Working Paper 2025.1.1.16

- Vol. 1, No. 1

ỨNG DỤNG KHOA HỌC DỮ LIỆU ĐỂ TỐI ƯU HOÁ HỆ THỐNG ĐIỀU HOÀ TẠI TRƯỜNG ĐẠI HỌC NGOẠI THƯƠNG CƠ SỞ THÀNH PHỐ HỒ CHÍ MINH

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Tóm tắt

Đề tài tập trung ứng dụng khoa học dữ liệu để tối ưu hệ thống điều hòa trong phòng học tại Trường Đại học Ngoại thương - Cơ sở II, nhằm nâng cao trải nghiệm người dùng. Nghiên cứu gồm các phần chính: Đầu tiên, Cơ sở lý thuyết - phân tích vai trò và tiềm năng của công nghệ điều hoà không khí trên toàn cầu và tại Việt Nam, từ đó định hướng phát triển đề tài. Tiếp theo, phần xây dựng giả thuyết nghiên cứu đề xuất ứng dụng cảm biến và công nghệ Inverter để tối ưu hiệu quả năng lượng. Trong phương pháp nghiên cứu, nhóm thực hiện thu thập dữ liệu thực tế bằng cảm biến đo nhiệt độ và khảo sát sinh viên nhằm đánh giá trải nghiệm người dùng. Cuối cùng, phần ứng dụng thực tiễn phân tích dữ liệu để xác định hướng cải tiến, đánh giá hạn chế và đề xuất phương án tối ưu hệ thống. Đề tài kỳ vọng không chỉ nâng cao trải nghiệm người dùng mà còn góp phần tiết kiệm năng lượng, giảm chi phí vận hành và thúc đẩy phát triển bền vững trong môi trường giáo dục.

Từ khoá: Khoa học dữ liệu, công nghệ điều hoà, tiết kiệm năng lượng, chi phí vận hành, phát triển bền vững.

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APPLYING DATA SCIENCE TO OPTIMIZE THE AIR CONDITIONING SYSTEM AT FOREIGN TRADE UNIVERSITY'S HO CHI MINH CITY CAMPUS

Abstract

The study focuses on applying data science to optimize air conditioning systems in classrooms at Foreign Trade University - Campus II, enhancing user experience. It consists of following key sections: First the theoretical foundation analyzes the role and potential of air conditioning technology globally and in Vietnam, shaping the research's direction. Next, the research hypothesis proposes using sensors and Inverter technology to improve energy efficiency. In the research methodology, real-world data is collected through temperature sensors and student surveys to assess user experience. Finally, practical applications involve data analysis to identify improvements, evaluate limitations, and propose optimization strategies. The study aims to enhance user experience, promote energy savings, lower operating costs, and promote sustainable development in the educational environment.

Keywords: Data science, air conditioning technology, energy savings, operating costs, sustainable development.

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1. Introduction

The global and Vietnamese air conditioning markets are all growing very strongly, especially in the tropical climates and humid conditions, with increasing demand as the driving factor. In Vietnam, the air conditioning industry valuation will be about $2.9 billion by the year 2025, with a perennial sales volume of about 2 million units (VCCorp.vn, 2022; VNEEP, 2023). While the tides are in favor of the industry, the constraint of this growth remains the aging technology and the product range being in more focus for obsolete products.

Air conditioners cool living or working spaces and save human life by preventing heat stress. Further, they protect sensitive electrical equipment and improve air quality, thereby enhancing work and study performance (Tiến Dũng, 2023).

In the context of climate change and the increasing demand for air conditioning, optimizing cooling systems in educational environments has become crucial. Vietnam, especially Ho Chi Minh City, experiences prolonged tropical heat, significantly impacting students' learning efficiency and indoor air quality. However, existing air conditioning systems still have many limitations, including high energy consumption and inefficient temperature regulation.

The novelty of this project lies in the application of data science and sensor technology to collect and analyze real-world classroom data, leading to targeted improvements. By integrating IoT for automatic temperature adjustment based on class schedules or developing a more intelligent inverter system that adapts to room size and external temperature, this research aims to enhance user experience while promoting energy efficiency. Furthermore, it provides a foundation for advancing air conditioning technology in Vietnam, addressing both immediate user needs and long-term sustainability.

2. Theoretical framework

2.1 The Role and Potential of Air Conditioners Innovation Globally and in Vietnam.

Throughout history, the innovation of air conditioners has been deeply intertwined with the progress of humanity. The first idea of air conditioning came in 218 when emperor Varus Avitus covered a mountain with snow to cool the breeze as it flowed into the palace. This gave humans the idea of cooling through the cold air, until 1758 when Benjamin Franklin and John Hadley developed the concept further, frosting water using the evaporation of diethyl ether, laying the foundation for the tools and refrigerants used in the first refrigerators and ice makers (Alston, 2020). The refrigerants of an air conditioner were better developed by Michael Faraday in 1823 when he did an experiment involving the compression and liquefaction of certain gases (especially ammonia) (Sharp, n.d.). All of the concepts above helped Dr.Gorrie develop the first form of air conditioning in 1842 to cool hospital rooms for yellow fever patients in Apalachicola, which is considered a substantial precursor to modern refẻigerators (the Florida Inventors Hall of Fame, 2014). Until 1902 when Willis Carrier realized that air could be dried by passing through water to create a mist and designed the first air conditioning system, pioneering a new industry that would improve everyday life (Amy Tikkanen, 2025). From that moment on, air conditioners have been constantly improving and gaining popularity among citizens. Air conditioning has dramatically changed the ways humans live through its various applications, it helps to cool down electronic devices, prevent diseases from scorching weather, and even change architecture and infrastructure because in the past people could only build buildings to a certain height before it gets intolerably hot, but with air conditioning, this was not a problem for skyscrapers anymore. In conclusion, the air conditioner is one of the most important inventions in history and reflects the distinct development of each era. In the 4.0 era we know today, it is essential to understand and improve air conditioners according to the constant development of AI and technology. Because of that, to entirely comprehend how our team can enhance air conditioning, we provide a deep look into the recent evolutions of air conditioners.

In the development of air conditioners, the refrigerants used for them have constantly been updated. In the 1930s Midgey had proven that Freon (also known as R12 and R22) was non-toxic and nonflammable, making it a better alternative to ammonia and propane (Mark Bernstein, 2010). Then, people became more aware of the environment and started to use R32 and R410A to protect the ozone layer, because R32 and R410A have a low GWP (Global warming potential) level and are more environmentally friendly compared to R12 and R22 (6). Another way people used to improve air conditioners is to set automatic features, for example, using inverters in the 2010s helped to reduce energy consumption and maintain stable temperature by cooling when temperatures exceed the set point and heating when it drops below the desired level, had been shown to have saved energy better than the old version which constantly turns on and off, also gained the flexibility to meet the customer's exễpctations (Daikin, 2025). Through these advancements, it is noticeable that the development of air conditioners has been profoundly impacted by the progress of each era. Therefore, understanding the continuous evolution of AI and the Internet of Things (IoT) presents a promising direction for development and innovation. This is the path that our team should and must focus on to optimize air conditioners and enhance the consumer experience.

The first step we took was to narrow the scope of our research to Foreign Trade University, Campus II. This allowed us to gather objective feedback from students across various classroom models while taking into account Vietnam's tropical climate. This is also what sets our project apart from previous research on the development and improvement of air conditioners. Our team applied data analysis to optimize cooling system operations and conducted experiments to compare the initial hypothesis with the actual needs of consumers. From this, we have also discovered the potential of developing air conditioners in Vietnam when it is a tropical climate country, especially in regions like Ho Chi Minh City, which frequently experiences prolonged heat waves. This not only affects work efficiency but also damages the city's infrastructure. However, as a developing country, Vietnam currently lacks the resources and technology to produce advanced air conditioning systems so the domestic cooling industry primarily focuses on small ammonia-based units, which are outdated and fail to meet modern demands. Lacking the new technology in Vietnam's air conditioners model, however, air conditioners are widely used in companies, factories, schools, restaurants, and industries such as food processing and physical-chemical technology, highlighting their importance and the urgent need for further investment in this sector. From a statistical perspective, it shows that Vietnam has been recognized as one of the largest air conditioner markets in Southeast Asia, with an average of 2 million units sold annually (2023) and the market is projected to reach a value of $2.9 billion by 2025 (Lê Thúy, 2023), yet the number of businesses directly involved in manufacturing and improving air conditioners remains limited. Experts predict that the consumer electronics market in Vietnam is estimated to be worth approximately 100 trillion VND annually, with air conditioners accounting for 31%, televisions 29%, refrigerators 22%, and washing machines 18% (Nguyễn Đăng, 2024). Given the increasing demand driven by the country's hot and humid weather conditions, focusing on improving and enhancing air conditioning systems in Vietnam is both urgent and crucial.

2.2 Hypothesis Development

To begin the research, we first proposed experimental methods to obtain opinions from Foreign Trade University students regarding the quality of air conditioners in the school and formulated hypotheses.

Research in fluid dynamics suggests that thermal stratification, where warm air rises and cooler air settles near the floor, contributes to uneven air distribution and significant temperature differences within a room (ESTA, 2013). This can be caused by various factors, one of which is inefficient heating and cooling systems. Most systems, such as ceiling-mounted air conditioners, rely on fixed airflow directions, often resulting in cold spots near the unit and warm spots in areas farther away. This uneven air distribution has been widely studied in controlled environments, with research highlighting its impact on temperature regulation and energy consumption. However, there is limited data on how this impacts user comfort and cooling efficiency in real-world settings like classrooms and lecture halls. We hypothesized that uneven cold air distribution in rooms user comfort (Hypothesis 1). To test this, we could monitor the temperature distribution in a classroom with an air conditioning system over several hours. We would place temperature sensors throughout the room, track variations, and conduct surveys to assess user comfort levels in different areas. Additionally, we could measure the system's energy consumption and compare it across scenarios with and without improved airflow distribution.

Another limitation is the absence of advanced technology for dynamic adjustment. Many systems currently in use are designed with fixed cooling settings, requiring manual intervention to change temperature or airflow. They lack sensors to detect changes in room occupancy or outside temperature, which are critical in Vietnam's climate where weather conditions and room usage can change rapidly. This limitation becomes increasingly concerning given the growing demand for cooling. According to the "Future of Cooling in Southeast Asia" by International Energy Agency (IEA), cooling is projected to account for nearly 40% of peak electricity demand in Southeast Asia by 2040, up from approximately 10% in 2018. Additionally, the total household electricity consumption in the region is expected to quadruple during the same period, with cooling as the dominant factor driving this increase (Figure 1) (*Southeast Asia Energy Outlook 2018*, 2019).

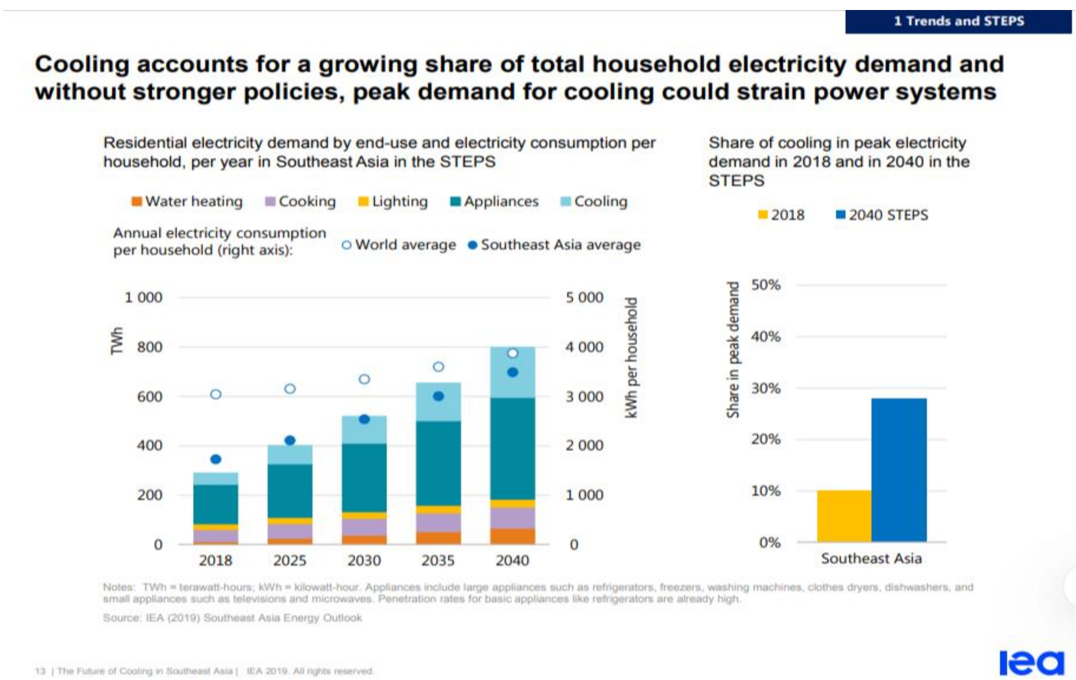


Figure 1: Cooling accounts for a growing share of total household electricity demand

Source: International Energy Agency (2019), The Future of Cooling in Southeast Asia.

As cooling demand increases, the energy consumption issue will become even more pronounced if systems cannot quickly respond to changes in environmental factors such as temperature or changes in room occupancy. Without improvements in air conditioning efficiency or dynamic control technologies, the energy demands of cooling could significantly strain power systems. This highlights the importance of improving air conditioners' efficiency to address growing energy demands. Therefore, we proposed that the inability of air conditioning systems to adjust based on real-world demand significantly increases energy consumption (Hypothesis 2). To us, the rooms with adaptive cooling systems would consume less energy compared to those with fixed settings, especially during low-occupancy periods.

2.3 Predicted Outcomes of the Research

Optimizing the cooling system, particularly by evenly distributing airflow across classrooms, lecture halls, and workspaces, is anticipated to improve overall cooling efficiency. By implementing advanced airflow models based on fluid dynamics principles, the system can minimize uneven air distribution, where some areas are excessively cold while others remain warm. This optimization will help maintain stable temperatures throughout all parts of a room, creating a comfortable environment for students and faculty. Consequently, it will enhance focus and productivity, leading to improved learning outcomes and academic performance. In addition to improving cooling performance, the adoption of smart cooling technologies can result in substantial energy savings. These systems can predict cooling demand in real-time based on factors such as the number of occupants in a room, outdoor temperature, and scheduled usage. This ensures that the system only operates when necessary, instead of running continuously throughout the day. By incorporating temperature sensors, the system can precisely adjust room temperatures, thereby optimizing cooling capacity and reducing energy waste. Energy usage can also be further reduced through the use of smart systems that automatically adjust their output or shut off entirely in underused spaces. This is particularly beneficial for areas with low occupancy or during non-peak hours. It is predicted that energy consumption would decrease by 10-15% in such areas, leading to significant energy savings during houts when classrooms or facilities are not in use.

2.4 Practical Implications

By reducing energy consumption and enhancing cooling performance, universities can achieve significant savings in operational costs. This is especially crucial in contexts where educational budgets are constrained. The savings on electricity and maintenance costs for the cooling system can be reallocated to other essential areas, further improving educational quality. Furthermore, the integration of automated control systems and intelligent sensors will enhance the university's ability to manage energy efficiently. These systems will automatically adjust cooling output based on real-world needs without requiring manual intervention, reducing the burden on facility management teams. The increased automation in energy management will result in greater system efficiency and reliability.

The success of this research could serve as a model for adopting similar energy optimization solutions in other educational institutions and public facilities nationwide. This not only has the potential to reduce operational costs but also contributes to environmental conservation efforts by lowering overall energy consumption. The increased application of smart technologies in public institutions represents a step toward sustainable development.

2.5 Predicted Survey and Implementation Results

We expected that our surveys conducted on classroom temperatures would reveal a significant reduction in temperature disparities across different areas of the room. Areas that were previously too cold or too warm would exhibit more consistent and comfortable temperatures. This data would serve as compelling evidence to demonstrate that optimizing the air conditioning system effectively enhances user comfort in educational spaces. Our research would also show a substantial reduction in energy use following the implementation of optimization solutions. Smart cooling systems with adaptive capabilities are expected to minimize unnecessary cooling activity, resulting in considerable energy savings for the university. Nevertheless, the results from our research can pave the way for expanding this solution to other educational institutions across the country. Thus, leading to more sustainable energy use and enhanced learning environments for students nationwide.

3. Research Methodology

3.1 Tools and models used

We have noticed that the university put in sustainable air ventilation and cooling systems; however, many of these units are distracting because they are not functioning properly. A case study, using keyword analysis, aimed to pinpoint these problems rather than speculate, and to clarify the definitions of sustainability and system assessment.

Objective measurements were made possible by using an Environment Online Continuous Monitoring System (RS485 Modbus RTU ES35-SW), whereas high-precision sensors were placed at six strategic points in each classroom (corner of the building, under the AC unit, and beside the teacher's desk). The continuous data flow for assessing thermal comfort and satisfaction with live data analysis was ensured by RS485-to-Wi-Fi converters (ZLAN7106M).

In order to minimize errors and obtain exactness in the measurements, ample precautionary measures were followed during the survey. Recognizing that subjective opinions vary, the survey was held in various classes in one room in order to gather as many views as possible. Besides, since day-to-day fluctuations in weather could have posed a threat to the readings, we ensured that during the survey all curtains and doors were closed so that variations in outside temperature would not influence the inside environment. It was also noted that when measuring room temperature, a certain amount of interference in terms of infrared radiation could be generated by the people. Thus, at this point in time, keeping in view the sensor reading, the participants were asked to wait outside the room while the measurements were taken. Finally, since altitude has its effect on temperature readings, and sensors might perceive the heat coming from the ground, we decided to hang the sensor at a certain height, preventing any heat transmitted from the ground from intervening with the results. Such a systematic approach allowed for standard environmental conditions and eliminated potential variables that could have compromised the accuracy of our temperature measurements. With an equally careful control of external influences and human interference, the results could effectively represent the exact room conditions, adding credibility and reliability to the overall findings.

3.2 Specific implementation

These are the specific steps to follow.

Step 1: The ES35-SW sensor has to be installed at predetermined locations throughout the classroom and securely fixed: obstruction towards more precise measurements must be avoided. Consequent to its final installation, this sensor will be connected to the RS485 interface with the ZLAN7106M converter for the purpose of easy data transmission.

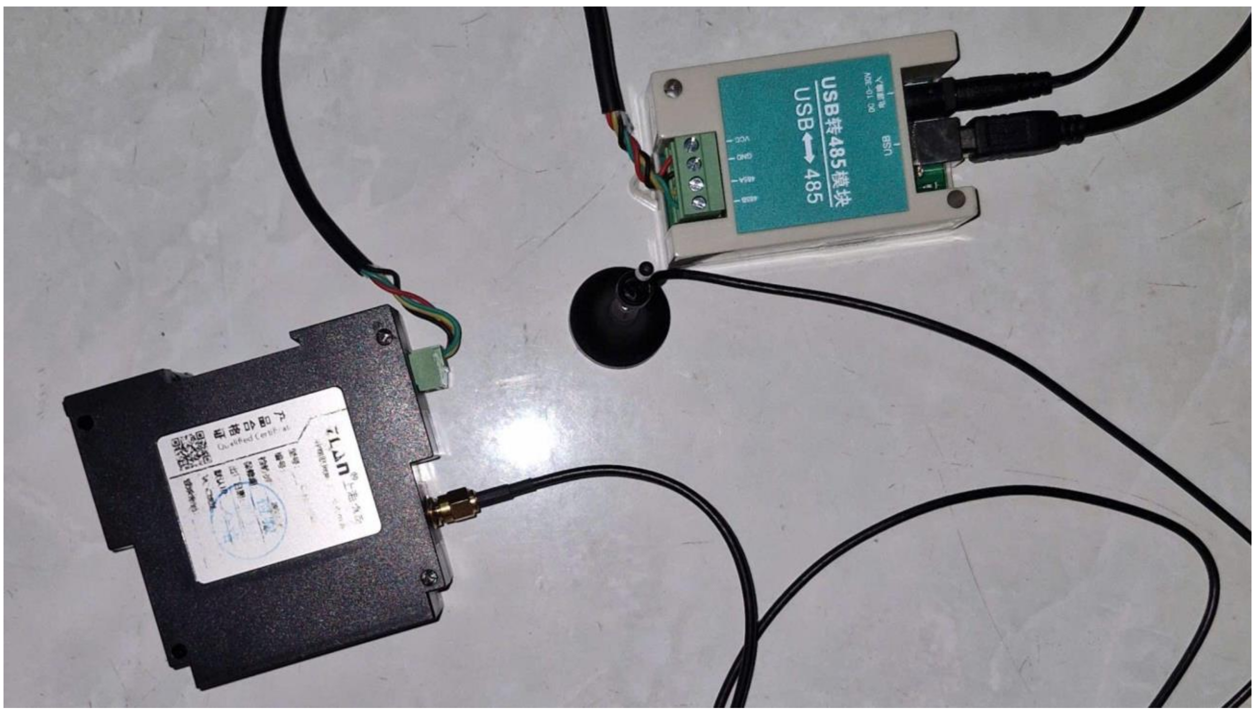


Figure 2: The RS485 to Wi-Fi Converter ZLAN7106M

Figure 3: RS485 Modbus RTU Temperature and Humidity Sensor ES35-SW

Step 2: Connect the RS485 to Wi-Fi Converter ZLAN7106M to a Computer via USB Port.

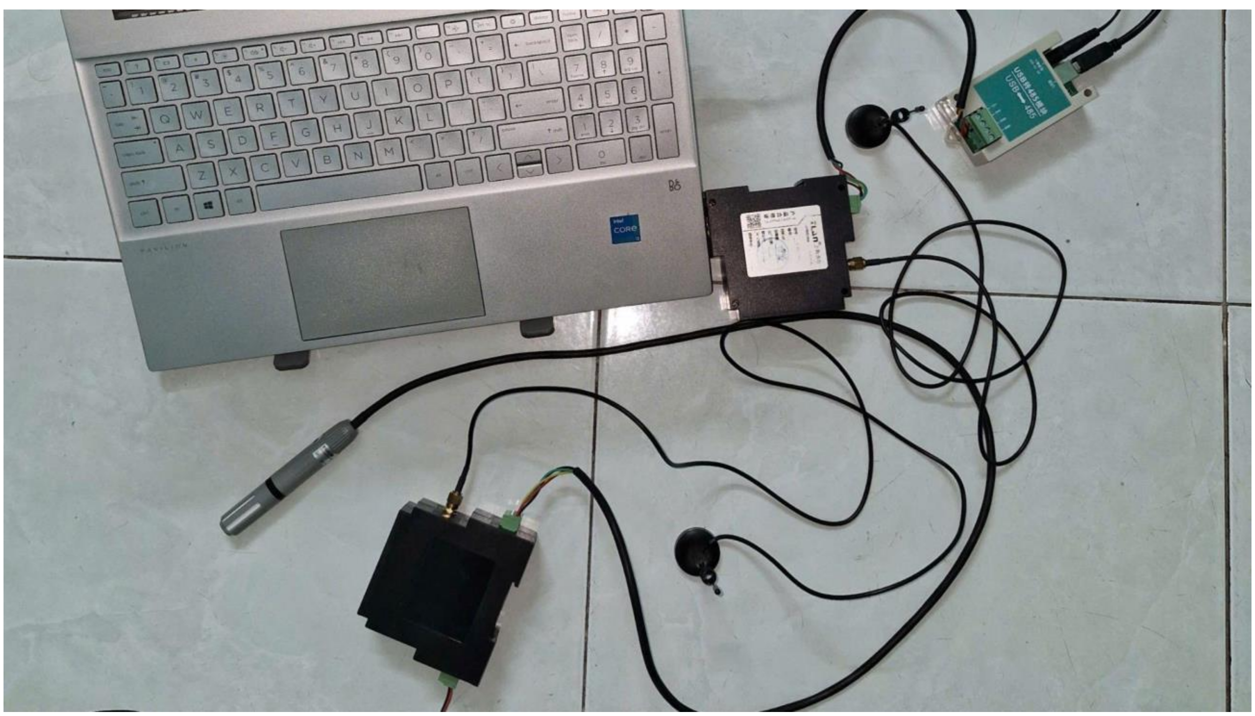


Figure 4: The computer is connected to the RS485 to Wi-Fi Converter ZLAN7106M and the RS485 Modbus RTU Temperature and Humidity Sensor ES35-SW

Step 3: Configure the Insight Sensor Software.

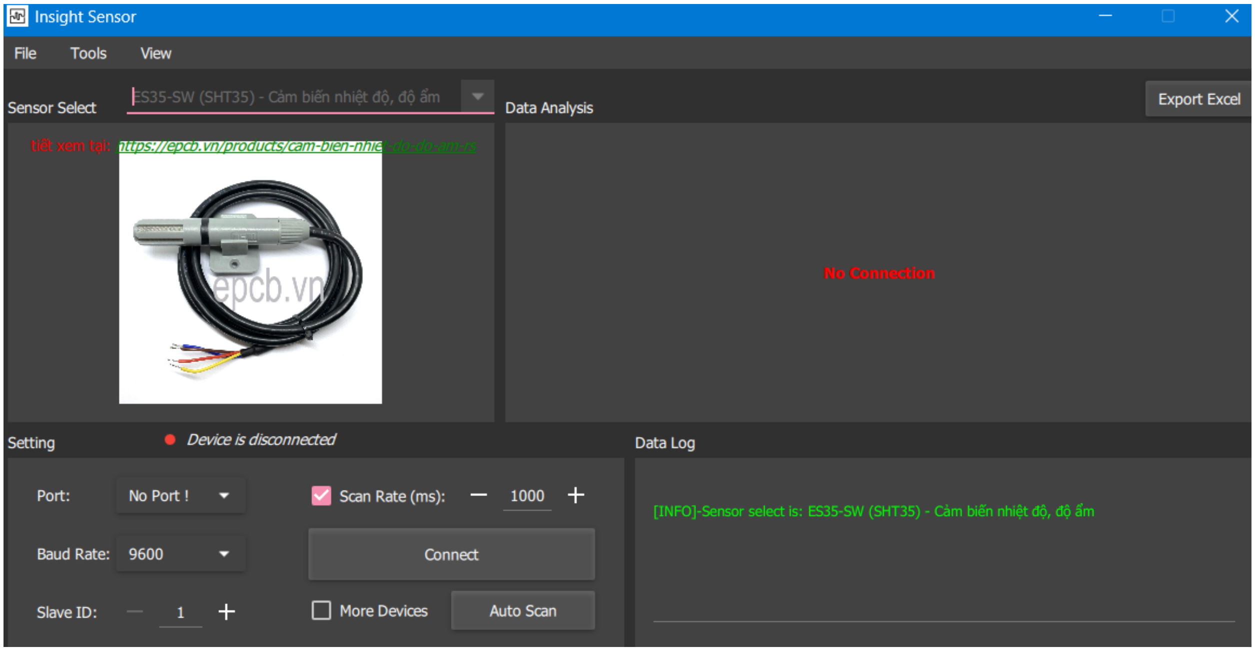


Figure 5: Insight sensor software interface

Step 4: Export the Collected Results to an Excel File.

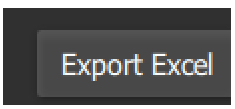


Figure 6: Insight sensor excel export function

Correlations and trends amongst the thousands of data points received from various sensors are identified through regression, t-tests, ANOVA, cluster, and time series analyses. Related survey responses allowed comparisons linking subjective comfort with objective temperature readings. The findings were drawn clearly in several comprehensive graphs and charts, followed by recommendations for improvements to the air conditioning system of the schools. Thus, this larger investigation added to the understanding of HVAC performance in schools in terms of energy efficiency and student comfort.

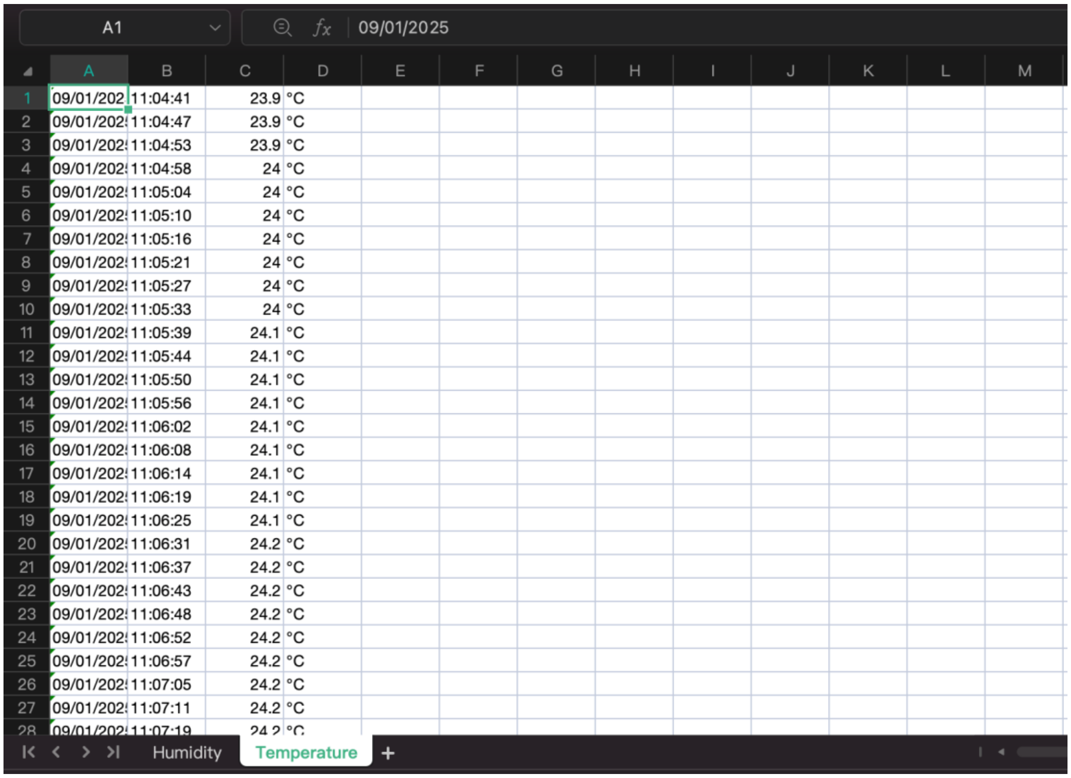
4. Result and Discussion

4.1 Statistical Tables and Comparisons

Our results consist of three parts in the following order: room temperature measurement experiments, student opinion surveys, and the establishment of airflow models in classrooms.

Temperature Diagrams of Measured Rooms:

To obtain a temperature diagram, we start by using a temperature sensor to measure different positions in the classroom, typically selecting 5 to 6 locations for accuracy. At each position, we conduct measurements for an average duration of 10 minutes. Since the sensor is equipped with a software that connects to the laptop, this feature is used to monitor real-time data and later export the results into an Excel file.



	A	B	C	D
1	09/01/202	11:04:41	23.9	°C
2	09/01/202	11:04:47	23.9	°C
3	09/01/202	11:04:53	23.9	°C
4	09/01/202	11:04:58	24	°C
5	09/01/202	11:05:04	24	°C
6	09/01/202	11:05:10	24	°C
7	09/01/202	11:05:16	24	°C
8	09/01/202	11:05:21	24	°C
9	09/01/202	11:05:27	24	°C
10	09/01/202	11:05:33	24	°C
11	09/01/202	11:05:39	24.1	°C
12	09/01/202	11:05:44	24.1	°C
13	09/01/202	11:05:50	24.1	°C
14	09/01/202	11:05:56	24.1	°C
15	09/01/202	11:06:02	24.1	°C
16	09/01/202	11:06:08	24.1	°C
17	09/01/202	11:06:14	24.1	°C
18	09/01/202	11:06:19	24.1	°C
19	09/01/202	11:06:25	24.1	°C
20	09/01/202	11:06:31	24.2	°C
21	09/01/202	11:06:37	24.2	°C
22	09/01/202	11:06:43	24.2	°C
23	09/01/202	11:06:48	24.2	°C
24	09/01/202	11:06:52	24.2	°C
25	09/01/202	11:06:57	24.2	°C
26	09/01/202	11:07:05	24.2	°C
27	09/01/202	11:07:11	24.2	°C
28	09/01/202	11:07:19	24.2	°C

Figure 7: Temperature table of Room A403

A1 | fx | 09/01/2025

	A	B	C	D
1	09/01/202	11:04:41	46.7	%RH
2	09/01/202	11:04:47	46.6	%RH
3	09/01/202	11:04:53	46.5	%RH
4	09/01/202	11:04:59	46.5	%RH
5	09/01/202	11:05:04	46.5	%RH
6	09/01/202	11:05:10	46.4	%RH
7	09/01/202	11:05:16	46.3	%RH
8	09/01/202	11:05:22	46.3	%RH
9	09/01/202	11:05:27	46.3	%RH
10	09/01/202	11:05:33	46.2	%RH
11	09/01/202	11:05:39	46.1	%RH
12	09/01/202	11:05:45	46	%RH
13	09/01/202	11:05:50	46	%RH
14	09/01/202	11:05:56	45.9	%RH
15	09/01/202	11:06:02	45.8	%RH
16	09/01/202	11:06:08	45.8	%RH
17	09/01/202	11:06:14	45.8	%RH
18	09/01/202	11:06:20	45.8	%RH
19	09/01/202	11:06:26	45.7	%RH
20	09/01/202	11:06:31	45.6	%RH
21	09/01/202	11:06:37	45.7	%RH
22	09/01/202	11:06:43	45.6	%RH
23	09/01/202	11:06:49	45.5	%RH
24	09/01/202	11:06:52	45.5	%RH
25	09/01/202	11:06:58	45.5	%RH
26	09/01/202	11:07:06	45.5	%RH
27	09/01/202	11:07:11	45.5	%RH
28	09/01/202	11:07:19	45.4	%RH

Humidity | Temperature

Figure 8: Humidity table of Room A403

The exported file will contain detailed temperature and humidity readings recorded approximately every 5 seconds. After collecting the data, calculate the average temperature for each measured location, then compile and summarize the results into a table displaying the temperature readings for each position in the classroom:

Teachers' table: 26,85°C				Angle 1: 26,0°C
		AC 1: 25,75°C		
Angle 2: 25,85°C				Angle 3: 26,1°C

Figure 9: Room B502

Teachers' table: 24,55°C				Angle 1: 26,0°C
		AC 1: 24,15°C		
		AC 2: 24,1°C		
Angle 2: 24,2°C				Angle 3: 26,1°C

Figure 10: Room A204

Teachers' table: 25,1°C				Angle 1: 24,4°C
		AC 1: 22,5°C		
		AC 2: 23,65°C		
				Angle 3: 23,4°C

Figure 11: Room A403

				Teachers' table 25,55°C
			AC: 24,85°C	
		The middle of the 4 ACs: 25,1°C		
Angle 2: 25,15°C				

Figure 12: Room A305

Temperature Survey from Students' Seats:

We define the color coding for students' perception of their seating temperature as follows: orange indicates that the students feel hot, yellow represents a slightly less hot sensation, green means the temperature feels normal, light blue signifies a cool feeling, and dark blue represents a cold sensation.

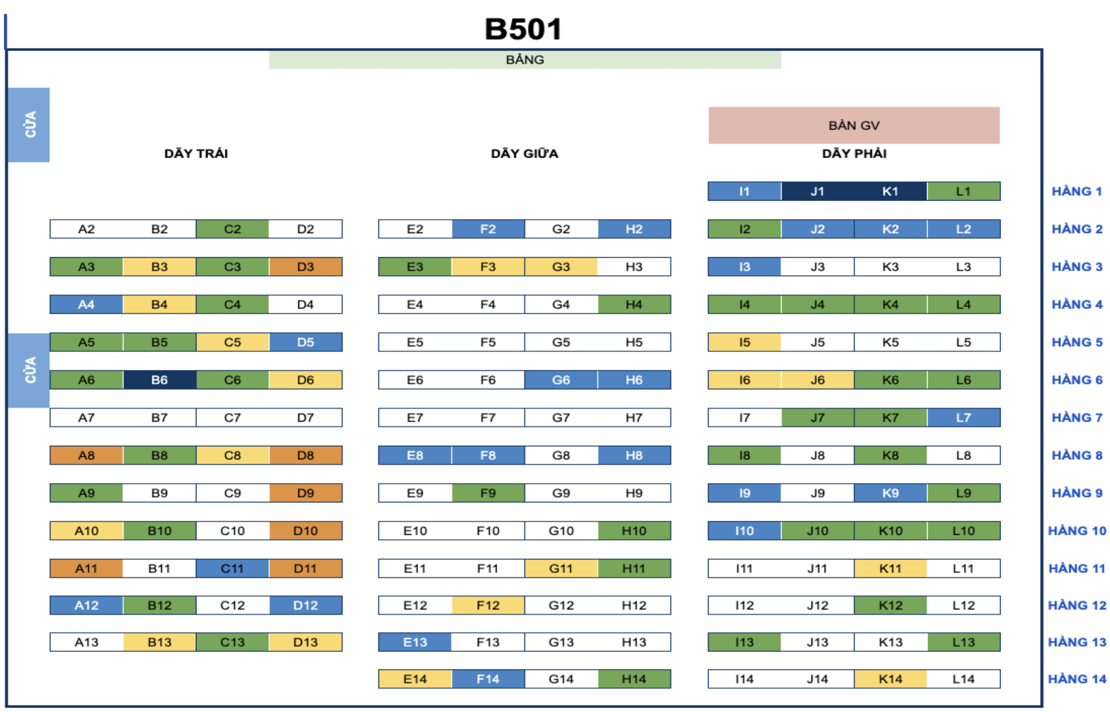


Figure 13: Room B501

Figure 14: Room A402

Figure 15: Room B301

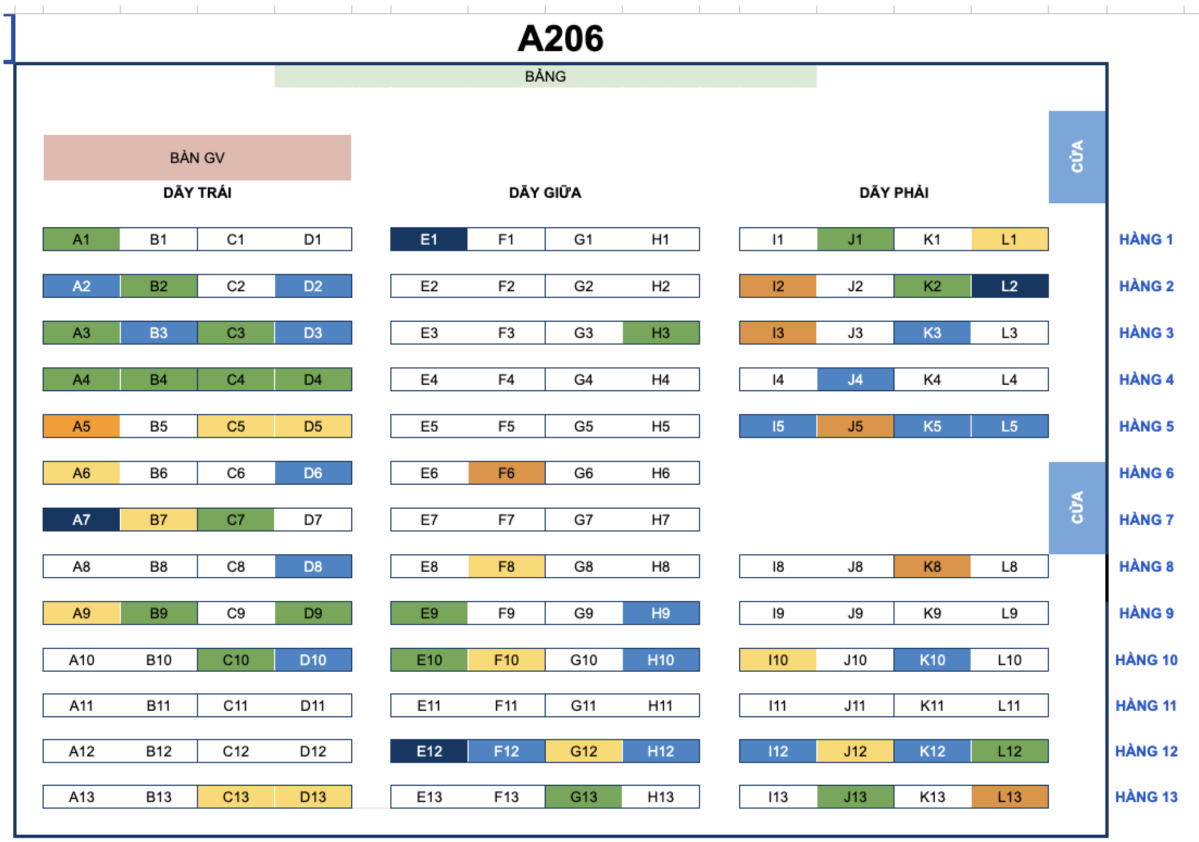


Figure 16: Room A206

This project was carried out with the support of postgraduate students from the University of Technology - Faculty of Transportation Engineering, in developing a 3D experimental model to support the research and development of the project's content.

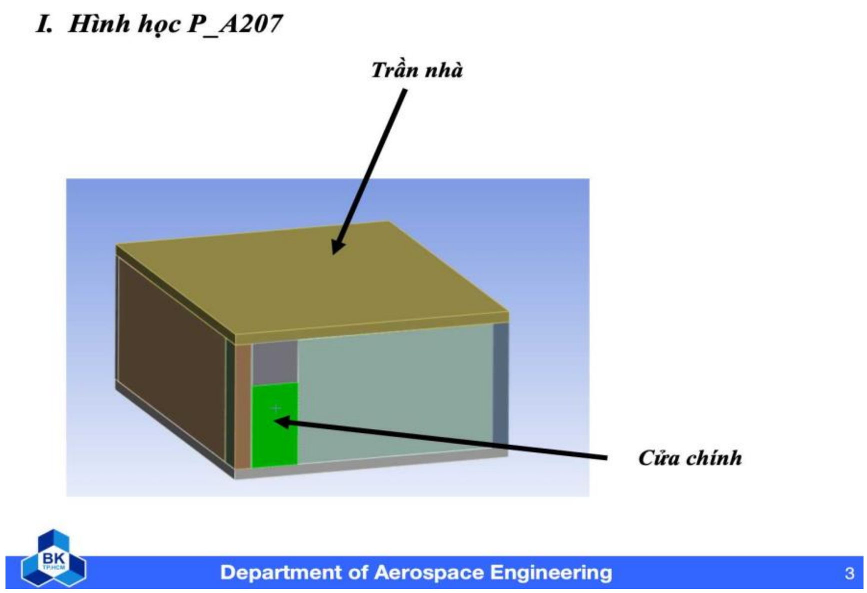


Figure 17

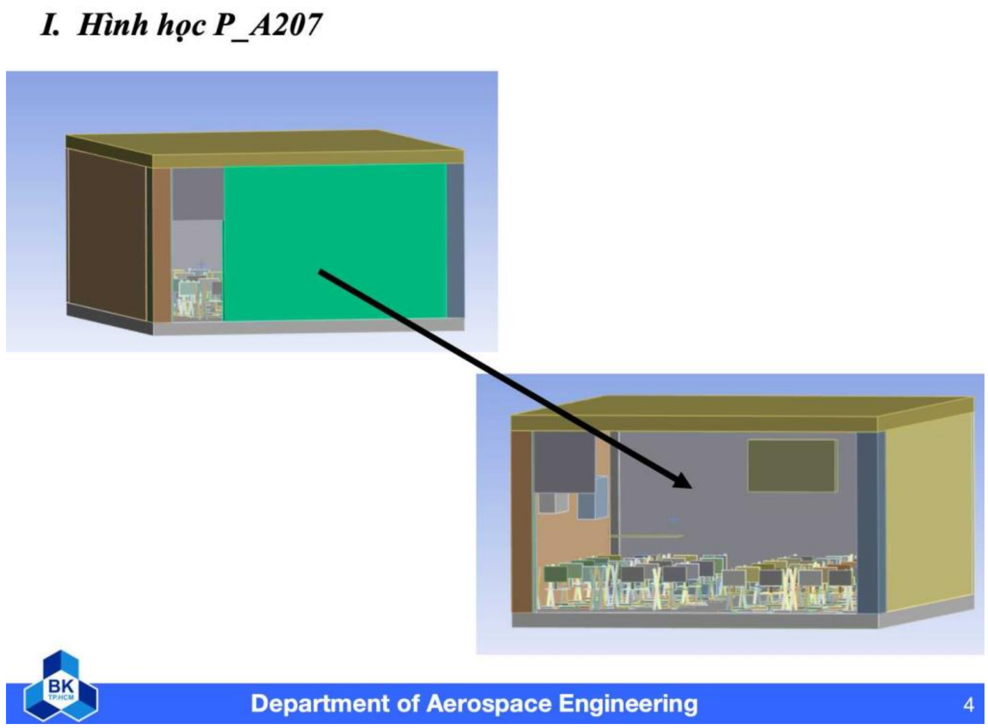


Figure 18

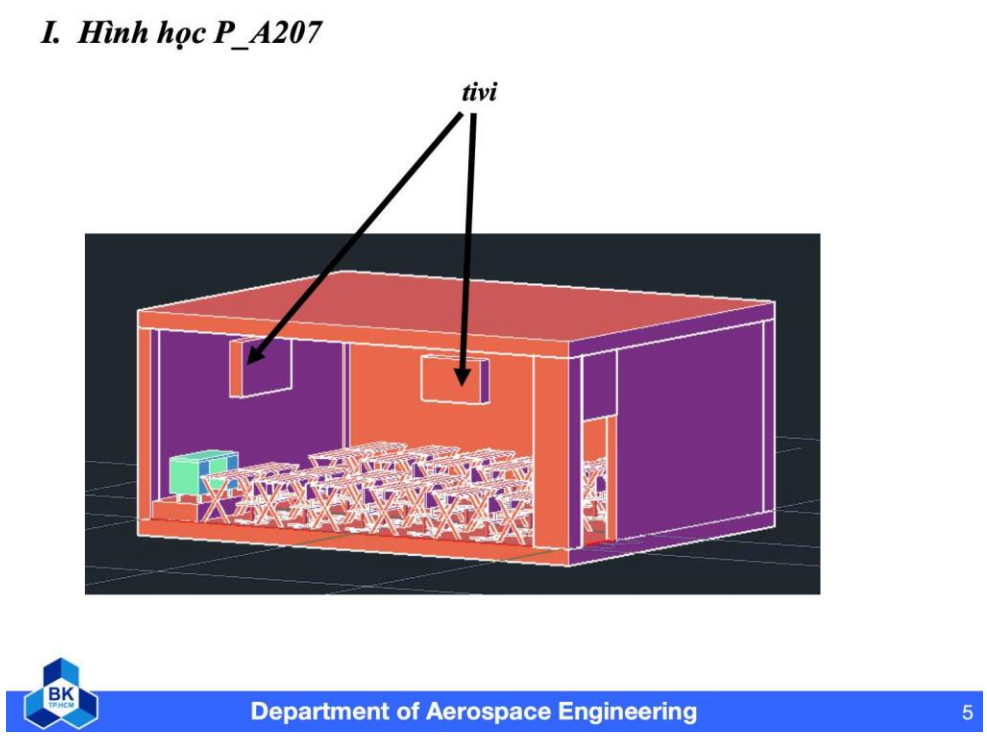


Figure 19

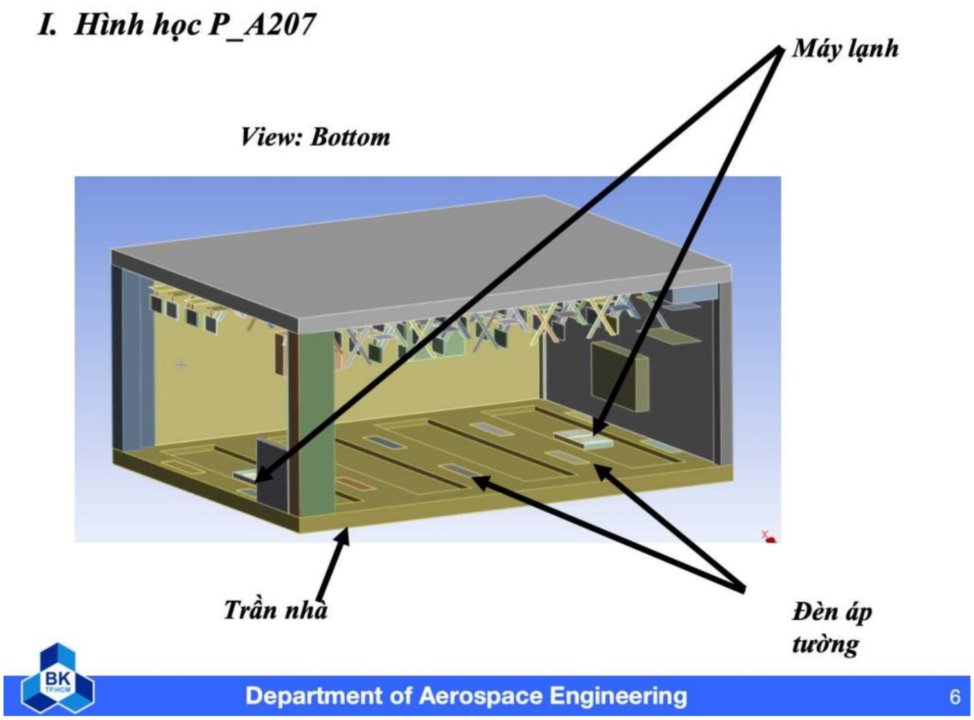


Figure 20

4.2 Detailed Analysis:

The temperature disparity across different areas can be explained by the following factors:

Firstly, air circulation from the air conditioning system is unevenly distributed, it often concentrates in a specific direction. Those sitting close to the direct airflow feel cooler, whereas areas which are farther away or obstructed by furniture, people, etc..., often receive less cool air, resulting in a warmer sensation.

Additionally, temperature stratification plays a significant role: cooler air tends to settle near the floor, while lighter, warmer air rises, making people in elevated positions (e.g., at the teacher's desk) feel warmer compared to those closer to the ground.

The materials and room layout also influence the temperature. Areas near glass windows or exposed to sunlight are usually warmer due to heat absorption, whereas well-insulated areas remain cooler. Poor air circulation can also lead to temperature differences, creating "pockets" of warm, stagnant air and cooler regions.

Moreover, individual perception and sensitivity to temperature vary among people, as everyone has a different level of thermal comfort. Finally, heat-generating sources such as electronic devices or high occupant density can raise the temperature in certain areas.

After completing the three experiments, the team concluded that the air conditioning units in the classrooms at Foreign Trade University Campus 2 need further improvement, as multiple air streams cause discomfort for some students due to the cold, while other areas remain warm. This demonstrates that we have not yet optimized the airflow of the air conditioners, leading to wasted energy and discomfort for users. From this, the team identified the existing issues and proposed an improvement plan using AI, IoT, and Inverter technology.

4.3 Comparison with Previous Research

Advances in Inverter technology focus on optimizing air conditioning systems through feedback control, ensuring stable temperatures and reducing energy consumption. Compared to other research, such as improving VRF system condenser efficiency via CFD simulations or designing heat recovery air conditioners for hot water supply, Inverter technology emphasizes core technological enhancements rather than hardware redesign or new feature integration.

In comparison to studies applying predictive control or evaluating energy efficiency in buildings, Inverter research delves into the device level, optimizing operations without reliance on external conditions. This highlights the potential of Inverter technology to directly and comprehensively improve air conditioning system performance.

4.4 Discussion

4.4.1 Innovative and Practical Applications

The application of data science to optimize the air conditioning system at Foreign Trade University brings significant innovations and practical values. Firstly, the integration of AI and algorithms predicts cooling demands using historical and real-time data, like class schedules, weather, and occupancy. This enables automatic adjustments, minimizing energy waste while ensuring comfort. Additionally, IoT technology with sensors monitoring temperature, humidity, and air quality enhances student and faculty experiences. The system maintains optimal air quality in crowded spaces like auditoriums and libraries, promoting health, satisfaction, and learning performance.

Another breakthrough is the integration of blockchain technology to manage energy consumption data. This not only ensures transparency but also supports detailed analysis and optimization of energy allocation, thereby establishing effective energy-saving policies. Furthermore, applying energy optimization models helps reduce operational costs during peak hours, freeing up resources for other institutional activities.

Beyond immediate benefits, this system supports research and education in data science and sustainable energy. Students and faculty can utilize data from the system for practical applications and research, while also building collaborative projects with businesses to advance technology.

Finally, Foreign Trade University's Ho Chi Minh City Campus can pilot this model as a foundation for replication in other educational institutions. This initiative positions the university as a pioneer in technological innovation and contributes to sustainable development goals in education and the community.

4.5 Benefits and Limitations

4.5.1 Benefits

Applying data science to optimize the air conditioning system at Foreign Trade University's Ho Chi Minh City Campus offers significant benefits, creating positive impacts not only on operations but also in building a modern and sustainable learning environment.

Firstly, real-time data analysis and machine learning algorithms enable the air conditioning system to automatically adjust its capacity according to actual conditions, optimizing energy consumption and minimizing waste. This not only reduces operational costs but also minimizes environmental impact, aligning with the university's sustainable development objectives.

Moreover, the intelligent air conditioning system ensures stable temperature, humidity, and air quality in areas like lecture halls, libraries, and large auditoriums, enhancing the learning and working experience for students and faculty. This is particularly crucial in the context of academic and research activities, which require a clean and focused environment to improve comprehensive health and concentration.

Additionally, the optimized system provides a rich data source for research on sustainable energy, data science, and IoT technology. Students and faculty have opportunities to undertake practical projects, fostering innovation and collaboration with businesses. Finally, the successful implementation of this initiative could position Foreign Trade University as a pioneer in education, affirming its leadership in applying modern technology for efficient management and operations.

4.5.2 Limitations

Data science has become an essential tool for optimizing air conditioning systems, reducing energy consumption, enhancing operational efficiency, and improving indoor air quality. However, its application involves numerous challenges, from data collection and processing to analytical model development and practical deployment.

One fundamental challenge is the collection and processing of data. Modern air conditioning systems often integrate multiple sensors to measure temperature, humidity, airflow, and energy consumption. However, data from these sensors is often inconsistent, noisy, or incomplete, reducing accuracy in analysis and optimization. Environmental factors like dust or high humidity can distort sensor readings, leading to inaccurate predictions. Expanding the data collection system is also a major issue, particularly when deployed in large buildings or industrial complexes. Installing and maintaining a comprehensive network of sensors in such spaces requires significant investment and frequent maintenance.

Developing data analysis models for air conditioning optimization is another significant challenge. Building machine learning or deep learning models requires a large amount of training data, which can be difficult to obtain from diverse operational systems under varying conditions. A lack of representative or consolidated data across independent systems can greatly reduce the reliability and efficiency of these models. Furthermore, real-time data processing for optimization demands robust computational power and the ability to integrate complex technologies, placing significant pressure on computing resources.

The diversity of environments in which air conditioning systems operate is another challenge. These systems are used in vastly different spaces, from small apartments to large commercial centers and industrial complexes. Each space requires tailored adjustments for optimization, as general models may not be effective when applied to systems under varying climatic or architectural conditions. External factors such as weather changes, user numbers, and inconsistent usage levels further complicate prediction and optimization.

Finally, the cost of implementing data science solutions remains a significant barrier. Integrating advanced analytical tools into existing air conditioning systems requires substantial investment in technology, hardware, and software. Maintenance and upgrades of these systems are also costly, particularly for small organizations or underdeveloped regions. Additionally, the demand for highly skilled personnel with interdisciplinary knowledge in data science, air conditioning technology, and energy management is growing, making it harder to find qualified experts to develop and sustain these projects.

In summary, while data science offers great potential for optimizing air conditioning systems, its application faces numerous complex challenges. Overcoming these barriers requires extensive research, advanced technical solutions, and close collaboration among experts from various fields.

4.5.3 Opportunities

The project "Applying Data Science to Optimize the Air Conditioning System at Foreign Trade University's Ho Chi Minh City Campus" could develop intelligent air conditioning systems capable of automatically learning and adjusting to actual user needs. This allows the system not only to operate efficiently under standard conditions but also to adapt flexibly to sudden environmental changes.

The project also opens opportunities to optimize the maintenance of the university's air conditioning system. Data analysis algorithms can predict faults or malfunctions, enabling a shift from periodic to condition-based maintenance, reducing downtime, and extending equipment lifespan.

Another critical opportunity is contributing to sustainable development and reducing greenhouse gas emissions. Energy-efficient air conditioning systems significantly reduce CO_2 emissions from the university, supporting environmental protection goals. According to estimates by the United Nations Environment Programme (UNEP, 2022), applying data science can reduce total emissions in the construction sector by 10-20%, driving urban development toward sustainability.

In addition to cost savings and environmental protection, the project improves user experience. Intelligent air conditioning systems can personalize temperature and humidity conditions to suit user habits and preferences, providing maximum comfort. This is especially important during university events, workshops, and meetings, ensuring a pleasant experience.

In conclusion, applying data science to optimize air conditioning systems offers benefits in energy and cost efficiency, environmental protection, and user experience. It opens new opportunities for sustainable development and innovation in the field.

4.5.4 Recommendations

Improving technology and applying data analysis to air conditioning systems in academic environments offers countless practical and comprehensive benefits.

Firstly, intelligent systems with automatic temperature adjustment capabilities minimize energy consumption. This not only significantly reduces operational costs but also contributes to reducing greenhouse gas emissions - a major factor in climate change.

Moreover, air conditioning systems with advanced inverter technology and temperature sensors ensure optimal energy efficiency. By maintaining stable temperatures without continuous operation, users save electricity and extend equipment lifespan. This is especially important in universities, where air conditioning is frequently and continuously used.

The ability to automatically schedule based on real-time data is another strong point. Systems can start before users enter a room, ensuring a comfortable space from the beginning without wasting energy when rooms are unoccupied. This greatly enhances user experience, creating a more comfortable learning and working environment.

In terms of health, intelligently designed airflow distribution avoids uneven temperature differences, reducing discomfort or negative health impacts. This is vital for ensuring safety and comfort in enclosed environments.

Finally, the improved air conditioning system promotes sustainable energy management. It not only meets the current needs of educational institutions but also lays the foundation for the development of intelligent energy solutions in the future. Widespread deployment of such systems will contribute to creating modern, eco-friendly, and energy-saving learning and working environments.

5. Conclusion

5.1 Summary of Research Findings

Technological improvements and the application of intelligent data analysis in air conditioning systems of universities bring many practical benefits. Smart systems reduce energy consumption, limit greenhouse gas emissions, and protect the environment. Simultaneously, their ability to automatically adjust to real-time demands not only enhances energy efficiency but also improves user experiences, creating a comfortable, stable, and health-friendly environment. These advancements meet current requirements while promoting sustainable energy management for the future.

5.2 Proposed Solutions

The improved air conditioning system, equipped with inverter technology and intelligent temperature sensors, allows automatic on/off operation upon reaching preset levels, reducing energy waste and extending equipment lifespan. Inverters ensure stable temperature maintenance without continuous operation, using feedback control models for optimized performance. Additionally, integrating time-based and scheduling data ensures the air conditioning system operates efficiently and provides maximum comfort by starting at the appropriate time.

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