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Development of an Integrated IoT-Based Sanitation System for Air Conditioning Split Units

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Abstract

The COVID-19 pandemic underscored the critical importance of effective sanitation methods, particularly in indoor environments where air quality and ventilation significantly influence viral transmission risks. This study introduces an innovative Integrated IoT-Based Sanitation System for Air Conditioning Split Units designed to enhance indoor air quality and reduce the transmission risk of airborne diseases, including COVID-19. The system automates sanitation by leveraging Internet of Things (IoT) technology, utilising real-time environmental data to optimise disinfection protocols. The system was conceptualised, designed, developed, and evaluated through a rigorous research methodology encompassing the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) and quantitative analysis for efficiency, safety, and user satisfaction. Key findings demonstrate the system's effectiveness in distributing sanitising agents through split unit air conditioning systems, significantly improving indoor air quality. The IoT-enabled features allow for remote monitoring and control, ensuring precise and timely activation of the sanitation process. Through expert analysis and Content Validity Index (CVI) methods, the evaluation revealed strong consensus on the system's design quality, functional efficacy, and potential for widespread application in various indoor settings. Despite the positive feedback, minor areas for improvement in design neatness and component arrangement were identified, offering directions for future enhancements. Integrating IoT technology with air sanitation significantly advances public health measures, providing a novel approach to mitigating airborne transmission risks in enclosed spaces. The system's scalability and adaptability underscore its potential in addressing current and future health challenges, positioning it as a crucial tool in the ongoing fight against airborne diseases.

1. Introduction

The Covid-19 epidemic, caused by the SARS-CoV-2 virus, quickly became a global pandemic. The World Health Organization officially declared it a pandemic on March 11, 2020(Cucinotta & Vanelli, 2020). The virus was first detected in Wuhan City, Hubei Province, China. On January 12, 2020, the World Health Organization confirmed that a new type of coronavirus was the cause of the respiratory illnesses reported on December 31, 2019. The virus quickly spread across the globe, affecting countries worldwide, including Malaysia. The first incidence in Malaysia was reported on January 25, 2020, involving three Chinese people(Loo & Letchumanan, 2021).

According to recent research, COVID-19 spreads through three main modes of transmission: contact transmission (fomites), droplets transmission, and airborne (aerosol) transmission (Suwardi et al., 2021). This underscores the importance of environmental controls, particularly in indoor areas(Helli et al., 2022). Enhanced ventilation, particle filtration, and strategic air circulation are essential in reducing the risks of aerosol transmission. Therefore, to minimise the spread of viruses through aerosol transmission, engineering controls such as ventilation, particle filtration, air disinfection, masks, and engineering air circulation can be used as a low-cost but effective approach (Morawska et al., 2020)

Current disinfection methods utilised by health authorities utilise a range of technologies such as nano-spray tools, disinfection boxes, and tunnels. Nevertheless, there are issues over these medicines' efficacy and targeted consumer promotion, especially when done by entities without medical knowledge (Subbarow, 2020). Furthermore, the swift spread of the virus requires creative measures to guarantee cleanliness in home environments. Moreover, the effectiveness of quick disinfection techniques, such as those used in disinfection boxes or tunnel booths, has been doubted due to concerns about their incapacity to eliminate germs during the limited exposure intervals usually used (Subbarow, 2020; Morawska, 2020).

In response to this urgent need for efficient sanitation systems amid the pandemic's rapid spread, an IoT-based fogging/sanitation system has emerged as a promising solution that can significantly contribute to combating COVID-19 and other infectious diseases. The IoT-based fogging/sanitation system utilises the Internet of Things technology to automate and optimise the process of fogging and sanitation in various environments(Hu & Lamontagne, 2021). This system integrates sensors, actuators, and cloud-based platforms to monitor and control fogging(Baker et al., 2020). By leveraging IoT technology, the fogging/sanitation system can provide real-time data on environmental conditions and monitor the process accordingly. This ensures that the disinfection process is targeted, effective, and efficient in eliminating potential sources of contamination. This IoT-based fogging/sanitation system enhances cleanliness in home environments and can be implemented in other public spaces, such as schools, offices, hospitals, and transportation systems.

Integrating an IoT-based fogging/sanitation system with a split unit air conditioning system could further enhance the efficiency and coverage of sanitation efforts in response to the pandemic's spread. By linking the IoT-based fogging/sanitation system with the air conditioning system, the distribution of the sanitising agent can be more effectively dispersed throughout indoor spaces. The integration involves connecting the IoT system with the air conditioning unit's operation. The fogging/sanitation system can release the disinfectant when the air conditioning system is activated manually or automatically. This integration ensures that the sanitising agent is distributed evenly throughout the room, taking advantage of the air circulation patterns established by the air conditioning unit. Sensors and actuators in the IoT system can monitor environmental factors such as humidity, temperature, and occupancy to optimise the timing and intensity of fogging.

Moreover, the cloud-based platform of the IoT system can be used to collect and analyse data on the effectiveness of the sanitation process, adjusting parameters as needed. This approach allows for a more dynamic and responsive sanitation system, which can be crucial in settings like hospitals, schools, and public transportation, where air quality and sanitation are paramount. Overall, this integration represents a significant advancement in sanitation technology, harnessing the synergy between IoT and HVAC systems to combat the spread of infectious diseases like COVID-19 more effectively, thus ensuring a safer and healthier environment for individuals in various settings.

Nomenclature is included if necessary	
IoT	Internet of Things
IAQ	Indoor Air Quality

1.1 Research Background

The current COVID-19 pandemic, a significant worldwide public health crisis, has highlighted the crucial role of indoor air quality (IAQ) in reducing the transmission of viruses in enclosed spaces. The enduring characteristic of SARS-CoV-2, which can remain viable in the air for hours and on surfaces for days (Doremalen et al., 2020), emphasises the importance of ensuring indoor air cleanliness. The Agarwal et al. (2021) study highlights the importance of improving indoor air quality (IAQ) in enclosed areas. To ensure a safe and healthy indoor environment, the researchers recommend combining non-pharmaceutical and engineering control techniques, such as improved filtration and ventilation systems.

These techniques include enhanced filtration systems and increased ventilation, which can help remove infectious particles from the air and reduce the risk of transmission(Jia, Xiang, Guo, Guo, Guo, Cheng, et al., 2021). Furthermore, addressing indoor air quality is particularly significant in countries with high air pollution levels. In such settings, relying solely on reducing ambient pollutant concentrations to meet air quality standards may not be practical. Instead, improving indoor air quality through effective filtration and other technologies can provide tangible and immediate benefits in reducing exposure to harmful pollutants. In addition to enhanced filtration systems and increased ventilation, sanitisation methods can also play a crucial role in combatting the spread of the virus in indoor environments. Regular sanitisation protocols for frequently touched surfaces, such as doorknobs, light switches, and countertops, can help minimise the risk of viral transmission(Cassidy et al., 2020).

Sanitisation against coronaviruses can be achieved by using disinfectants and effective cleaning agents. Regular cleaning and disinfection of indoor surfaces, particularly in high-traffic areas, are crucial to reduce the presence of the virus, thus contributing to a safer indoor environment. Additionally, air purification systems employing UV-C light or HEPA filtration can aid in sanitising the air and targeting and neutralising airborne pathogens (Morris et al., 2021). However, conventional methods like fogging, although essential in medical and healthcare settings for eradicating pathogens, can be time-consuming (Sharma et al., 2023). For instance, an evaluation of a new fogging disinfection method demonstrated that although effective, it requires significant time for complete decontamination of spaces such as ward rooms and operating theaters (Nakata et al., 2001). This underlines the need for more efficient sanitization methods.

In the context of the COVID-19 pandemic, it is paramount to combine enhanced filtration, increased ventilation, and effective sanitization methods to combat the transmission of SARS-CoV-2 and improve overall indoor air quality. This research aims to develop an innovative sanitisation system integrated with existing split unit air conditioning systems. This system will utilise the airflow of the air conditioning system to distribute sanitising agents effectively. The technical aspects of combining a sanitisation module with split unit air conditioners must be addressed to ensure no compromise in the system's efficiency or indoor air quality.

Integrating IoT technology into air quality monitoring systems can significantly enhance the functionality of these systems by enabling smart control and monitoring of the sanitisation process through sensors (Jo et al., 2020). Studies by Lakhouit et al. (2020) and (Kumar, 2023) emphasise the critical role of maintaining Indoor Air Quality (IAQ) in healthcare settings and its impact on indoor pollutant concentrations, especially in the context of COVID-19. Elsaid et al. (2021) further support this by discussing the importance of HVAC systems in controlling the spread of COVID-19 and integrating air conditioning systems with air purification technologies.

By leveraging IoT technology, air quality monitoring systems can provide real-time particulate matter analysis, ensuring efficient indoor air quality monitoring and control (Jo et al., 2020). IoT-based monitoring platforms allow for the seamless integration of sensors with monitoring systems, facilitating data transmission to web servers in real-time (Lee et al., 2022). Additionally, IoT-based systems offer the advantage of wireless communication, minimizing the deficiencies caused by temporal and spatial lag in traditional sensor systems (Lee et al., 2022).

Furthermore, IoT-based air quality monitoring systems have been proposed to utilise micro-sensors for data collection, enabling real-time monitoring of various indoor air quality parameters (Taştan & Gökozan, 2019). These systems not only ensure lower power consumption but also provide superior interaction with the physical environment, enhancing the overall monitoring capabilities (Wang et al., 2022). In conclusion, integrating IoT technology into air quality monitoring systems offers a promising approach to enhancing Indoor Air Quality (IAQ) management. By enabling real-time monitoring, smart control, and seamless data transmission, IoT-based systems can play a crucial role in ensuring healthy indoor environments, especially in healthcare settings and during disease outbreaks like COVID-19.

The research will involve assessing the efficiency and coverage of the sanitisation process in various settings, ensuring compliance with health and safety standards, and conducting pilot testing for validation. The scalability and practical implementation aspects will be addressed, including manufacturing, installation, and maintenance of these integrated systems. Such integration promises a significant advancement in public health measures by providing a novel approach to enhancing indoor environmental quality, crucial in the ongoing fight against the COVID-19 pandemic and potential future airborne health threats.

1.2 Problems statement

The COVID-19 pandemic has highlighted the critical role of airborne transmission in spreading the virus, especially in indoor environments where air quality and ventilation are key factors. The virus can remain airborne for extended periods, influenced by the conditions within enclosed spaces. This risk is particularly pronounced in areas with air conditioning systems, where indoor air circulation can facilitate the spread of the virus. Poor ventilation increases the likelihood of virus transmission and elevates the concentration of airborne pollutants, including those carrying the coronavirus. These conditions necessitate effective sanitisation measures. However, conventional fogging and disinfection processes are time-consuming, often requiring up to three hours to decontaminate a single room. Factors such as temperature and humidity within indoor spaces can further influence the virus's viability and transmission risk. Given these challenges, there is a pressing need for an innovative solution. This paper proposes the development of an IoT-based fogging and sanitation system integrated with split air conditioning units. This system aims to enhance indoor air quality and reduce the transmission risk of COVID-19, leveraging the advantages of IoT for efficient, real-time monitoring and control of the sanitisation process.

1.3 Research Objectives

This research aims to develop and access an IoT-based fogging/sanitisation system tailored for air conditioning split units. The first objective involves the meticulous proposal of a design concept for the system, detailing the interplay between its components and the method for integrating it with existing air conditioning infrastructure. The second objective centres on the actual construction and programming of the IoT-based system, ensuring that its integration with split air conditioning units is smooth and does not compromise its primary functions. The final objective encompasses a dual-focus evaluation: firstly, testing the system's functionality, efficiency, and effectiveness in enhancing indoor air quality through metrics such as uniform distribution of sanitising agents, response time, and energy efficiency; and secondly, this phase will include a rigorous review by experts, assessing the system's design, safety, and operational functionality. This comprehensive approach aims to deliver a robust and efficient solution for improving indoor air environments, a necessity in addressing the challenges posed by pandemics.

2. Methodology

The research methodology is a crucial component that outlines the approach adopted for conducting this study, mainly focusing on the production, collection, and analysis of data. It is a foundational element that provides evidence to support the study's findings and conclusions. In this context, the study methodology centres around developing an Integrated IoT-Based Fogging/Sanitation System for Air Conditioning Split Units. This chapter delves into the rationale behind the chosen research method, underlining its relevance and applicability to the study's objectives. This methodology aims to investigate the problem at hand and present a comprehensive understanding of the research process, thereby facilitating a detailed description of the methods and techniques employed. By adopting this approach, the research encapsulates a blend of theoretical and practical insights, which provides a robust framework for the study.

2.1 Research Design

The researcher employs the ADDIE design model as a guiding framework for product development and the quantitative research methodology. As outlined by Aldoobie, (2015), the ADDIE design model is a widely recognised instructional design framework providing a systematic product development approach. This model incorporates five interrelated phases: Analysis, Design, Development, Implementation, and Evaluation. Each phase plays a critical role and continuously interacts with others to ensure the relevance and effectiveness of the entire process.

i. Analysis: This initial phase involves a detailed examination of the requirements for the IoT-based fogging/sanitation system. It is a comprehensive analysis that ensures the design aligns with the specific needs identified for air conditioning split units.

ii. Design: In the design phase, concepts and specifications for the IoT-based system are developed. Decisions regarding the layout, size, function, and overall design are made, drawing insights from the analysis phase to ensure that the design effectively addresses the research problem.

iii. Development: This phase involves the actual creation of the system, consideration of safety measures, and selection of appropriate components. It is where the theoretical design is transformed into a tangible product.

iv. Implementation: A dual approach is employed in the implementation phase. Initially, a customised questionnaire is created based on the product requirements and insights gathered throughout the development phase. This questionnaire is designed to assess the effectiveness of the solution quantitatively. Pilot testing is conducted to determine if the product effectively addresses the issue statement and fulfils the research's objectives. This entails gathering data on temperature and pressure and ensuring that it adheres to safety and design requirements. If the product fails to meet these requirements, a root cause analysis is performed, followed by a redesign and development process to resolve the concerns. This aims to streamline the phase's focus on assuring the product's efficacy and safety.

v. Evaluation: The final phase involves assessing the effectiveness of the IoT-based system and the survey method. Evaluation tools such as questionnaires are used to gather feedback, which is then analysed descriptively to determine the system's functionality and the effectiveness of the teaching aids.

3. Results and Discussion

In this section, the researchers present the results and thoroughly analyse the "Development of an Integrated IoT-Based Fogging/Sanitation System for Air Conditioning Split Units". The research concentrated on designing and developing a new system, with careful evaluation and verification of its effectiveness in enhancing indoor air quality through advanced fogging and sanitation methods. The foundation of this approach was the rigid and repetitive ADDIE Model, which entailed a methodical progression through the phases of Analysis, Design, Development, Implementation, and Evaluation. The researchers were able to customise the system by adopting this rigorous methodology to meet unique environmental and operational requirements. Additionally, the product continuously improved its capabilities based on feedback from real-world performance.

3.1 Analysis

On the Analysis Phase, the initial stage of the ADDIE design process, is crucial in creating the "Integrated IoT-Based Fogging/Sanitation System for Air Conditioning Split Units." In this preliminary stage, researchers thoroughly reviewed the information provided in Chapter 1 to guarantee that the established sanitation system effectively tackles the problems outlined in Chapter 1. Inspired by the Branch, (2009) perspective, the need analysis phase is the initial step to identify performance gaps and determine suitable measures to address them.

Within the scope of this study, conducting need analysis was crucial to comprehend the probability of difficulties arising. Branch, (2009) emphasised that the analysis phase identifies potential difficulties and develops appropriate action plans. In order to ensure that the sanitation system built focused on effective sanitation characteristics that fulfil all study objectives, researchers chose appropriate data analysis findings to move forward to the following stages.

3.1.1 Need Analysis

The need analysis phase was strategically utilised to close the gap between the current and desired states of sanitation systems for split units, aligning with Witkin, (1977) definition of need analysis as a methodological approach to identifying discrepancies between current conditions and desired outcomes. This phase involved identifying the specifications present in the current market, as described in Table 1, and examining the qualitative assessment of needs, as emphasised by (McKinney, 1987). In this context, need analysis is used to evaluate the value judgements of specific groups confronted with unique challenges that must be resolved. Furthermore, researchers discussed specifications for each sanitation equipment variation, noting the operational concept similarities but material differences. The sanitation systems components, such as pumps, heaters, nozzles, and disinfectant tanks, each presented unique advantages and disadvantages regarding performance, functionality, and development complexity.

Table 1 *Comparative Analysis of Sanitation and Fogging Systems for Split Unit Application*

Criteria	Sanitation System	Fogging System	Implications for Product Development
Structural Complexity	Simple	Complex	The inherent simplicity of the sanitation system structure is more conducive for integration with split units, offering a streamlined approach to installation and maintenance.
Additional Components	Utilises only a mist nozzle	It incorporates a heater to convert liquid to fog	The complexity of the fogging system's additional components, such as heaters, presents challenges regarding integration and reliability when applied to split units.
Process Control	Arduino Uno	Arduino Uno	Both systems employ Arduino Uno for remote control capabilities, indicating a standardised approach towards process management across different system types. However, the utility of Arduino Uno in managing the additional complexities of the fogging system requires further investigation to ensure seamless operation.

Table 1 delineates the comparative assessment of the sanitation and fogging systems, with a focus on structural complexity, inclusion of additional components, and process control mechanisms. The analysis underscores the suitability of the sanitation system for split units based on its simplicity, lesser dependency on complex additional components, and standardised process control methodology, ultimately guiding the development towards meeting product needs and research objectives. Table 2 shows the specifications of different fogging machines, emphasising spray distance, coverage area, and cost considerations. This detailed analysis of equipment specifications informed each sanitation device's component selection and design, laying a robust foundation for product design specifications discussed in subsequent topics.

Table 2 *Specifications of Fogging Machine Models*

Fogging Machine Model	Power (W)	Disinfectant Tank Capacity (litres)	Fogging Distance (m [sq ft])	Price Range (RM)
Model A 	1500	2.5	4 m (43 sq ft)	90.00 - 99.00
Model B 	1400	8	6708 m (22,000 sq ft)	95.00 - 120.00
Model C 	1500	Not applicable (No built-in tank)	457 m (1,500 sq ft)	69.00 - 80.00

3.2 Design

Researchers methodically followed a disciplined approach during the design phase to transform the conceptual foundation established in the analysis phase into concrete design suggestions. The phase was divided into three essential sub-topics: Design Specifications, Design Concepts, and Design Selection, each making a distinct contribution to the blueprint of the envisioned product.

3.2.1 Design Specifications

In the design phase of a project, establishing precise design specifications is crucial for guiding the development process towards a solution that addresses identified needs and aligns with the project's overarching objectives. According to Abdul Jalil (2000), these specifications act as a compass throughout the design journey, ensuring that the product's development focuses on achieving the desired outcomes. Critical considerations in defining design specifications include user interaction, material selection, safety protocols, performance benchmarks, cost-effectiveness, and size constraints. Each specification must be carefully balanced to harmonise the desire for an innovative sanitation system with practical considerations such as usability, manufacturing feasibility, and market suitability.

1. **User interaction**

User interaction specifications play a crucial role in designing a sanitation system that meets the needs and preferences of its users. These specifications encompass various factors such as ease of use, accessibility, and user preferences to ensure the system is user-friendly and efficient.

a) Ease of use is a fundamental aspect of user interaction specifications. A sanitation system should be designed in a way that is intuitive and easy for users to operate. This includes considerations such as clear labelling of controls, simple instructions for use, and ergonomic design to facilitate user interaction. Research by Wu (2020) highlights that designing innovative products with user-friendly interfaces and easy usability is crucial for enhancing user satisfaction, reducing errors, and ensuring success in the competitive market, as highlighted in the research.

b) Accessibility is another critical factor in user interaction specifications. The sanitation system should be accessible to users of all ages and abilities, including children, elderly individuals, and people with disabilities. This may involve adjustable height settings, tactile indicators for visually impaired users, and easy-to-reach controls. As mentioned by Aarhaug (2018), the concept of universal design advocates that the design of products, environments, programs, and services should be usable by all people to the greatest extent possible without needing adaptation or specialised design.

c) How people interact with the sanitation system is largely determined by their preferences. User groups' preferences can differ greatly from one another due to personal habits, cultural norms, and unique demands. Finding user preferences and incorporating them into the system's design can be facilitated by holding focus groups, user surveys, and usability testing. Buker et al.’s (2023) research reveals that although usability is valued more in product design than emotionality, emotional elements like uniqueness and beautiful design have a big impact on consumer acceptance and happiness.

2. **Material selection**

To ensure the effectiveness and sustainability of the Integrated IoT-Based Sanitation System for Air Conditioning Split Units, material selection specifications must prioritise durability, sustainability, and appropriateness. The selection of materials is significant because households' lack of financial resources sometimes hinders the construction of high-quality sanitation facilities due to the high costs of materials and skilled labour (Sakas et al., 2021). Ensuring the sustainability of sanitation systems requires addressing key principles based on experiences and literature reviews, emphasising the importance of proper selection and integration of technologies for a positive return on investment(Starkl et al., 2018).

Durability is a critical aspect of material selection. The durability of materials used in sanitation systems is essential to ensure the longevity and effectiveness of the system, especially in environments where maintenance may be challenging or costly. Research by Behsoodi et al. (2023) has shown that the durability of sanitation facilities is directly linked to their sustainability and long-term functionality.

In the context of IoT-based systems, the durability of materials is crucial for the overall reliability and performance of the system. Research conducted by Desbiens (2023) has emphasised the significance of selecting durable materials for IoT devices and platforms to ensure their longevity and resistance to environmental factors. Additionally, the durability of materials used in IoT systems can impact their energy efficiency and overall lifecycle cost.

When selecting materials for the Integrated IoT-Based Sanitation System for Air Conditioning Split Units, it is essential to consider the system's specific requirements, such as exposure to moisture, temperature fluctuations, and mechanical stress. Materials such as corrosion-resistant metals, high-quality plastics, and weatherproof coatings can enhance the system's durability and prolong its lifespan.

3. **Safety protocols**

In order to keep the sanitation system in accordance with applicable safety standards and regulations and, ultimately, protect users from potential injury, safety practices are essential. These procedures cover a variety of actions to stop mishaps, wounds, and health risks in the sanitation system.

4. **Performance**

Performance benchmarks are crucial in assessing the effectiveness and efficiency of sanitation systems. These benchmarks provide measurable criteria to evaluate various aspects of the system, including water usage, waste treatment efficiency, and overall functionality.

Water usage is a key parameter in evaluating the performance of a sanitation system. Monitoring the water consumed in the system is essential to ensure it is used efficiently. High water usage can indicate inefficiencies in the system, such as leakage or excessive flushing, leading to increased costs and environmental impact. Benchmarking water usage allows for comparison with industry standards and best practices to identify areas for improvement.

Overall functionality encompasses various aspects of the sanitation system, including infrastructure conditions, maintenance practices, and service delivery. Performance benchmarks for overall functionality may include system uptime, response times to maintenance issues, and customer satisfaction levels. By setting criteria for these parameters, stakeholders can assess the sanitation system's reliability and effectiveness in meeting the community's needs.

5. **Size constraints**

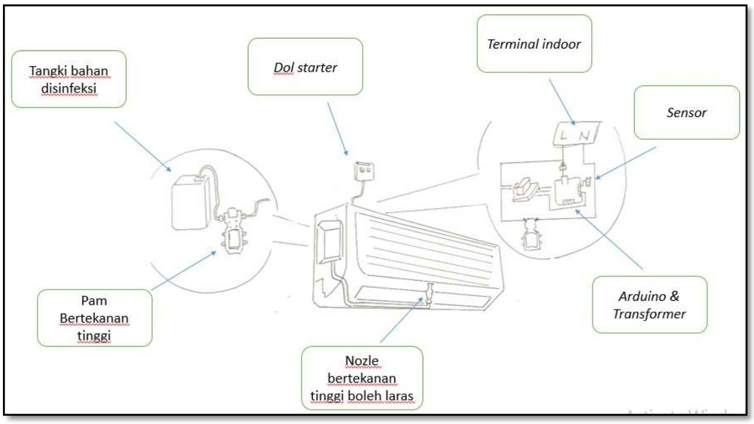
To successfully integrate an IoT sanitation system with an air conditioning split unit within size constraints, it is essential to consider the physical dimensions and installation requirements. The dimensions of the sanitation system must align with the available space and installation specifications to ensure seamless integration with the air conditioning unit. This integration should consider sanitation solutions' technical and socioeconomic aspects to suit the local context (Hendriksen et al., 2011).

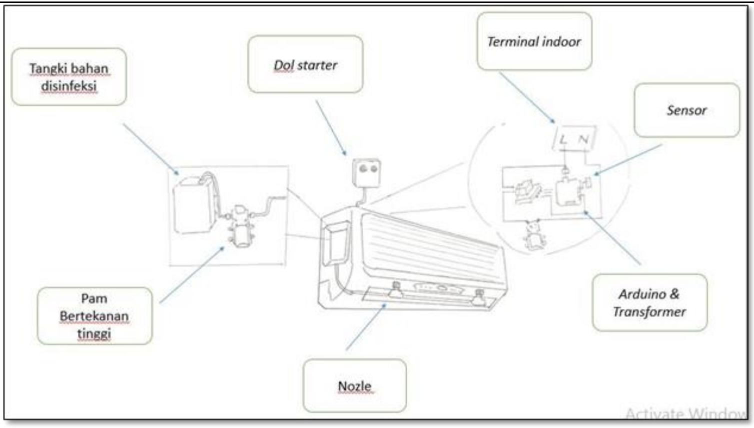
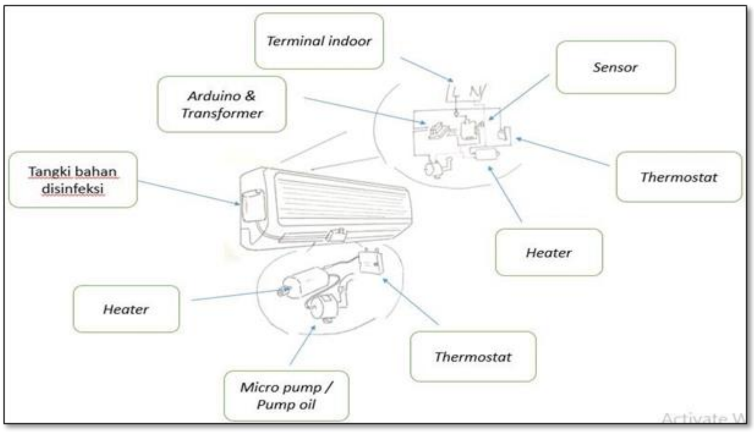
Furthermore, when addressing space limitations, it is crucial to evaluate the impact of the air conditioning system on indoor air quality. Research indicates that air conditioning systems' operation can influence respiratory virus transmission, with larger droplet sizes leading to more prolonged virus survival (Jia et al., 2021). Therefore, ensuring proper ventilation and monitoring air quality is critical when integrating IoT sanitation systems with air conditioning units.

3.2.2 Design Concepts.

Following the formulation of detailed design specifications, the project progressed to the Design Concepts sub-topic. This stage involved exploring potential design solutions articulated through initial sketches and refined through iterative expert consultations. This process was vital in transforming the abstract requirements and specifications into tangible design propositions, each embodying a unique approach to fulfilling the research's goals. The collaboration with experts ensured that each concept was rigorously evaluated for its feasibility, effectiveness, and alignment with the user needs and technical constraints outlined in the specifications. This exploratory process developed three distinct design concepts, each representing a viable pathway to achieving the desired outcomes of an efficient, user-friendly, and cost-effective sanitation system, as shown in Table 2.

Table 2 *Design Concepts for Integrated IoT-Based Sanitation System of Air Conditioning Split Units*

No.	Sketch	Description
Sketch A		i. An adjustable nozzle for effective spraying. ii. A 500 ml tank for disinfectant. iii. Quick and thorough disinfection process. iv. Covers areas from 5 to 10 meters away. v. Suitable for spaces of 200 to 400 square feet. vi. Simple design for easy use and maintenance.

Sketch B		i. Two nozzles. ii. A 500 ml disinfectant tank. iii. Moderate disinfection time. iv. Reach of 5 to 8 meters. v. Covers 200 to 600 square feet. vi. Simple construction.
Sketch C		i. A heater for better dispersion. ii. A 500 ml disinfectant tank. iii. Disinfects quickly but lasts longer and more efficiently. iv. Can cover 5 to 8 meters. v. Effective for areas of 200 to 600 square feet. vi. Higher cost. vii. Complex construction.

3.2.3 Design Selection.

In the design selection phase, researchers sought expert opinions and design recommendations. The primary aim was to ensure that the developed product aligned with the research's objectives, avoiding self-interest biases. Expert advice was also pivotal in gaining additional insights for product development. A matrix evaluation conducted by experts assessed the three design sketches, focusing on user preferences, material composition, safety, cost, size, and performance. The evaluation criteria ranged from "Poor" (1) to "Excellent" (5). The second design sketch received the highest overall score of 70 points, as shown in Table 3, indicating its potential for effective sanitation processes compared to the first and third sketches. This scoring reflected user convenience, material suitability, safety assurance, cost efficiency, size appropriateness, and performance efficacy.

Table 3 *Matrix Evaluation of Design Sketches by Experts*

Criteria	Sketch 1 (P1, P2, P3)	Sketch 2 (P1, P2, P3)	Sketch 3 (P1, P2, P3)
User Preference	4, 4, 4	4, 4, 4	4, 4, 4
Material	3, 3, 4	4, 4, 4	4, 3, 4
Safety	4, 3, 4	4, 4, 4	4, 4, 4
Cost	4, 3, 4	5, 4, 3	3, 3, 3
Size	3, 4, 4	4, 4, 4	3, 4, 4
Performance	3, 3, 3	3, 3, 4	5, 5, 5
Total	**63**	**70**	**66**

A matrix evaluation conducted by experts assessed various design sketches, focusing on user preferences, material composition, safety, cost, size, and performance. The evaluation criteria ranged from "Poor" (1) to "Excellent" (5). The second design sketch received the highest overall score of 70 points, indicating its potential for effective sanitation processes compared to the first and third sketches. This scoring reflected user convenience, material suitability, safety assurance, cost efficiency, size appropriateness, and performance efficacy.

The second design concept was ultimately selected to develop the split-unit IoT-based sanitation system. This decision was based on its ability to facilitate user operations and ensure safety and its superior performance in the expert evaluation. This system is expected to optimise the sanitation process in specified spaces, functioning efficiently based on the outlined factors.

3.3 Development

In the development phase, the research focused on creating a circuitry system essential for operating the pump and connecting sensors, which includes power sources and control boards, among other electronic components. Special electronic assembly tools were required to connect these components to the circuit boards. The development process involved circuit development, IoT programming, basic product development, product assembly, and the final product.

3.3.1 Circuit Development.

The power supply was derived from the air conditioning unit's power source, with the current split into two transformers for different voltage needs: one for the NodeMCU and relay (240v - 5v) and another for the pump and relay (240v - 12v). The development process in Table 4 involved careful wiring and programming to ensure the NodeMCU could control the pump via relay signals.

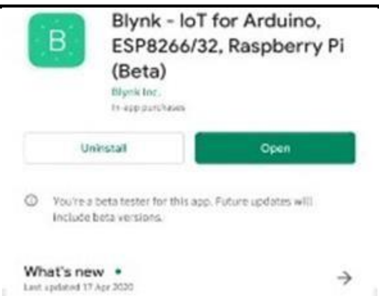
Table 4 *Circuit Development Phase*

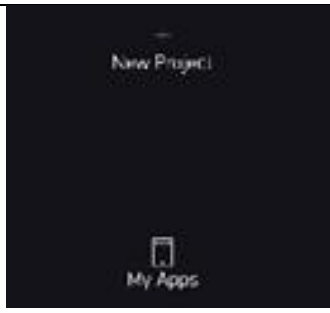
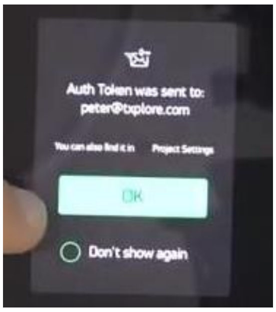
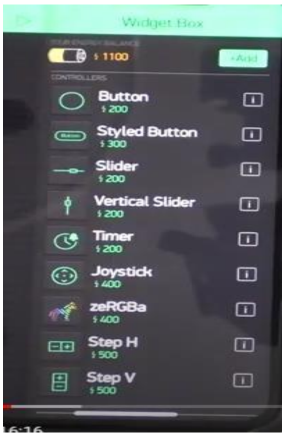
Phase	Description
Power Source	Use the air conditioner's power as the system's power source.
Current Splitting	Divide the current into two paths with a connector for two separate transformers.
First Transformer Connection	Connect the first transformer (240v to 5v) to the NodeMCU and the relay.
NodeMCU Wiring	Attach the positive (+) from the first transformer to the NodeMCU's Vin port and the relay and the negative (-) to the NodeMCU's GND port.
NodeMCU Programming	Program the NodeMCU to control the relay and turn the pump on and off.
Second Transformer Connection	Connect the second transformer (240v to 12v) to the pump and another relay.
Pump Wiring	Connect the positive (+) from the second transformer to the relay's common terminal and the pump to the relay's normally open (NO) terminal, with the negative (-) going directly to the pump.

3.3.2 IoT Programming.

IoT programming was achieved by installing Arduino and Blynk software on computers and smartphones. Blynk facilitated remote control and monitoring through an intuitive interface. Steps included downloading Blynk, creating a new project, selecting the ESP8266 control board, configuring widgets like buttons for system control, and programming the control board with a unique Blynk Authorization token.

Table 5 *Circuit Development Phase*

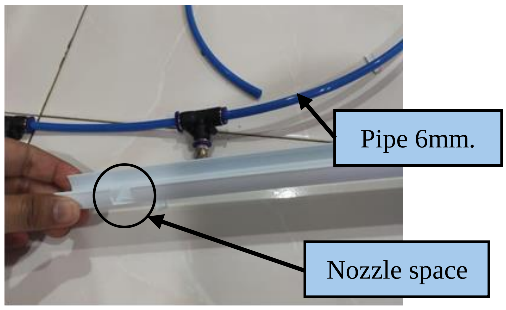
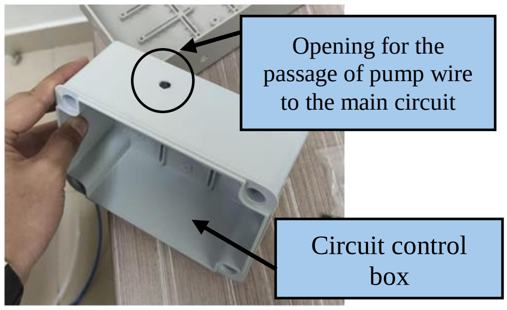
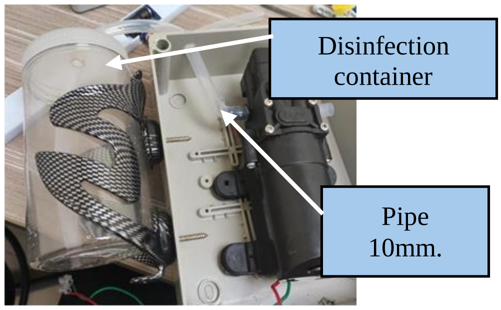
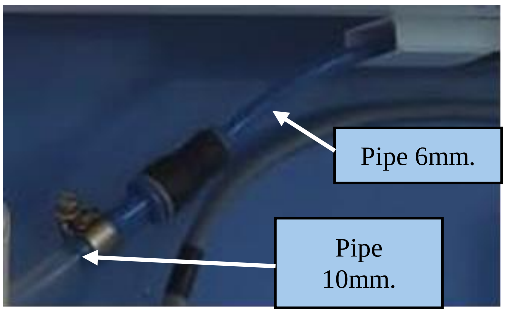
Step	Action	Figure
Blynk App Installation	Downloaded from Google Playstore or Apple Appstore and installed on smartphones.	

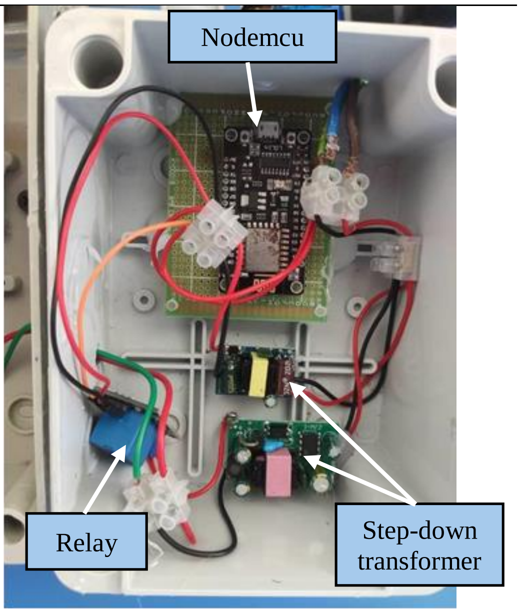
Project Creation	Initiated a new project in the Blynk App, selecting ESP8266 board and WiFi connection.	
Authorisation Token	The Blynk App generated a unique token to integrate with the control board's program.	
Widget Configuration	Button widget chosen for turning the system on/off; other widgets reviewed for potential inclusion.	
Code Integration	Unique Blynk code inserted into the Arduino program for remote control and monitoring.	

3.3.3 Basic Product Development.

This process involved constructing the system's physical components, including the sanitation pump housing, nozzle plumbing, control boxes for the pump and circuitry, and the disinfectant container. Measurements and specific adjustments were made to accommodate the system's design and functional requirements.

Table 5 *Basic Product Development*

Component	Description	Figure
Nozzle Housing	Measured and cut to fit the nozzle and plumbing, with a length of 5 meters for the housing.	
Nozzle Plumbing	Nozzle size measured and space made; three nozzles used for sanitation spraying, spaced 2 meters apart.	
Control Boxes	Two different sizes for the pump and circuitry to accommodate the larger pump size and ensure safety.	
Disinfectant Container Holder	A bicycle water bottle holder was repurposed to hold the disinfectant container.	
Pipe Connections	10mm pipe from the disinfectant container to the pump, and a reduction to 6mm from the pump to the nozzle.	

Complete circuit	The complete circuit is placed inside the control box.	

3.3.4 Product Assembly.

The final assembly integrated circuit components, main components, and piping into a complete product. This phase also emphasised the product's aesthetic appeal to engage users effectively.

3.3.5 Final Product.

The development phase concludes with an entirely built and functional IoT-based fogging/sanitation system explicitly designed for air conditioning split units, as shown in the Figure. This technology effortlessly combines with air conditioning systems to deliver enhanced sanitation.

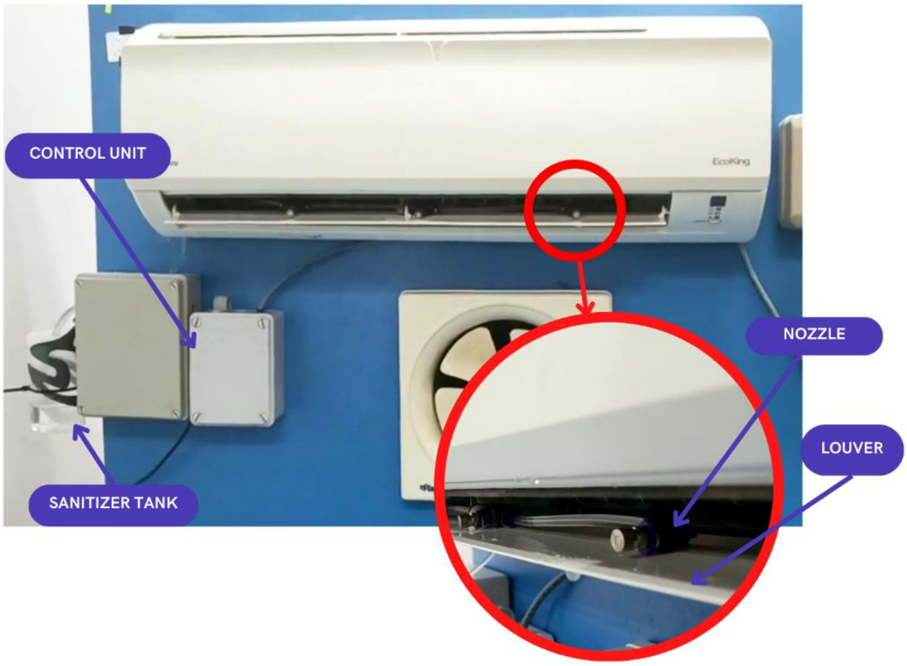


Fig. 1 *Final Product*

3.4 Implementation

Following the completion of the product development phase, the implementation work commenced with testing the fully developed product to evaluate its performance in terms of spray distance and the blower speed of the air conditioning system within the IoT-based sanitation unit for split units.

The analysis aimed to test whether different blower speeds (slow, medium, high) could affect the spray distance from the nozzle. For this research, data was gathered after the system was activated, and the researcher measured the spray distance based on the air conditioning blower speed over 15 minutes. Figure 2 illustrates a line graph showing the relationship between two variables: the blower speed of the air conditioner and the spray distance.

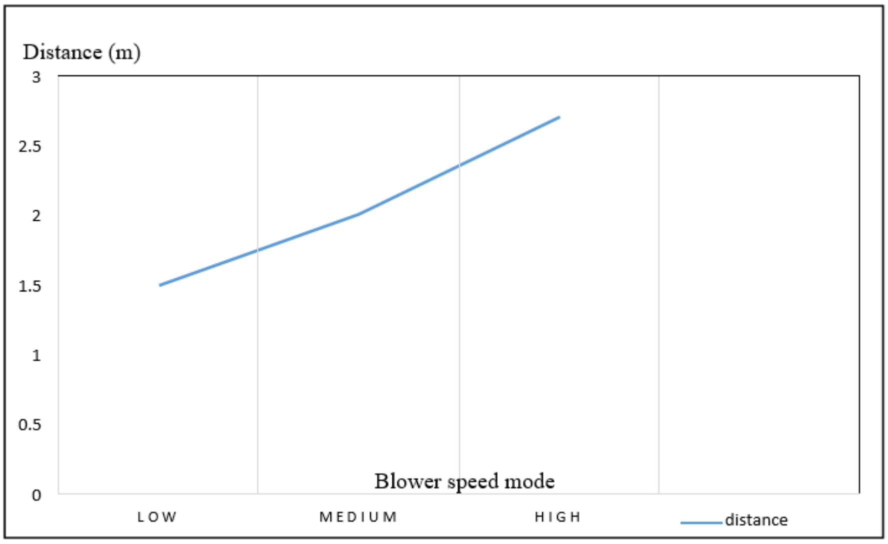


Fig. 2 *Blower Speed Graph Against Spray Distance*

The graph depicts a positive correlation between the air conditioner's blower speed and the distance the sanitation spray reaches. This visual representation is key in demonstrating that as the blower speed increases from low to high, there is a corresponding increase in the spray's reach. This information is essential for understanding the effectiveness of the IoT-based sanitation system. The graph effectively shows the impact of blower speed settings on the system's operational efficacy, confirming the hypothesis that blower speed is a significant factor in achieving the desired sanitation coverage. These findings underscore the system's versatility and potential adaptability to various environmental conditions and sanitation requirements.

3.5 Evaluation.

This phase was conducted through expert validation, where the product's functionality and adherence to the study's objectives were evaluated using a questionnaire. Five experts, including two lecturers and three HVAC engineers with at least five years of experience in refrigeration and air conditioning, were selected for this evaluation. The questionnaire covered various aspects such as product design, safety, functionality, and improvement suggestions.

3.5.1 Evaluation of Product Design.

In the product design evaluation, experts' feedback indicated a generally positive reception towards various aspects of the product. Most respondents agreed on the neatness of the design, suitability of materials used, appropriate size for split unit application, safety features, and ease of operation, as shown in Table 6. These findings align with previous research highlighting the importance of these factors in consumer satisfaction and product usability (Jeong, 2014).

However, the evaluation also identified minor disagreements among participants regarding certain aspects of the product design. Specifically, concerns were raised about the neatness of the wiring and the sturdiness of the installation. These discrepancies suggest potential areas for improvement to enhance the product's overall quality and user experience.

Table 6 *Expert Evaluation of the Product Design*

No.	Item	Yes	No
1	Does the SSUPI product have a neat design?	4	1
2	Are the materials used for developing the SSUPI suitable?	5	0
3	Does the SSUPI have an appropriate size for application on split units?	5	0
4	Is the design of the SSUPI safe to use?	5	0
5	Is the design of the SSUPI easy to operate?	5	0

To address the issue of wiring neatness, the researcher could consider redesigning the internal wiring system to ensure a more organised and visually appealing layout. This could involve implementing cable management solutions or redesigning the internal components to minimise visible wiring, thus enhancing the product's aesthetic appeal (Van Heugten, 2011). Regarding the sturdiness of the installation, the researcher may need to reevaluate the product's mounting mechanisms and structural integrity. Strengthening the installation components, such as brackets and fasteners, could help address concerns about stability and durability raised by some participants during the evaluation process (Robert et al., 2012).

3.5.2 Evaluation of Product Development.

Safety aspects received favourable responses, affirming the product's safety in terms of installation, electrical and electronic components compliance, and the safety of the disinfectant used. Despite the positive feedback, there was a call for better electrical connections and component layout neatness, as shown in Table 7. Compliance with electrical and electronic components standards is essential to guarantee that the product meets industry regulations and operates safely. Adhering to these standards ensures that the product is designed and manufactured to minimise electrical risks and hazards.

Table 7 *Expert Evaluation of the Product Development*

No.	Item	Yes	No
1	The installation of this product is robust and safe for use.	4	1
2	Electrical and electronic components are installed neatly and follow the specified standards.	4	1
3	The disinfectant material used is safe for users.	5	0
4	The design of this SSUPI is safe for use.	5	0

The safety of the disinfectant used in the product is also a critical aspect to consider. It is important to ensure that the disinfectant effectively kills harmful pathogens while being safe for use in the intended environment. This includes verifying that the disinfectant does not pose any health risks to users and is compatible with the product's materials to prevent damage.

While the product received favourable responses regarding safety, there were suggestions for improved electrical connections and a neat component layout. Enhancing electrical connections involves ensuring that all wiring and connections are secure, properly insulated, and free from potential short circuits. The neat component layout is essential for aesthetics and safety, as a well-organized layout can prevent accidental damage to components and facilitate maintenance and troubleshooting.

3.5.3 Evaluation of Product Functionality.

In the evaluation of the functionality aspects of the product, several key factors were identified as having high agreement rates among experts, as shown in Table 8. The suitability of materials used in the product was highlighted as a positive aspect, indicating that the materials chosen were appropriate for the intended purpose and contributed to the product's overall effectiveness. This aligns with previous research that emphasises the importance of selecting materials that are durable, easy to clean, and compatible with the disinfectants being used.

Table 8 *Expert Evaluation of the Product Functionality*

No.	Item	Yes	No
1	Are the materials required by SSUPI safe for development?	5	0
2	Is the layout of SSUPI components neat?	4	1

3	Can the pump used distribute disinfectant to the nozzle effectively?	4	1
4	Does this application provide convenience and save time for users to perform disinfection processes at home?	5	0

One of the key functionalities that received high approval rates was the product's effectiveness in facilitating the disinfection process remotely. This suggests that users found the product efficient and reliable in carrying out its intended function of disinfecting surfaces from a distance. Remote disinfection technologies have recently gained importance due to the need for contactless solutions in various settings, such as healthcare facilities, public spaces, and transportation (Lastovicka-Medin & Vanja, 2021).

However, it is essential to note that some concerns were raised regarding the arrangement of components and the efficacy of the pump in dispensing the disinfectant. These concerns highlight areas for potential enhancement in the product design and functionality. Addressing these issues could further improve the product's user experience and overall performance.

3.5.4 Expert Approval Analysis via CVI.

Content validity is crucial in ensuring the overall validity of an evaluation. Therefore, a systematic approach to validate the content or the produced product should be employed, grounded in evidence and best practices. Experts measure the product's content validity using the Item Content Validity Index (I-CVI), which nominally determines agreement (Yes) or disagreement (No). Polit et al. (2007) calculate I-CVI as 1 when experts respond with 'Yes' and 0 for 'No.' For panels with five or fewer experts, the I-CVI must be 1.00. The items with an I-CVI of .78 or higher for three or more experts could be considered evidence of good content validity. Meanwhile, the recommended S-CVI value for content validity is 0.8. Tables 9, 10, and 11 present the obtained item content validity index analysis.

Table 9 *Expert Evaluation for Product Design*

Item	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total Agreement	I-CVI	UA
Q1	1	1	0	1	1	4	0.8	0
Q2	1	1	1	1	1	5	1	1
Q3	1	1	1	1	1	5	1	1
Q4	1	1	1	1	1	5	1	1
Q5	1	1	1	1	1	5	1	1
S-CVI/Ave							0.96	
S-CVI/UA								0.8

The I-CVI values assessed by experts regarding product design range from 0.8 to 1.0, with only one item not achieving 1.0 due to its less neat design. The average S-CVI value for design is 0.96, meeting the set expert approval level, with the recommended S-CVI for content validity at 0.8.

Table 10 *Expert Evaluation for Product Development*

Item	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total Agreement	I-CVI	UA
Q1	1	1	0	1	1	4	0.8	0
Q2	1	1	1	1	0	4	0.8	0
Q3	1	1	1	1	1	5	1	1
Q4	1	1	1	1	1	5	1	1
S-CVI/Ave							0.90	
S-CVI/UA								0.5

The I-CVI values evaluated by experts regarding product development range from 0.8 to 1.0. Two items did not achieve 1.0 due to less neat circuit connections within the control box. The average S-CVI value for design is 0.9, thereby meeting the expert approval level set.

Table 11 *Expert Evaluation for Product Functionality*

Item	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total Agreement	I-CVI	UA
Q1	1	1	1	1	1	5	1	1
Q2	1	1	1	0	1	4	0.8	0
Q3	1	1	1	0	1	4	0.8	0
Q4	1	1	1	1	1	5	1	1
S-CVI/Ave							0.90	
S-CVI/UA								0.5

The I-CVI values evaluated by experts in terms of functionality also range from 0.8 to 1.0, with two items not achieving 1.0 due to the less neat arrangement of components within the control box. The average S-CVI from the design perspective is 0.9, satisfying the expert approval level requirement.

4. Conclusion

Experts praised the product's neatness, material compatibility, appropriate size for split unit applications, safety features, and user-friendly features, all of which spoke to its well-thought-out design. These aspects are crucial for consumer satisfaction and product usability, echoing findings from previous research (Jeong, 2014). However, minor discrepancies regarding wiring neatness and the sturdiness of installations were noted, indicating areas for design enhancement to boost product quality and user experience.

Functionality evaluation identified the product's effectiveness in facilitating the disinfection process remotely as a standout feature, reflecting the growing importance of contactless solutions. The selection of materials and the product's overall design were recognised for suitability and contribution to its effectiveness. However, concerns about the component arrangement and the pump's efficacy in disinfectant dispensation suggest further opportunities to enhance the product's design and functionality, enriching the user experience and performance.

The systematic application of the CVI method demonstrated substantial expert approval across evaluated aspects, with I-CVI values ranging from 0.8 to 1.0 across product design, development, and functionality. These findings, supported by high S-CVI values, indicate strong content validity and expert consensus on the product's adherence to evaluation criteria. The meticulous approach to content validation underscores the importance of expert feedback in affirming the product's quality and effectiveness.

The comprehensive evaluation of the product across design, development, safety, and functionality aspects, underscored by expert analysis through CVI, confirms the product's high potential in meeting the intended objectives. While the overall expert feedback is exceedingly positive, highlighted areas for improvement provide valuable directions for future product enhancements. Addressing these aspects, particularly in design neatness and component arrangement, can significantly elevate the product's market readiness and user satisfaction. This evaluation validates the product's current strengths and charts a path for continuous improvement, aligning with best practices and industry standards for safety and effectiveness.

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