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A DIRECT DIGITAL CONTROLLER-BASED SMART BUILDING AUTOMATION SYSTEM

Priyanandhini V Assistant Professor Department of Computer Science with Artificial Intelligence, SRM Arts and Science College, KTR Campus, Tamilnadu, India. priyanandhinics@srmasc.ac.in

ABSTRACT

This abstract provides a synopsis of a smart building automation system that makes use of Direct Digital Controllers (DDCs), outlining its main features and their significance. The system's capacity to control airflow patterns, meet regulations, and maximise energy usage is highlighted through thorough calculations and analysis. We talk about switching from Modbus Remote Terminal Unit (RTU) to Building Automation and Control Networks (BACnet) so that building devices can talk to one other and work together better. Highlighting supervisory controllers' function in defect detection, energy optimisation, and system management, the abstract also mentions their graphical monitoring and control capabilities. In sum, the abstract summarises the ways in which smart building automation systems based on distributed ledger technology can help create intelligent and user-centric built environments while also being cost-effective and environmentally friendly.

Keywords-
Smart Building, Energy Efficiency, Direct Digital Controller

1. INTRODUCTION

Smart buildings are an essential part of today's infrastructure due to the fast changing technology landscape. Incorporating state-of-the-art digital control systems allows these structures to reach hitherto unseen levels of sustainability, comfort, and efficiency. The DDC is an important participant in this field because it is a high-tech gadget that allows for the accurate monitoring and administration of different building systems [1]. In this introductory piece, we'll take a look at the basics of smart building automation systems that use Direct Digital Controllers, and how they can change the game when it comes to building operations and maintenance.

Building automation systems (BAS) have come a long way since its inception, moving from manually controlled to fully automated systems powered by digital technologies. Nevertheless, due to their reliance on proprietary protocols and hardware, these initial systems had limited capability and scalability. DDCs allow for better optimisation, control, and monitoring of building systems in real-time, and they are a game-changer in the field of building automation [2]. Precision and efficiency in managing HVAC, lighting, security, and energy management systems are achieved with DDCs through the use of digital signals and algorithms, as opposed to older analogue or pneumatic control systems. A DDC system relies on sensors to gather data, actuators to manage the system, a controller based on a microprocessor, and software for configuration and programming. Integrating various building subsystems into a unified whole, DDCs promote interoperability and data transmission by using digital communication protocols like BACnet, Modbus, or LonWorks.

Incorporating a smart building automation system that is based on a Direct Digital Controller brings numerous advantages that improve the facility's performance, energy efficiency, occupant comfort, and maintenance. The ability to obtain insights into building operations, discover anomalies, and optimise energy consumption through real-time monitoring and analytics is one of the key advantages. DDCs provide for exact management of HVAC systems, which minimises energy waste while maximising regulation of temperature, humidity, and air quality [3].

Smart building automation systems are made even more powerful by the merging of DDCs with Internet of Things (IoT) and cloud computing [4]. Automated decision-making, optimisation of building operations, and adaptation to dynamic environmental changes are all possible with DDC-based systems that use machine learning algorithms and predictive analytics. Cloud integration also allows for remote building system monitoring and management, which is great for large-scale deployments because of the scalability and flexibility it provides. Smart building automation systems based on Direct Digital Controllers are revolutionising building management with their intelligence, efficiency, and control. These systems lay the groundwork for resilient, user-centric, and environmentally friendly physical environments by utilising digital technologies, the internet of things, and cloud computing.

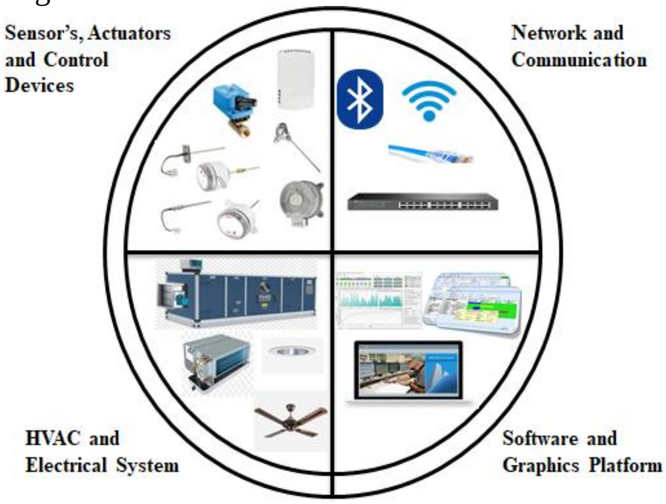

Fig.1. Smart Building

2. RELATED WORK

Building Energy Management System (BEMS) intelligent controllers and optimisation govern comfort and energy performance to support expansion. It discusses the Sustainable Development Goals (SDGs), critical difficulties, and how to develop cutting-edge BEMS technology to alleviate global problems. It examines building load profile fluctuations and high-resolution energy consumption data. Measurement of aggregate [5] and end-use load variety aids future research and projections. After SLR, 97 works were relevant to energy-efficient building software requirements assessments. Software criteria and vast data characteristics emphasise the necessity for customised solutions for several building kinds [6]. The study recommends micro services architecture for software flexibility. We test how much the hybrid architecture lowers bus operation costs for specific models. In different weather circumstances, it reaches global optimal points better than other control systems [7]. Reinforcement learning and a multi-agent energy cost game optimise hybrid system performance and reduce computational complexity. Different lighting systems suit different buildings depending on daylight, occupancy patterns, retrofitting costs, and smart management [8].

To maximise lighting system energy savings and efficiency, examine the building's features and external factors. EMSs-in-Bs designs over 40 years to see what factors affected their evolution and patterns. Results, synopses, challenges, future paths, [9] and scope-based recommendations for improving building energy management systems finish the document. IoE-enabled BEMS reduce energy utilisation and greenhouse gas emissions [10]. The research proposes a numerical metadata inference method for zone-level BAS data. Its accuracy in point type categorization and association [11] without data labelling makes it interesting for building energy systems analysis. New categorization features, data format matching algorithms, and challenging HVAC settings will be researched. Using categorization, prediction, backup, and set point algorithms, it offers an EBMS for Singaporean commercial buildings to reduce costs [12]. Real-life simulations revealed EBMS may save 61.42% on residential and industrial electricity expenditures. Unique ACODAT-based autonomous building HVAC system control architecture. Data Acquisition Tasks (DATs) track goals and changes, and machine learning adapts [13]. Wirelessly connecting sensor modules to the control hub may be necessary. Collotta et al. [14] and Hu et al. [15] showed that Bluetooth or Zigbee-Wi-Fi can do this. Wi-Fi is popular for IoT home automation.

Smart appliances and IoT devices use networks to connect to the internet. Wireless communication technology' portability and ease of use make installation easier. However, unreliable internet connectivity could hamper the functionality of devices that rely heavily on network communication. While power line transmission is preferred, Song [16] indicates that cable communication is an alternative. This was demonstrated by Naing et al. [17] who automated a cooling fan, lights, and door buzzer using temperature, light intensity, and motion sensors.The automation system by Peter et al. [18] uses a variety of sensors to monitor the environment and provide data to an Arduino Uno. The Arduino Uno then controls domestic appliances using relays.

Khiyal et al. [19] suggested many home automation methods. GSM-based methods interface with microcontrollers, the main controllers for household appliances, using mobile phone technology. To enable SMS, connect a GSM module to the microcontroller via a port. This system lacks a GUI, making it unpleasant. Users must memorise the system's command and access codes to use it. A wireless RF network and speech recognition software are another option. Visual Basic code using the Microsoft Speech API and a microphone records, digitises, and delivers the spoken command to a computer for processing. When Schaeferet al. identify a voice command, control signals are delivered to the appliance addresses to start the required processes [20]. However, the tested system sometimes misidentified speech commands.

3. AREA AND CUBIC FEET PER MINUTE (CFM) CALCULATION

3.1 Area-1

Keeping track of the CFM calculations for two separate areas—the automation and transducer lab on the SRMIST-KTR campus and the Electronics and Instrumentation department on the fifth floor of the Hi-Tech building—is crucial for keeping records of airflow patterns and making sure everything is up to code. The CFM documentation process is outlined here. In common parlance, a "Automation Lab" is a room set aside specifically for the study of control and automation systems, along with a variety of relevant instruments and equipment. The main goal of an Automation Lab is to offer a controlled setting where automation solutions may be designed, tested, and experimented with for various industry applications.

$$Area = Length \times Width \quad Area = 36ft * 29ft$$

$Area \ = \ 1044ft^2$

$CeilingHeight = 8ft$;

TocalculateAirChangesperhour

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

$ACH = 12.931$

CFM=1799

CalculatingtheCFMforElectricheatload

$$CFM = \frac{Voltage \times Amps \times 3.414}{\delta T \times 1.08}$$

The amount of air that the HVAC system moves is called the intended airflow, and it is measured in cubic feet per minute (CFM).

Voltage measured in volts for the HVAC system.

An amp reading indicates how much power the HVAC system uses.

The conversion factor between watts of electrical power and British thermal units (BTUs) per watt is 3.414.

For alternative heat sources, The impact of direct sunshine on windows= One non-functional unit equals six. The problem is that the Fan Coil Unit (FCU) system hasn't been planned according to the area it's supposed to service. When it comes to HVAC performance in a given space, the design of a fan coil unit (FCU) system is paramount. Problems with operation, discomfort, and inefficiency could arise from an FCU system that is too small for the space. Inadequate temperature control and discomfort for inhabitants might result from an FCU that is inadequate, which struggles to fulfil the heating or cooling demands of the area. On the flip side, excessive wear and tear on equipment, inefficient energy use, and short cycling might result from an overly large FCU..

3.2 Area-2

A typical "Area-2" at a laboratory is one that is prepared to work with transducers in terms of research, testing, and experimentation. There are many different areas that make use of transducers—devices that change the energy of one type into another—such as electronics, acoustics, and instrumentation.

$Area = 28ft * 16ft$

Area = 448ft^2

CeilingHeight=8ft;

Area-1Availabilityofunits=2;

Capacityofeachunits =400CFM

CapacityofTotalunits=800CFM

TocalculateAirChangesperhour

$$ACH = \frac{800 \times 600}{448 \times 8}$$
$$ACH = 13.39$$

CalculatingtheCFMForArea

$$CFM = \frac{448 \times 8 \times 13.39}{60}$$
$$CFM = 799.99$$

CalculatingtheCFMforElectricheatload

$$CFM = \frac{230 \times 6 \times 3.414}{12.6 \times 1.08}$$
$$CFM = 346$$

Both units are operational, and the transducer lab does not experience a significant amount of heat load. Based on the computation, we may examine the space and available cooling units to compare the Automation Lab and the Transducer Lab's cooling capacities. In contrast to the 450 square foot Transducer Lab, which has 2 tonnes of refrigeration capacity (2TR), the 1044 square foot Automation Lab has 3 tonnes of refrigeration capacity (3TR). In comparison to the Transducer Lab, which has a smaller area and less cooling capacity (2TR), the Automation Lab may be better at sustaining lower temperatures due to its bigger area and greater cooling capacity (3TR).

3.3 DDC

DDC is a digital technique for managing and regulating mechanical systems, including HVAC systems. DDC systems enable more precise and versatile control by converting analogue signals representing factors like as temperature, pressure, and humidity into digital signals. In order to interpret input data and carry out control algorithms, direct digital control systems make use of digital controllers, which are usually microprocessors or microcontrollers. Fast data processing and real-time adjusting capabilities characterize these controllers.

Schedules, set point controls, and proportional-integral-derivative (PID) loops are all examples of complex control schemes that fall under the purview of DDC functions. Not only do these features keep occupants comfortable, but they also guarantee optimal energy utilisation. A foundational component of contemporary building automation, DDC's speed in data gathering, analysis, and response promotes operational efficacy, cost savings, and energy efficiency.

One of DDC systems' well-known qualities is the amount of energy it efficiently uses. Compared to conventional control approaches, they are able to optimize performance while reducing energy usage by constantly monitoring and modifying system parameters. In order to improve the efficiency and effectiveness of HVAC and other mechanical systems, this technology finds extensive application in commercial and industrial structures.

4. SYSTEMDESIGN

In order to improve operational efficiency, occupant comfort, and energy performance, a Building Automation System (BAS) or Building Management System (BMS) is used to track and adjust different building systems and equipment.

Networks at the field level allow sensors, actuators, and controllers to communicate with one another. Interoperability between devices from different manufacturers is made possible via common communication protocols such as BACnet, Modbus, and LonWorks.

The building management system (BMS) is accessible to building operators via a graphical user interface (GUI) accessible on desktops, laptops, and mobile devices. Users can see data in real-time, change set points, see alarms, and create reports all through the interface. Gateways for Integration: Building management systems (BMS) frequently connect to various other technologies and systems within a building, including security systems, energy management software, and fire alarms. In order to provide a comprehensive and interoperable building environment, integration gateways allow various systems to communicate with one other in a seamless manner.

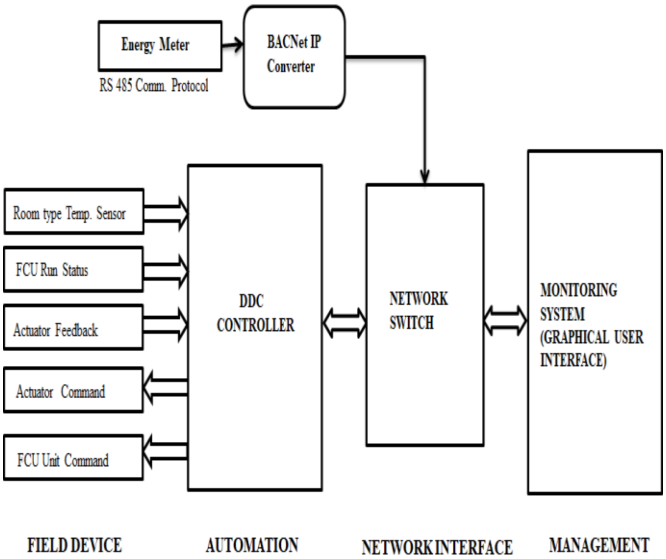

Fig.2. Implementation Diagram

4.1 Controllers

Integrating central plants and big built-up air handlers into your current Metasys network is made easy with the cost-effective solutions provided by the Metasys Network Control Engine Series controller. Expanding and improving your Metasys setup to get enhanced insight and more management of the power usage? Johnson Controls NCEs are the ideal choice because they combine the capabilities of a field equipment controller with those of a network supervisor, IP network connectivity, I/O point connectivity, and direct digital control. Uses enterprise- and automation-level standards for communication as appropriate.

Incorporates DDC and network monitoring controller capabilities. This building controller has passed the BACnet Testing Lab's certification process. In order to improve the efficiency, security, and comfort of your building's residents as well as your own decision-making abilities, it is necessary to establish a unified platform for all relevant communications.

5. CONFIGURATION OF INPUTS & OUTPUTS

Important first steps in installing control and automation systems in buildings include configuring the controller's inputs and outputs. When talking about controllers, inputs usually mean data or signals that are received by the controller, and outputs are signals or commands that are transmitted to actuators or otherdevices. During setup, users choose which input sources should trigger which controller actions.

Fig.3. Experimental Setup

To feed data into the controller, users must first locate and set up any necessary sensors or devices. Some examples of such data sources are temperature sensors and occupancy detectors. In order to get reliable readings, you need to configure the input by choosing its kind, placing it, and adjusting its scale parameters.

Table 1.Configuration of Inputs

S.No	Data Entry Sites
1	Environment Heat
2	Operating Conditions of FCU-1
3	Operating Conditions of FCU-2,
4	Utilisation Sensor-1
5	Utilisation Sensor-2
6	FCU Actuator Feedback

Input data and control strategies inform the controller's output, which users can set up to communicate with various devices such as actuators, valves, and more. This requires defining the input conditions, the range of the output signal, and how it responds to those conditions. In order to configure an output, one may need to do things like define fail-safe behaviours, specify the control method, or adjust the settings of a proportional-integral-derivative (PID).

Table 2.Configuration of Outputs

S.No	Final Results
1	First Command Unit-1
2	Command of the FCU Unit-2
3	Tasks for Lighting and Fans - 1
4	Tasks for Lighting and Fans - 2
5	Control of FCU Actuators

6. CONVERSIONOFMODBUSRTUTOBACNETPROTOCOL

In a master-slave architecture, a master device sends out requests or queries to other devices, in this example the energy metres, and the slave devices answer with the data that the master device requested. The network's data exchange is made efficient and organised by this request-response system.

The two forms of Modbus communication are the Remote Terminal Unit (RTU) and the American Standard Code for Information Interchange (ASCII). Unlike ASCII, which uses plain text for data transmission, RTU is more widespread and uses binary encoding. Data transmission speeds and application requirements are two of the main considerations when deciding between these technologies.

Several benefits can be gained by integrating energy metres with Modbus communication. Industries can optimise usage and save costs with the help of proactive energy management made possible by real-time monitoring of energy consumption. In addition, a vendor-neutral environment is promoted by the standardised nature of Modbus, which guarantees interoperability across devices from different manufacturers.They are made to conform to all the rules and regulations in the business world.

Internet Protocol (IP) networks are used by BACnet/IP, a version of the BACnet protocol. This paves the way for BACnet devices to integrate with the internet's foundational networking protocols like TCP/IP and Ethernet. The ubiquitous and scalable communication in current building automation systems is made possible by BACnet/IP, which takes advantage of IP networks.

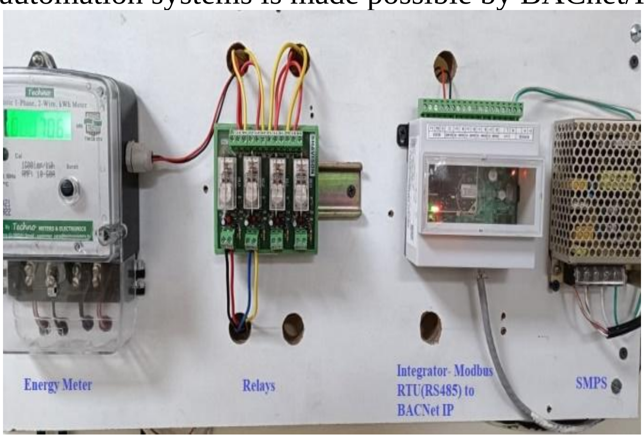

Fig.4. Module kit-Modbus to BACNet IP Conversion

Services and Objects: BACnet specifies a common set of services and objects that devices can utilise for communication. Objects stand in for different parts of a system or device (such temperature, lights, and alarms), and services specify what those parts may do (like read and write).

The main objective of BACnet is to guarantee that devices from various manufacturers can communicate with one another. Devices are able to comprehend and react to one another's demands because of a standardised data model and communication protocols.

BACnet/IP Addressing: BACnet/IP allows devices to be identified on an IP network by assigning them an IP address. Because of this, devices can talk to each other through local networks or the web. Both IPv4 and IPv6 addresses are compatible with BACnet/IP.

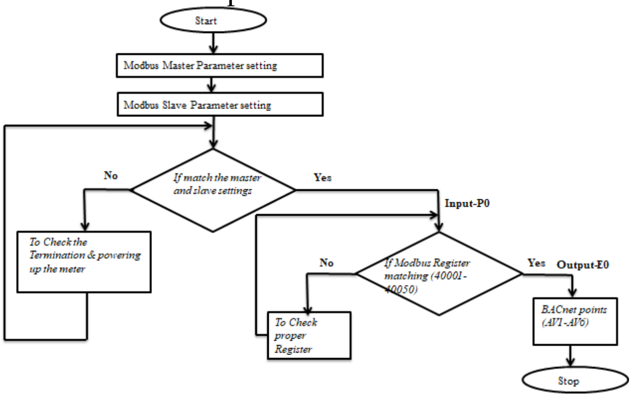

Fig.5. Flow Chart of Data Conversion

7. GRAPHICS-MONITORINGCONTROL

In the field of building automation and control systems, a supervisory controller is the brains behind all the different subsystems that work together to keep a structure running smoothly. Efficiency, comfort, and energy savings are the goals of its operation, which is based on monitoring, coordinating, and optimising the performance of various building systems. The supervisory controller is the central processing unit (CPU) of an automated building system. It takes readings from field controllers and sensors, processes them, and then sends out commands to devices and actuators to keep the building at a constant, predetermined temperature and humidity. One main goal is to make it easier to manage all the different systems in a building in one place.

Acquiring Data: A network of sensors spread out across the building continuously gathers data for supervisory controllers.humidity, temperature, occupancy, and power usage are just a few of the factors that these sensors can measure. By compiling this data in real-time, the controller can get a full picture of the building's condition.

The capacity of the supervisory controller to communicate with and integrate with different subsystems and devices is critical to its operation. Everything from HVAC systems to lighting controls to security systems and beyond falls under this category. The controller is in constant contact with the field controllers, who are in charge of individual areas or systems in the structure. When it comes to coordinating the building's activities with energy saving objectives, the supervisory controller plays a crucial role.

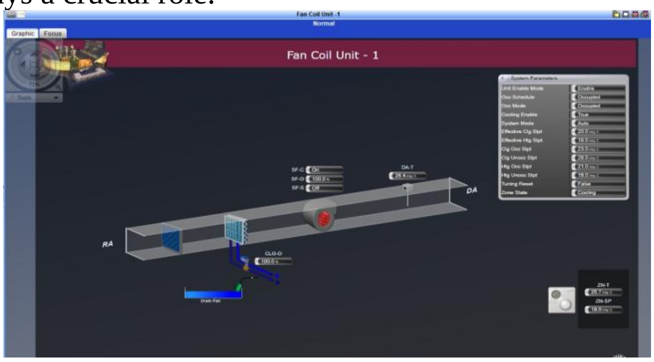

Fig.6. FCU Graphics-mapping points

Fig.7. Floor Graphics

Alarm and Fault Detection: The building's systems are constantly being monitored by the supervisory controller for any signs of abnormalities or problems. The controller raises red flags and notifies operators to fix the problem when a sensor detects an out-of-range condition or when equipment fails. Reduced downtime and increased system reliability are results of this preventative method of defect detection.

8. RESULTS

By plotting the date against the energy consumption (with values ranging from 10.32 KWh to 33.13 kWh) from the 17th of October 2023, to the 16th of November 2023, one can see the trend in energy use during that time. The consumption of energy values are shown on the y-axis and time is shown on the x-axis of the graph.

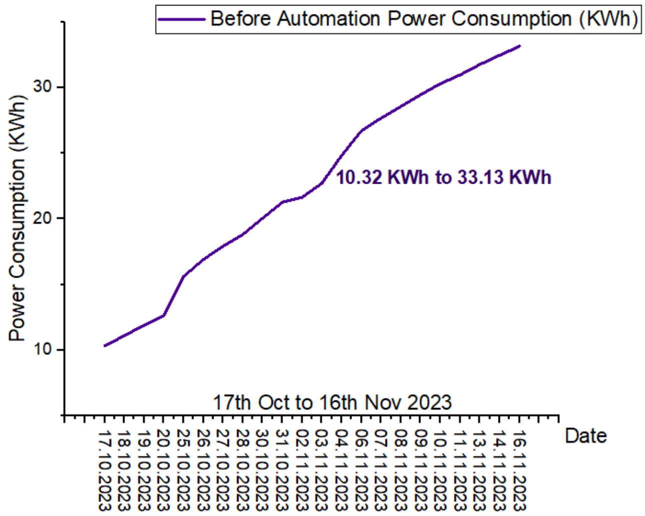

Fig.8Before Automation Power Consumption

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

Building management systems in particular have reaped the benefits of automation in terms of reduced energy use. Energy consumption was marked by inefficiency and a lack of dynamic control before automation. A revolutionary change has occurred with the advent of intelligent automation systems, most notably those that use DDC controllers.

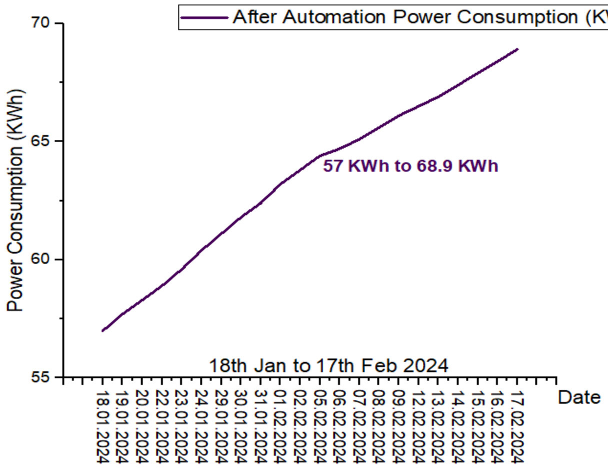

Fig.9. After Automation Power Consumption

The same after automation representing the relationship between date and energy consumption from January 18, 2024, to February 17, 2024, with energy values ranging from 57KWh to 68.9KWh allows for a visual understanding of the energy consumption trend over this period.

Energy expenses were higher due to less-than-ideal utilisation practices prior to automation. Because of their inability to respond to changing environmental circumstances, manual control methods wasted energy. Automation made it possible to fine-tune the performance of HVAC, lighting, and other equipment thanks to DDC controllers' constant monitoring and management capabilities. A more intelligent and adaptive method of building management was achieved by the system's response to current circumstances and the incorporation of occupant sensors.

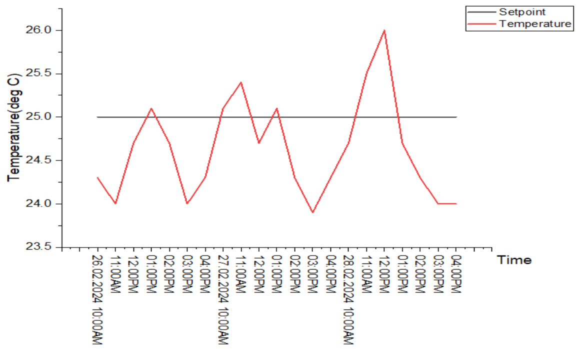

Fig.10. Maintain the Room Temperature

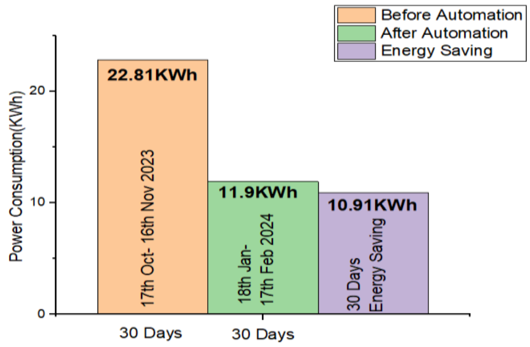

Fig.11. Comparison of power consumption for before, after automation and energy saving

The room's temperature is automatically controlled after automation depending on the set point and occupant comfort, allowing for energy savings, with a set point of 25◦C and a maintenance range of ± 1◦C.

9. CONCLUSION

For efficient management of building operations, a smart building automation system based on a Direct Digital Controller (DDC) has been extremely advantageous. The significance of CFM estimates in preserving ideal airflow patterns and guaranteeing conformity with standards is highlighted by the comprehensive analyses and computations performed for Area-1 and Area-2. With DDC technology, HVAC systems can be precisely controlled and monitored, leading to better energy usage and more comfortable occupants. The shift from Modbus RTU to BACnet also improves the automation framework's responsiveness and integration by making it easier for different building devices and systems to communicate and work together. System management, problem detection, and energy optimisation are all made even better with the help of supervisory controllers' graphical monitoring and control features. Using before-and-after energy usage data, we can see how DDC-based automation systems help create smart, sustainable, and user-centric designed environments by cutting down on inefficiencies and saving money. Incorporating Direct Digital Controllers is a huge step forward in contemporary building automation; it boosts operating efficiency, saves money, and improves environmental performance.

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