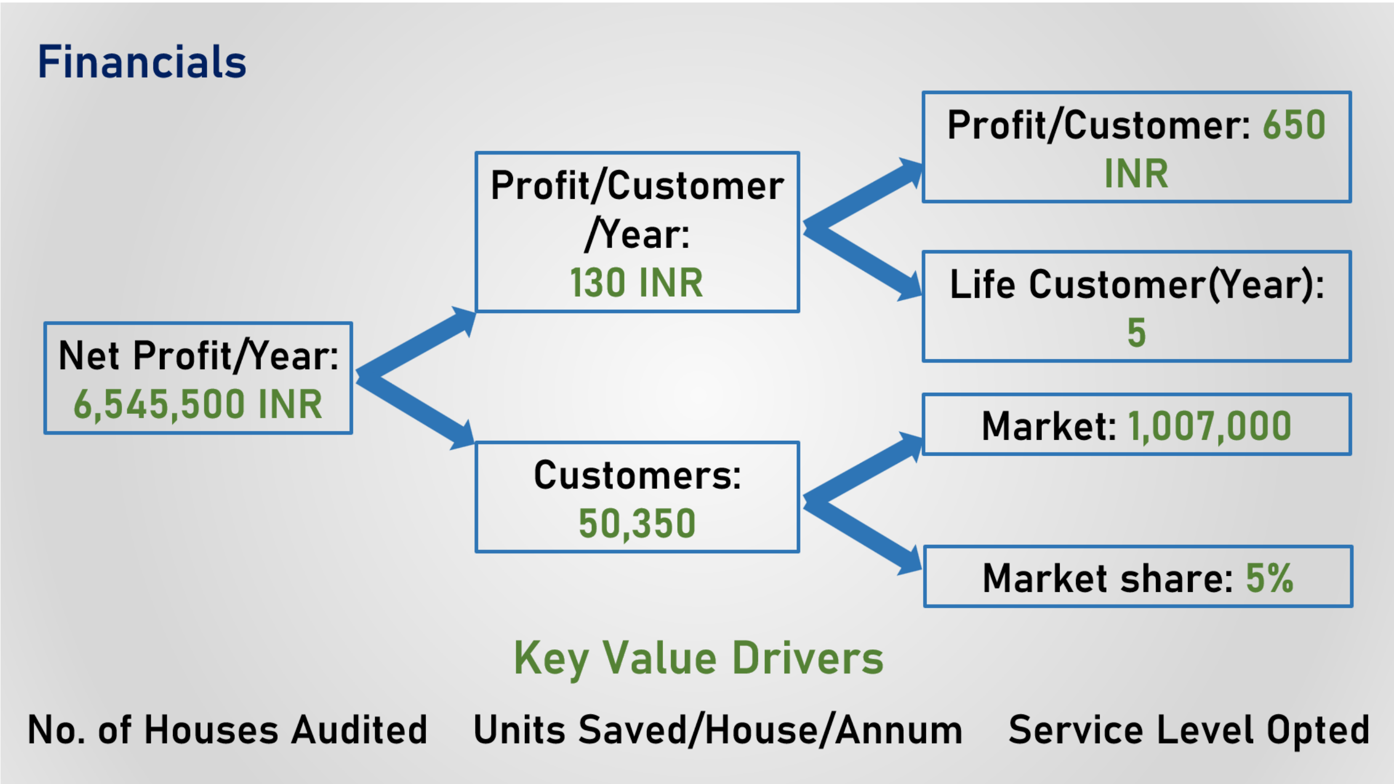

Fig. 12.1: Financial Tree & Key Value Drivers

X. CONCLUSION:

In order to combat the problem of significant energy demand in residential buildings, our team of engineering students spanning multiple departments came up with a solution using a web – based user interface and hardware – based energy monitoring and appliance automation system as data sources for a machine learning and statistics – based model that analyses consumption, benchmarks users and provides forecasts and suggestions for reducing energy consumption, and by extension, electricity bill and carbon footprint.

We are targeting middle to high income households in metro cities with fast paced lifestyles and awareness of the climate crisis. After surveying 100+ potential customers, we are pitching to them a solution that saves them time and money and also reduces their carbon footprint without disrupting their lifestyle, compromising comfort and costing either zero or minimal up front capital investment.

The portal has been developed, and the first iteration of both the ML and statistical models have been trained on a real – life dataset, yielding promising results. The hardware kit is being developed in our EES (Energy, Environment & Sustainability) Lab and is currently able to read energy consumption of a simulated load bank and send that data to the cloud. A new prototype is being worked on in parallel that will be able to automatically control appliances from sensor data.

Given buildings have an operational lifecycle of at least 60 – 80 years, this solution can provide value to the customer, the environment and net zero policy makers for a prolonged period of time and play a foundational role in India's shift to a circular economy.

We believe this solution provides significant value to its customers, generates revenue and takes steps towards monitoring and reducing the energy consumption of residential buildings, and has the potential to bring us closer to a world where net zero energy consumption and circular economy are a reality.

XI. REFERENCES:

- Eco Niwas: https://www.econiwas.com/tools.php
- Energy Star Benchmark: https://www.energystar.gov/buildings/benchmark/analyze_benchmarking_results
- Django (Portal Backend): https://www.djangoproject.com/
- ADAFRUIT IO (IoT): https://io.adafruit.com/
- Google Colab (ML): https://colab.research.google.com/
- https://www.thehindu.com/news/cities/mumbai/Fixing-Mumbai-Electricity-from-waste/article60527006.ece
- https://www.indiamart.com/proddetail/solar-power-purchase-agreement-service-10944075973.html