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Building Automation in Pharmaceutical Industry

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Abstract

Maintaining precise environmental conditions is essential in pharmaceutical manufacturing to meet regulatory standards and ensure product integrity. This study introduces a smart Building Automation System (BAS) integrated with an Energy Management System (EMS), designed specifically for pharmaceutical applications. The system employs Air Handling Units (AHU) and Variable Air Volume (VAV) components, along with real-time sensing, to automatically control temperature, humidity, and air cleanliness. Using industrial protocols such as BACnet and Modbus, the solution enables centralized oversight and automated control via a supervisory system. It also incorporates predictive maintenance and demand-based energy optimization, contributing to operational efficiency. The proposed model improves energy savings, minimizes human intervention, enhances fault detection, and supports compliance with GMP and FDA guidelines. This implementation demonstrates how automation can create cleaner, safer, and more energy-efficient environments in the pharmaceutical sector. This project is proudly sponsored by Johnson Controls, whose support and expertise have been instrumental in the development and deployment of this advanced automation solution.

Keywords: Building Automation System (BAS); Heating; Ventilation and Air Conditioning (HVAC) Control; Pharmaceutical Industry; Air Handling Unit (AHU); Variable Air Volume (VAV)

Introduction

In the pharmaceutical industry, maintaining stringent environmental control is critical to ensure the safety, efficacy, and quality of drug products. Controlled parameters such as temperature, humidity, and air pressure directly impact the manufacturing process, especially in cleanroom environments where contamination must be minimized. Traditional HVAC systems play a vital role in achieving these conditions but often involve high energy consumption and manual oversight, which can lead to inefficiencies and operational challenges.

Building Automation Systems (BAS) have emerged as a solution to automate and optimize HVAC operations, enabling precise control over environmental parameters while improving energy efficiency. By integrating Air Handling Units (AHU) and Variable Air Volume (VAV) systems with real-time sensor data, intelligent controllers, and energy

management systems (EMS), BAS can adapt dynamically to changing conditions. This integration is particularly important in pharmaceutical manufacturing, where compliance with regulatory standards such as Good Manufacturing Practice (GMP) and Food and Drug Administration (FDA) guidelines is mandatory.

This paper presents a smart BAS framework specifically designed for pharmaceutical environments. The proposed system focuses on seamless AHU and VAV integration, real-time monitoring, predictive maintenance, and energy optimization. By leveraging advanced communication protocols like BACnet and Modbus, along with supervisory control through SCADA/HMI interfaces, the system aims to reduce energy consumption, minimize human intervention, and ensure regulatory compliance. Such automation not only enhances operational efficiency but also contributes to sustainability goals through adaptive energy management.

Related Works

Recent studies highlight the growing importance of Building Automation Systems (BAS) integrated with energy management solutions to enhance operational efficiency in industrial settings. Liu and Huang (2024) [1] presented an optimization model using Building Information Modelling (BIM) and Computational Fluid Dynamics (CFD) to improve HVAC performance in pharmaceutical facilities, demonstrating how precise AHU and VAV control can ensure environmental stability. Meng et al. (2016) [2] experimentally evaluated an advanced VAV system showing that coordinated AHU-VAV operation significantly enhances thermal regulation across controlled spaces. Cheng and Chen (2012) [3] proposed a robust control algorithm for VAV- based AHU systems, which optimizes both static pressure and supply air temperature, directly contributing to system responsiveness and energy savings.

A novel AHU-VAV configuration with a single coil for both heating and cooling was introduced by Nassif (2023) [4], which reduces complexity and energy consumption while maintaining airflow integrity. Stamatescu et al. (2019) [5] applied support vector machine (SVM) models to AHU datasets for fault detection and energy efficiency modeling in smart pharmaceutical buildings. Similarly, Gunay et al. (2022) [6] used building simulations to develop fault-tolerant sequences of operation for VAV-AHU systems, highlighting their critical role in avoiding unplanned downtimes in Good Manufacturing Practice (GMP) compliant environments.

Merabet et al. (2021) [7] provided a systematic review of AI-driven intelligent control systems for HVAC, confirming their efficacy in automating AHU-VAV operations in pharmaceutical settings. Chen et al. (2023) [8] tested AHU and VAV responses under realistic conditions using a hardware-in-the-loop testbed, facilitating the evaluation of performance in lab-validated, simulated environments.

Building Automation System

A Building Automation System (BAS) is an integrated control system that manages and monitors various building services such as heating, ventilation, air conditioning (HVAC), lighting, security, and fire safety. By utilizing sensors, actuators, and controllers connected through communication networks, BAS enables automated and centralized supervision of these subsystems. This centralized control allows for improved operational efficiency, occupant comfort, and reduced energy consumption by optimizing system performance based on real-time data.

In modern buildings, especially in industrial and pharmaceutical facilities, BAS plays a vital role in maintaining strict environmental conditions. Pharmaceutical manufacturing requires precise control over temperature, humidity, and air pressure to meet quality standards and regulatory requirements like Good Manufacturing Practice (GMP). BAS automates these controls by integrating with HVAC components such as Air Handling Units (AHU) and Variable Air Volume (VAV) systems, allowing zone- specific regulation of airflow and environmental parameters critical for cleanroom operations.

Communication protocols such as Building Automation and Control Network (BACnet) and Modbus are commonly used in BAS to facilitate interoperability between different devices and systems from various manufacturers. These protocols enable seamless data exchange, allowing the BAS to gather sensor readings, send control commands, and integrate with higher-level systems like Energy Management Systems (EMS) and Smart Grids. Such integration helps monitor energy usage, optimize power consumption, and support demand response strategies, contributing to sustainability and cost savings.

Additionally, modern BAS incorporates advanced features like predictive maintenance, alarm management, and remote monitoring through Supervisory Control and Data Acquisition (SCADA) or Human Machine Interface (HMI) platforms. These capabilities help detect anomalies early, reduce downtime, and enhance system reliability. By automating routine tasks and providing real-time insights, BAS reduces the need for manual intervention, minimizes human errors, and supports compliance with safety and regulatory standards. Overall, BAS is essential for ensuring efficient, safe, and sustainable building operations in complex environments like pharmaceutical industries.

Block Diagram

The block diagram represents a comprehensive HVAC automation system tailored to the pharmaceutical industry, emphasizing precise environmental control, monitoring, and regulatory compliance.

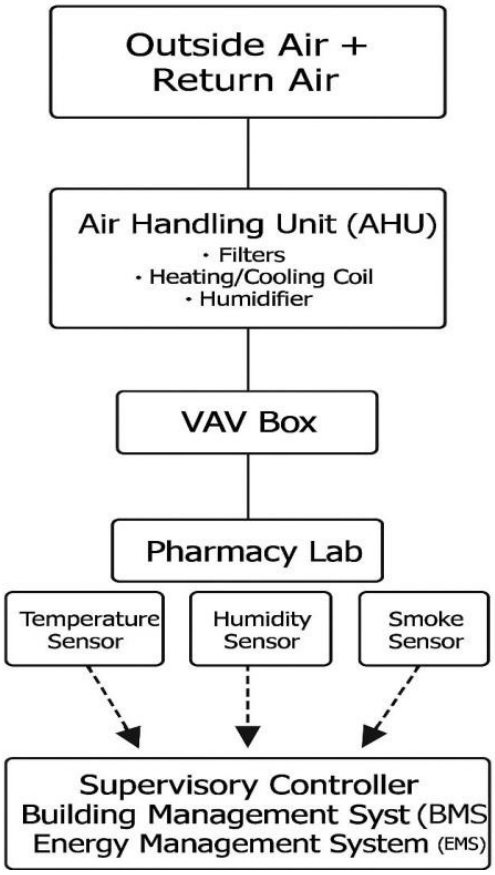

Fig 1. Block Diagram

1. Air Handling Unit (AHU)

- **Function:** Core system component that conditions incoming air before it is distributed.
- **Subcomponents:**

-**Filters (HEPA):** Remove dust, particulates, and airborne contaminants.

-**Cooling/Heating Coil:** Regulates air temperature as per cleanroom requirements.

-**Humidifier:** Maintains precise moisture levels to prevent static and preserve product quality.

- **Importance in Pharma:** Ensures clean, conditioned air critical for GMP and FDA compliance.

2. Variable Air Volume (VAV System)

- **Function:** Adjusts airflow in individual zones based on real-time demand.
- **Advantages:**

-Improves energy efficiency by reducing airflow where not needed.

-Provides zone-wise temperature and pressure control.

- **Importance in Pharma:** Maintains pressure gradients between rooms (e.g., positive pressure in clean areas) and avoids cross-contamination.

3. Sensor Network

- **Components:**

-**Temperature Sensors:** Maintain $\pm 0.5^{\circ}C$ accuracy to prevent drug degradation.

-**Humidity Sensors:** Keep RH between 30–60% for product stability.

-**Smoke Detectors:** Provide early fire detection; integrated with alarms**.**

-**Purpose:** Real-time monitoring for immediate control actions and compliance logging.

4. Building Management System (BMS) / Energy Management System (EMS)

- **BMS:**

-Monitors and controls HVAC, lighting, alarms, and access.

-Displays real-time data through SCADA/HMI interfaces.

- **EMS:**

-Optimizes power use via load management and smart scheduling.

-Reduces utility costs and carbon footprint.

- **Importance in Pharma:** Supports automated control, compliance documentation, and predictive maintenance.

5. Pharmacy Laboratory Environment

- **Requirement:** Highly controlled space for drug compounding, testing, and storage.
- Environmental Needs:

-Stable temperature and humidity.

-High-frequency air changes (6–20 ACH).

-Strict cleanliness and pressure control.

- **Role in Automation:** Receives precisely conditioned air via ducts and VAV boxes, monitored by sensors, and adjusted by BMS in real-time.

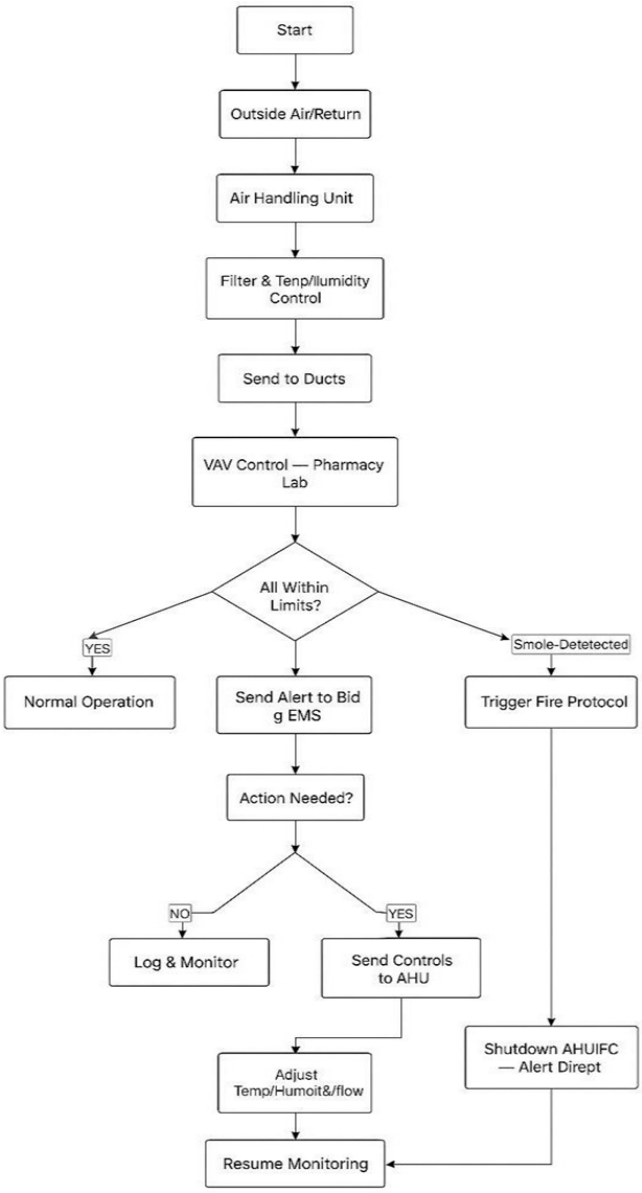

Fig 2. Flowchart

1. Air Handling and Conditioning

- The process starts by **mixing fresh outdoor air** with **recirculated return air** to balance quality and energy use.
- This mixed air passes through an **Air Handling Unit (AHU)** where:

-**Filters** remove dust and contaminants (HEPA filters for pharma).

-**Heating/Cooling coils** adjust the temperature as per set requirements.

-**Humidifiers or dehumidifiers** regulate moisture levels to protect sensitive pharmaceutical products.

2. Air Distribution and Zoning

- The conditioned air flows through a **duct network** to different facility zones.
- **Variable Air Volume (VAV) boxes** regulate how much air is delivered to each zone, allowing for:

-Customized temperature and pressure control.

-Efficient energy use by adjusting air based on demand in each area.

3. Environmental Monitoring

- A **network of sensors** is deployed in the pharmacy lab to continuously monitor:

-**Temperature:** To keep products stable and processes safe.

-**Humidity:** To avoid moisture-related degradation or contamination.

-**Smoke:** For early fire detection and safety assurance.

- This helps ensure **regulatory compliance** with GMP and FDA guidelines.

4. Control and Feedback via BMS/EMS

- The **Building Management System (BMS)** or **Energy Management System (EMS)** collects sensor data in real-time.
- It performs **automatic analysis** and takes actions such as:

-Adjusting airflow through VAV boxes.

-Activating heating or cooling to correct temperature.

-Modifying humidity levels as required.

- Ensures energy-efficient operations and minimal manual intervention.

5. Emergency Response

- In case of **smoke or fire detection**, the system:

-Sends alerts to the BMS and triggers evacuation alarms.

-Shuts down the HVAC system to **prevent smoke spread**.

-**Activates fire suppression** systems like sprinklers or gas discharge units.

-Notifies emergency responders automatically.

- Ensures occupant safety and equipment protection.

Fig 3. Metasys User Interface

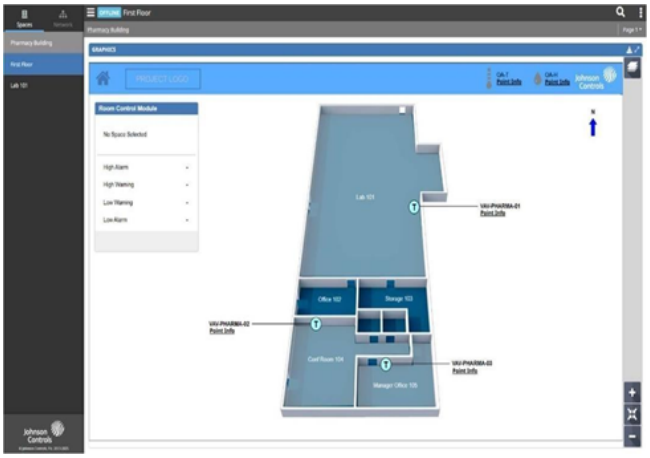

Fig 4. First floor plan showing VAVs assigned for respective lab and rooms

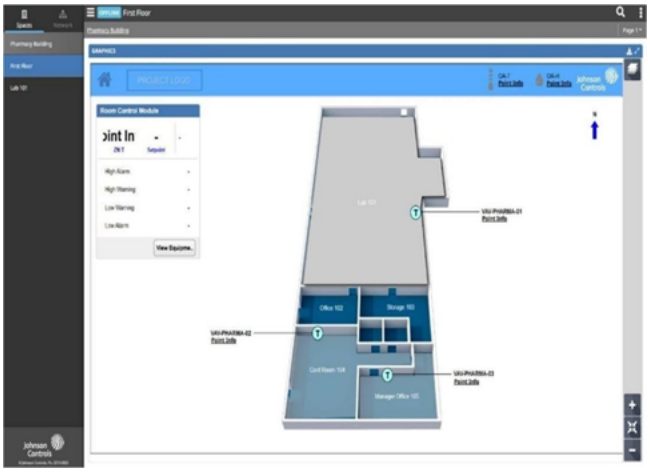

Fig 5. Pharmacy lab 101 real time monitoring details (zone temperature , setpoint)

Results

In our project, we used **Metasys UI** by **Johnson Controls** to enhance visualization and control in pharmaceutical building automation. It provided an intuitive interface for real-time monitoring and efficient management of critical parameters.

Key Features:

- **Custom Graphics**: Created interactive visuals using Graphics Manager and Editor for clear process visualization.
- **Real-Time Data**: Displayed live updates of temperature, humidity, and equipment status for precise control.
- **User Navigation**: Added navigation buttons for easy access to different system views.
- **System Integration**: Linked graphics to automation controls for direct monitoring and adjustments.
- **User Experience**: Used prebuilt templates and symbols to design functional and user-friendly graphics.

Conclusion

In conclusion, the implementation of automation in the pharmaceutical industry represents a significant advancement in operational efficiency and product quality. By integrating technologies such as robotic process automation (RPA) and artificial intelligence (AI), companies can streamline repetitive tasks, enhance precision, and reduce human error. This transformation not only accelerates production timelines but also ensures compliance with stringent regulatory standards, ultimately safeguarding patient safety. Furthermore, automation facilitates better data management and analysis, leading to informed decision-making and innovation in drug development. As the industry continues to evolve, embracing automation will be crucial for maintaining competitiveness and meeting the growing demands of the market. The future of pharmaceutical manufacturing lies in leveraging these technologies to create a more efficient, reliable, and responsive production environment.

In conclusion, the integration of automation within the pharmaceutical industry is pivotal for enhancing operational capabilities and ensuring product integrity. The shift towards automated systems allows for significant improvements in accuracy, efficiency, and sterility, which are essential in a field where precision is paramount.

References

1) Liu L, Huang Y. HVAC Design Optimization for Pharmaceutical Facilities with BIM and CFD. *Buildings*. 2024;14(6):1627. Available from: https://dx.doi.org/10.3390/buildings14061627.
2) Meng Q, Yan X, Ren Q, Adeli H. Variable air volume air-conditioning experiment system with advanced controls. *Indoor and Built Environment*. 2016;25(3):114–127. Available from: https://doi.org/10.1177/1420326X14540314.
3) Cheng S, Chen Y, Chan CHK, Lee T, Chan HL, Qin J, et al. A Robust Control Strategy for VAV AHU Systems and Its Application. *Advances in Intelligent and Soft Computing*. 2012;p. 635–642. Available from: https://doi.org/10.1007/978-3-642-27552-4_85.
4) Ebrahimi P, Ridwana I, Nassif N. Solutions to Achieve High-Efficient and Clean Building HVAC Systems. *Buildings* . 2023;13(5):1211. Available from: https://doi.org/10.3390/buildings13051211.
5) Stamatescu G, Stamatescu I, Arghira N, Fagarasan I. Data- driven Modelling of Smart Building Ventilation Subsystem. 2019. Available from: https://arxiv.org/abs/1901.06263.
6) Gunay HB, O'brien W, Beausoleil-Morrison I. Fault- tolerant sequences of operation for VAV AHU systems through building performance simulation. *Proceedings of the 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*. 2022;p. 1–10. Available from: https://doi.org/10.1145/3563357.3564053.
7) Merabet GH. Intelligent Building Control Systems for Thermal Comfort and Energy-Efficiency: A Systematic Review of Artificial Intelligence-Assisted Techniques. 2021. Available from: https://arxiv.org/abs/2104.02214.
8) Chen Z. Development of a Hardware-in-the-loop Testbed for Laboratory Performance Verification of Flexible Building Equipment. 2023. Available from: https://arxiv.org/abs/2301.13412.