Enhanced IoT-Based Simulation for Air Handling Unit (AHU) Operational Training

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***Abstract*— In the evolving educational technology landscape, integrating Internet of Things (IoT) technologies transforms traditional teaching and learning approaches into more active, collaborative, and self-directed processes. This study introduces an advanced teaching solution to enhance engineering education, particularly in air conditioning and refrigeration: the IoT-embedded Simulation of Teaching Aids for Air Handling Unit (AHU) Operation. Utilising the comprehensive ADDIE instructional design model, this project progressed through five phases: analysis, design, development, implementation, and evaluation. The IoT integration facilitates real-time data monitoring and interactive learning experiences, offering a hands-on approach to understanding complex engineering concepts. Three domain experts rigorously evaluated the effectiveness of this teaching aid through a series of assessments focusing on design, development, and functionality. Feedback from these evaluations confirmed the teaching aid's success in engaging students and enhancing their learning process. Recognised for its quality materials, safety, and organised components, along with its innovative use of IoT technology, this product successfully fulfils the objectives of this study. It represents a significant step forward in modernising engineering education.**

Keywords*— *Simulation Teaching Aids, Air Handling Unit (AHU), ADDIE Instructional Design, Internet of Things (IoT).

I. Introduction

The Ministry of Education Malaysia has formalized the country's vision through the Vocational Education Transformation Plan starting from 2012, aiming to produce self-assured, skilled workers and entrepreneurs, enhancing the country's high-income generation[1]. This vision integrates with the National Education Policy's goals to boost skilled labour and vocational career paths, emphasizing cooperation with industries to elevate vocational education's quality. This synergy between plans underlines the critical role of teaching and learning processes in equipping Technical and Vocational Colleges' graduates with necessary future-facing skills, thus aligning educational outcomes with industry needs.

The significance of teaching aids within this educational framework cannot be overstated. Research by [2] and [3] underscores the transformative impact of teaching aids in enhancing the delivery of educational content. These tools facilitate a more effective communication of learning materials compared to traditional verbal methods and elevate the potential of students and teachers alike. Integrating teaching aids into the educational process significantly improves student achievement by fostering greater interest and engagement in their studies.

In the context of vocational education, the Diploma in Refrigeration and Air Conditioning Technology offered by Vocational Colleges is a prime example of specialised training designed to meet industry needs [4]. This program covers essential topics such as fan ventilation and air handling unit maintenance, equipping students with the necessary knowledge and practical skills for the industry. As detailed by [2], the curriculum ensures that students are well-versed in operating, installing, and maintaining air conditioning systems, adhering to strict safety standards.

The importance of understanding air handling units (AHUs) is emphasised by [5] and [6], who describe AHUs as critical components equipped with various sensors to ensure optimal air quality and system performance. This technical knowledge and practical skills prepare students for real-world challenges in the field. Reference [7] advocates for the focused use of teaching aids in this learning process to facilitate a smoother and more interactive educational experience, thereby enhancing the practical understanding and application of these complex systems.

However, the urgency for improved teaching methodologies is underscored from the previous papers that shows significant challenges and propose solutions in the teaching and learning particularly within the HVAC domain. [8] identify that vocational students face difficulties with complex technical concepts and lack adequate practical training resources in HVAC systems. Similarly, [9] & [6]highlight barriers such as limited access to Air Handling Units (AHUs) and a lack of hands-on practice, alongside curriculum misalignments with industry demands. This trend underscores the critical need for improved teaching methodologies and aids to effectively convey complex engineering concepts and enhance student outcomes in vocational education, especially within the HVAC sector.

In conclusion, integrating teaching aids into vocational education, particularly in specialised courses like the Diploma in Refrigeration and Air Conditioning Technology, is beneficial and essential. By enhancing the quality of teaching and learning, these aids play a pivotal role in preparing a

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skilled workforce ready to meet the demands of the industry, thereby contributing to the nation's broader educational and economic goals.

The research aims to integrate IoT technology with a physical setup to simulate and monitor changes in pressure, temperature, and humidity within Air Handling Units (AHU). This method enhances the learning experience by providing real-time data and interactive simulations, facilitating a deeper understanding of AHU operations without needing actual equipment. The effectiveness and functionality of this IoT-based simulation will be thoroughly evaluated to ensure its reliability and educational value.

II. METHODOLOGY

In developing the product, the research extensively applied the ADDIE model, a widely recognized framework in effective product design[10]. This approach entailed a systematic progression through the ADDIE phases: Analysis, Design, Development, Implementation, and Evaluation, ensuring a comprehensive and iterative process in crafting the educational tool. Each stage played a pivotal role in refining the product's design and functionality, aligning with pedagogical objectives and user needs.

A. Analysis

Study done by [11] highlights the critical role of the analysis phase in product development, emphasizing its importance in aligning the product with consumer needs and satisfaction, which in turn, optimizes budget, time, and effort. Meanwhile, [12] underline the complexities in engineering education, pointing out the challenges students face in grasping intricate theoretical concepts.

In this research, the Simulation of Teaching Aids for Air Handling Unit (AHU) Operation extends beyond merely imparting practical skills to include a comprehensive theoretical understanding as well. This innovative educational tool enhances students' comprehension of AHU systems' operational intricacies. The analysis differentiates between single-zone and multi-zone commercial AHU systems, which, despite sharing foundational principles, diverge in terms of components and operational dynamics. Key common elements such as cooling coils, centrifugal fans, and air filters are identified. The research further delves into system selection analysis for either single-zone or multi-zone configurations. During the product's development phase, critical considerations were given to factors such as cost-efficiency, product dimensions, safety, and manufacturability, leading to the selection of the Single Zone AHU System design for its cost-effectiveness and simpler structural complexity.

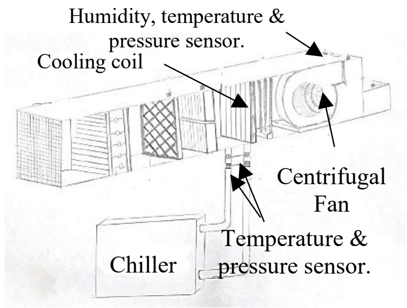
In the current research, the cooling coil—an essential component in the AHU system tasked to cool the air—was a focal point for need analysis. The study embarked on a comparative analysis between cooling coils sourced from window-type air conditioners and from vehicles. The findings revealed that vehicle cooling coils emerged as the more fitting choice for this research, primarily due to their compact size, which necessitates minimal spatial allocation, and their cost-effectiveness compared to the window-type cooling coil air conditioning.

The study also included a comparative analysis of air filters, focusing on panel filters and aquarium filters to assess their respective merits and limitations. The choice eventually favored aquarium-type filters over panel filters due to several key advantages: aquarium filters are more readily available, incur lower costs, and offer ease of installation during the development phase of the product. Consequently, the integration of the Single Zone AHU System, vehicle cooling coil, and aquarium filter was determined to be the most suitable configuration for the development of the Simulation of Teaching Aids for Air Handling Unit (AHU) Operation, aligning with the research's analytical needs and objectives.

B. Design

Prior to finalizing the optimal design, the researcher developed and assessed multiple design concept to ensure alignment with the predetermined specifications outlined in the analysis phase. Three distinct designs were conceptualized, each varying in terms of cost, component layout, safety features, and user-friendliness. These preliminary designs were presented to HVAC experts for evaluation, who then provided their recommendations based on a set of defined criteria. According to Table 1, which detailed the comparative analysis of these designs, the third option emerged as the preferred choice. This design notably excelled in meeting the comprehensive design specifications, thereby earning the highest endorsement from the expert panel.

TABLE I. THREE DESIGN CONCEPTS OF THE PRODUCT

<table>
<tr><th>Design</th><th>Detail design of the product</th></tr>
<tr><td>1</td><td>
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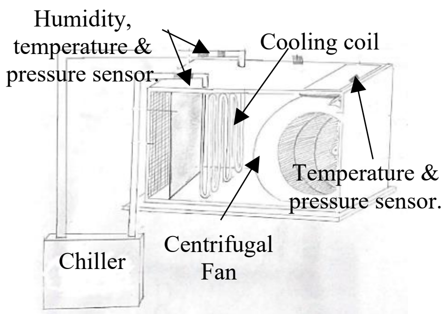
<tr><td>2</td><td>
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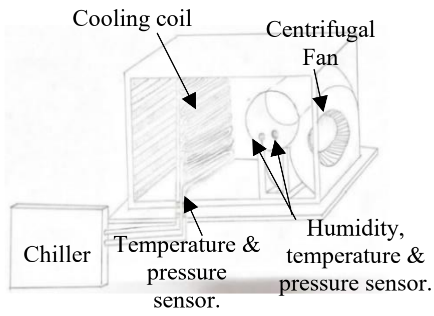
<tr><td>3</td><td>
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Figure 1 illustrates the schematic diagram of the product, embodying an educational tool that incorporates a system for measuring and displaying various parameters. To evaluate the performance of this operational system, sensors for pressure (P), temperature (T), and humidity (H) are strategically positioned within the setup. The assembly utilizes a pressure transducer, an RTD temperature sensor, and a humidity sensor to gather real-time data. Upon collecting the readings, the control system processes this information and transmits it to a server via the Internet. This data is then further analysed and made accessible through the Blynk application, which users can interact with on smartphones and laptops, facilitating a comprehensive understanding of the AHU's operational dynamics.

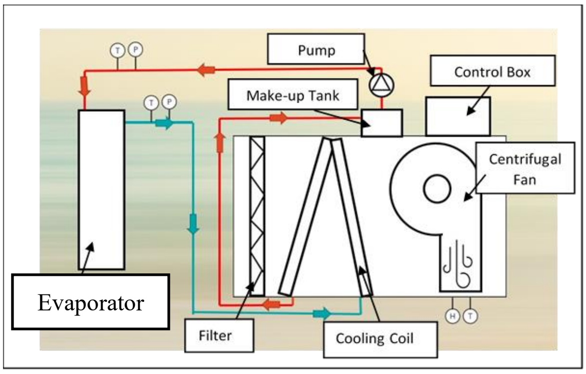
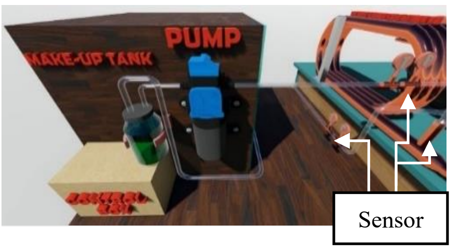
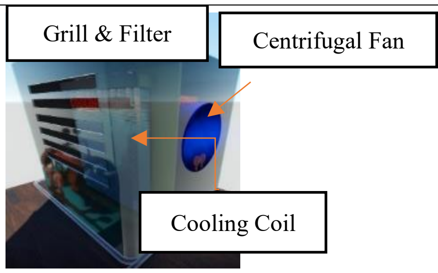


Fig. 1. Position of the sensor and main component of the product.

The enhancement of the product involves integrating an Arduino-branded control board, specifically the Wemos model, to facilitate the system's acquisition of temperature, pressure, and humidity data. The placement of temperature and pressure sensors both inside and outside the chiller system, extending to the AHU system coil, is strategic. Additionally, temperature and humidity sensors are installed at the air mains system inlet to enable the detection of variations in humidity and air temperature. Table 2 showed the precise positioning of each sensor within the product, ensuring optimal data collection for accurate system analysis and monitoring.

TABLE II. POSITION OF THE SENSOR & MAIN COMPONENTS

Item	Location
Position of the sensor.	
Main Components	

C. Development

In this critical phase, the final design concepts established during the design stage is actualized through meticulous implementation. Specifically, the selection of components is guided by a comprehensive evaluation of the research findings, ensuring that each element aligns with the empirical evidence. Subsequently, the installation of these components is meticulously carried out, adhering to the design concept selected in the design phase. This process not only involves the physical assembly of components but also entails a rigorous validation procedure to ensure that each part functions within the system as intended, thereby operationalizing the theoretical constructs into a tangible, working model.

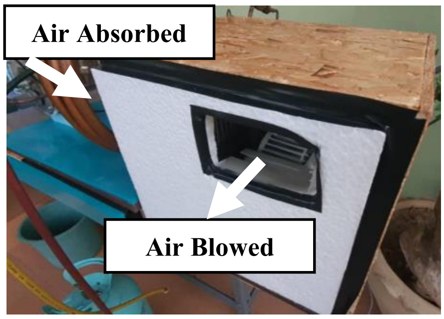
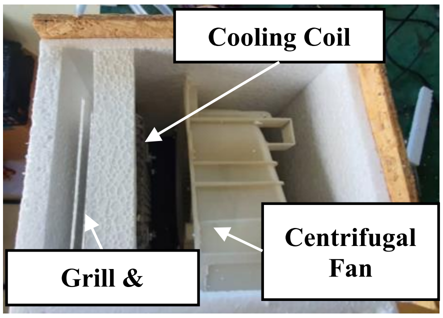
1) Product Development process

In the initial phase of the product development, the investigative team meticulously constructed the foundational framework of the product. Subsequently, they methodically positioned the principal components, including the filtration system, cooling coil, and centrifugal mechanisms, within this established structure. Upon the culmination of the assembly phase, the research team embarked on a rigorous examination to identify any potential issues such as water leakage or malfunctions within the installed components.

Following this, the researchers strategically embedded sensors at predetermined locations within the device, undertaking comprehensive Internet of Things (IoT) wiring and programming tasks to enhance the product's functionality and connectivity. The subsequent stage involved a thorough reassessment of the product to evaluate its operational efficacy and to conduct the necessary refinements for optimal performance.

To provide a clear understanding of the product's internal configuration, Table 4 is presented, delineating the airflow dynamics and the precise positioning of each component within the product's framework, thereby offering valuable insights into its structural and functional design.

TABLE III. AIRFLOW DIRECTION & COMPONENT POSITION

Item	Location
Airflow direction	
Main component position	

2) IoT Development process

Simulation of Teaching Aids of Air Handling Unit (AHU) Operation requires using Arduino and IoT. Consequently, the Arduino and Blynk software is loaded on smartphones and computers and will be used during the device's operation. Figure 2 shows the smartphone acquiring data by utilising the Blynk application from sensors installed on the project.

Incorporating the Blynk application in this product is to function as an intermediary for transmitting information between the control server and the smartphone. Subsequently, this application is effortless to handle and user-friendly. Furthermore, the device utilises the Arduino IDE application, which functions as a platform for programming and controlling the board. This program can analyse data collected from sensors that measure pressure, temperature, and humidity. The collected data will be transmitted to the server, received by the Blynk program, and converted into the user's preferred language.

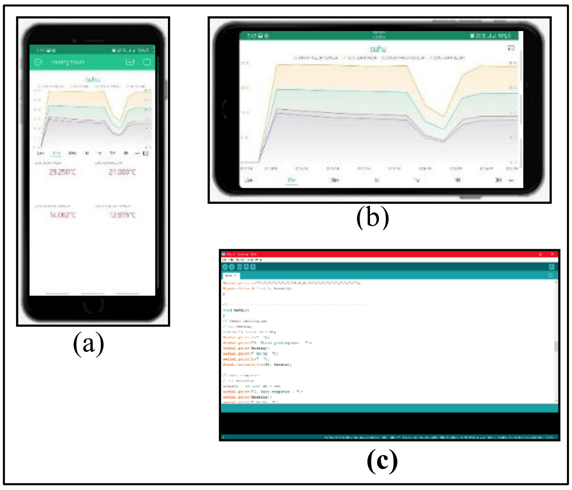


Fig. 2. (a) Main interface from Blynk App. (b) Temperature graph interface from Blynk App. (c) Arduino software used by researcher.

D. Implementation

The implementation phase is a critical step that focuses on evaluating the functional performance of the developed product. Researchers will meticulously analyse the data gathered from each sensor integrated into the device during this stage. This analysis is vital to confirm the fidelity of the results, ensuring they accurately reflect the real-world performance of the Air Handling Unit system. The research team will execute rigorous testing protocols to ascertain that the product meets and aligns with the core objectives and problem statement outlined in the study. Following this, identifying and addressing any emerging issues will occur, marking a crucial juncture in the project's lifecycle.

In instances where the product demonstrates suboptimal functionality, particularly from an educational standpoint, the team will seize the opportunity for refinement and enhancement. This iterative process, fundamental to the research methodology, will involve revisiting and revising the initial stages of the ADDIE model. Researchers aim to improve the product incrementally through this systematic approach, ensuring it serves its intended purpose and contributes significantly to the educational landscape.

E. Evaluation

The utilisation of a questionnaire served as a pivotal instrument for evaluation in this study, primarily to garner feedback on the developing product and to verify its alignment with the research's objectives. In pursuit of informed and reliable responses, the research team meticulously selected a panel of experts comprising two educators and a technician. These individuals were proficient in refrigeration and air-conditioning and possessed a substantial breadth of experience, each exceeding a decade in their respective fields.

The construction of the questionnaire was strategically oriented to address the fundamental inquiries posited by the research questions. This approach ensured that each item on the questionnaire directly contributed to the overarching research aims. Regarding response format, the questionnaire adopted a binary 'Yes or No' structure, facilitating a clear and concise assessment of expert judgment. The questionnaire's content encompassed various dimensions, including product design, development, and functionality—each being critical to the comprehensive evaluation of the product.

Before its dissemination among the selected experts, the questionnaire underwent a rigorous validation process. This process involved a review by lecturers from the Faculty of Technical and Vocational Education, UTHM, ensuring the instrument was methodologically sound and pertinent to the study's needs. This preliminary step was crucial in reinforcing the credibility and relevance of the feedback mechanism established through the questionnaire.

III. RESULTS AND DISCUSSIONS

Upon completion of product development, experts proceeded with the evaluation phase by distributing questionnaires. The data collected from the surveys were analysed to ascertain whether the product aligned with the researchers' objectives. Several factors must be considered in this assessment process, including product design, development, and functionality.

A. *Evaluation of product design*

The results presented in Table IV demonstrate a consensus among experts regarding the effectiveness of the five product design elements. These elements include engaging students in teaching and learning, suitability of materials used, teaching aids capable of displaying pressure change, temperature, and humidity, as well as safety and ease of operation.

TABLE IV. PRODUCT DESIGN EVALUATION

No	Item	Yes	No
1	Does the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation design attract students' attention in class?	3	
2	Is the material used to develop this Simulation of Teaching Aids of Air Handling Unit (AHU) Operation suitable?	3	
3	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation successfully designed to display pressure, temperature, and humidity?	3	
4	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation safe to use?	3	
5	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation easy to operate?	3	

This comprehensive agreement reflects the increasing recognition of the importance of effective product design in educational contexts. For instance, [13] emphasises product design educators' challenges in preparing students to design digital products. They note that integrating physical and digital aspects of product design is crucial, a concept that aligns with the multifaceted nature of the teaching aids developed in the present study, including the elements of usability and display capabilities [13].

Moreover, the focus on student engagement resonates with [14] discussion on product design education. They argue that product design teaching should emphasise innovative thinking, a principle inherently connected to the appeal of educational aids in engaging students, as seen in the unanimous approval of the simulation's attractiveness.

Furthermore, the emphasis on safety and ease of operation aligns with [15] insights on product success in engineering education. Shetty highlights the need for product design courses to familiarise students with concepts and techniques that ensure safety and efficiency, underscoring the relevance of these criteria in successfully implementing the Air Handling Unit (AHU) simulation. These correlations validate the findings of Table IV and contextualise them within the broader landscape of product design in educational technology, highlighting the critical role such aids play in enhancing the learning experience through engagement, safety, and operational ease.

B. *Evaluation of product development*

The results shown in Table V provide a thorough assessment of the product development. The consensus among experts on all five items reflects a successful integration of critical elements in educational technology. These elements include safe materials, well-arranged components, effective detection of changes in humidity, pressure, and temperature, a user-friendly smartphone display, and convenience for teachers in explanation processes.

TABLE V. PRODUCT DEVELOPMENT EVALUATION

No	Item	Yes	No
1	Is the material required by Simulation of Teaching Aids of Air Handling Unit (AHU) Operation safe to develop?	3	
2	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation well arranged?	3	
3	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation successfully developed to detect the effect of changes in humidity on pressure and temperature?	3	
4	Are the layout and the reading on your smartphone user-friendly?	3	
5	Will this application provide convenience to teachers during the explanation to the students?	3	

However, the experts' suggestions for improvement, like integrating a speed controller circuit in the fan unit and enhancing the interface from numerical to labelled data, point towards further enhancements. These recommendations align with the evolving standards of IoT-based educational tools. For instance, [16] emphasised the value of educational simulations in practical learning environments, such as a flight simulator for teaching aeronautical management. This underscores the importance of realism and user interaction in simulation-based learning.

Additionally, the focus on the safety and usability of the materials resonates with the findings of [17], who explored the computerised simulation of air handling units' energy consumption. Their work underlines the significance of choosing appropriate materials and configurations for simulations to accurately represent real-world scenarios, which is crucial for educational purposes.

Furthermore, the suggestion to enhance the interface from numerical to labelled data echoes the principles found in applying virtual simulation technology in teaching air pollution control engineering. Such advancements in interface design can greatly facilitate user comprehension and engagement, thereby improving the educational efficacy of the simulation [18].

These insights collectively highlight the essential aspects of successful IoT-based simulations in educational settings, emphasising safety, user interface design, and real-world applicability to enhance learning experiences.

C. *Evaluation of product functionality*

The evaluation of product functionality, as shown in Table VI, reveals positive feedback on the AHU simulation's functionality, with unanimous expert agreement on all items. These include the display of temperature and humidity readings, the effectiveness of the IoT application on smartphones, and the user-friendliness of button icons and reading displays. The experts' suggestion to incorporate additional measuring instruments, such as air velocity sensors for intake and outlet, CO^2 sensors for carbon dioxide, and air quality sensors for volatile organic compounds (VOC), reflects the growing trend of comprehensive air quality monitoring in IoT-based systems.

TABLE VI. PRODUCT FUNCTIONALITY EVALUATION

No	Item	Yes	No
1	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation able to display temperature readings on the inputs and outputs of the Air Handling Unit (AHU) system?	3	
2	Is the Simulation of Teaching Aids of Air Handling Unit (AHU) Operation able to display humidity readings in the air to be delivered?	3	
3	Does the IoT application display on the smartphone work well?	3	
4	Is the button icon and reading display easy to understand?	3	
5	Do all the icons or buttons in the app work well?	3	

The significance of incorporating a CO^2 sensor and other air quality monitoring tools in educational environments is underscored by [19], who emphasises the importance of monitoring indoor air pollutants using IoT systems to manage respiratory conditions. Similarly, [20] study on IoT systems for monitoring indoor air quality and occupancy in a classroom context highlights the relevance of real-time data acquisition for maintaining occupant comfort and safety, aligning with the proposed enhancements to the AHU simulation.

Moreover, the development of an IoT-based indoor air quality monitoring platform, as discussed by [21], demonstrates the feasibility and effectiveness of integrating various sensors, including VOC and CO^2, to monitor air quality in real time. This aligns with the experts' recommendation for the AHU simulation to enhance the learning experience regarding air quality behaviour.

Furthermore, the suggestion to incorporate various levels of HEPA filters in the AHU unit for educational purposes resonates with the work of [22], who explore low-cost sensor technology and cloud computing for real-time air quality monitoring, emphasising the importance of data visualisation and user engagement.

These findings demonstrate the increasing significance of integrating modern sensors and user-friendly interfaces in IoT-based instructional simulations. This integration enhances the learning experience in HVAC education and provides real-world applicability and user engagement.

IV. CONCLUSION

The integration of the Simulation of Teaching Aids for the Air Handling Unit (AHU) Operation into educational settings represents a significant advancement in the realm of teaching and learning. This innovation facilitates smoother knowledge delivery by teachers and ensures the achievement of learning objectives, thereby enhancing the overall educational process. The product's comprehensive development covers all crucial aspects, from design to functionality, aligning with the objectives of the study.

Moreover, the simulation tool's effectiveness is further evidenced by the ease with which students can comprehend the entire AHU system. This understanding is bolstered by the product's user-friendly features, including clearly labelled components, practical design, and safety measures. Such attributes make the teaching sessions more effective and increase the practicality and safety of the learning environment.

Incorporating Internet of Things (IoT) technology within the product is a pivotal aspect. IoT facilitates early exposure for students to advanced technologies, making the teaching and learning process more exciting and engaging. This increased engagement is crucial in sparking student interest and motivation, encouraging them to delve deeper into their studies.

In conclusion, the utilisation of the Simulation of Teaching Aids for AHU Operation stands as a testament to the profound impact of evolving technology on the education system. It marks a transition towards more efficient and effective educational methodologies and highlights the potential of technology-enhanced learning tools in shaping future educational landscapes. As technology progresses, tools like this simulation are poised to become integral to educational technology, fostering a more interactive, engaging, and comprehensive learning experience.

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