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A Smart Building Automation using DDC Controller

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Abstract: - The term "Direct Digital Control (DDC) Controller" describes the capability of programming Heating, Ventilation, and Air Conditioning (HVAC) equipment. It can be applied to lower costs, optimize energy use, and automate processes. The fact that a DDC for construction automation offers continuous control and monitoring of several factors, including moisture, temperature, lighting, and ventilation, is one of its main advantages. A DDC can assist in making sure the building is always functioning at ideal circumstances, which can result in increased energy efficiency and lower energy expenditures, by regularly monitoring these factors. The utilization of occupancy sensors is another method that DDC can contribute to energy conservation. These sensors have the ability to recognize when humans are in a space and modify the HVAC and lighting controls appropriately. For instance, the DDC can save energy by turning down the lights and adjusting the HVAC system in an unused room. In addition to overseeing and managing diverse aspects, a DDC may additionally be employed to maximize the efficiency of apparatus like pumps, boilers, and chillers. A DDC can assist in ensuring that equipment is working at maximum efficiency, which can help save the consumption of energy and maintenance costs. It does this via tracking equipment performance and making necessary adjustments to settings. In general, employing a DDC for construction management can assist increase cost effectiveness, boost energy efficiency, and enhance occupant comfort and safety.

Keywords: Smart Building, Energy Efficiency, Direct Digital Controller.

I. Introduction

An essential component of the intelligent power system for energy conservation is SMART buildings. It is commonly recognized that the business sector contributes significantly to the world's energy consumption, which is thought to account for almost one-third of all consumptions. The buildings in the commercial sector are made up of a variety of energy-consuming amenities, including lights, elevators, office equipment, and HVAC [1] Building Management System (BMS) monitors and regulates building energy use through intelligent automation and sensors. Building facilities consume a lot of energy, hence numerous energy- efficient techniques have been created to address the problem. On the other hand, every building is different in terms of its goals, surroundings, structure, and usage habits. This resulted in numerous specialized construction solutions and unresolved problems from the client's standpoint, like cost containment. These problems have been found to have a potential remedy in machine learning approaches [3]. One kind of artificial intelligence that may acquire knowledge without explicit programming is machine learning. Research and development have gone into this adaptable technology for several commercial applications. Control improvements, quality classifications, and predictive maintenance are a few examples. For information to be transmitted, the system also needs a dependable communication route. One possible remedy for this problem is the Multi Agent System (MAS). A computerized collection of interacting intelligent agents, or MAS for short, can be either software or hardware-based entities. It is intended to resolve complex problems that are beyond the capabilities of a single agent. Because MAS can integrate complex computation algorithms, it is widely used for dependable and effective communication in a variety of industries. Preemptive [4] building demand participation that incorporates smart building operations into bulk power system energy scheduling. It allows individual customers to engage in the wholesale power market and makes full use of the flexibility of buildings' energy consumption. This technique intelligently schedules the use of battery storage and HVAC management using a form of predictive control based HVAC control algorithm. However, it doesn't cover the building as a whole just the HVAC system. Furthermore, a lot depends on how customers behave while they are in different buildings.

II. Related Work

Intelligent controllers and optimization strategies in Building Energy Management Systems (BEMS) are directed towards sustainable development, [1] emphasizing their efficacy in enhancing energy performance and managing comfort level. It identifies key barriers, analyzes the connection with Sustainable Development Goals (SDGs), and provides insights for developing advanced BEMS technologies to address global challenges. It has

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investigates variability in building load profiles, presenting a methodology to analyze high-resolution energy consumption data. Variability in aggregate [2] and end-use load categories, providing insights into isolating and quantifying variability for future research and predictive modeling.

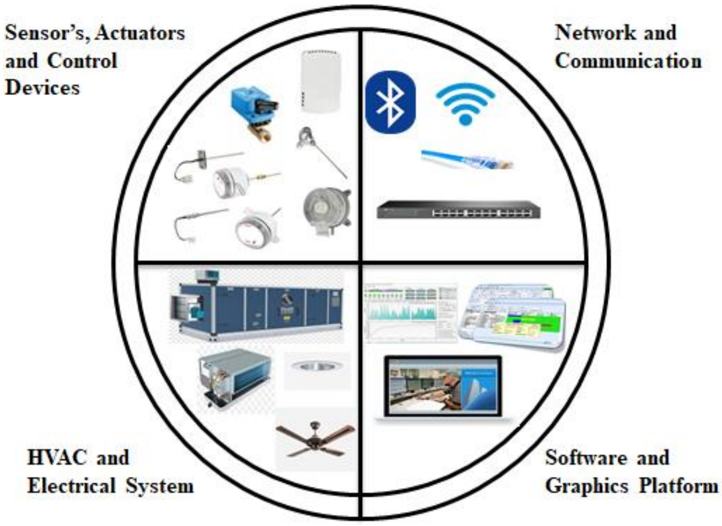

Fig. 1 Smart Building

It's conducted an SLR to analyze software requirements for energy-efficient buildings, identifying 97 relevant works. It highlights the essential role of big data characteristics and introduces software requirements, emphasizing the need for tailored solutions across [3] different building types. Additionally, the study suggests the adoption of micro services architecture for enhancing software versatility in this context. The efficiency of the hybrid architecture proposed for minimizing operational costs for chosen buses is evaluated. It indicates superior performance compared to other control strategies [4], achieving global optimal points under various weather conditions. The hybrid system combines multi-agent energy cost game and reinforcement learning, offering optimal results with reduced computational complexity. The different assets within active buildings and discusses their challenges and opportunities in future energy systems. Future research directions include assessing the value of active buildings, exploring peer-to-peer transactions, [5] designing emergency response mechanisms, enhancing energy system resilience, and studying occupant behavior from a social sciences perspective. The suitability of different lighting systems for various types of buildings [6], emphasizing factors such as daylight availability, occupancy patterns, retrofitting costs, and smart management strategies. It highlights the importance of considering building characteristics and external conditions to optimize energy savings and efficiency in lighting systems. EMSs-in-Bs designs over 40 years to identify evolving trends and factors influencing their development. It concludes with insights on findings, summaries, challenges, future directions [7], and scope-based remarks for enhancing energy management systems in buildings. Building Energy Management Systems (BEMS) leveraging Internet of Energy (IoE) technologies play a crucial role in reducing energy consumption and greenhouse gas emissions [8]. It highlights challenges such as energy efficiency optimization and real-time data collection, while proposing improved methodological frameworks for future BEMS strategies. IoE-based BEMS applications offer potential for significant energy savings and CO_2 emission reductions through advanced algorithms and sustainable building practices. The article presents a metadata inference method for zone-level BAS data using only numerical information. It achieves high accuracy in classifying and associating point types [9], even without intuitive data labels, demonstrating potential for broader applications in building energy systems analysis. Future work will focus on handling complex HVAC configurations and exploring additional classification features and matching strategies for diverse data types. Introduces an EBMS, an intelligent cost reduction strategy for Singapore commercial buildings, utilizing classification, prediction, backup, and set point algorithms [10]. EBMS achieved up to 61.42% savings in electricity costs based on real-life simulations, with potential applications in industrial and residential settings. A novel autonomic ACODAT-based management architecture for multi-HVAC systems in buildings. It employs Data Acquisition Tasks (DATs) to detect deviations and ensure trajectory towards set goals, utilizing machine learning techniques for flexibility and adaptation [11]. Real data from Teatro Real in Madrid demonstrates successful detection and reconfiguration capabilities during start-up, promising energy efficiency gains. Future work will expand this approach to various building types and incorporate meta-learning for autonomous knowledge updates. Integration with existing BMS standards is also planned to optimize HVAC control in smart buildings.

III. Area And CFM Calculation

3.1 Area-1

Documenting the Cubic Feet per Minute (CFM) calculation for two different areas an automation and transducer lab in SRMIST-KTR campus, Hi-Tech building 5th floor under Electronics and Instrumentation department and it's an essential for maintaining a record of airflow patterns and ensuring compliance with standards. Here's a guide on how to document the CFM. An "Automation Lab" typically refers to a dedicated space equipped with various tools, equipment, and technologies focused on automation and control systems. The primary purpose of an Automation Lab is to provide a controlled environment for designing, testing, and experimenting with automation solutions across different industries application.

Area = *Length* X *Width* Area = 36ft X 29ft

Area = 1044ft^2

Ceiling Height = 8ft;

Availability of fam coil units are 3

Capacity of each units = 600CFM

Capacity of Total units=1800CFM

To calculate Air Changes per hour

$$ACH = \frac{CFM\ X\ 60}{Area\ X\ Ceiling\ Height}$$

$$ACH = \frac{1800\ X\ 60}{1044\ X\ 8}$$

ACH = 12.931

Calculating the Area CFM

$$CFM = \frac{Area\ X\ Height\ X\ ACH}{60}$$

CFM = 1799

Calculating the CFM for Electric heat load

$$CFM = \frac{V\ X\ I\ X\ 3.414}{\delta T\ X\ 1.08}$$

$$\delta T = Supply\ Air - Return\ Air$$

Airflow (CFM): The desired airflow in Cubic Feet per Minute, representing the volume of air moving through the HVAC system.

V: The voltage supplied to the HVAC system.

I: The current drawn by the HVAC system.

3.414 (BTUs per watt): A conversion factor from electrical power (watts) to British Thermal Units (BTUs).

1.08: A constant representing the specific heat of air and the density of air, used to convert the temperature difference from degrees Fahrenheit to BTUs.

Temperature Difference of Supply and Return Air: The temperature difference between the air supplied into the space and the air returned from the space, measured in degrees Fahrenheit.

$$CFM = \frac{230\ X\ 6\ X\ 3.414}{12.6\ X\ 1.08}$$

CFM = 346

For Other Heat Sources

Direct sunlight affect windows are 6, and 1 Fan Coil Unit (FCU) is not working. The issue is that the FCU system has not been appropriately designed based on the area. The design of an FCU system is critical to ensure optimal heating, ventilation, and air conditioning (HVAC) performance within a specific space. If the FCU system is not adequately sized for the area, it can result in in- efficiencies, discomfort, and potential operational problems. Properly sizing an FCU involves considering factors such as the size of the space, thermal characteristics of the building, occupancy patterns, and temperature requirements. If the FCU is undersized, it may struggle to meet the heating or cooling demands of the area, leading to insufficient temperature control and discomfort for occupants.

Conversely, if the FCU is oversized, it can lead to short cycling, energy wastage, and increased wear and tear on the equipment.

3.2 Area-2

A "Area-2" typically refers to a laboratory setting equipped for the study, testing, and experimentation with transducers. Transducers are devices that convert one form of energy into another, and they find extensive applications in various fields, including electronics, acoustics, and instrumentation.

Area = 28*ft* X 16*ft*
Ceiling Height = 8ft;
Availability of fan coil units are 2
Capacity of each units = 400CFM
Capacity of Total units=800CFM
ACH = 13.39
CFM = 799.99
The CFM for Electric heat load is 346

There is no much heat load on transducer lab and both the units are functional. To compare the cooling capacities of the Automation Lab and Transducer Lab based on the calculation, we can analyze the area and available cooling units. The Automation Lab has an area of 1044 square feet with functional of 3 tons of refrigeration (3TR), while the Transducer Lab has an area of 450 square feet with functional of 2 tons of refrigeration (2TR). The Automation Lab has a larger area and more cooling capacity (3TR), making it potentially more effective in maintaining lower temperatures compared to the Transducer Lab with a smaller area and less cooling capacity (2TR).

3.3 DDC

Direct Digital Control (DDC) is a method of controlling and managing mechanical systems, such as heating, ventilation, and air conditioning (HVAC), using digital technology. In DDC systems, analog signals representing various parameters like temperature, pressure, and humidity are converted into digital signals, allowing for more precise and flexible control. DDC systems use digital controllers, typically microprocessors or microcontrollers, to analyses input data and execute control algorithms. These controllers are capable of processing information rapidly and making adjustments in real-time.

Direct Digital Control (DDC) is a technology widely employed in building automation systems, and its functions play a pivotal role in enhancing the efficiency and precision of environmental control within facilities. DDC functions involve the direct management of various building systems, such as HVAC, lighting, and security, through digital communication and microprocessor-based controllers. These controllers receive sensor data in real-time, enabling swift and accurate adjustments to environmental parameters.

DDC functions encompass the implementation of sophisticated control strategies, including proportional-integral- derivative (PID) loops, set point control, and scheduling. These functions not only ensure optimal energy usage but also contribute to maintaining occupant comfort. Addition- ally, DDC facilitates remote monitoring and control, allowing building operators to oversee and adjust system performance from a centralized location. The ability to gather, analyze, and respond to data rapidly distinguishes DDC, making it a cornerstone in modern building automation, promoting energy efficiency, cost savings, and overall operational effec tiveness.

Sensors and Actuators: DDC systems rely on sensors to mea- sure environmental variables and actuators to adjust system components. The sensors provide feedback to the digital controller, which then determines the appropriate actions to maintain desired conditions.

Programming and Algorithms: DDC systems use software programming and algorithms to implement control strategies. These algorithms can be customized to meet specific requirements and optimize energy efficiency.

Communication Protocols: DDC systems often utilize communication protocols such as BACnet or Modbus to enable interoperability between different devices and systems. This allows for integration with other building automation systems.

Remote Monitoring and Control: One of the advantages of DDC is the ability to monitor and control systems remotely. This is particularly valuable for managing multiple buildings or widely distributed systems from a centralized location.

Energy Efficiency: DDC systems are known for their energy efficiency. By continuously monitoring and adjusting system parameters, they can optimize performance and reduce energy consumption compared to traditional control methods. Overall, DDC offers a more sophisticated and dynamic approach to system control, providing greater flexibility, efficiency, and the ability to adapt to changing conditions in real-time. This technology is widely used in commercial and industrial buildings to enhance the performance and energy efficiency of HVAC and other mechanical systems.

IV. System Design

A Building Management System (BMS), also known as a Building Automation System (BAS), is designed to monitor, control, and optimize various building systems and equipment to enhance operational efficiency, occupant comfort, and energy performance.

Field-Level Networks: These networks facilitate communication between sensors, actuators, and controllers at the field level. Common communication protocols include BACnet, Modbus, and LonWorks, allowing interoperability between devices from different manufacturers.

Supervisory Level: This level includes supervisory controllers that aggregate data from field-level controllers. It often involves the use of programmable logic controllers (PLCs) or other supervisory devices. The supervisory level is responsible for coordinating the operation of various sub systems.

Building Level: At the building level, central servers or soft- ware platforms manage and coordinate the overall operation of the BMS. This level provides a centralized interface for building operators to monitor and control the entire system. It may also include data storage and analysis functions.

User Interface: Building operators interact with the BMS through a graphical user interface (GUI) on computers or mobile devices. The interface allows users to monitor real- time data, adjust set points, view alarms, and generate reports. Integration Gateways: BMS often integrates with other building systems and technologies, such as fire alarms, access control, and energy management systems. Integration gateways enable seamless communication between different systems, creating a holistic and interoperable building environment.

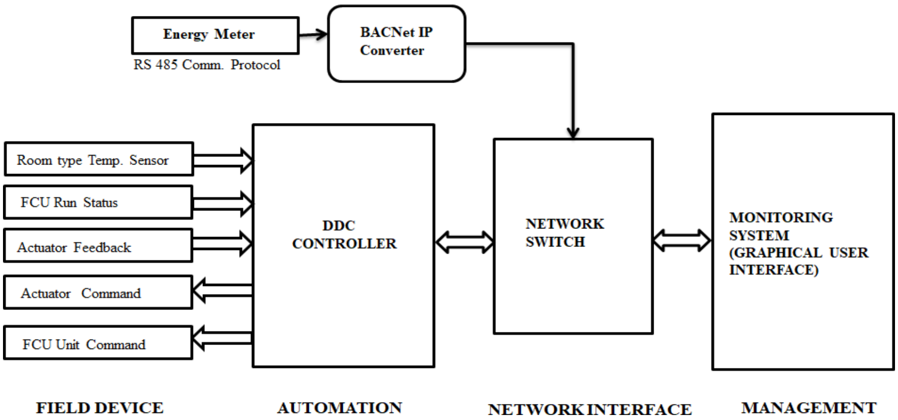

Fig.2 Implementation Diagram

4.1 Controllers

The Metasys Network Control Engine Series controller's pro- video cost effective solutions designed specifically for integrating central plants and large built-up air handlers into your existing Metasys network. Johnson Controls NCEs combine network supervisor capabilities and IP network connectivity with the I/O point connectivity and direct digital control capabilities of a Field Equipment Controller – making our NCEs the ideal choice for expanding and improving your Metasys installation to get better data visibility and more control over your energy usage. Communicates using commonly accepted IT standards at the automation and enterprise level.

Web-browser based user interface allows access from any supported Web browser. Supports up to 32 field controllers on an N2 bus, LonWorks network or BACnet MS/TP bus.

Combines functionality of a DDC and network supervisory controller. Tested by the BACnet Testing Lab and certified as a BACnet Building Controller. To communicate on a single platform to deliver the information you need, allowing you to make smarter, savvier decisions while enhancing your occupants' comfort, safety and productivity.

V. Configuration Of Inputs & Outputs

Configuring inputs and outputs to a controller is a crucial step in building automation and control systems. Inputs typically refer to signals or data received by the controller, while outputs are signals or commands sent by the controller to actuators or other devices. In the configuration process, users define the relationships between specific input sources and desired controller actions.

Fig.3 Experimental Setup

For inputs, users identify and configure sensors or devices that provide information to the controller. This can include temperature sensors, occupancy detectors, or other data sources. Configuration involves specifying the type of input, its location, and its scaling parameters to ensure accurate readings. On the output side, users configure the controller to send signals or commands to actuators, valves, or other devices based on the input data and control strategy.

Table.1 Configuration of Inputs

S.No	Input Points
1	Room Temperature
2	FCU-1 Run Status
3	FCU-2 Run Status
4	Occupancy Sensor-1 Status
5	Occupancy Sensor-2 Status
6	FCU Actuator Feedback

This involves specifying the type of output signal, its range, and its behavior in response to specific input conditions. For instance, configuring an output might involve setting the control algorithm, proportional-integral-derivative (PID) parameters, or defining fail-safe behaviors.

Accurate and thoughtful configuration of inputs and outputs is essential for the controller to effectively manage and optimize the controlled system. It ensures that the controller responds appropriately to sensor inputs, enabling precise and efficient control over heating, cooling, ventilation, or other building automation functions.

Table 2. Configuration of Outputs

S.No	Output Points
1	FCU Unit-1 Command
2	FCU Unit-2 Command
3	Light and Fan Command-1
4	Light and Fan Command-2
5	FCU Actuator Control

VI. Conversion Of Modbus RTU To BACnet Protocol

The Modbus communication protocol operates on a master-slave architecture, where a master device initiates communication by sending requests or queries, and the slave devices, in this case, the energy meters, respond with the requested data. This request-response mechanism ensures efficient and organized data exchange within the network.

Modbus communication can occur in two modes: RTU (Remote Terminal Unit) and ASCII (American Standard Code for Information Interchange). RTU is more common and uses binary encoding for data transmission, while ASCII uses plain text. The choice between these modes depends on factors such as data transmission rates and the specific requirements of the application.

Integrating energy meters with Modbus communication offers several advantages. Real-time monitoring of energy consumption allows for proactive energy management, helping industries optimize usage and reduce costs. Moreover, the standardized nature of Modbus ensures interoperability between devices from different manufacturers, promoting a vendor-neutral environment.

Techno Make energy meters are known for their accuracy, reliability, and advanced features. These meters typically incorporate modern technologies to provide precise measurements of electrical parameters such as voltage, current, power, and energy consumption. They are designed to meet industry standards and regulatory requirements.

Key features of Techno Make energy meters may include digital displays, communication interfaces for data retrieval, and compatibility with communication protocols like Mod- bus. These features enable effective energy management, allowing users to monitor consumption patterns and optimize energy usage.

BACnet/IP is a variant of the BACnet protocol that operates over Internet Protocol (IP) networks. This allows BACnet devices to communicate using the standard networking technologies that power the internet, such as Ethernet and TCP/IP. BACnet/IP leverages the benefits of IP networks, enabling widespread and scalable communication in modern building automation systems.

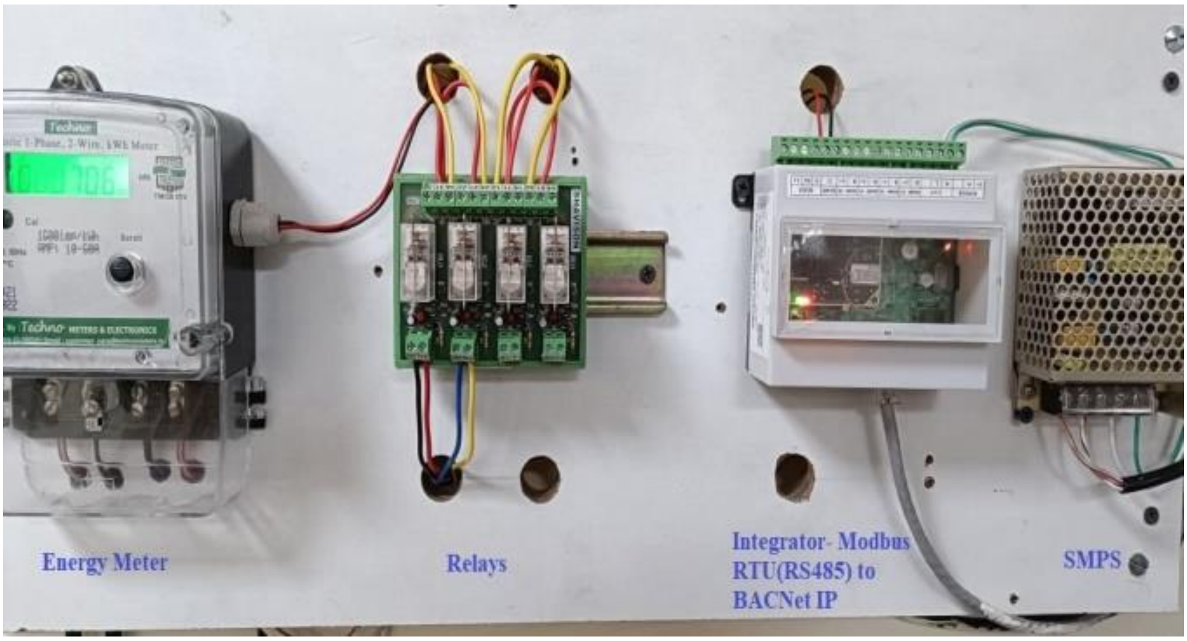

Fig.4 Module kit-Modbus to BACNet IP Conversion

Objects and Services: BACnet defines a standardized set of objects and services that devices use to communicate. Objects represent various aspects of a device or system (e.g., temperature, lighting, alarms), while services define the actions that devices can perform (e.g., read, write).

Interoperability: BACnet’s primary goal is to ensure interoperability among devices from different manufacturers. This is achieved through a standardized data model and communication methods, allowing different devices to understand and respond to each other’s requests.

BACnet/IP Addressing: In BACnet/IP, devices are assigned IP addresses, making them identifiable on an IP network. This enables communication between devices over local net- works or the internet. BACnet/IP can use both IPv4 and IPv6 addressing.

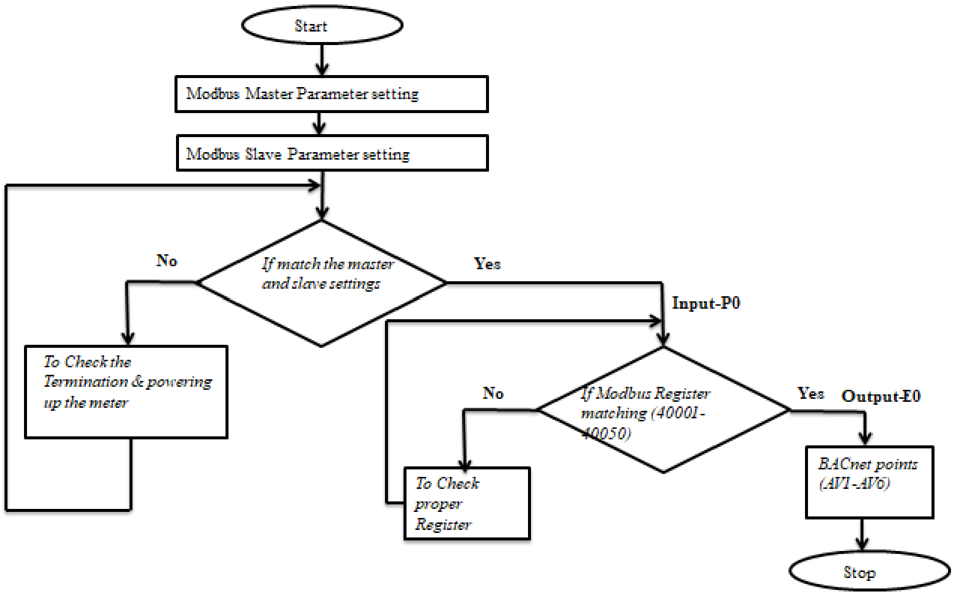

Fig.5 Flow Chart of Data Conversion

VII. Graphics-Monitoring Control

A supervisory controller, in the realm of building automation and control systems, serves as the centralized intelligence orchestrating the operation of various subsystems within a facility. Its principle and operation revolve around overseeing, coordinating, and optimizing the performance of diverse building systems to ensure efficiency, comfort, and energy savings. At its core, the supervisory controller acts as the brain of the building automation system. It receives data from sensors and field controllers, processes this information, and issues commands to actuators and devices to regulate and maintain the desired conditions within the facility. The over- arching principle is to provide a centralized and streamlined approach to managing complex building systems.

Data Acquisition: Supervisory controllers continuously gather data from a network of sensors distributed throughout the building. These sensors measure parameters such as temperature, humidity, occupancy, and energy consumption. The controller collates this real-time data, forming a comprehensive understanding of the building's status.

Fig.6 FCU Graphics-mapping points

Integration and Communication: A key aspect of the supervisory controller's operation is its ability to integrate with various subsystems and devices. This includes HVAC systems, lighting controls, security systems, and more. The controller communicates with field controllers, which are responsible for specific zones or systems within the building. Through communication protocols such as BACnet or Modbus, the supervisory controller establishes a cohesive network, ensuring interoperability among different components.

Control Algorithms: Supervisory controllers employ sophisticated control algorithms to analyze incoming data and make decisions on how to optimize system performance. These algorithms may include PID, fuzzy logic, or model predictive controller, depending on the complexity of the building systems and the desired outcomes. The goal is to maintain environmental conditions within predefined set points while minimizing energy consumption.

Energy Management: A crucial aspect of the supervisory controller's role is energy management. By analyzing data trends, occupancy patterns, and external factors such as weather conditions, the controller can implement strategies to reduce energy usage. This may involve adjusting HVAC set points, optimizing lighting schedules, or implementing demand response measures. The supervisory controller is instrumental in aligning building operations with energy conservation goals.

Alarm and Fault Detection: The supervisory controller actively monitors the building systems for anomalies and faults. If a sensor reports an out-of-range condition or a piece of equipment malfunctions, the controller triggers alarms and alerts operators to take corrective action. This proactive approach to fault detection contributes to system reliability and minimizes downtime.

Fig.7 Floor Graphics

VIII. RESULTS

Creating a graph representing the relationship between date and energy consumption from October 17, 2023, to November 16, 2023, with energy values ranging from 10.32 KWh to 33.13 kWh allows for a visual understanding of the energy consumption trend over this period. The x-axis of the graph represents time and, the y-axis represents energy consumption values.

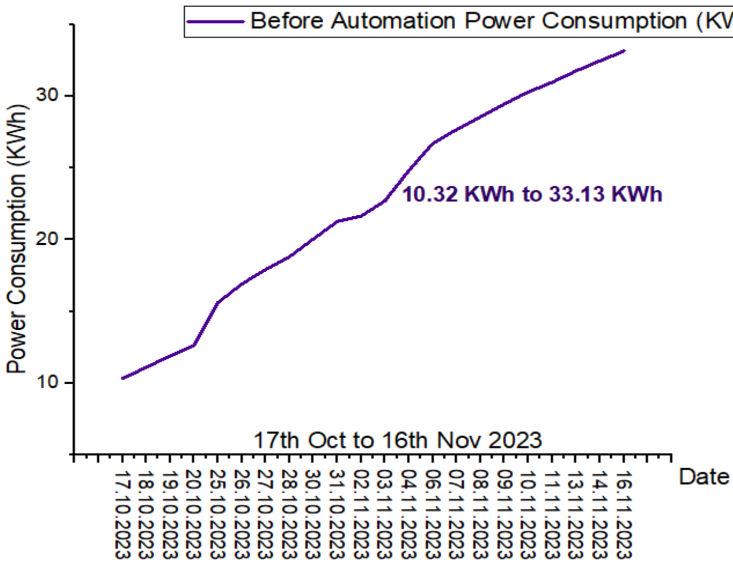

Fig.8 Before Automation Power Consumption

Table.3 Power Consumption (KWh) of FCU's Before Automation and After Automation

Before Automation		After Automation	
Date	**Power Consumption (KWh)**	**Date**	**Power Consumption (KWh)**
17.10.23	10.32	18.01.24	57
18.10.23	11.12	19.01.24	57.7
19.10.23	11.91	20.01.24	58.3
20.10.23	12.65	22.01.24	58.9
25.10.23	15.63	23.01.24	59.6
26.10.23	16.91	24.01.24	60.4
27.10.23	17.93	29.01.24	61.1
28.10.23	18.82	30.01.24	61.8
30.10.23	20.05	31.01.24	62.4
31.10.23	21.27	01.02.24	63.2
02.11.23	21.65	02.02.24	63.8
03.11.23	22.72	05.02.24	64.4
04.11.23	24.83	06.02.24	64.7
06.11.23	26.71	07.02.24	65.1
07.11.23	27.67	08.02.24	65.6
08.11.23	28.56	09.02.24	66.1
09.11.23	29.45	12.02.24	66.5
10.11.23	30.3	13.02.24	66.9
11.11.23	30.97	14.02.24	67.4
13.11.23	31.76	15.02.24	67.9
14.11.23	32.46	16.02.24	68.4
16.11.23	33.13	17.02.24	68.9

The implementation of automation technologies, particularly in the context of building management systems, has yielded substantial energy savings. Prior to automation, energy consumption was characterized by inefficiencies and lack of dynamic control. With the introduction of smart automation systems, notably using Direct Digital Control (DDC) controllers, a transformative shift has been observed.

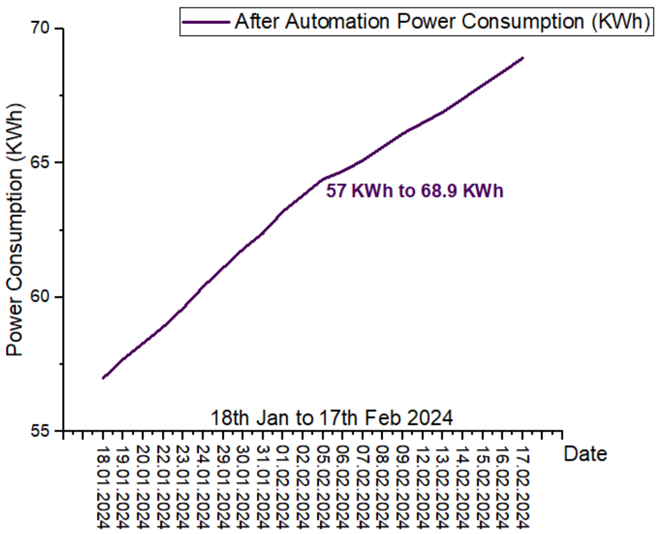

Fig.9 After Automation Power Consumption

Before automation, energy utilization was often suboptimal, resulting in higher energy expenditures. Manual control systems struggled to adapt to fluctuating environmental conditions, leading to unnecessary energy consumption. However, the adoption of DDC controllers facilitated a significant enhancement in energy efficiency. After the implementation of automation, the continuous monitoring and control capabilities of DDC controllers allowed for precise adjustments in HVAC, lighting, and equipment operation. The system's responsiveness to real-time conditions, coupled with the integration of occupancy sensors, led to a more intelligent and adaptive building management approach.

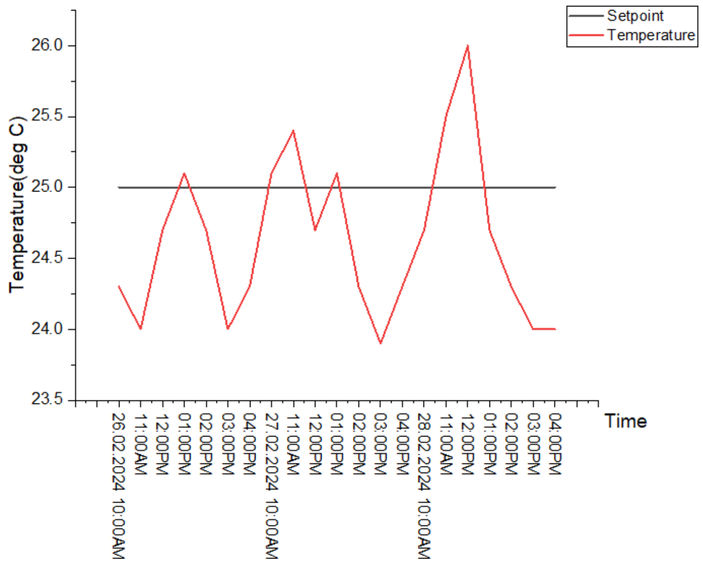

Fig.10 Maintain the Room Temperature

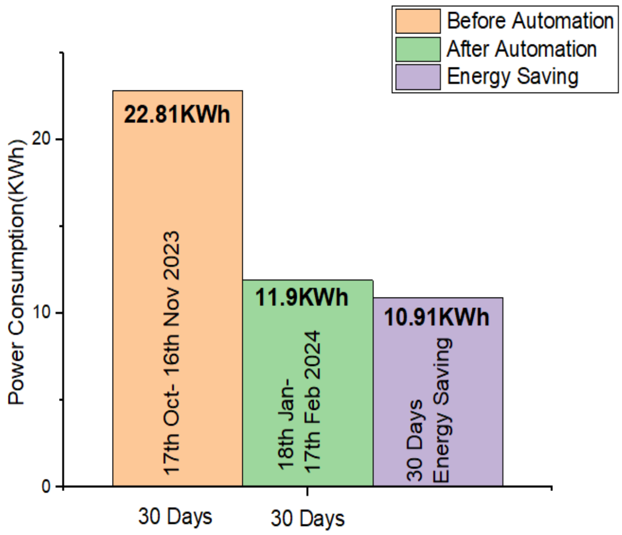

Fig.11 Comparison of power consumption for before, after automation and energy saving

Room temperature set point set as 25℃ and its maintained ± 1℃. so after automation control the room temperature based on temperature set point and occupant comfort with energy saving.

IX. Conclusion

Implementing automation in the cooling system for a 500 square feet area resulted in a significant reduction in power consumption. Before automation, the system consumed 22.8 kWh of power over 30 days, while after automation, the consumption dropped to 11.9 kWh over the same period. This represents an energy saving of approximately 47%.

The conclusion drawn from this data is that automation can effectively optimize energy usage in cooling systems, leading to considerable energy savings. This not only reduces electricity bills but also contributes to environmental conservation by lowering overall energy consumption.

Automation in cooling systems can lead to significant energy savings, as demonstrated by the reduction in power consumption from 22.8 kWh to 11.9 kWh for a 500 square feet area with 2 FCU. Extending this automation to larger spaces has the potential to yield further energy savings, contributing to cost reduction and environmental sustainability.

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