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Building the Future: Energy Efficiency and Sustainable Design

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Abstract

The research work aims to present an extensive study of energy-efficient green buildings with a focus on the latest technologies, strategies and hence their environmental and economic consequences. It dives deep into what green building is, including 1) site sustainability, 2) energy efficiency, 3) water efficiency, 4), material efficiency, and 5) design. The study discusses how green buildings are planned, in a way to consume the least amount of energy and leave the smallest environmental impact, through the use of renewable energy systems, passive design strategies (considering factors such as orientation and layout), efficient HVAC systems (Heating Ventilation Air Conditioning Systems), smart technologies (to automate and control building components for efficiency) and also Green Roofs, Bio-walls or Geothermal Systems with an appropriate use of natural light. We also delve into how building form and orientation can be manipulated to increase energy and light generation. The societal advantages of green building, such as lower carbon emissions and better preservation of natural resources, are not fully highlighted. The study highlights that green building is a significant contributor in addressing climate change and achieving sustainable development battle. It presents four key approaches to reducing energy consumption and mitigating CO_2 emissions in buildings: a) incorporating passive design principles that harness solar energy, b) utilizing low-embodied energy materials, c) employing energy-efficient appliances to reduce operational energy use, and d) integrating renewable energy technologies. In conclusion, the study emphasizes the essential role energy-efficient green buildings play in addressing climate change and advancing sustainable development. Through a detailed exploration of various technologies and strategies, it highlights the necessity of adopting energy-efficient approaches in both the design and operation of modern buildings.

Keywords: Energy efficiency, HVAC systems, solar energy, climate change, green buildings

INTRODUCTION

Green buildings are the future step to safeguard the environment from the effects caused due to human actions. There are several problems with the current way of building architectural structures which has many problems like loss of energy, increased GHGS, and increased wastage of non-renewable natural resources. However, the initial capital cost is higher as compared to traditional buildings, but green buildings have a lower operating cost and a higher life expectancy than traditional buildings [1–3].

The construction industry is one of the largest consumers of resources and energy worldwide. Buildings are responsible for approximately 40% of global CO_2 emissions, 40% of natural resource usage, and nearly 40% of total waste generation over their life cycle. This has earned the industry the label of the “40% sector”. Sustainable development in construction, particularly for residential

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buildings, emphasizes the selection of eco-friendly materials, the adoption of sustainable building methods, and efficient management during the use, operation, and eventual demolition of structures. The core focus is on minimizing CO_2 emissions, reducing energy consumption, and preserving natural resources to mitigate the environmental impact of the construction industry. Weerasinghe *et al*. studied the life cycle costs of green-certified buildings and conventional buildings, and it turns out that the life cost of green buildings was reduced by 24 to 28% compared to conventional buildings [4].

In recent years, to maintain good heating and ventilation demand in buildings, the continuous operation of HVAC systems has caused the wastage of building's energy consumption, environmental pollution, and the destruction of energy structures. So, it is necessary to reduce the resource assumption of the system as far as possible, improve the defects of high energy and low efficiency of the conventional system, increase the research efforts of HVAC, maximize the use of renewable resources, and promote the joint development of economic and social benefits [5].

Figure 1 shows the amount of carbon dioxide produced during the life cycle of a building from its formation to its end. Solar energy, derived from the Sun's radiant light and heat, is harnessed through a variety of technologies, including solar power for electricity generation, solar thermal energy for heating, and solar architecture. As a key renewable energy source, these technologies are categorized into passive or active systems based on their approach to capturing, distributing, or converting solar energy. Active solar techniques, such as photovoltaic panels, concentrated solar power, and solar water heating, directly capture and utilize solar energy. Passive solar techniques, on the other hand, focus on optimizing building design by positioning structures to maximize sunlight, using materials with high thermal mass or light-reflecting properties, and creating layouts that facilitate natural air circulation [6–9].

TECHNOLOGIES AND STRATEGIES

Technology often becomes a focal point after a strategy is established, as challenges with existing requirements, available technologies, or siloed tools across teams become evident during execution. Understanding these technological needs and constraints is crucial for effective strategic planning.

Several strategies exist for developing energy-efficient green buildings, including:

- Cool roofs,
- Green insulation,
- Solar power,

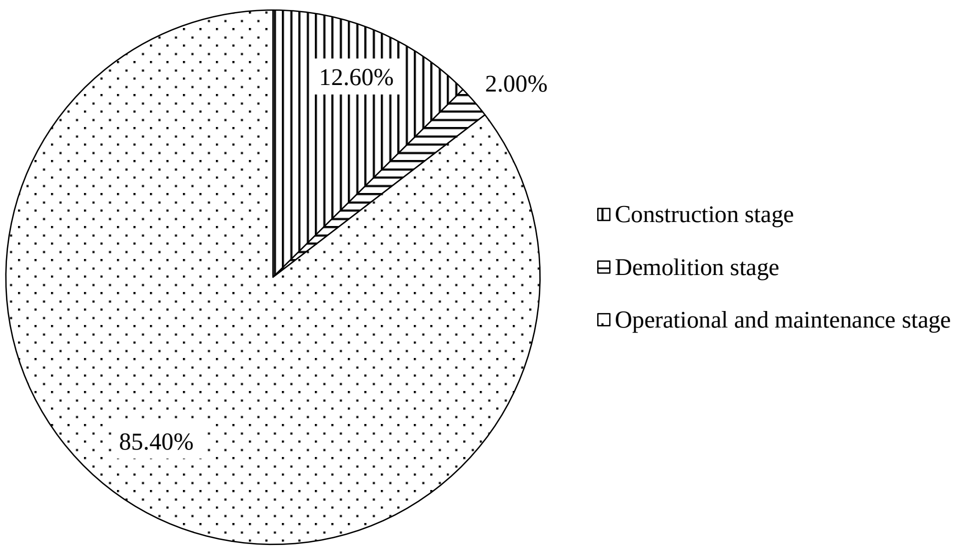

Figure 1. Percentage of CO_2 emissions produced in building life cycle.

- Biodegradable materials,
- Electrochromic materials smart glass,
- Geothermal heating,
- Net-zero energy concepts,
- Low-emitting materials, and
- Energy-efficient HVAC systems.

Among these, this study specifically focuses on the strategy of utilizing energy-efficient HVAC systems to enhance building sustainability [10–12].

IMPORTANCE OF HVAC SYSTEMS

When buying HVAC systems, 83% of consumers give consideration to issues other than price, with 38% stating that system reliability is their top priority. Businesses spend more than $10 billion a year on HVAC maintenance and repairs. India's HVAC systems market is expected to expand by USD 3.98 billion between 2023 and 2028, at a compound annual growth rate of 10.77%.

Figure 2 shows the projected future market scope for HVAC Systems.

Energy-Efficient HVAC System

The system has such main components as an air-conditioned room of the fabric plant, the fresh, bypass, and exhaust air dampers, damper actuators, ventilation, exhaust air fans, humidifier pumps, driver inverters for humidification, temperature, humidity, airflow, and differential air pressure sensors and controllers. Figure 3 shows the general schematic diagram of the single-zone HVAC-controlled system for fabric plants. The ideal temperature and humidity levels are generally 25°C and 70%, respectively, in fabric air condition systems.

The cooling process is performed by utilizing the cold water used for humidification by mixing fresh air supplied by an outdoor damper in the fabric air condition systems. Heating processes have been made by the circulation of indoor air that generates heat from machines, lights, and people, using bypass dampers. According to the desired temperature value, the temperature controller directs the damper actuators. If the controlled zone temperature is to be raised, the controller commands the bypass dampers in the direction of the opening position, and conversely the fresh and exhaust dampers in the direction of the closing position. The rate of opening and closing values must be the same values to equilibrate air pressure between indoors and outdoors.

Figure 2. Market share for HVAC systems.

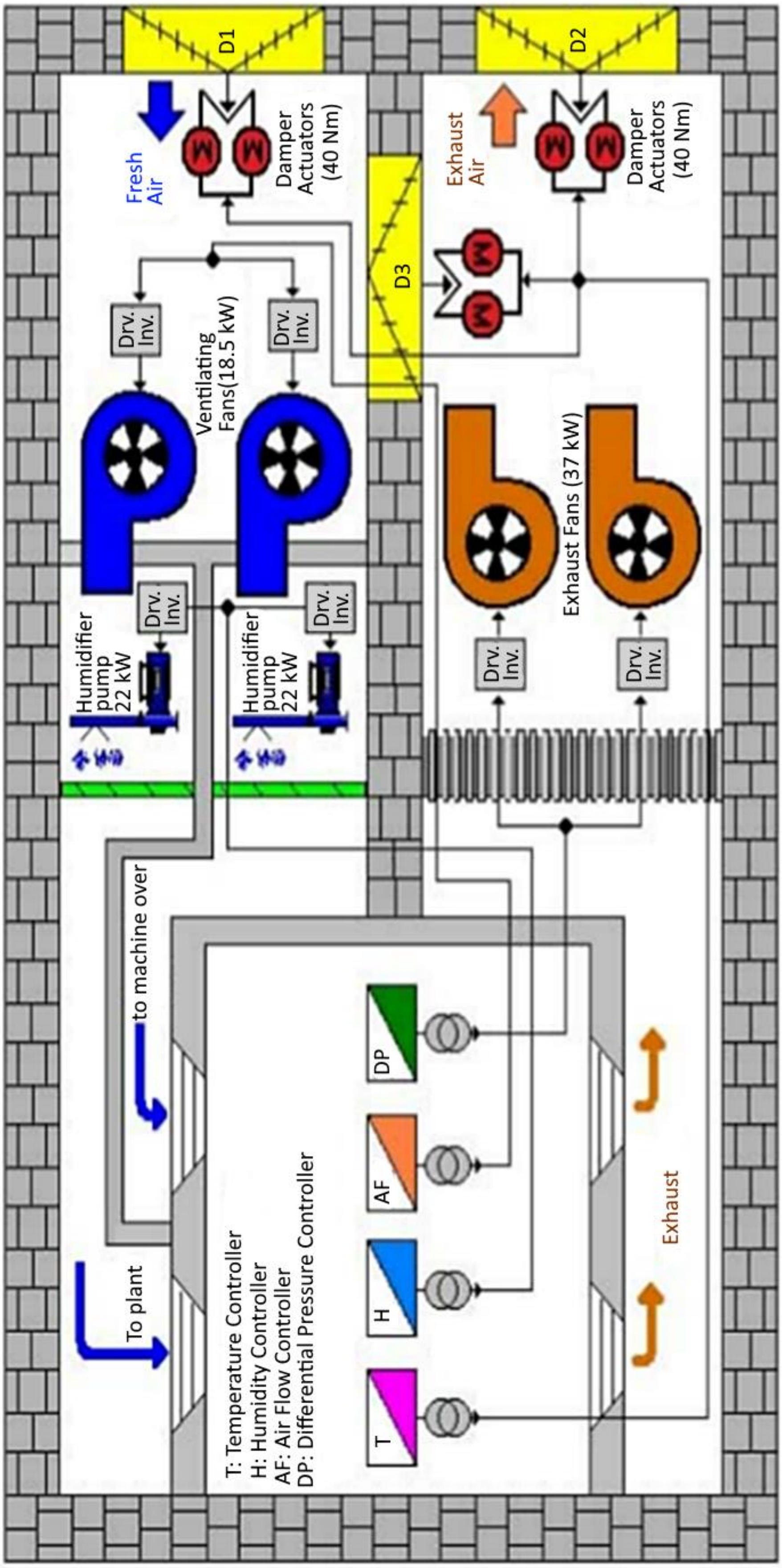

Figure 3. General block diagram of the controlled HVAC system for plants.

Humidifier pumps, nozzles, fresh air dampers, exhaust air dampers, ventilating, and exhaust fans of controlled systems have been shown in Figure 4 [5].

Ventilation and exhaust fans operated at a fixed rotation speed. Energy consumed by the ventilation and exhaust fans corresponds to 40% of the total energy spent in a plant. To decrease energy consumption, the driver inverters have been used for speed control of ventilation and exhaust fan drivers according to desired airflow capacity and differential air pressure in the designed control system [13–17].

Development of the HVAC System

The proposed research work has designed and developed a prototype for HVAC Systems. This HVAC System uses Allen Bradley PLC to control room pressure and temperature.

This system uses Allen Bradley PLC for controlling the HVAC system. The software RSLOGIX 500 has been used for designing the ladder logic of the program and communicated it with the PLC using RSLINX Classic [6]. The cable used for communication was RS-232 cable which uses DF-1 protocol to communicate. HOLLYSYS HMI screen has been integrated with PLC to control the room parameters [7].

A combination of temperature and pressure is controlled and maintained in the room. To control temperature, an electric heating coil of 1000 W rating which operates on 230 V AC is used. To control pressure, a solenoid valve is used which controls the input of a compressor which supplies a continuous pressure. An emergency solenoid valve is provided in case of over-pressure buildup if there is a malfunction in pressure control and it rises abnormally. The emergency valve will release all the pressure. The Figure 5 shows the algorithm for the program:

This is a two-door entry system that helps in maintaining the room environment more efficiently. Only one door can be opened at a time. If the secondary outdoor is opened the primary indoor cannot be opened and vice versa.

Figure 4. General view of HVAC unit of controlled system.

Figure 5. Ladder logic for HVAC System.

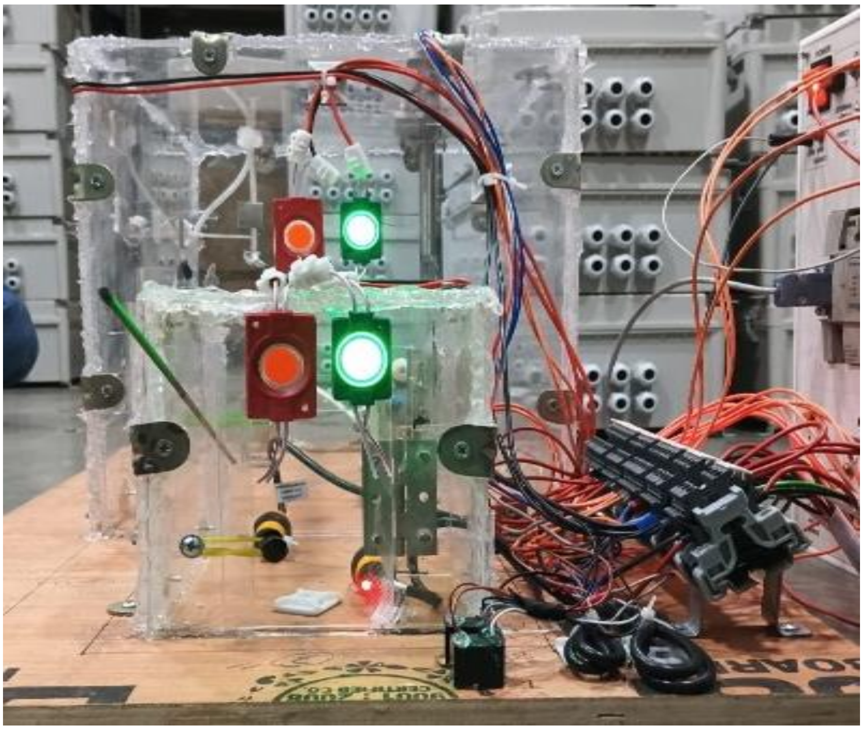

Figure 6. Two-door entry system.

The door algorithm is shown in Figure 6 is for safeguarding the pressure and temperature built in the room. The algorithm indicates whether the primary door to the environment-controlled room can be opened or not by the indicator RED and green LEDs. The green indicator denotes that the door can be opened and the red indicator denotes that the door cannot be opened.

In this algorithm, a basic comparator function is used for temperature and pressure to compare the current room temperature with the desired temperature and according to control the heating coil. For pressure, the same comparator function is used to compare the current room pressure with the desired pressure, and accordingly, the compressor coil is controlled.

HARDWARE SETUP

The wiring diagram in Figure 7 shows the whole configuration is designed in AutoCAD software [8]. As the diagram shows, we have used three relays and two SMPS of 24 and 5 V for powering the relays, the solenoid valve, and the proximity sensors. Experimental setup of the HVAC System in the development phase is shown in Figure 8. Components used in the HVAC System is shown in Figure 9.

RESULTS AND DISCUSSION

Comfort and Thermal Performance

Surveys or assessments of occupant comfort levels, including temperature and pressure control, offer valuable feedback on the HVAC system's performance.

Cost Analysis

Cost-benefit analysis of the HVAC system's implementation and operation, including upfront cost, and maintenance expenses, helps assess its economic viability.

Implementing Building Automation Systems (BAS)

It allows for centralized control and optimization of key building systems, such as HVAC, lighting, and more. These systems provide occupants with real-time feedback on energy usage through smart meters and user-friendly interfaces, encouraging energy-efficient behaviour.

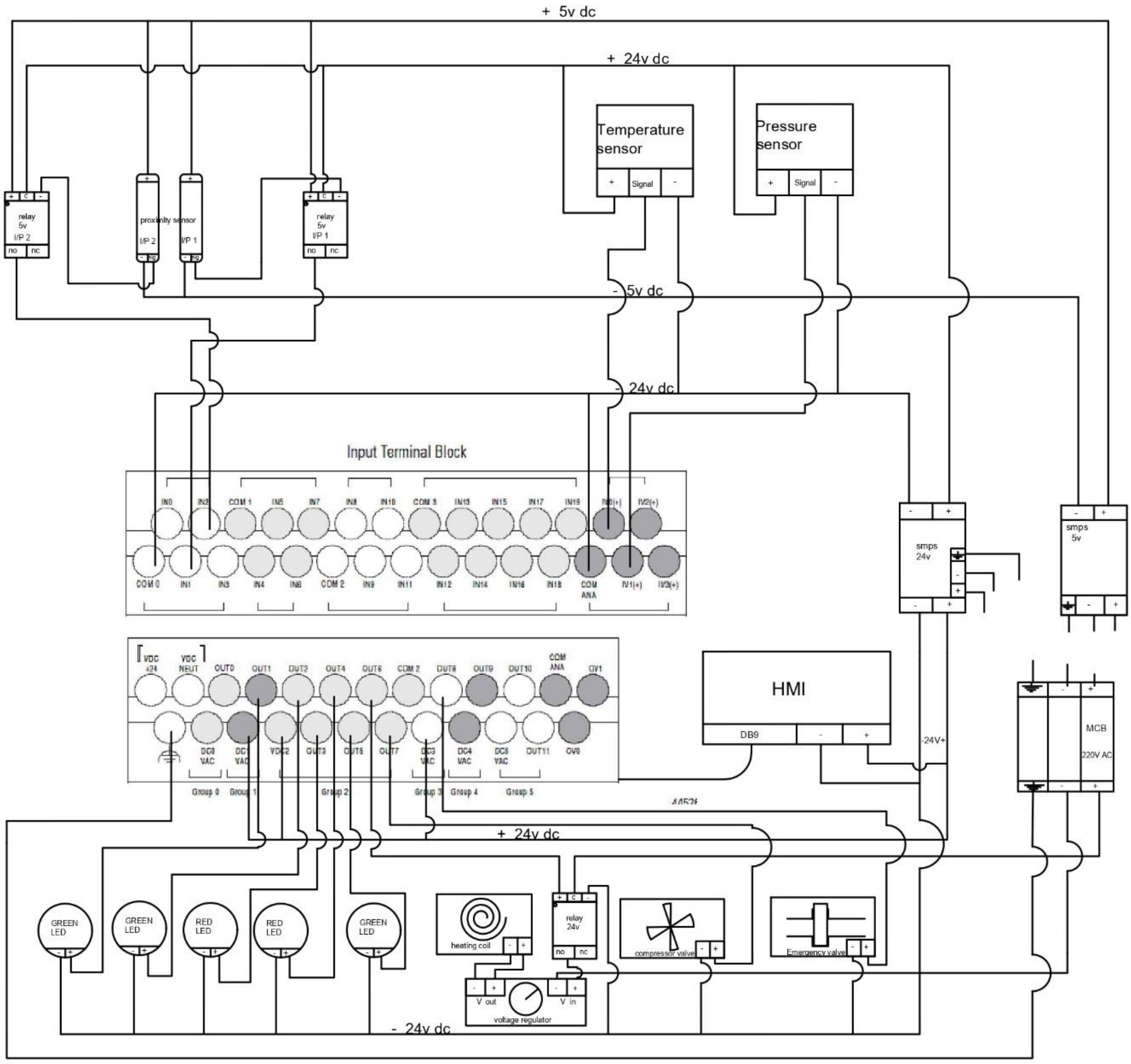

Figure 7. Wiring diagram of HVAC System.

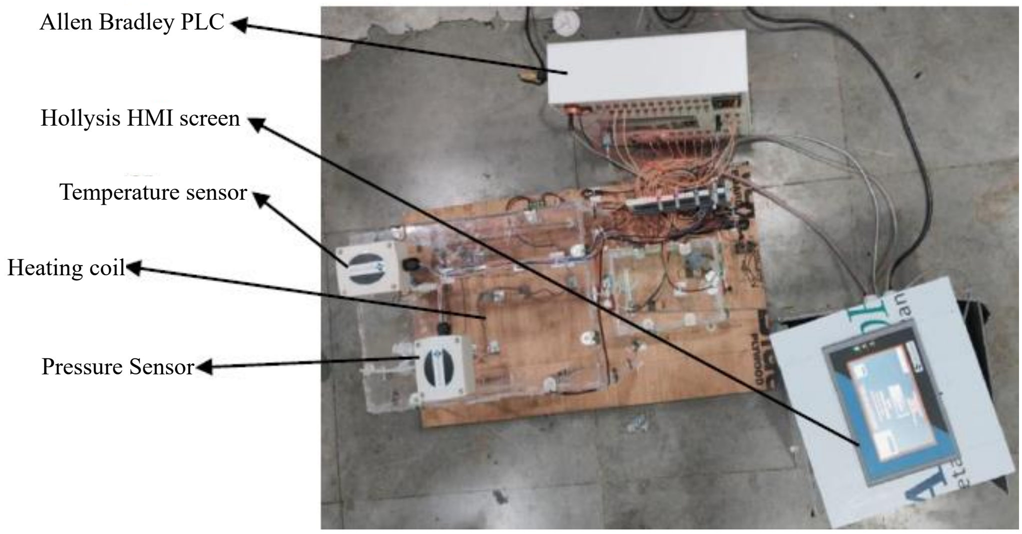

Figure 8. Experimental setup of the HVAC System in the development phase.

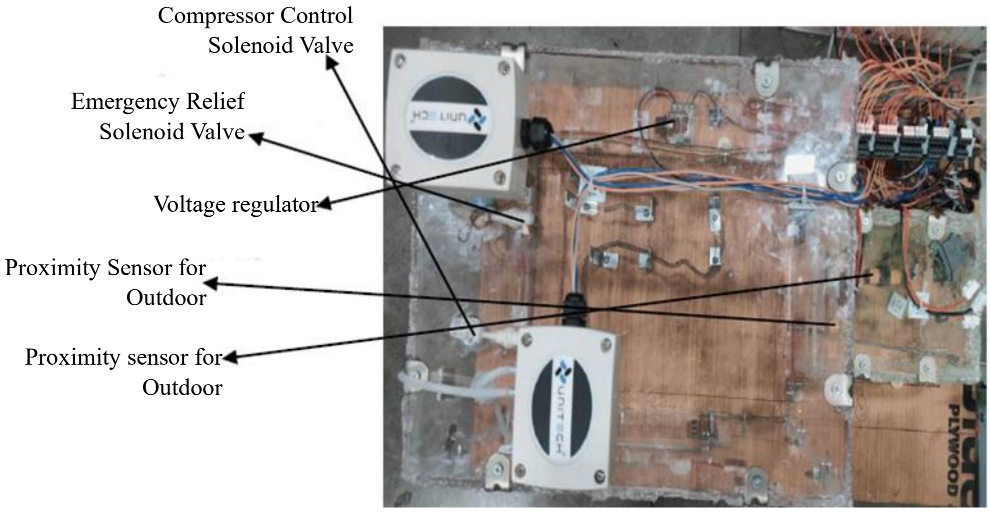

Figure 9. Components used in the HVAC System.

Future Research Directions

Identification of gaps in knowledge or unresolved issues in HVAC system design and operation paves the way for future research endeavours.

By presenting comprehensive results and engaging in insightful discussions, the research work contributes to the advancement of knowledge in HVAC system design, operation, and optimization, thereby informing industry practices and promoting sustainable building environments.

CONCLUSION

In summary, designing an HVAC (Heating, Ventilation, and Air Conditioning) system plays a vital role in achieving comfort, energy efficiency, and maintaining high indoor air quality within a building. Through meticulous planning, and careful selection of equipment, an effective HVAC system can be engineered to meet the specific needs of the occupants and the building itself. Moreover, sustainability should be a priority in HVAC design, with a focus on reducing energy consumption and minimizing environmental impact using renewable energy sources, efficient equipment, and advanced building automation systems. Ultimately, a well-designed HVAC system not only provides thermal comfort but also contributes to the overall functionality and sustainability of a building, enhancing occupant satisfaction and productivity while reducing operating costs and carbon footprint. Therefore, investing in thoughtful HVAC design is essential for creating healthier, more comfortable, and sustainable indoor environments.

To conclude, we were successfully able to control the pressure and the temperature of the room which had a volume of 36000 cm^3. We selected the desired pressure and temperature through the HMI interface which was controlled by the compressor and heating coil.

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