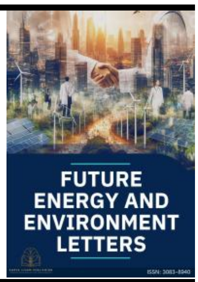
KARYA ILHAM PUBLISHING
CONNECTING MINDS, BRIDGING IDEAS, INSPIRING READERS

Future Energy and Environment Letters

Journal homepage:
https://karyailham.com.my/journals/index.php/feel/index
ISSN: 3083-8940



Air Conditioning System Maintenance Automation with Smart Sensors for Energy Efficiency

Muhamad Asrul Affendi Mat Nor[1,*], Farah Waheda Othman[2], Irdayanti Mat Nashir[3], Sudiyatno[4]

[1] Department of Automotive Technology, Pasir Salak Community College, Jalan Lebuh Paduka, Changkat Lada, 36800 Kampung Gajah, Perak, Malaysia
[2] Department of Information Technology and Communication, Sultan Idris Shah Polytechnic, Sungai Lang, 45100 Sungai Air Tawar, Selangor, Malaysia
[3] Faculty of Technical and Vocational, Sultan Idris Education University, Tanjung Malim, 35900, Perak, Malaysia
[4] Department of Mechanical Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Indonesia

ARTICLE INFO

Article history:
Received 22 November 2024
Received in revised form 5 December 2024
Accepted 12 December 2024
Available online 25 December 2024

Keywords:
Maintenance; devices; split unit type air conditioning; electricity saving

ABSTRACT

A decrease in the performance of a split unit type air conditioning system can be caused by a number of factors, such as airflow obstruction by foreign matter or component maintenance problems. As a result, the use of electricity becomes inefficient, causing operating costs to increase. This study aims to develop a device that can warn users about the appropriate time for maintenance of split unit air conditioning systems. The two main objectives of this study are: first, design and build a sensor that can tell users the best time to carry out maintenance; second, analyze the capability of this sensor as a tool to measure Coefficient of Performance (COP) for split unit air conditioning. In addition, this study also aims to provide a deeper understanding of COP measurement as well as how the sensor can help improve the energy efficiency of the air conditioning system. The research methodology involves analyzing the performance of the split unit air conditioning system by considering the COP as well as the air flow speed in the condenser and evaporator. The best COP achieved is 5.19, while the lowest COP is 1.98. This study found that optimal maintenance should be done when the COP is in the range of 2 to 4. Using this sensor, electricity can be saved significantly by carrying out maintenance at the right time, simultaneously reducing operating costs and increasing the energy efficiency of the air conditioning system.

1. Introduction

1.1 Study Background and Problem Statement

The climate in Malaysia is generally hot and humid (tropical) throughout the year, with an average annual rainfall of 250 cm and an average temperature of 27 °C. These persistent heat and humidity conditions significantly impact the indoor environmental comfort of buildings, influencing both the design and operation of indoor environmental systems. As a result, effective climate control measures are essential to address these challenges. Studies indicate that the total number of air-

* *Corresponding author.*
E-mail address: asrul@staf.kkpsa.edu.my

https://doi.org/10.37934/feel.1.1.3647

conditioning units in residential buildings in Malaysia was 493,082 in 1999 [1]. The energy consumed by air conditioning applications accounts for 30% of global energy consumption [2,3]. Furthermore, it is anticipated that societal development will lead to a significant increase in power consumption for air conditioning, further impacting overall electricity consumption [4]

One of the main problems for this type of air conditioning is the low operational efficiency as well as the waste of cost and energy when maintenance is done earlier than necessary. Furthermore, increasing global pressures have prompted Malaysia to adapt an energy mix strategy to address the growing energy demand while promoting development [5].

The device proposed in this project is designed to evaluate the performance of the system based on the Coefficient (COP), which is the main indicator of the operational efficiency of the air conditioning system. A study by Jahangeer *et al*., [2] and Kalkan *et al*., [6] showed that the use for air conditioning in buildings accounts for energy between 30% and 45% of the total energy requirements and can reach up to 70% in hot areas [7]. This shows the urgent need to improve the efficiency of the system to achieve the goals of energy saving and environmental sustainability.

High discharge and high condensing temperature and pressure are known to significantly degrade air conditioning performance. This situation causes increased energy consumption, reduced cooling capacity, reduced heat reduction by the condenser, and lower COP [8,9]. Therefore, considering the high energy requirements of air conditioning systems in buildings, studies to improve the performance of these systems are very important.

Poor air conditioning system maintenance practices can lead to more frequent outages, which can cause inconvenience or even disaster. So, air conditioning system maintenance must be more consistent, efficient and cost effective [10]. Regular servicing helps detect potential issues early, ensuring that the system operates optimally and extends its lifespan. A well-maintained AC system not only improves energy efficiency, reducing operating costs, but also ensures that the system can perform at its best, minimizing the likelihood of unexpected failures. Thus, adopting a proactive and systematic approach to maintenance is crucial for avoiding disruptions, maintaining comfort, and ensuring cost-effectiveness in the long term. Air conditioning system maintenance is not just about fixing problems as they arise, but about implementing a routine, comprehensive maintenance strategy that prevents breakdowns, ensures system reliability, and optimizes overall performance.

Thorough and frequent cleaning of the condenser and evaporator coils using specialized chemicals and methods is crucial, as dirty or clogged coils can significantly impact the system's efficiency and cooling capacity. To ensure that the coils operate at maximum efficiency, they should be cleaned regularly using specialized chemicals and cleaning methods. Using the right cleaning agents helps break down and remove stubborn grime, mold, and mineral deposits that can build up over time. Special techniques, such as coil cleaning sprays, foam cleaners, or pressure washing, are designed to effectively clean without damaging the delicate coil surfaces. This routine maintenance not only helps restore the system’s cooling capacity but also reduces the risk of overheating and mechanical failure due to blocked airflow. neglecting to clean the coils can significantly impair the air conditioning system’s ability to function properly, leading to higher operational costs and poorer cooling performance. Regular, professional cleaning is an investment that pays off by improving energy efficiency, enhancing system longevity, and ensuring a more comfortable indoor environment.

This project aims to develop a smart sensor device capable of warning users about the right time to perform maintenance on a split unit type air conditioning system. Although energy efficiency has been improved within individual systems, achieving seamless integration among these systems remains a critical goal [11]. That way, maintenance can be done at the right time to ensure maximum operational efficiency, while reducing energy waste and costs. Maintenance is suggested when system performance shows a drop below optimal level.

Despite extensive research on air conditioning systems, several gaps remain unaddressed. Current systems primarily rely on scheduled maintenance rather than real-time performance-based indicators, leading to unnecessary maintenance or delays in addressing efficiency losses, which increases energy waste and costs. While the impact of poor maintenance practices and airflow obstructions on performance, such as reduced Coefficient of Performance (COP) and higher energy consumption, is well-documented, there is a lack of affordable, user-friendly solutions to detect and resolve these issues proactively. Furthermore, existing studies focus on individual system improvements but fail to address seamless integration or sustainable approaches tailored to tropical climates like Malaysia, where persistent heat and humidity pose unique challenges. Additionally, while research has identified the optimal maintenance range based on COP values, practical tools to monitor and alert users in real-time are limited. This project bridges these gaps by developing a smart sensor device capable of identifying the precise time for maintenance based on COP, ensuring optimal system performance, reducing electricity consumption, lowering costs, and promoting sustainability in air conditioning technology.

This study determined the best COP for the selected unit was 5.19, while the lowest COP was 1.98. Based on the analysis, the optimal maintenance time is when the COP is in the range of 2 to 4, which indicates the need for maintenance intervention to avoid efficiency degradation. The results of the study showed a significant decrease in performance due to airflow obstruction in the condenser and evaporator, resulting in a lower COP. With this device, users can identify the most accurate maintenance time, while maintaining the performance of the split unit type air conditioning system at the best level and reducing the use of electricity and operating costs. This situation also emphasizes the need for a more sustainable approach in air conditioning technology to reduce the impact on the environment [12].

1.2 Objectives

To achieve the results of this study, two main objectives have been identified, namely:

i. Design and produce a smart sensor device capable of warning users about the most suitable time to carry out maintenance on split unit type air conditioning systems, to improve energy efficiency and avoid cost wastage.

ii. Analyzing the capability of the sensor device as a tool for measuring the Coefficient of Performance (COP) of the split unit air conditioning system to evaluate the level of operational efficiency effectively and accurately.

2. Literature Review

Split-unit air conditioning systems consist of two units: the outdoor unit, which contains the compressor, condenser, and capillary tube, and the indoor unit, which houses the evaporator. The system's performance is heavily influenced by operating conditions, which are defined by parameters such as discharge temperature, discharge pressure, condensing temperature, suction temperature, and suction pressure [13]. These factors significantly affect its efficiency and functionality.

The thermal load of a building is determined by two main factors: external heat load and internal heat load. External heat load depends on outdoor climatic conditions, which are beyond the control of the building's users. Internal heat load arises from factors like the number of occupants, electrical appliances, lighting, and occupant activities [14]. Given that air-conditioning systems are influenced by various factors such as outdoor conditions, occupancy variations, and seasonal changes, the predictive control method is highly suitable for optimizing their performance [15]. This method anticipates changes and adjusts system operations efficiently, improving performance and saving energy.

In a typical configuration, the compressor increases the refrigerant's pressure from low in the evaporator to high in the condenser. After compression, the refrigerant transitions from a hot gas to a liquid as it releases heat through the condenser coil and fan. This vapor compression cycle, widely used in residential and industrial air conditioning, is one of the most energy-intensive systems, accounting for 13.7% to 16% of residential electricity consumption [16]. This underscores the need for designing more energy-efficient air conditioning systems to reduce energy usage.

As a major contributor to building energy consumption, the green development of the HVAC industry plays a critical role in energy saving, emission reduction, and sustainable development [17]. By focusing on eco-friendly innovations, the HVAC sector reduces energy usage and minimizes environmental impact, aligning with global sustainability goals. To lower HVAC energy consumption, adopting optimized system designs and enhancing building insulation is essential [17]. Improved insulation minimizes heat exchange, reducing the HVAC system's workload and enabling it to operate more efficiently. Optimized designs further enhance performance by ensuring the system functions effectively with minimal energy waste. Together, these strategies help achieve significant energy savings, reduce emissions, and support environmental sustainability.

Good control mechanism and optimization parameter has primarily been a foundation for an effective energy efficiency and good thermal comfort in the HVAC system. The HVAC system reliability and stability are extremely important such that minor system malfunctioning may lead to bad consequences like energy wastage and thermal discomfort [18]. A good control mechanism and the optimization of key parameters are essential foundations for achieving both energy efficiency and optimal thermal comfort in HVAC (Heating, Ventilation, and Air Conditioning) systems. Effective control strategies enable the HVAC system to operate at its best, ensuring that energy consumption is minimized while maintaining the desired indoor climate. This balance between energy use and comfort is crucial for reducing operational costs and improving overall performance.

In split-unit systems, the compressor and condenser operate independently of the cooling unit, connected by millimeter-diameter pipes and insulation to link the cooling ducts. This setup is ideal for small residences, such as homes and offices, and is often equipped with a four-way valve, which enhances functionality and operational versatility [19].

A vapor compression refrigeration system relies on four main components: a compressor, condenser, expansion valve, and evaporator. These components drive the cooling process by inducing changes in the thermodynamic properties of the refrigerant, enabling energy transfer between the refrigerant and the environment [20,21]. Graphical tools, such as pressure-enthalpy (p-h) diagrams (Fig.1), are utilized to visualize heat transfer and assess refrigeration cycle performance. In these diagrams, the high-pressure and low-pressure regions are separated, with the saturated vapor line distinguishing the superheated vapor from the liquid phases and the quality line indicating constant dryness fractions in the two-phase region.

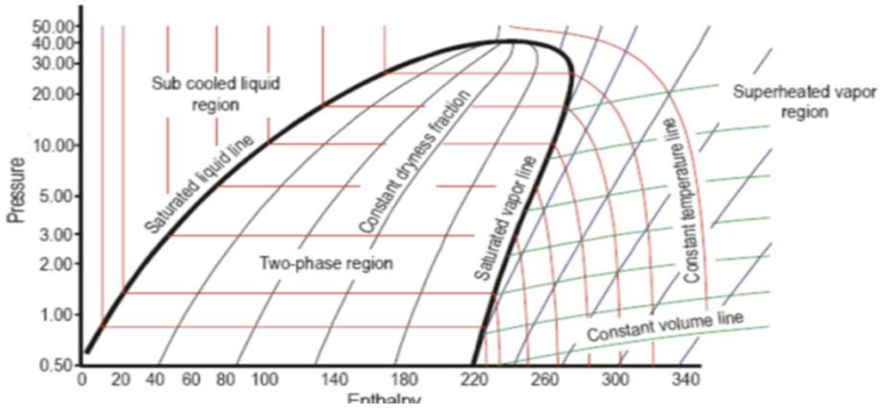


Fig. 1. p-h diagram (hvac-eng.com, 2022)

For improved energy prediction and efficiency in these systems, it is essential to consider the nonlinearity between temperature and electricity consumption, which can challenge traditional correlation coefficient-based methods and hinder their application in engineering contexts [3]. Meanwhile, evaporative cooling cells offer a cost-effective, energy-efficient alternative or complement to vapor compression, especially effective in specific climates [22].

To promote sustainable air conditioning, Kang *et al*., [23] evaluated low-cost air quality sensors to improve environmental impact monitoring. While these sensors were less precise than traditional methods, they provided high-resolution spatial data, particularly useful when deployed in dense networks. With growing concerns about energy consumption and environmental impact, the development of efficient and eco-friendly air conditioning technologies has become a key area of innovation, emphasizing sustainability [24]. Temperature measurement is a critical parameter in air conditioning and refrigeration systems. Accurate measurements are essential for analyzing operating conditions and evaluating system performance effectively [25].

Based on study from Harby *et al*., [26] demonstrated that utilizing an evaporative condenser significantly enhances system performance, achieving a 58% reduction in energy consumption and a remarkable 113.4% performance improvement. Similarly, Yang *et al*., [27] explored the integration of spray evaporative cooling in air-cooled chillers, which reduced compressor power and improved the system's COP by 4%-8%. Collectively, these studies highlight the potential of evaporative cooling methods to optimize energy efficiency and performance in cooling systems, emphasizing their application in both system-wide and component-specific contexts. Study from Piyanut *et al*., [11] highlights the use of ultrasonic sensors to detect refrigerant leaks in refrigeration systems, showing significant energy savings when leaks are fixed promptly. The findings demonstrate that addressing leaks can reduce energy usage by 7% for a 10% leak, 17% for a 20% leak, and 59% for a 30% leak. These results suggest that the system effectively improves efficiency and reduces environmental impact.

Maintenance is important to keep all components working properly. Preventive maintenance practices, such as quarterly or semi-annual checkups, are recommended to prolong the lifespan of the air conditioning systems. The increase of condensing temperature could also be caused by the reduction of air flow in the condenser caused by air blockage. The effect of the obstacle decreases with the increase of the distance between the condenser and the obstacle. The effect diminishes when the obstacle was placed at a distance of 50 cm or more [13]. An increase in condensing temperature can occur due to reduced airflow in the condenser, often caused by air blockage. The impact of the blockage decreases as the distance between the condenser and the obstacle increases.

The effect becomes negligible when the obstacle is positioned at least 50 cm away from the condense.

Facility managers also employ a multi-faceted approach to minimize disruption to occupants during maintenance, including scheduling major tasks during off hours, utilizing remote monitoring and control capabilities and coordinating with building managers and occupants to understand peak usage periods. Preventive maintenance practices, combined with strategic planning and the use of advanced monitoring tools, are critical to ensuring that air conditioning systems function efficiently and reliably over the long term. By minimizing disruption and addressing issues proactively, facility managers can ensure a comfortable environment for occupants while optimizing system performance and reducing operational costs.

This action is being taken to prevent damage to the device or component and ensure it operates efficiently. There are several maintenance approaches to ensure that equipment lasts throughout its life, including reactive, preventive, predictive, and reliability maintenance. Preventive maintenance involves routine checks to ensure the system is functioning properly and to avoid unexpected breakdowns. For low electricity consumption, maintenance planning is important to reduce electricity bills. If there is damage to the air conditioning system, users are advised to refer to highly skilled technicians for repairs to ensure the system operates at its maximum potential [28].

3. Methodology

3.1 Design

This phase focuses on the process of designing and developing a device prototype that serves as an air conditioning system maintenance time indicator. Computer-Aided Design (CAD) software will be used to design the prototype of this device, allowing a clear and detailed visualization of the components to be developed. The use of CAD software also helps in identifying the dimensions, arrangements, and specifications of the required components.

Based on previous literature and design studies, several key components have been selected to measure the performance of the air conditioning system, including sensors to monitor the COP and air flow in the system. The device prototype is designed to generate relevant performance data, such as air flow speed and temperature, which will then be sent to an application developed specifically for this purpose.

The application is programmed to automatically receive and process data, then display the performance percentage of the air conditioning system. This application facilitates the user in monitoring the efficiency of the system and warns when the performance level drops to a level that requires maintenance. Figure 2 shows an illustration of this prototype design and the arrangement of the main components involved.

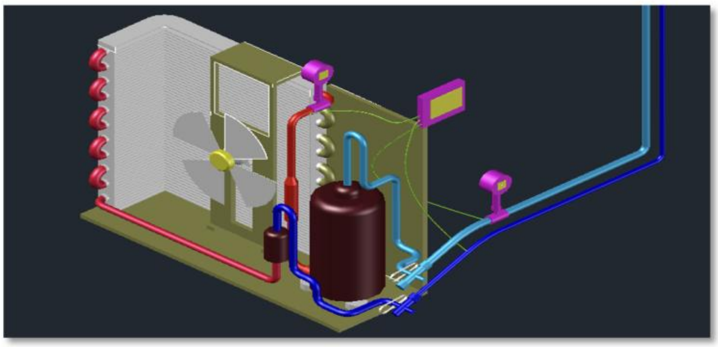


Fig. 2. System design in the outdoor unit

3.2 Design Concept

This system is developed based on the p-h diagram for the basic refrigerant cycle, where the performance of the system will be calculated using the enthalpy (h) based on the diagram. The data obtained will be calculated using the COP formula for the basic refrigerant cycle.

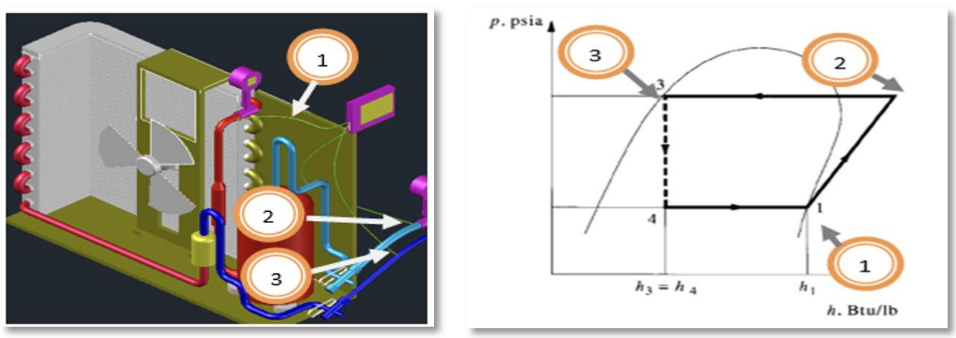
Based on the p-h diagram, temperature and pressure are needed to determine enthalpy (h). The temperature will be measured in several main parts: the compressor suction side, the compressor discharge side, and the evaporator inlet side, with temperature sensors installed at each location. The pressure will be measured on the suction and discharge side of the compressor using a manifold gauge. This measured data will be entered into the software application.

The software used, which is Microsoft Excel, will calculate and display the percentage of system performance as well as the best percentage level for air conditioning maintenance.

3.3 Fabrication

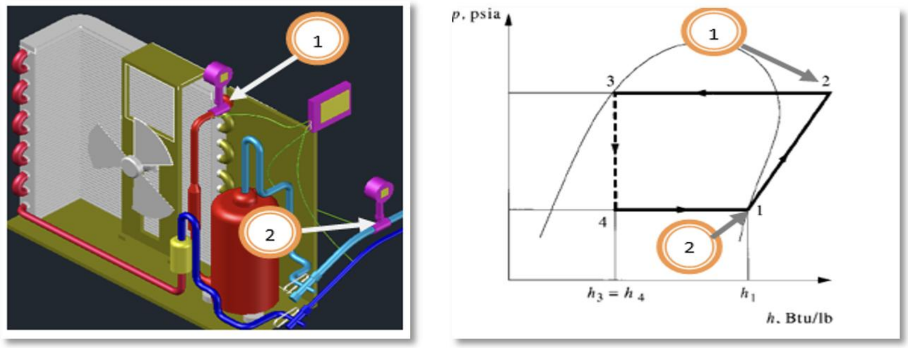
The selected components will be installed using an installation method based on the basic refrigerant cycle. As for the pressure gauge, the split unit type air conditioning system will be modified by installing a gauge manifold on the suction and discharge compressor channel to measure the pressure value.

The temperature sensors will be connected via Arduino and installed at three different locations: the evaporator inlet, the compressor suction channel, and the compressor discharge channel, to obtain temperature readings at each of these points. The sensor installation location is determined based on the p-h diagram to ensure the accuracy of the measured data. In addition, digital pressure gauges will be placed in two locations, namely on the suction line and the discharge line on the compressor, to ensure consistent pressure readings.



(a) Sensor location (sensor) installed (b) The location of the p-h diagram

Fig. 3. Installation method (a) Sensor location (sensor) installed (b) The location of the p-h diagram



(a) Location of the pressure gauge (meter gauge) (b) The location of the p-h diagram

Fig. 4. Installation method (a) Location of the pressure gauge (meter gauge) (b) The location of the p-h diagram

4. Result and Discussion

The Coefficient of Performance (COP) of the split unit type air conditioning system was recorded and calculated through experiments to identify the performance of the system in different conditions. This experiment aims to evaluate the state of the system when performing high or low, by using the method of reducing the air flow speed on the system. This method simulates the real situation, where foreign matter adhering to the fins reduces the heat transfer efficiency of the condenser and evaporator units. In this context, when the condenser and evaporator operate at their maximum level, it is considered to produce a higher COP for the system.

Personal Comfort System (PCS) provides a promising means of meeting the demand. The PCS in conjunction with fan use, which is regarded as the most prevalent thermal adaptation behaviour, offers advantages in terms of conditioning the indoor thermal environment, modulating the person's interaction with the surrounding environmental control system, and reducing the excessive use of energy on HVAC [29]. Furthermore, a Personal Comfort System contributes to energy efficiency by reducing the excessive use of HVAC systems. Since occupants can fine-tune their comfort with a fan or localized control settings, the overall reliance on large-scale air conditioning or heating systems is minimized. This leads to a reduction in energy consumption, as the HVAC system does not need to work as hard to maintain a uniform temperature across the entire building. As a result, the PCS offers a sustainable way to improve thermal comfort while lowering energy costs, making it an attractive option for both residential and commercial buildings seeking to optimize energy use. he Personal Comfort System, when used alongside fan technologies, not only enhances individual comfort and thermal satisfaction but also promotes energy conservation by reducing the demand on traditional HVAC systems. This combination of personalized control and energy efficiency positions the PCS as a valuable tool for improving indoor environmental quality while minimizing energy consumption.

Four experiments were conducted to determine the performance percentage of a split unit air conditioning system. This experiment involved modifying the performance of the system by reducing the air flow rate on the condenser and evaporator. In the first experiment, the air flow rates in the condenser and evaporator were gradually reduced to 25%, 50%, 75%, and 100%. In the second experiment, the condenser airflow rate was set at 25%, while the evaporator airflow rate was varied from 25% to 100%. Next, in each stage of the experiment, the condenser air flow rate was increased to 50%, 75%, and finally 100%, while maintaining the evaporator air flow rate that changed from 25% to 100% according to the procedure. This approach aims to simulate real conditions where high impurities cause reduced heat transfer in the condenser and evaporator. Experimental data has been recorded and analysed through graphs to provide a clear picture of system performance in various airflow conditions.

Figure 5 shows that reduced air flow speed will result in COP performance for the affected system. It has also been proven that the condensing unit will cause a significant impact on the performance of the air conditioning system. This involves daily checks, regular inspections and routine maintenance tasks such as cleaning, lubrication and minor adjustments to keep the air conditioning components in good condition. Specialized tools and technologies, including leak detectors, gauges and refrigerant recovery machines, are utilized to effectively diagnose and address any issues with the systems [10]. A combination of daily checks, regular inspections, and routine maintenance tasks, supported by specialized diagnostic tools, is essential for keeping air conditioning systems in good working condition. By identifying and addressing issues early on, these practices help maintain system efficiency, extend the lifespan of the components, reduce energy consumption, and ensure that the cooling system operates reliably when needed most.

Table 1
COP data for condenser and evaporator

	Condensor	Evaporator
COP	2.92	4.29
	3.03	4.37
	4.28	4.82
	4.82	5.02
	5.19	5.19

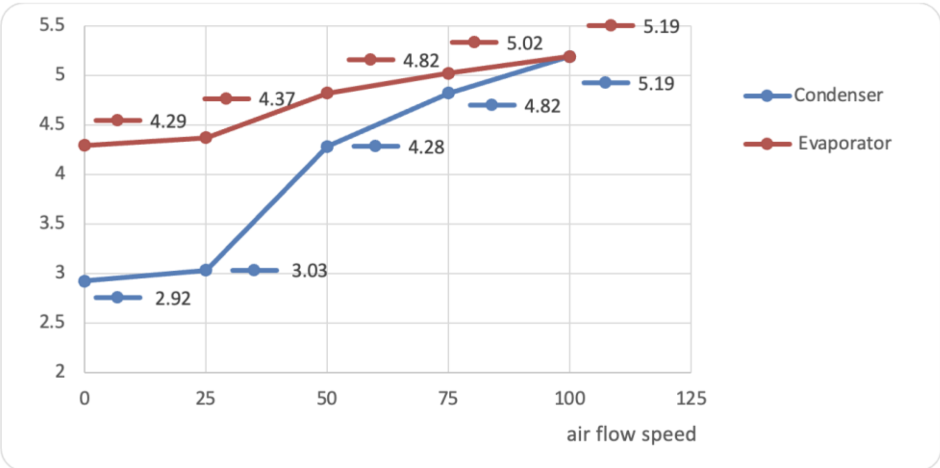


Fig. 5. Performance percentage for condenser and slow evaporator airflow speed

Figure 6 shows the decrease in airflow speed for both the evaporator and condenser units. The graph proves that the air conditioning system operates with a lower coefficient of performance when the air flow to the condenser and evaporator is obstructed. In the airflow speed condition at 0%–200%, the system is in a very bad condition, with the airflow completely blocked due to dirt on the coil. This situation not only increases the consumption of electricity but can also cause serious damage to air conditioner components if left on for too long. At 200%–400%, the system is still in poor condition, where dirt partially obstructing airflow continues to increase electricity consumption. Immediate maintenance is required to prevent performance degradation. On the other hand, at 400%–500%, the air conditioning system is in good condition, operating efficiently without any significant obstructions. Therefore, regular maintenance is very important to ensure that the system continues to function properly and avoid major damage.

Table 2
Data taken from the experiments carried out

25%		50%		75%		100%	
P1	0.483	P1	0.521	P1	0.563	P1	0.582
P2	1.896	P2	2.037	P2	2.104	P2	2.202
T1	25.12	T1	25.46	T1	26.5	T1	26.41
T2	58.06	T2	62.55	T2	64.4	T2	67.94
T3	19.07	T3	22.04	T3	24.2	T3	26.93

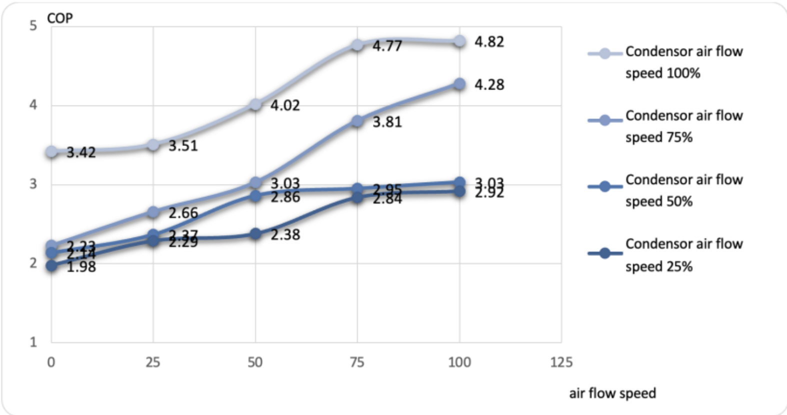


Fig. 6. Performance percentages for both condenser and evaporator fans are slow

5. Conclusion

This study focused on monitoring the performance and efficiency of air conditioning systems to ensure good air quality, reduce energy consumption, and save costs. Key findings highlight the importance of technical expertise, specialized tools, and comprehensive maintenance strategies for HVAC technicians and facility managers in Malaysia. These practices are critical in maintaining system reliability, enhancing energy efficiency, and reducing operational costs, particularly in the country's hot and humid climate [10,30,31].

A performance monitoring system for air filters in air ducts was developed, offering practical guidance to maintenance teams and users. It ensures timely maintenance, especially for split-unit air conditioners, while supporting energy-efficient operations. Innovative technologies like cooling vests further demonstrate how personal cooling solutions can enhance thermal comfort and energy efficiency.

However, the adoption of smart sensors in air conditioning systems faces several potential barriers, including financial constraints due to high initial investment costs, technical challenges such as integration with existing infrastructure and system complexity, and social factors like resistance to change and lack of awareness about the benefits of these technologies. Cost-effective maintenance hinges on the competence of personnel, emphasizing proper scheduling, skilled execution, and minimizing errors. By optimizing maintenance processes and operations, this approach stabilizes energy consumption, extends system lifespan, and promotes sustainability. Ultimately, the improvements in air quality contribute significantly to enhancing human well-being.

Acknowledgement
This research was not funded by a grant.

References
[1] Munaaim, M. Arkam C., Karam M. Al-Obaidi, and M. Azizul Abd Rahim. "Performance Comparison of Solar Assisted and Inverter Air-Conditioning Systems in Malaysia." *Journal of Design and Built Environment* (2017): 53-61. https://doi.org/10.22452/jdbe.sp2017no1.5
[2] Jahangeer, K. A., Andrew AO Tay, and Md Raisul Islam. "Numerical investigation of transfer coefficients of an evaporatively-cooled condenser." Applied Thermal Engineering31, no. 10 (2011): 1655-1663. https://doi.org/10.1016/j.applthermaleng.2011.02.007
[3] Chao Xun, Huan Zheng, and Zhaoyu Han. 2024. "Decomposition of Air Conditioning Electricity Consumption Based on Effective Duration." PLoS ONE 19 (8): e0308459–59. https://doi.org/10.1371/journal.pone.0308459.
[4] Rahmat Iman Mainilv, Ahmad Wisnu Sulaiman, Afdhal Kurniawan Mainil, and Azridjal Aziz. 2024. "Performance Enhancement of Split Air Conditioner During Evaporative Cooling Application". Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 86 (2):147-56. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/8144.
[5] Khattak, Muhammad Adil, Jun Keat Lee, Khairul Anwar Bapujee, Xin Hui Tan, Amirul Syafiq Othman, Afiq Danial Abd Rasid, Lailatul Fitriyah Ahmad Shafii, and Suhail Kazi. 2018. "Global Energy Security and Malaysian Perspective: A Review". Progress in Energy and Environment 6 (September):1-18. https://www.akademiabaru.com/submit/index.php/progee/article/view/1047.
[6] Kalkan, Naci, E. A. Young, and Ahmet Celiktas. "Solar thermal air conditioning technology reducing the footprint of solar thermal air conditioning." Renewable and Sustainable Energy Reviews16, no. 8 (2012): 6352-6383. https://doi.org/10.1016/j.rser.2012.07.014
[7] Al Horr, Yousef, Bourhan Tashtoush, Nelson Chilengwe, and Mohamed Musthafa. "Operational mode optimization of indirect evaporative cooling in hot climates." Case Studies in Thermal Engineering 18 (2020): 100574. https://doi.org/10.1016/j.csite.2019.100574
[8] Yau, Y. H., and H. L. Pean. "The performance study of a split type air conditioning system in the tropics, as affected by weather." Energy and Buildings72 (2014): 1-7. https://doi.org/10.1016/j.enbuild.2013.12.010
[9] Windy H. Mitrakusuma, Apip Badarudin, Susilawati, Hafidz Najmudin, and Andriyanto Setyawan. 2021. "Performance of Split-Type Air Conditioner under Varied Outdoor Air Temperature at Constant Relative Humidity". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 90 (2):42-54. https://doi.org/10.37934/arfmts.90.2.4254.
[10] Teh , Penny, and Siti Hamidah Husain. 2024. "Strategizing Effective Maintenance Strategies for Air Conditioning Systems in Commercial Buildings in Malaysia: A Systematic Literature Review". Journal of Advanced Research Design 118 (1):42-55. https://doi.org/10.37934/ard.118.1.4255.
[11] Piyanut Saengsikhiao, Juntakan Taweekun, and Chayapat Prapaipornlert. 2024. "The Improvement of Energy Efficiency in Refrigeration Systems Using Ultrasonic Sensors". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 119 (1):189-95. https://doi.org/10.37934/arfmts.119.1.189195.
[12] Luis Guillermo Obregon, Guillermo Eliecer Valencia, and Jorge Eliecer Duarte. 2024. "Air Conditioning Research Evolution from 2008 to 2019: A Scientometric Analysis". Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 73 (1):59-68. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/6473.
[13] Windy H. Mitrakusuma, Apip Badarudin, Susilawati, Hafidz Najmudin, and Andriyanto Setyawan. 2021. "Performance of Split-Type Air Conditioner under Varied Outdoor Air Temperature at Constant Relative Humidity". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 90 (2):42-54. https://doi.org/10.37934/arfmts.90.2.4254.
[14] Chang Choo Khean, Zulkiflle Leman, Nor Mariah Adam, and Eris Elianddy Supeni. 2023. "Effects of Building Materials on Building Thermal Load in Malaysian Institutional Library". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 107 (2):191-207. https://doi.org/10.37934/arfmts.107.2.191207.
[15] Ibrahim Oleolo, Hayati Abdullah, Maziah Mohamad, Mohammad Nazri Mohd Jaafar, Akmal Baharain, and Sapiah Sulaiman. 2024. "Multi-Circuit Air-Conditioning System Modelling for Temperature Control". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 83 (2):14-24. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/7793.
[16] Varalakshmi, R., & Arunachalam, K. (2020). Covid-19: Role of faculty members to keep mental activeness of students. Asian Journal of Psychiatry, 51, 102091.https://doi.org/10.1016/j.ajp.2020.102091

[17] Hu, Yongsheng, Mingyu Zheng, Xiaowen Niu, Rui Ning, Ye Rong, and Lei Lu. “Research on the Green Development of the HVAC Industry.” Atlantis Press, July 14, 2024. https://doi.org/10.2991/978-94-6463-447-1_26.
[18] Alzoubi, H. (2020). Energy efficiency in residential air conditioning systems: A review. Energy Reports, 6, 123-135. https://doi.org/10.1016/j.egyr.2019.10.012
[19] Ibrahim Oleolo, Hayati Abdullah, Maziah Mohamad, Mohammad Nazri Mohd Jaafar, Akmal Baharain, and Sapiah Sulaiman. 2024. “Multi-Circuit Air-Conditioning System Modelling for Temperature Control”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 83 (2):14-24. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/7793.
[20] Rachmad Imbang Tritjahjono, Kasni Sumeru, Andriyanto Setyawan, and Mohamad Firdaus Sukri. 2024. “Evaluation of Subcooling With Liquid-Suction Heat Exchanger on the Performance of Air Conditioning System Using R22/R410A/R290/R32 As Refrigerants”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 55 (1):1-11. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/3045.
[21] Sulastri Sabudin, Mohamad Syafiq Mohamad Noor, Mohammad Kamil Abdullah, Mohd Faizal Mohideen Batcha, and Juntakan Taweekun. 2024. “Performance Evaluation of a Split Unit Air-Conditioner Retrofitted With Hydrocarbon Refrigerant (HC22)”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 82 (1):126-32. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/7708.
[22] Bander Abdulrazaq Aldorihim. 2024. “Comparative Analysis of Air Conditioning Unit Performance with and without External Cooling System,” October. https://doi.org/10.20944/preprints202410.2333.v2
[23] Kang, Ye, Lu Aye, Tuan Duc Ngo, and Jin Zhou. 2021. “Performance Evaluation of Low-Cost Air Quality Sensors: A Review.” Science of the Total Environment, November, 151769. https://doi.org/10.1016/j.scitotenv.2021.151769.
[24] Rasuli, Mohammad Azim, and Shuichi Torii. 2024. “A Review on Solar Air Conditioning Systems.” Journal of Sustainable Energy Revolution 4 (1): 1–13. https://doi.org/10.37357/1068/jser/4.1.01.
[25] Andriyanto Setyawan, Apip Badarudin, Muhammad Arman, and Susilawati. 2022. “Evaluation of Air Conditioner Performance Using Different Methods of Temperature Measurement”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 100 (2):23-32. https://doi.org/10.37934/arfmts.100.2.2332.
[26] Harby, K., Doaa R. Gebaly, Nader S. Koura, and Mohamed S. Hassan. "Performance improvement of vapor compression cooling systems using evaporative condenser: An overview."Renewable and sustainable energy reviews58 (2016): 347-360.https://doi.org/10.1016/j.rser.2015.12.313
[27] Yang, Hua, Lan Rong, Xuanchen Liu, Liansheng Liu, Man Fan, and Na Pei. "Experimental research on spray evaporative cooling system applied to air-cooled chiller condenser."Energy Reports6 (2020): 906-913. https://doi.org/10.1016/j.egyr.2020.04.001
[28] Ruxton, C. (2016). Tea: Hydration and other health benefits. Primary Health Care, 26(8), 34-42. https://doi.org/10.7748/phc.2016.e1162
[29] Fakhrizal Akbar Ilmiawan, Sheikh Ahmad Zaki, Ahmad Faiz Mohammad, Farah Liana Mohd Redzuan, Mohd Radzi Ali, and Hom Bahadur Rijal. 2024. “Personal Comfort System Approach Associated With Fan Usage: A Review”. Journal of Advanced Research in Applied Sciences and Engineering Technology 37 (2):14-24. https://doi.org/10.37934/araset.37.2.1424
[30] I Made Rasta, and I Nyoman Suamir. 2024. “Air Conditioning System Performance of a City Hotel Appraised for Energy Use Efficiency”. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 83 (1):118-39. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/7771.
[31] Thomas, Douglas S., and Douglas S. Thomas. The costs and benefits of advanced maintenance in manufacturing. Gaithersburg, MD, USA: US Department of Commerce, National Institute of Standards and Technology, 2018. https://doi.org/10.6028/NIST.AMS.100-18