Introduction

Awareness of saving energy has become the need of the hour.[1] Nowadays many new developments have taken place that is resulting in a switch from traditional energy production ways to environment friendly ones.[2] In recent years, there has been a growing number of industries choosing other technologies such as solar or hydro over fossil fuels.[3] However, the energy used in the building sector remains an issue. This is mainly because to conserve energy in buildings the behaviour of its occupants must be changed.[4] This can be done by providing personalized feedback regarding the usage of energy to make the occupants more energy aware. However, combining energy usage with personalized behaviour and then providing tailored feedback is a difficult task.[5] [6] However, with the use of the Internet of Things (IoT) technology various applications can be carried out by combing real-time data coming from numerous sensors and then processing that to develop occupant-tailored energy-aware messages.[7]

1.1 Importance of Energy Management in Commercial Buildings

Energy management in commercial buildings is a critical concern for several reasons, primarily due to its substantial impact on operational costs and environmental sustainability.[8] Globally, commercial buildings are major consumers of energy, significantly influencing energy usage patterns and environmental footprints. Commercial buildings in the United States contribute to around 40% of the overall energy consumption, emphasizing their significant significance as major energy users.

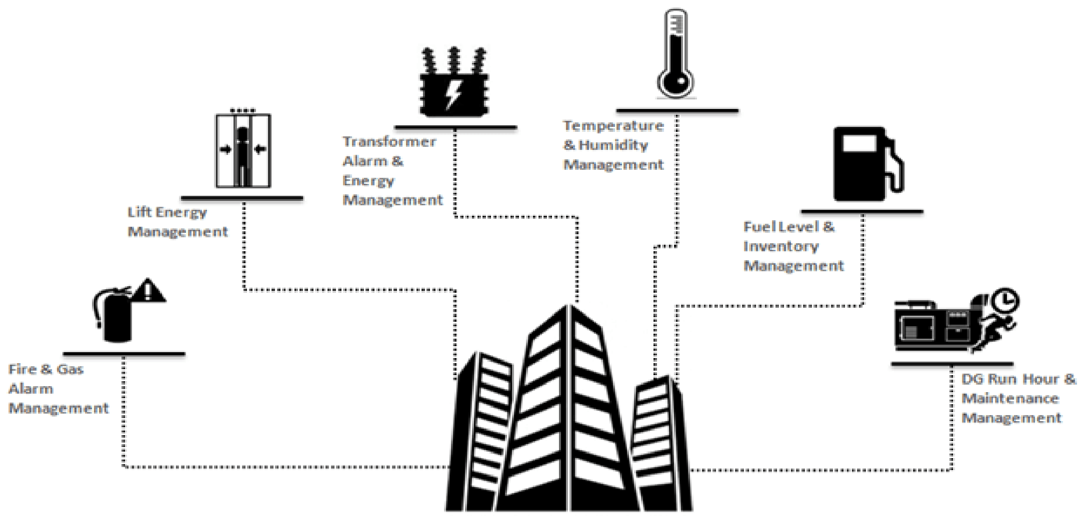

Fig.1.1 : Importance of Energy Management in Commercial Buildings [9]

1.1.1 Economic Benefits

Efficient energy management in commercial buildings directly translates to decreased operational expenses. Energy costs are among the largest operating expenses in commercial buildings, and reducing these costs can significantly improve profitability.[10] Implementing energy-efficient practices and technologies can lead to substantial reductions in energy consumption, which directly lowers utility bills. Moreover, with energy prices being volatile, effective energy management shields businesses from the unpredictability of energy cost fluctuations, ensuring more predictable financial planning.[11]

1.1.2 Environmental Impact

Commercial buildings contribute significantly to global energy consumption, leading to considerable environmental implications, particularly in terms of carbon emissions. Energy production is primarily sourced from fossil fuels, which when burned, release large quantities of carbon dioxide a leading greenhouse gas.[12] Commercial buildings may minimize their carbon footprint by decreasing energy use, helping mitigate climate change. This shift is crucial in the global effort to meet international climate targets and transition towards more sustainable practices.[13]

1.1.3 Regulatory Compliance and Market Trends

There is an increasing regulatory focus on reducing energy consumption and enhancing building efficiencies. Many regions are implementing stricter building codes and standards that mandate energy performance benchmarks. Compliance with these regulations not only avoids potential fines but can also enhance a building's marketability.[14] Additionally, there is a growing trend in the real estate market valuing green certified buildings higher than conventional ones. Energy-efficient buildings often achieve higher occupancy rates and increased asset values.[15]

1.1.4 Social Responsibility

Organizations are facing growing responsibility for the environmental consequences of their actions. Stakeholders, including investors, tenants, and the public, are demanding greater environmental stewardship from corporate entities.[16] Effective energy management in commercial buildings demonstrates a commitment to sustainable practices, enhancing an organization's reputation and fulfilling corporate social responsibility objectives.[17]

1.1.5 Technological Innovations

Developments in technology, particularly the integration of IoT (Internet of Things) and smart building technologies have transformed energy management in commercial buildings. These technologies enable the continuous monitoring and management of energy use in real-time, enabling more accurate and automatic modifications to optimize energy efficiency. The capacity to collect and analyse substantial amounts of data also yields valuable insights that might facilitate better-informed decision-making in relation to energy practices.[18]

The importance of energy management in commercial buildings is underscored by its significant benefits across economic, environmental, regulatory, and social domains. As the pressure to improve building sustainability intensifies, the role of advanced technologies in facilitating effective energy management strategies becomes increasingly vital.[19]

1.2 Role and Potential of IoT in Enhancing Energy Efficiency

The Internet of Things (IoT) represents a transformative shift in how buildings are managed, offering unprecedented control and efficiency in energy management. The application of IoT in commercial buildings encapsulates a comprehensive integration of hardware and software to enhance the operational performance of energy systems, thereby reducing consumption and costs.[20] Below are key aspects where IoT is reshaping energy management in commercial buildings:

1.2.1 Real-Time Energy Monitoring

IoT devices allow for the continuous monitoring of energy usage across various systems inside a building, such as HVAC, lighting, and office equipment. This real-time data collection is fundamental in identifying patterns, peak usage times, and potential inefficiencies. By understanding these dynamics, facility managers can implement more effective energy-saving measures.[21]

1.2.2 Automated Control Systems

IoT enables the automation of building systems through smart controls that adjust settings based on real-time data. For instance, thermostats that are linked to the

Internet of Things (IoT) have the capability to modify the temperature by considering occupancy patterns and external weather conditions. Likewise, lighting systems may be programmed to reduce brightness or switch off when rooms are vacant.[22] This degree of automation not only improves comfort but also greatly reduces energy inefficiency.

1.2.3 Predictive Maintenance

IoT technologies transform maintenance from a reactive to a proactive strategy. Sensors can predict equipment failures before they occur by analysing data trends such as temperature fluctuations, vibrations, and energy consumption. This predictive approach prevents downtime and the extra costs associated with emergency repairs, while also ensuring that all equipment operates at peak efficiency, thus conserving energy.[23]

1.2.4 Demand Response and Load Management

IoT systems can participate in demand response programs by automatically adjusting energy consumption during peak periods. This not only helps to distribute the load evenly throughout the grid but also lowers energy expenses caused by peak pricing. Buildings can, for example, temporarily reduce HVAC usage or shift the operation of heavy machinery to off-peak hours, effectively decreasing the building's operational expenses and energy use during costly peak times.[24]

1.2.5 Enhanced Decision Making

The integration of IoT devices generates a vast amount of data, which can be analysed to inform strategic decisions. Advanced analytics may provide valuable information on how to improve energy consumption and save expenses. These findings may be used by decision-makers to create specific energy conservation strategies, devise more effective building designs, and allocate resources towards energy-efficient technology.[25]

1.2.6 Integration with Renewable Energy

IoT can also enhance the incorporation of renewable energy sources like solar and wind into building energy systems. IoT sensors can optimize the use of renewables by monitoring weather conditions and adjusting energy consumption accordingly. For example, during high solar output, an IoT system can maximize the use of solar power while minimizing reliance on the grid.[5]

1.2.7 Smart Grid Compatibility

IoT devices can communicate with the smart grid to improve energy efficiency at a larger scale. This compatibility helps in adjusting energy consumption based on broader grid demands, contributing to overall energy efficiency and sustainability.[26]

The role of IoT in improving energy productivity in commercial buildings is multidimensional, offering benefits from operational efficiencies to strategic energy usage reductions. As more buildings adopt IoT technologies, the potential for significant energy and cost savings increases, positioning IoT as a central element in the future of sustainable building management.

1.3 Smart Buildings: Revolutionizing Modern Infrastructure

Smart buildings leverage advanced technology and integrated systems to enhance the operational efficiency, comfort, safety, and sustainability of building environments. By utilizing the Internet of Things (IoT), artificial intelligence (AI), and other digital tools, smart buildings provide a dynamic and responsive approach to managing and optimizing various building functions.[27] This comprehensive use of technology transforms traditional buildings into active participants in energy management and user experience optimization.

1.3.1 Key Features of Smart Buildings

1. Connectivity and Integration Smart buildings are characterized by a high degree of connectivity, with numerous devices and systems interconnected via the IoT. This integration allows for seamless communication between systems such as lighting, HVAC, security, and more.[28], [29] By enabling these systems to share information and operate cohesively, buildings can optimize their operations for energy efficiency, comfort, and safety.

2. Energy Efficiency Smart buildings prioritize energy management as a fundamental aspect. By using sensors and automated systems, these buildings have the ability to substantially decrease energy usage and expenses. Smart HVAC systems optimize heating and cooling by using real-time occupancy data, while intelligent lighting systems decrease power use by taking advantage of natural light and occupancy.[30]

In addition, smart buildings often include sustainable energy sources such as solar panels and are designed to seamlessly interact with intelligent power networks in order to maximize energy efficiency and generation.

3. Enhanced Security Smart security systems in smart buildings include advanced surveillance technologies, access control systems, and IoT sensors that detect anomalies and potential security breaches. These systems can be integrated with mobile devices, allowing real-time security updates and remote management, enhancing overall building security and occupant safety.[31]

4. Improved Occupant Comfort Smart buildings prioritize occupant comfort by adapting the environment to meet the preferences and needs of its users. Environmental conditions such as lighting, temperature, and air quality are automatically adjusted based on occupancy and individual preferences, which are often learned over time through AI and machine learning algorithms.[32]

5. Predictive Maintenance Utilizing data from various sensors, smart buildings can predict when and where maintenance is needed before systems fail. This proactive approach prevents downtime, extends the life of equipment, and saves money on emergency repairs and inefficient operations. Predictive analytics can forecast issues with HVAC systems, elevators, plumbing, and electrical systems, scheduling maintenance only when needed.[33]

6. Sustainability Smart constructions subsidise to sustainability goals by reducing energy ingestion, minimizing waste, and utilizing eco-friendly materials and systems. By optimizing energy use and integrating green technologies, these buildings play a vital role in decreasing the carbon footprint and supporting environmental sustainability.[34]

7. User Interaction and Adaptability Smart buildings often feature interactive interfaces and apps that allow occupants to personalize their environment. These systems learn from interactions and adapt to changes in user behaviour or environmental conditions, continuously improving efficiency and comfort.[35]

1.3.2 Challenges and Future Outlook

While smart buildings offer numerous benefits, they also face challenges such as high initial costs, complexity in integration, and concerns over data privacy and cyber security. Addressing these challenges requires robust security protocols, effective data management strategies, and ongoing investment in technology upgrades.[36]

Addressing these challenges requires robust security protocols, effective data management strategies, and ongoing investment in technology upgrades.[36]

As technology evolves, the future of smart buildings looks toward even greater integration of AI, machine learning, and IoT. The continuous advancement of 5G technology and edge computing will augment the functionalities of intelligent buildings, making them more efficient, adaptable, and user centric.[37]

Smart buildings represent the forefront of building technology, offering a more sustainable, efficient, and comfortable future for urban development. As they continue to evolve, these intelligent structures will become standard in the drive towards smarter, more sustainable cities.[38]

1.4 Importance/ Rational of proposed Investigation

Why do we need to save energy?

- India is ranked 87th out of 115 nations in the global energy transition ranking. [1]
- To fulfil and maintain the growing energy requirements of the nation [4].
- To fulfil the energy requirements and maintain the entire progress of society, including health and safety.
- To guarantee the long-term supply and use of energy in a manner that is environmentally and socially responsible.

Why commercial buildings?

- Commercial buildings in the United States account for 30% of energy use. [2]
- 30 % amount of energy can be saved by using simple techniques like adoption of energy-aware behaviors by occupants [3].
- Buildings consume approximately 80% of their life cycle energy during their operation [5].
- Commercial buildings do not focus on energy conservation as no one takes ownership of these facilities. Hence people tend to spend unnecessary energy when they reach the office or their working space.

- Hence people tend to spend unnecessary energy when they reach the office or their working space.
- This attitude leads to an almost 80% loss of energy [5], which eventually leads to a large carbon footprint.

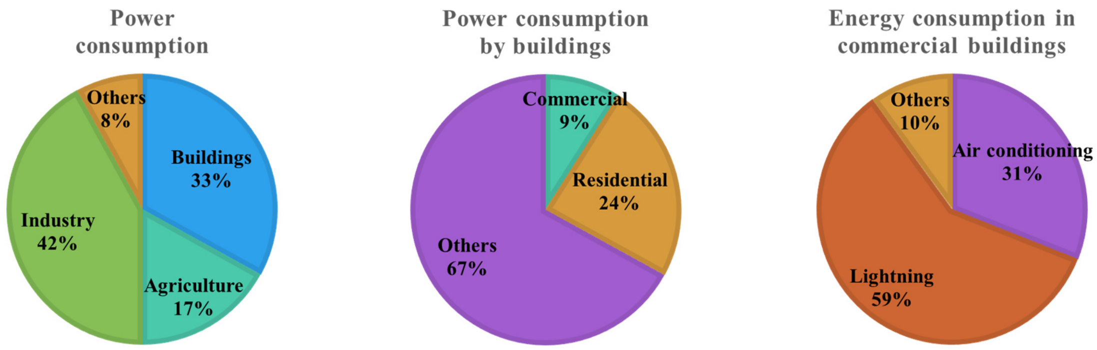

Fig. 1.2 : Percentage of power consumption

In India, building sector consumes 33 % of electricity out of the total electricity consumption. Out of which, 24 % is consumed by residential buildings and 9 % by commercial [4]. In commercial buildings lighting, HVAC and other appliances consume 59 %, 31 % and 10 % energy respectively [10].

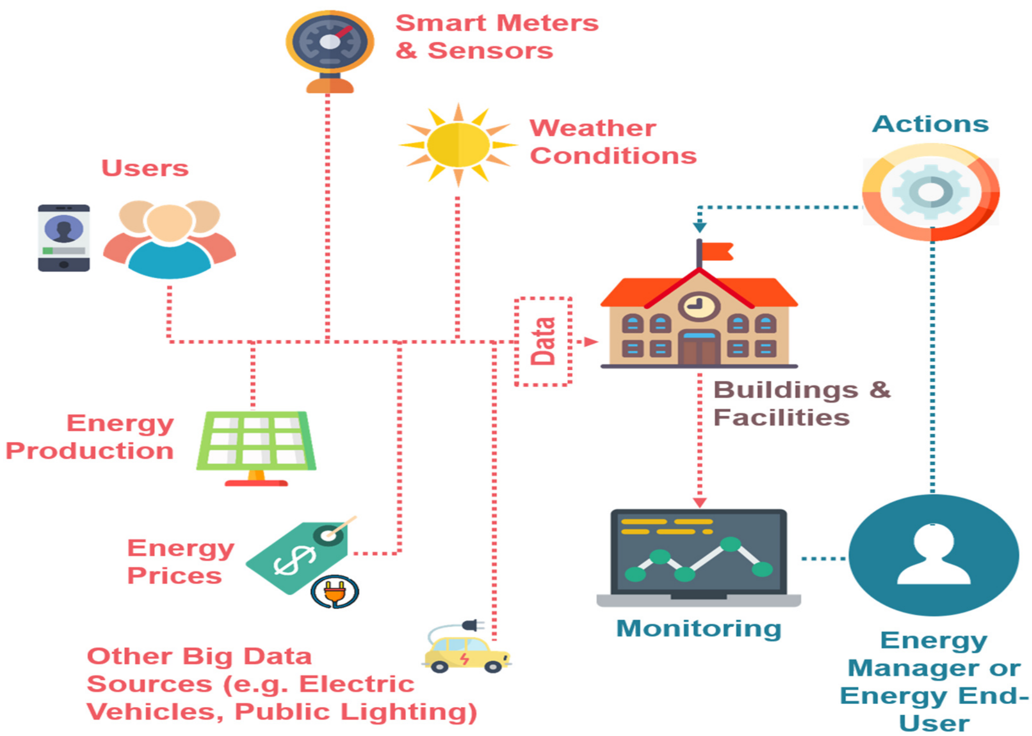

Figure 1.3: Energy management solution [10]

Many studies based on machine learning, deep learning, Internet of Things (IoT), etc., have been performed for energy management. Out of this, IoT based smart systems allow the collection and integration of a vast number of sensors. This sensor data can be analysed further, and action plans can be created based on their data.

1. **Review of work already done on the subject:**

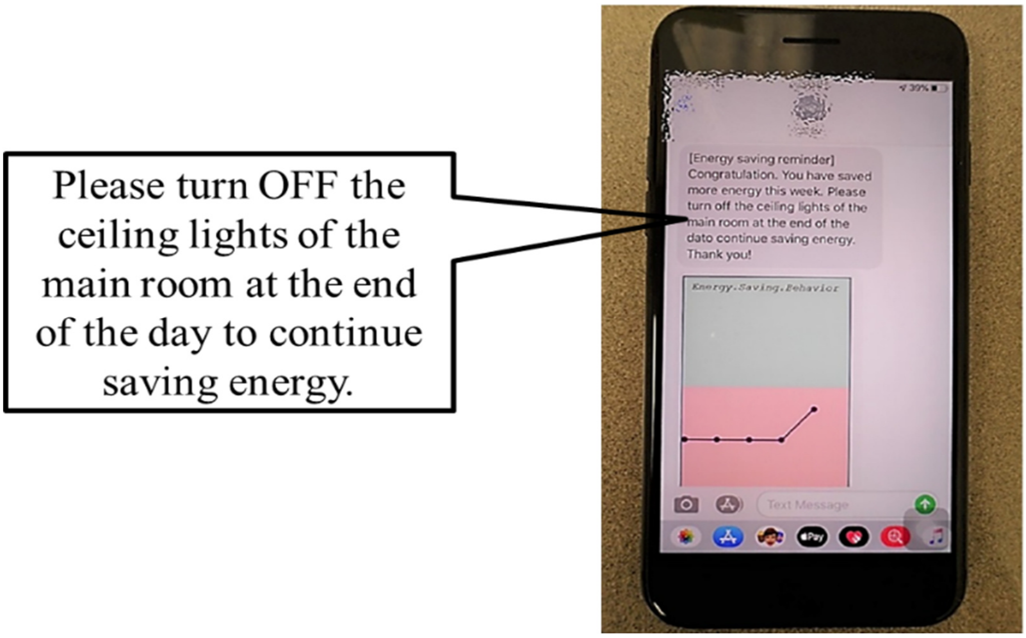

Fig. 1.4 : Feedback to occupants based on energy-aware behaviour [2]

Rafsanjani [2] have developed a smartphone application that keeps a track of the energy usage and behavior of ten occupants in a building over 12 weeks. The method was divided into seven parts. In the first part, they used the advanced internet-connected meters that are installed in the electric panels of most commercial buildings to get the data of energy consumption. Next, they used the Wi-Fi network in the buildings to study the number and behavior of the occupants. In addition, the WiFi network also gives information about the behavior of the last leaving occupant. Then, they use the collected data to calculate the Energy-use Efficiency Index (EEI) for each day. This value of EEI is given to a trained deep learning model to identify whether the energy consumption for the particular day was efficient or not. Next, they also studied the behavior of the occupants and combined it with the EEI value to give personalized feedback to the occupants. Their results showed a 34 % improvement in the energy use in the commercial building. One of their observations was that the last people to leave the building often neglect the lighting which results in an excess of energy wastage.

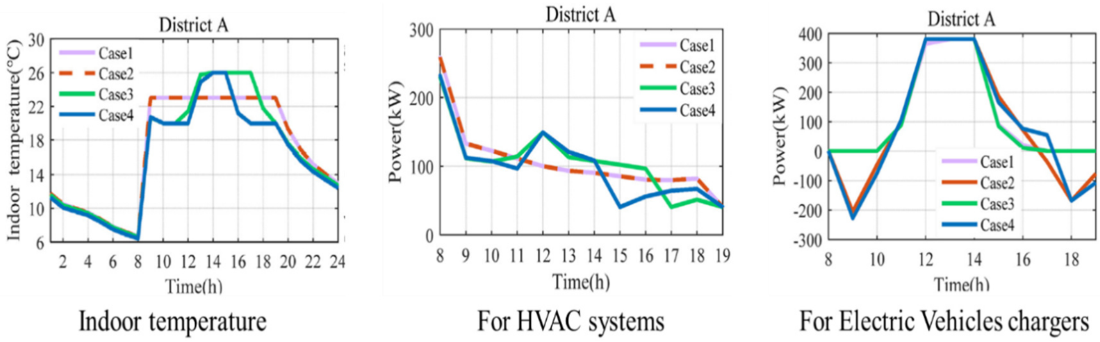

Fig. 1.5: Graphs of indoor temperature and power consumption versus time as gathered by sensors [6]

Li et al. [6] use the flexible resources in the buildings to optimize the energy consumption of the Active Distribution Network (ADN) in office buildings. They constructed an optimization model for the Heating, Ventilation and Air Conditioning (HVAC) and the Electric Vehicle (EV) chargers in the building based on the traveling habits of the occupants. Next, they made an ADN optimization model using a Mixed-Integer Second-Order Cone Programming (MISOCP) model. Then they developed a method to learn the consumption of energy in the ADN. They tested their model in the winter-heating scenario and the results showed a decrease in the ADN losses and energy consumption.

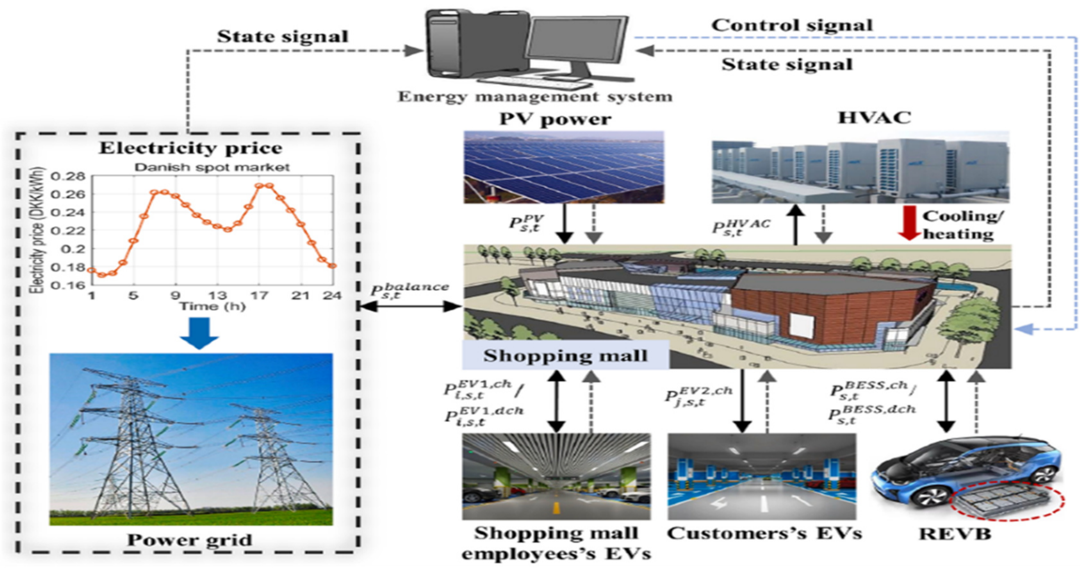

Fig. 1.6: Power supply system of a shopping mall [26]

Xu et al. [26]have developed a strategy for a renewable power supply system in a shopping mall while considering the behaviors of vehicle use and the temperature ranges. They considered two Electric Vehicles (EV) and studied their stochastic behavior to build models. They tested the use of Retired Electric Vehicle Batteries to achieve optimization. Finally, they used a stochastic optimization method to manage the energy. Their results showed that using Photovoltaic and REVB in the commercial building reduces the consumption of energy by almost 82.2 % and 83.3 % respectively.

Index	Indicator	
	Title	Unit
I_{GBT-11}	Electricity per floor area	KWh/m^2
I_{GBT-12}	Electricity per use per area	kWh/m^2 for lighting, cooling, other uses
I_{GBT-13}	Fuel used for heating per floor area	lt/m^2 (either Heating oil or Natural Gas)
I_{GBT-14}	Electrical Energy per floor area and user	kWh/m^2/user or kWh/m^2/manhour
I_{GBT-15}	Fuel used for heating per floor area and user	lt/m^2/user
I_{GBT-21}	Electrical Power	kW (constant metering)
I_{GBT-22}	Electrical Power Factor	cosφ
I_{GBT-31}	CO_2 emissions for Electricity per floor area	tn/m^2
I_{GBT-32}	CO_2 emissions for Heating per floor area	Lt/m^2
I_{GBT-33}	Produced electricity by RES (PVs)	kWh
I_{GBT-41}	Cost of Electricity per floor area,	€/m^2
I_{GBT-42}	Cost of Fuel used for Heating per floor area	€/m^2
I_{GBT-43}	Monthly calculation of the electricity cost and potential projection through correlation with degree days and users	-

Fig. 1.7 : To facilitate energy management, their suggested system collects, analyses, and shows data from four primary sets of indicators collected using IoT system [39]

Marinakis et al. [39] have proposed and designed an architecture for an IoT based intelligent energy management system for buildings. They utilized the data collected from different platforms and provided daily and weekly feedback to the end users as well as personalized feedback for individual buildings using their developed prediction models. Their proposed architecture consisted of three distinct parts namely, the data integration layer, then came the prediction rules, and finally the suggestions/feedback. Various parameters were considered in the data integration layer such as occupant behavior, weather, energy bills, amount of energy produced, and the other details of the building. They also proposed a semantic framework based on the Ztreamy system.

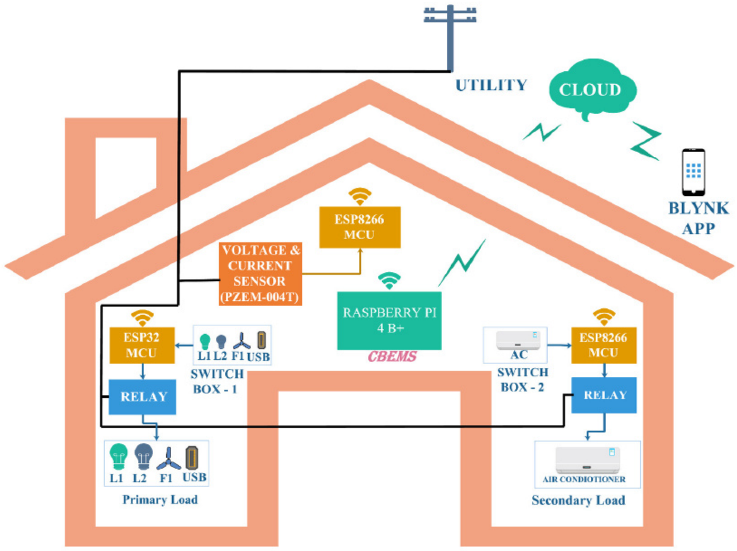

Fig. 1.8 : Placement of components in an IoT-based energy management system [7]

Karthick et al. [7] have designed an energy management system using a Smart Compact Energy Meter (SCEM) to monitor the usage of energy and the quality of the power in a commercial building. They have also used a Demand Side Management (DSM) using IoT. They have employed an ARM microcontroller that is robust enough to carry out tasks such as acquiring vast amounts of sensor data and processing it. The system can detect disturbances and classify them. It can also check the consumption and the data exchange inside the building. These tasks all require the continuous optimization of the system. Further, they tested their application in a commercial building and used the Blynk mobile application to monitor and control the appliances. The use of their system showed a significant decrease in energy consumption.

1.5 Research Gaps

With the use of various sensing technologies and actuators, the IoT-based energy management systems can continuously monitor, learn, and react to numerous changes in the environment. But IoT based energy management systems face a few drawbacks as witnessed from the literature review. Most studies reported in the literature, work on IoT systems that give feedback to the occupants based on their current or short term behavior. It was seen that behavioral change in the occupants of a commercial building lasted only as long as the IoT system was providing feedback [2]. This was because the behavior patterns of the occupants were mostly studied from data like who leaves the building last or how many people occupy a room. In commercial buildings, it can be tough to provide personalized feedback to every individual in the room by studying their actions. Hence it is important to build a system that can continuously monitor the behavior of every person in the room for a long duration. This data with the sensor data can be used to recognize certain behavior patterns and provide personalized feedback.

Another problem that IoT systems face is the security of data. Collecting personalized information about the users in the room will require safeguarding all the incoming sensor data from any type of cyber threat. Most of the existing studies on IoT based energy management systems do not report how the information will be secured. Further, as IoT systems use a variety of sensors placed in different locations to collect readings, the sensors must be in places that will not obstruct the detection range of the sensor but will also avoid any intention/unintentional damage to the sensors due to the occupants. The position of the sensors is another point that a lot of studies have seemed to miss out on.

1.6 Problem Statements

- Instead of analysing only the data collected from the building appliances, is it possible to also analyse the behaviour of individual occupants and use that to provide personalized feedback?
- Can the outdoor temperature and lighting conditions be compared to that of the indoor conditions to optimize the energy use?
- Can we estimate the temperature and lighting conditions at different times of the day and then inform the occupants when to enable/disable the HVAC or lighting system?
- Can the meter readings be used to understand which appliances other than HVAC and lights consume the highest amount of energy and then decide an optimal time to use them?
- Can the above-mentioned points be combined into a singular system to manage the energy in a commercial building?

1.7 Aim

This project aims to use the data gathered from various sensors such as temperature and light sensors and incorporate this with the Internet of Things (IoT) to analyze the consumption of energy in a commercial building. Next, to use the footage of the CCTV cameras installed in these buildings to analyze the occupant behavior and the number of occupants using computer vision techniques. Finally, try to combine the before mentioned things to build a system that will make commercial buildings becoming more energy efficient.

1.8 Objectives of The Proposed Study

Objective 1: To utilize the CCTV camera footage and analyse it using computer vision techniques to study the occupancy of a building and also the behaviour of the occupants.

Objective 2: The research will also involve obtaining sensor data for interior and exterior room temperatures in a commercial building and comparing them to verify HVAC energy usage.

Objective 3: To utilize an IoT device to monitor the lighting conditions within a commercial building and compare it to the lighting outside, i.e., day or night. To analyze occupants' lighting usage based on collected data and send alerts.

Objective 4: To Check the electric meter and estimate energy waste from non HVAC and lighting appliances. To analyze energy consumption and do pattern analysis to determine which devices consume energy based on usage.

1.9 Scope

- The scope of this project is to use the CCTV footage from commercial buildings to count the number of occupants in the building and analyse the behaviour of these occupants and give them alerts and warnings by detecting correct or incorrect behaviour using computer vision techniques.
- The project will also involve gathering sensor data for sensing the temperature from inside and outside the rooms in a commercial building and comparing the two to check the energy wastage due to the HVAC systems in the building.

Collecting sensor data for detecting the lighting conditions inside and outside the rooms of a commercial building will also be done. This information will be compared to see the energy consumption due to the lighting systems in the building.

- Then, the electric meter readings for the building will be collected and an estimation of the amount of energy consumed by the other appliances apart from HVAC and lights such as microwaves, printers, and scanners will be done. This will be combined with a pattern analysis method to check at what time of the day excess energy is being consumed and determine the device which may be consuming it.
- Lastly, the temperature, light, and other appliances' energy data will be correlated with the behaviour and number of the occupants in the building to provide personalized feedback and alerts related to the energy usage.

1.10 Hypothesis

H0: Most commercial buildings use HVAC systems set at a temperature similar to that of the outdoor temperature.

H1: HVAC systems are left running throughout the building despite of having no occupancy or only a few occupants in one room.

H2: Most commercial buildings use lights throughout the building despite of having bright daylight outdoors.

H3: Lights are left turned ON even when the occupancy in the building in zero or is confined to a few rooms.

H4: Occupants in the commercial buildings make use of the other appliances whenever they feel the need to resulting in them being left ON for longer durations.

H5: Occupants in commercial buildings will respond to warnings about excess energy consumption and modify their behaviours based on them.