USABILITY EVALUATION OF IOT BASED HVAC DASHBOARD

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Computer Science and Information Technology
Department of Mathematics and Computer Science
Faculty Of Science
Chulalongkorn University
Academic Year 2023

การประเมินความสามารถในการใช้งานแดชบอร์ดของระบบปรับอากาศแบบไอโอที

น.ส.รูบินา เชรดธา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาวิทยาการคอมพิวเตอร์และเทคโนโลยีสารสนเทศ
ภาควิชาคณิตศาสตร์และวิทยาการคอมพิวเตอร์
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2566

Thesis Title	USABILITY EVALUATION OF IOT BASED HVAC DASHBOARD
By	Miss Rubina Shrestha
Field of Study	Computer Science and Information Technology
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รูบินา เชรดธา : การประเมินความสามารถในการใช้งานแดชบอร์ดของระบบปรับอากาศแบบไอโอที. (USABILITY EVALUATION OF IOT BASED HVAC DASHBOARD)
อ.ที่ปรึกษาหลัก : นกุล คูหะโรจนานนท์

วิทยานิพนธ์นี้นำเสนอการประเมินความใช้งานของอินเตอร์เฟซแผงควบคุมระบบทำความร้อน, ระบายอากาศ, และปรับอากาศ (HVAC) ที่ฉลาดผ่านการศึกษาทางวัฒนธรรม. วัตถุประสงค์คือการประเมินปัญหาทางการใช้งานและประเมินประสบการณ์ของผู้ใช้ในอินเตอร์เฟซผ่านการวิเคราะห์ทั้งปริมาณและคุณภาพ. การศึกษาได้รับผู้เข้าร่วม 20 คนจากประเทศทั้งสาม, พิจารณาถึงความคุ้นเคยและไม่คุ้นเคยกับระบบ HVAC ที่ฉลาด. ผู้เข้าร่วมทำกิจกรรมต่าง ๆ โดยใช้แผงควบคุม พร้อมทั้งให้ความเห็นที่ตั้งใจออกมา. การประเมินทางปริมาณวัดผลเชิงประสิทธิภาพ, ประสิทธิภาพ, และความพึงพอใจของผู้ใช้โดยใช้มาตรฐาน ISO:9241-11:2018, ในขณะที่การประเมินทางคุณภาพเน้นการระบุปัญหาในการใช้งานจากความเห็นของผู้เข้าร่วมและเปรียบเทียบกับหลักการออกแบบ UI ที่กำหนดไว้. ผลการวิจัยเปิดเผยถึงความท้าทายในการทำกิจกรรม, โดยเฉพาะสำหรับกิจกรรมที่ 2, 7, และ 8. คะแนนประสิทธิภาพที่เชื่อมโยงกับเวลาและคะแนนความพึงพอใจหลังจากกิจกรรมยังแสดงถึงปัญหาในการออกแบบปัจจุบัน. การวิเคราะห์ทางคุณภาพเน้นปัญหาที่เกี่ยวข้องกับการมองเห็นของระบบ, ความสอดคล้อง, การจับคู่กับโลกแสนจริง, และขาดข้อมูลที่เป็นประโยชน์. ผลการวิจัยชี้ชัดถึงการปรับปรุงทางอินเตอร์เฟซ, เช่น การเพิ่มประสิทธิภาพของหน้าหลัก, การใช้ชื่อเรื่องที่สอดคล้อง, การหลีกเลี่ยงภาษาที่ยากเข้าใจ, การให้คำอธิบายด้วย tooltips, และการดำเนินการตัวกรองข้อมูลที่ดีขึ้น. ถึงแม้จะมีความคุ้นเคยในการใช้ระบบฉลาดมากขึ้นในประเทศจีนและไทย, พบว่าผู้เข้าร่วมทุกสัญชาติกำลังเผชิญกับความท้าทาย และไม่ได้เป็นไปเพียงแค่ผู้เนปาลที่แสดงถึงอินเตอร์เฟซที่ไม่ดีของแผงควบคุม. โดยรวม, การศึกษานี้มีส่วนร่วมในการเข้าใจความท้าทายในการใช้งานของแผงควบคุม HVAC ที่ฉลาดผ่านการทำการศึกษาประสบการณ์การใช้งานทางวัฒนธรรมและนำเสนอความรู้สู่การปรับปรุงประสบการณ์ของผู้ใช้และประสิทธิภาพของระบบ.

สาขาวิชา	วิทยาการคอมพิวเตอร์และเทคโนโลยีสารสนเทศ	ลายมือชื่อนิสิต ....
ปีการศึกษา	2566	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

6378504023 : MAJOR COMPUTER SCIENCE AND INFORMATION TECHNOLOGY

KEYWORD: Usability Testing; IoT; HVAC; Smart HVAC Dashboards

Rubina Shrestha : USABILITY EVALUATION OF IOT BASED HVAC DASHBOARD. Advisor: Assoc. Prof. NAGUL COOHAROJANANONE, Ph.D.

This thesis presents a usability evaluation of a smart Heating, Ventilation, and Air Conditioning (HVAC) dashboard interface through a cross-cultural study. The objective is to assess the usability problems and evaluate the user experience of the interface through quantitative and qualitative analysis. The study recruited 20 participants from three different countries, considering their familiarity and unfamiliarity with smart HVAC systems. The participants performed a set of tasks using the dashboard while providing think-aloud feedback. The quantitative evaluation measured effectiveness, efficiency, and user satisfaction based on the ISO:9241-11:2018, while the qualitative evaluation focused on identifying usability issues based on participant feedback and comparing them against established UI design heuristics. The results revealed challenges in task completion, particularly for tasks 2, 7, and 8. The time-based efficiency and post-task satisfaction scores also indicated issues with the current design. The qualitative analysis highlighted problems related to system status visibility, consistency, real world match, and lack of helpful information. The findings suggest potential improvements to the interface design, such as enhancing the landing page, using consistent titles, avoiding jargon, providing explanatory tooltips, and implementing better data filtering options. Despite more familiarity of usage of smart systems among Chinese and Thai, it is found that challenges are faced by participants of all nationalities and not just Nepalese which indicates a bad UI of the dashboard. Overall, this study contributes to understanding the usability challenges of smart HVAC dashboards by conducting a cross-cultural usability study and provides insights for enhancing user experience and system performance.

Field of Study:	Computer Science and Information Technology	Student's Signature ....
Academic Year:	2023	Advisor's Signature ....

ACKNOWLEDGEMENTS

Firstly, I would like to thank Associate Professor Dr. Nagul Cooharojananone, my thesis advisor, for his valuable guidance, support, and the direction without which this research would not have been possible.

Also, I would like to end my gratitude towards my thesis committee members Assistant Professor Dr. Pakawan Pugsee and Dr. Suporn Pongnumkul for providing valuable feedbacks during the proposal of the thesis.

Finally, I would like to express my sincere and heartfelt appreciation and gratitude to my family for their endless support and continuous faith in me.

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CHAPTER 1
INTRODUCTION

1.1 Overview

Heating, Ventilation and Air Conditioning (HVAC) is a system that manages heating and cooling in buildings to improve the indoor air quality by regulating the temperature and moisture levels. One of the main purposes of an HVAC system is to provide 'conditioned air' which means that the air should be clean, and the temperature, humidity, and movement of air should be within certain acceptable comfort ranges [1]. Some of the main functionalities of HVAC systems include maintaining the temperature (heating/cooling), humidifying and dehumidifying to maintain moisture content, and ventilating (air change rates between indoor and outdoor) [2][1]. These functions of HVAC system make sure that the indoor air remains conditioned. Although HVAC systems play a vital role in maintaining the indoor air quality, it has been presumed to consume significant amount of energy [1][3], especially due to lack of monitoring [4] resulting in compromised energy efficiency. One solution to solving the energy efficiency issue is to have an IoT enabled smart HVAC system which allows real time remote monitoring hence leading to minimal power usage for energy conservation.

Over the years, IoT has helped change our homes into smart homes which are defined by their internet-connected technologies that led to home automation and remote management [5]. Similarly, IoT also helps make HVAC system smarter by connecting it to various sensors such as temperature, humidity, power consumption and the obtained sensor information can be viewed on dashboard. Smart HVAC dashboards help monitor and capture humidity, temperature, and aircon data in real-time which leads to optimized energy consumption [3][4]. With smart home apps like Google Home, Apple Home, Amazon's Alexa etc., people have easily been able to control their home appliances such as aircons, cctv cameras and so on from their smartphones. Hence, integrating smart HVAC dashboards into smart home apps would ensure everything runs smoothly without any technical problems due to its ability to remotely control, manage and monitor everything in a single place.

According to the Digital Market Outlook, the number smart homes in the world is expected to reach 478 million by 2025 [6], and according to Zion Market Research, global smart HVAC control market is expected to reach 28.3 billion by 2025 [7], yet there has not been enough research done to evaluate the usability of either of them, especially smart HVAC interfaces/dashboards. Hence, one of the main goals of this thesis is to find the usability problems in the UI of smart HVAC dashboard by conducting a cross culture usability evaluation to check if the dashboard is usable by people who are both familiar and unfamiliar with the concept of smart dashboards.

A simple IoT based HVAC system has been implemented in one of the classrooms at Mahamakut Building, Chulalongkorn University, where various sensors such as temperature, door open/close status and power consumption have been used as shown in Fig. 1. There are two temperature sensors for monitoring the room temperature and humidity, two sensors that show the open and close status of the two doors in the classroom and additionally there are also sensors for monitoring the power consumption of the aircon. All the data from these installed sensors are shown on the Dashboard, which is a smart HVAC dashboard interface for remote monitoring. An example of the interface of Dashboard is shown in Fig. 2. This interface is used in this study for the purpose of conducting cross culture usability evaluation.

The inspiration for conducting usability evaluation of the smart HVAC dashboard stemmed from both the growing significance of global smart HVAC systems as specified earlier and a personal experience using the interface. Recognizing the increasing importance of smart HVAC technologies in the global context, the decision to evaluate usability aligned with broader trends in smart building management. Additionally, a crucial personal inspiration arose from my own encounter with the smart HVAC dashboard, wherein numerous aspects of the interface proved confusing during the initial user experience. This firsthand encounter prompted me to compile a list of user tasks based on common HVAC functionalities, aiming to assess the interface's clarity and ease of use. By involving five participants in the usability evaluation, the study sought to validate and substantiate the my initial concerns. The outcomes of the experiment indeed confirmed the existence of usability issues within the interface, thus providing concrete evidence to address and enhance the user experience of the smart HVAC dashboard. This dual inspiration, grounded in both global technological trends and personal usability challenges, underscored the importance of user-centered design and contributed valuable insights for optimizing the smart HVAC dashboard interface by conduction a usability evaluation.

Figure 1 Classroom at Mahamakut Bldg. where sensors are installed

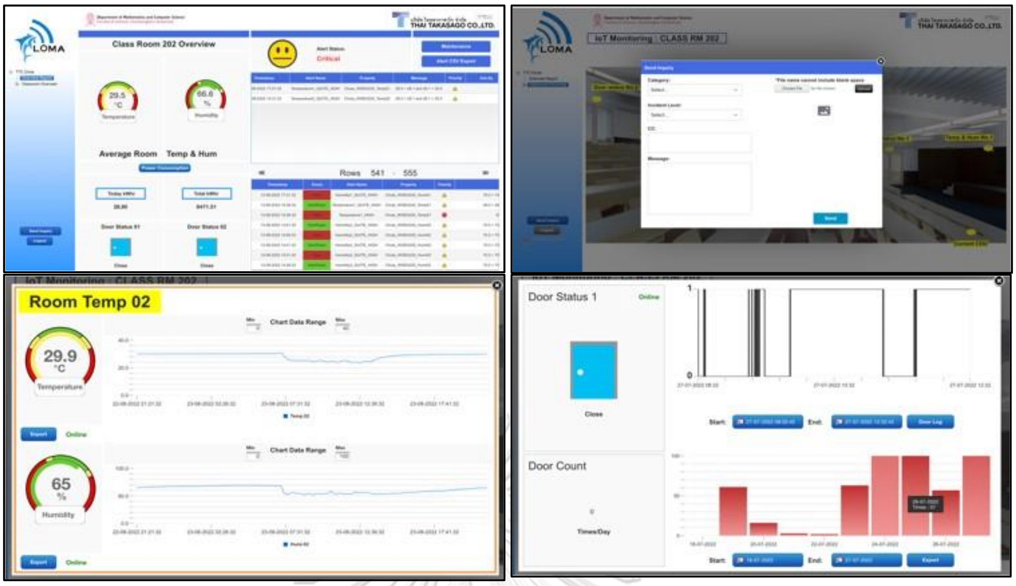

Figure 2 Example interfaces of Dashboard

1.2 Objectives

- To assess problems in the current smart HVAC interface based on insights gained from participants.
- To suggest solutions on the existing user interface based on the problems detected.

CHAPTER 2
BACKGROUND AND LITERATURE REVIEW/RELATED WORK

2.1 Background

Usability evaluation is the process of assessing a product or system's user experience to determine how well it meets the needs of its users. There are two main concepts of usability which are "qualitative" (formative) and "quantitative" (summative), where qualitative evaluation focuses on detection of the problems in the user interface and quantitative evaluation focuses on calculating various metrics associated with meeting the task goals [8][9].

Some of the common usability evaluation techniques include heuristic evaluation, cognitive walkthrough, and usability testing among many others where, heuristic evaluation and cognitive walkthrough are expert-based methods while usability testing is a user-based method. Expert-based method is also known as inspection method in which experts inspect the user interface and predict the problems that the users might have, and user-based method is also known as testing method where usability problems are identified based on the tasks given to the users by observing them [8].

This study specifically is focused on the identification and detection of issues within the smart HVAC dashboard through usability testing of the user interface. Usability testing, a proven and effective technique for evaluating user interfaces [10], is employed to gain valuable insights into user interactions and potential challenges, contributing to the enhancement of the overall usability of the smart HVAC dashboard.

2.2 Literature Review/Related Work

Salman, Wan Ahmed and Sulaiman [8] conducted a usability evaluation on the smartphone user interface where they used heuristic evaluation method using 5 experts to determine usability problems which was completed by testing with 8 participants. Although a lot of usability problems in the interface were detected just from heuristic evaluation, conducting usability testing with the actual users resulted in detection of more usability problems.

Ritthiron and Jiamsanguanwong [11] evaluated the usability of a library website by conducting usability test on 7 different user tasks. Quantitative evaluation was done based on the effectiveness, efficiency, and satisfaction of the interface and for qualitative evaluation, they encouraged the use of think-aloud protocol. Similarly, Escanillan-Gallera and Vilela-Malabanan [12] conducted usability testing on mobile web energy monitoring system for quantitative analysis. The techniques used in these two studies have been taken into consideration for implementing the methodology used in this study.

Magdalena, Ruldeviyani, Sensuse and Bernando [13] have proposed a strategy to increase the use of BI dashboards by conducting usability testing and heuristic evaluation. Similarly, Camargo et al. [14] presented usability evaluation of dashboard for assessing the trustworthiness of cloud applications through usability testing and set of questionnaires. On the other hand, Cho and Choi [15] applied the concept of affordance factors to improve the usability of user interfaces in smart homes. All three of these studies form a very strong basis for the current research. The results from these studies have been used as guidelines for designing the user tasks to conduct usability test on the smart HVAC dashboard.

Almasi, Bahaadinbeigy, Ahmadi, Sohrabei and Rabiei [16] performed a literature review on various tools used for usability evaluation of dashboards. This review comprehensively explores usability evaluation methods, categorizing them into inspection and testing with a particular focus on questionnaires. It highlights the significance of combining qualitative and quantitative approaches in usability evaluation. It also talks about the usage of various metrics such as effectiveness, efficiency and satisfaction as defined by ISO for quantitative analysis. The study highlights System Usability Scale (SUS) as the predominant and extensively utilized questionnaire tool for extracting user satisfaction insights. Additionally, it also talks about some of the well-known heuristics formulated by Neilsen and Holzinger, serving as some important references for conducting usability evaluation.

Nimbarte, Smith, and Gopalakrishnan [17][0] conducted research centered on the development and evaluation of energy visualization dashboards. In their initial phase, preceding the actual experiment, participants were allocated time to acquaint themselves with the system through viewing and interaction. The study employed usability testing to collect data on performance measures, utilizing a questionnaire format for user tasks related to the dashboard. Participants were tasked with promptly responding to the questions. Additionally, a user satisfaction questionnaire was administered to evaluate mental workload, with participants providing ratings on a scale ranging from 1 to 100.

Novikova, Belimova, Dzhumagulova, et al. [18] conducted extensive research into the usability of visualization models concerning HVAC data. The study included a thorough laboratory usability experiment, wherein participants engaged in a questionnaire consisting of tasks categorized by difficulty—easy, medium, and difficult. These tasks encompassed diverse aspects, including understanding the general HVAC system working mode, conducting qualitative assessments, and formulating hypotheses. Furthermore, the study employed a range of metrics, such as frequency of use, time spent on tasks, and subjective evaluations, to conduct a comprehensive analysis.

Nomiso, Tanaka, and Costa [19] conducted a study on the usability of a web portal designed for an Internet of Everything (IoE) system in smart buildings aimed to monitor and control environmental variables like temperature, humidity, and user thermal comfort. The initial version of the interface underwent usability evaluation through a user review involving 17 participants, following the DECIDE framework. Participants were tasked with exploring the web interface, and feedback was collected through a questionnaire containing both open-ended and Likert-scale questions. This feedback played a crucial role in the subsequent redesign of the interface. This study underscored the significance of adopting user-centered design principles in IoE applications to enhance overall user experience.

Switzer, Hutzel, Dib, and Ostanek [20] conducted a study focusing on improving energy dashboards for net zero energy buildings by applying User Experience (UX) principles. The study used a pretest and posttest survey methodology to evaluate users' ability to navigate and interpret an energy dashboard. The research integrated UX principles, Key Performance Indicators (KPIs), and net zero analysis to enhance the dashboard's design. The paper introduced a new net zero energy dashboard and categorized users based on their technical background to tailor the dashboard to their needs. The results indicated a statistically significant improvement in users' ability to identify building performance metrics after implementing UX principles. The study highlighted the importance of considering diverse user groups in energy dashboard design enhanced user experience.

The aforementioned related works collectively provided a robust foundation for shaping the methodology, analysis, and providing better suggestions for the UI in this study.

CHAPTER 3
METHODOLOGY

3.1 Apparatus and Participants

The main objective of this study is to conduct usability testing for the purpose of quantitative as well as qualitative evaluation of the smart HVAC dashboard interface. The main aim of conducting the usability test is to find out if the dashboard is usable by people both in technical as well as non-technical fields. A total of 20 participants were recruited and a remote moderated usability test was conducted which was carried out via the Zoom app. The ages of the participants fell between 18-35 and the recruited participants belong from 3 different countries. The participants chosen for the study were either currently enrolled in undergraduate programs or had already completed their undergraduate education. They represented diverse academic backgrounds, including engineering, communication arts, business administration (BBA/MBA), nursing, commerce, and economics. Out of the 20 participants selected, 10 are from Nepal, 6 are from China, and 4 are from Thailand which represents a cross culture in the usability evaluation. Although the participants recruited are from three different countries, all the participants had a good level of fluency in English and the experiment was conducted mostly in English language. In Nepal, the usage of smart systems such as smart homes or smart HVAC is relatively low while it is not an unknown fact that in China, smart systems are widely used due to their technological advancement, and Thailand is in between Nepal and China in terms of technology. One of the goals of this study is to make sure that the smart HVAC dashboard is easy to understand and use by people who are both familiar and unfamiliar with such systems hence participants are recruited from Nepal, China, and Thailand, taking the familiarity and unfamiliarity of usage into consideration. Before the actual experiment, it is predicted that the usability test conducted with Chinese nationals will yield an excellent usability score followed by Thai due to their familiarity with using smart systems and a relatively lower usability for Nepalese nationals due to lesser exposure to such systems.

3.2 Procedure

Fig. 3 shows the summary of the overall procedure.

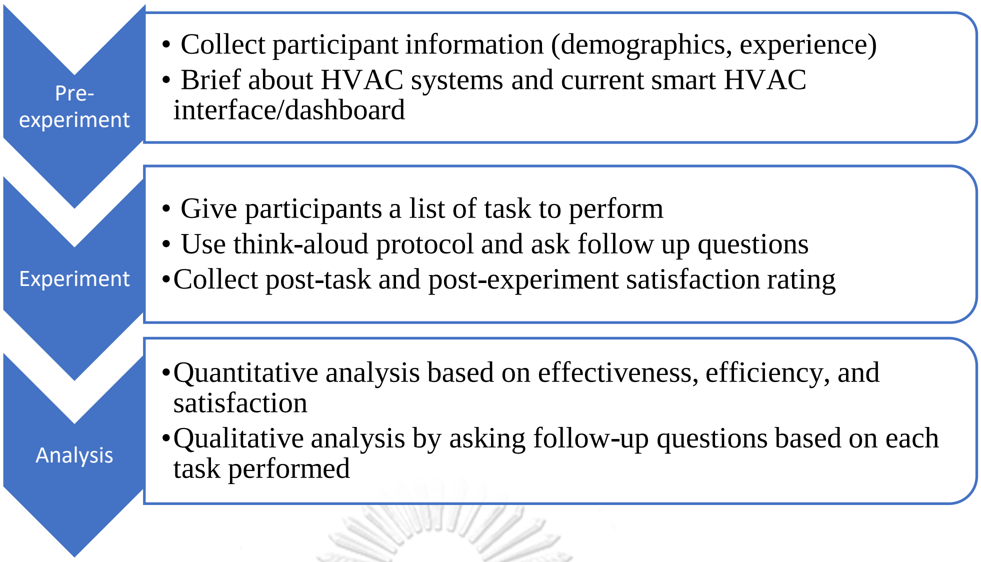

Figure 3 Summary of the Procedure

3.3 Pre-experiment

Before the actual experiment, pre-experiment is conducted where questions are asked to the participants to collect the demographics and their experience about using other similar interfaces. Fig. 4 shows the pre-experiment questionnaire asked to the participants. During the pre-experiment, the participants are also briefed about the smart HVAC systems in general and about the current smart HVAC dashboard.

1. What is your current occupation?
2. How old are you? If not comfortable in disclosing the age, you can give me a range.
3. How would you rate your familiarity with using computers on a scale of 1 to 5?
4. Do you have an experience of using a smart home application (such as Google Home)? If yes,
   a. when was the last time you used it?
   b. How often do you use it?
   c. What do you mainly use it for?
5. Have you ever heard of Internet of Things (IoT)?
6. Have you ever heard of HVAC systems?
7. Do you have an experience of using dashboards of any sort (such as BI dashboards, energy dashboards etc.)?

Figure 4 Pre-experiment Questionnaire

Pre-experiment helped to gain insights about the participants in various categories such as demographic summary, familiarity with smart home technology, awareness of IoT and HVAC systems, and experience with using various kinds of dashboards. The participant demographics have been detailed in the Apparatus and Participants section. The outcomes for the remaining categories can be referenced in Table 1.

Table 1 Pre-experiment result

Participants	**Nationality**	**Occupation/Academic Background**	**Familiarity with smart homes**	**Awareness of IoT**	**Awareness of HVAC**	**Experience with using dashboards**
P1	Chinese	Bsc. Computer Science	Yes	Yes	Yes	Yes
P2		MBA	Yes	Yes	Yes	Yes
P3		BBA	Yes	Yes	No	Yes
P4		M.Eng Computer Engineering	Yes	Yes	Yes	Yes
P5		Communications Arts	Yes	Yes	No	Yes
P6		Communications Arts	Yes	Yes	No	Yes
P7	Thai	Bsc. Computer Science	Yes	Yes	No	Yes
P8		Msc. Computer Science	Yes	Yes	No	Yes
P9		Communications Arts	Yes	Yes	No	Yes
P10		Communications Arts	Yes	No	No	Yes
P11	Nepalese	Electrical Engineer	Yes	Yes	Yes	Yes
P12		BBA	Yes	Yes	No	Yes
P13		BBA	Yes	No	No	Yes
P14		Communications Arts	Yes	Yes	No	Yes
P15		Commerce	No	No	No	Yes
P16		B.Eng Computer Engineering	Yes	Yes	Yes	Yes

P17		Economics	No	No	No	Yes
P18		Nursing	No	No	No	Yes
P19		MBA	Yes	Yes	No	Yes
P20		MBA	Yes	Yes	No	Yes

The data in the table provides a comprehensive overview of the participants involved in the pre-experiment phase for usability testing of the smart HVAC dashboard. A significant portion, 85%, of the recruited participants had a familiarity with using smart home applications, indicating a baseline understanding of the technology involved. Notably, participants from China and Thailand had a higher level of familiarity, using these applications almost daily for different kind of purposes. While a majority of participants from Nepal were also acquainted with smart home applications, their frequency of use was not as pronounced as that of their counterparts from China and Thailand. Moreover, a substantial number of participants demonstrated awareness of the Internet of Things (IoT), with some possessing a high-level understanding but not delving into intricate details. It was observed that only 25% of participants were familiar with HVAC where only a few participants from China and Nepal were familiar with it, and even among those, the knowledge was generally superficial. Interestingly, all recruited participants possessed experience with various types of dashboards, with a predominant familiarity with Business Intelligence (BI) dashboards.

The detailed participant profiles outlined in the table establishes a strong foundation for the subsequent analysis of their interactions and feedback during the actual experiment phase, facilitating a comprehensive understanding of how diverse user characteristics may influence the evaluation of the smart HVAC dashboard.

3.4 Experiment

After the pre-experiment, the actual experiment was conducted by giving participants tasks to perform one at a time and all the participants were encouraged to use a think-aloud approach which is helpful for the qualitative evaluation. The list of user tasks prepared for the participants is shown in Table 2. Tasks were divided based on 3 levels: easy, medium, and difficult.

In preparation for the actual usability experiment, a set of user tasks for evaluating the HVAC dashboard was established. To determine the difficulty levels of these tasks, even before the pre-experiment, a preliminary mock experiment was conducted with a group of 5 test participants, the same group that was used to validate my concerns regarding the user interface of the dashboard. Participants were provided with the list of tasks and were observed as they navigated through the interface where the mock experiment focused on the factors such error rates and most importantly participants' feedback. Based on these insights, tasks were categorized into three levels: easy, medium, and difficult. The categorization aimed to reflect the varying levels of complexity users might encounter. This iterative process, involving real user interactions, allowed for a better classification of tasks, ensuring that the final list used in the usability experiment better aligned with users' expectations and challenges.

Table 2 List of user task

	User Tasks	**Level**
1.	Find the average room temperature and humidity	Easy
2.	Find out how much power the aircon has consumed today	
3.	Find out the total power the aircon has consumed since the day of installation	
4.	Check the status of the two doors (whether they are open or close)	
5.	Navigate to any one of the temperature and humidity dashboards (out of the two) and check if there has been any fluctuation within the day. If there has been a seeming fluctuation, find out around what time the temperature and humidity reached the highest and the maximum recorded temperature and humidity	Medium
6.	Navigate to either one of the door status dashboards and find out how many times the door has been opened today and find out how many times it was open on 28 June 2022	
7.	On 28 June 2022, find out around what period the door was kept open for the longest from 10 in the morning until 7 in the evening	Difficult
8.	Suppose that your dashboard is not working properly, and you want to inquire your HVAC provider. Send an inquiry to your HVAC provider regarding your problem (you can also capture the screen of the page you are having trouble with and upload it while sending the inquiry)	

The actual experiment was conducted with the participants with the intention of detecting problems in the current interface by quantitative and qualitative evaluation. As per the International Organization for standardization (ISO), ISO:9241-11:2018 [21], usability is defined as "the extent to which a system, product or service can be used by specified users to achieve specified goal with effectiveness, efficiency and satisfaction" where, effectiveness refers to accuracy and completeness with which users achieve specified goals, efficiency refers to the resources used in relation to the results achieved (resources include time, human effort etc.), and satisfaction is the extent to which the user experience that results from actual use meets the user's needs and expectations. Hence, the quantitative evaluation in this study is done based on effectiveness, efficiency, and user satisfaction and qualitative evaluation is done by observing the participants while they perform each task. Hence, the quantitative evaluation is done based on effectiveness, efficiency, and user satisfaction and qualitative evaluation will be done by observing the participants while they perform each task.

Effectiveness is measured based on task success rate.

$$\text{Success Rate} = \frac{n}{t} \times 100\% \qquad (1)$$

Where:

n: no. of participants who completed task successfully
t: total no. of participants

The efficiency is measured in terms of time as follows:

$$\text{Time-based-efficiency} = \frac{\sum_{i=1}^{N} \frac{n_{ij}}{t_{ij}}}{N} \qquad (2)$$

Where:
N: no. of tasks
nij: result of task i by user j (1 if completed else 0)
tij: time taken by user j to complete task i

The satisfaction is assessed in two levels which are post-task satisfaction and post-experiment satisfaction. Simple Ease Question (SEQ) is used for the post-task satisfaction which helps to measure the perceived difficulty of the user to complete a specific task which is measured in a 7-point rating scale while System Usability Scale (SUS) by Brooke [22] is used for the post-experiment satisfaction. It consists of 10 questionnaires in total where the odd numbered questionnaires have a positive implication towards the UI while the even numbered questionnaires have a negative implication [23]. For each questionnaire, the participants give a score based on a Likert Scale [24] which ranges from "Strongly Disagree" to "Strongly Agree". The method defined in [22] is used to calculate the SUS score which can be between 0 to 100 (0 representing very poor UX and 100 representing good UX). Fig. 5 represents the post-experiment questionnaire based on SUS designed by Brooke.

Questions	1	2	3	4	5
1. I think I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think I would need the support of a technical person to be able to use the system					
5. I found the various functions in the system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I need to learn a lot of things before I could get going with this system					

1 = Strongly Disagree **4 = Agree**
2 = Disagree, 3 = Neutral **5 = Strongly Agree**

Figure 5 Post-experiment Questionnaire based on SUS

After each task, in addition to the post-task satisfaction questionnaire, follow up questions are also asked to the participants based on the actions they perform to complete each task to gain more insight for qualitative evaluation. Table 3 shows the post-task questionnaires asked to each participant. The experiment is concluded by asking post-experiment questionnaire based on SUS as discussed earlier.

Table 3 Post-task Questionnaire

	Questions
1.	You seem to have spent quite a bit of time on this page. May I know what were you thinking?
2.	How easy or difficult was it for you to navigate to the correct page to perform the specified task?
3.	What do you think of the layout of this page?
4.	Although you completed the specified task, you seemed to have taken quite a long time to find the answer for the given task. Was there any kind of difficulty you faced while performing the task?
5.	You seemed to have clicked on Power Consumption several times while performing the given task. May I know what you were thinking?
6.	What are your thoughts on the tables on the right-hand side of this interface after having given an explanation about what they are for? Do you think the information shown is necessary? Do you still want to be able to hide/minimize the table like you mentioned before?

7.	On this page I saw that you were constantly hovering over the thing circled in orange (). May I know if you were looking for anything?
8.	Is there anything that caused you frustration while performing the specified task?
9.	On a scale of 1 to 7, overall, how would you rate the specified task? (1 being Very Difficult and 7 being Very Easy)

CHAPTER 4
RESULT AND ANALYSIS

4.1 Quantitative Analysis

The quantitative evaluation in this study is done based on Effectiveness, Efficiency, and User Satisfaction as defined by ISO:9241-11:2018.

4.1.1 Effectiveness

Fig. 6 shows the visual representation of success rate for each of the 8 tasks defined and Fig. 7 shows the success rate for each task based on the nationalities. As seen in Fig. 6, participants had the most difficulty and faced challenges for tasks 2, 7 and 8. The success rate for task 2 was only 50% even though it fell under the category of an easy task. Fig. 7 also verifies that participants of various nationalities had difficulties in tasks 7 and 8 where the success rate for all nationalities is below average. Additionally, it can be seen that Chinese faced problems in a lot of tasks compared to other nationalities even though they are more familiar to such system which shows that the current UI is not very user friendly to even the experienced and familiar users. This was caused by a non-standard dashboard design highlighting the lack of user-friendliness.

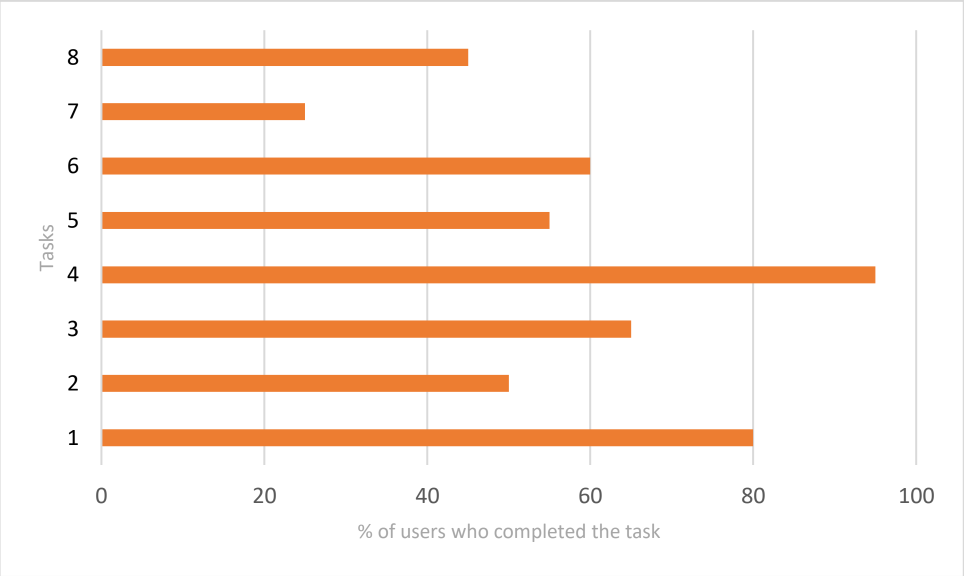

Figure 6 Success Rate

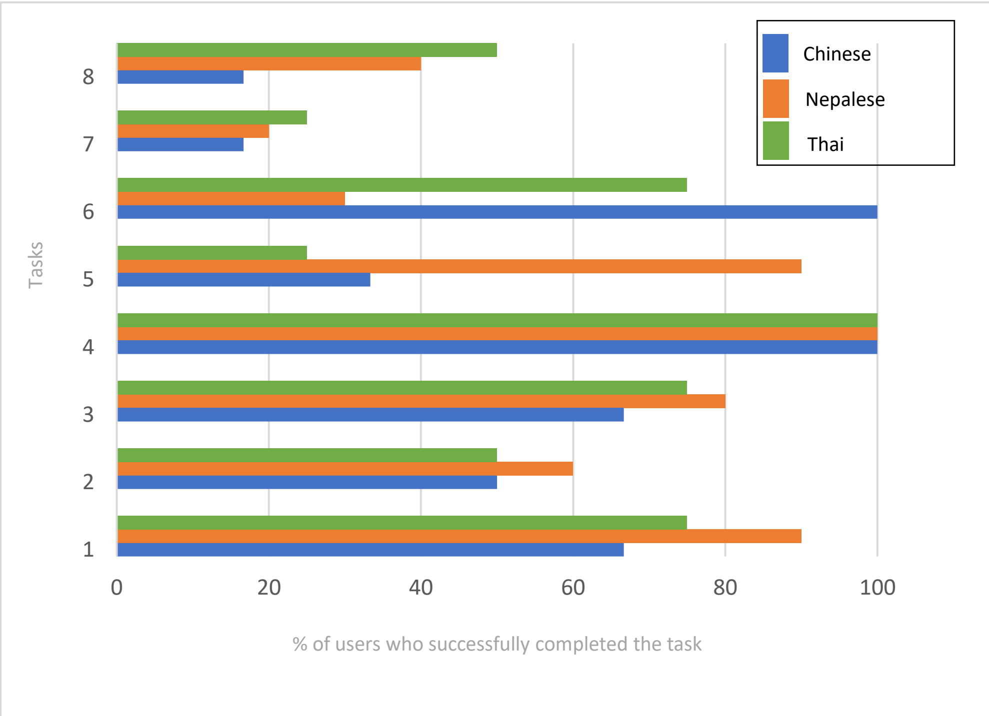

Figure 7 Success Rate grouped by nationality

4.1.2 Efficiency

Efficiency is measured based on time. The maximum time to complete the task was set for tasks of each level as: 1 minute for easy, 3 minutes for medium, and 6 minutes for difficult. If users were unable to finish the task in the specified time, it is deemed to be marked as unsuccessful. Fig. 8, Fig. 9, and Fig. 10 show the average time taken by participants to complete a particular task, average time taken by participants of each nationality to complete a task, and the time-based efficiency achieved in goals/sec for each task respectively. It is clear from Fig. 8, Fig. 9, and Fig. 10 that the participants could smoothly finish task 4 while the average time to finish tasks 2 and 7 exceeds its benchmark times which are 1 minute and 6 minutes respectively, followed by tasks 5 and 6 for which the average time almost exceeded its benchmark time. Fig. 9 shows that the time taken to complete a task by each nationality almost match to each other for all tasks except task 6 where Chinese were relatively able to complete the task a little earlier than the other two nationalities. Furthermore, the time-based efficiency for tasks 2, 5, 7, and 8 is almost nearing 0 as shown in Fig. 9 indicating that users had the most problems in finishing these tasks. The results from this have some correlation with the results from the success rate used to measure effectiveness.

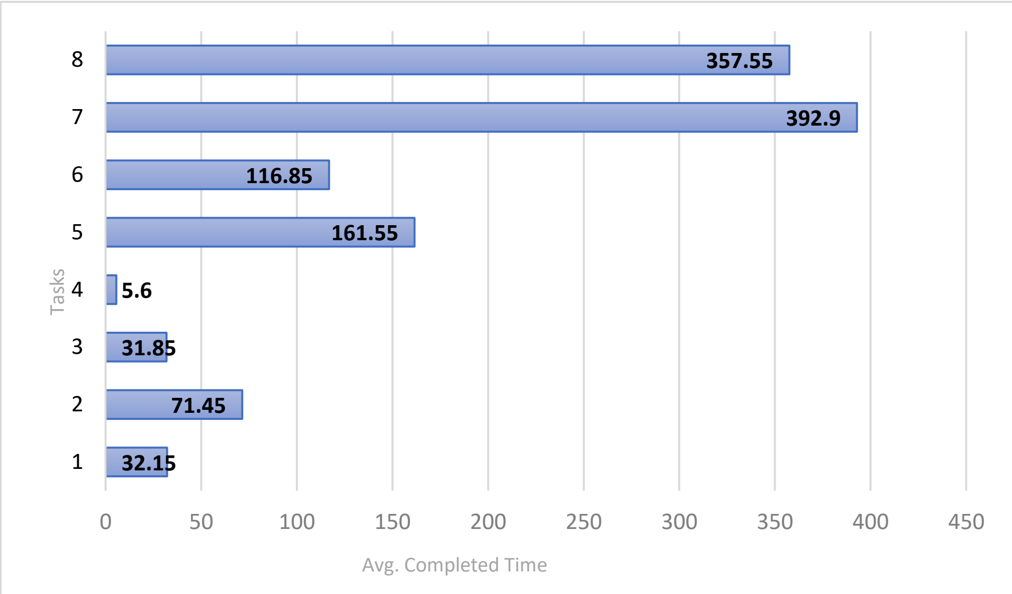

Figure 8 Average time taken to complete the task

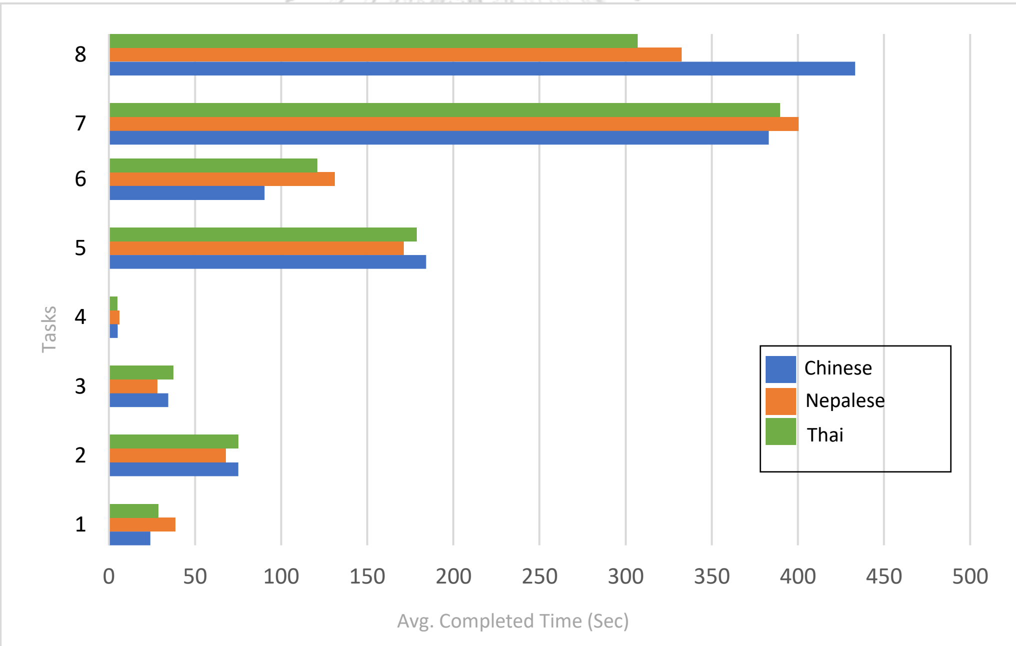

Figure 9 Average time taken to complete task grouped by nationality

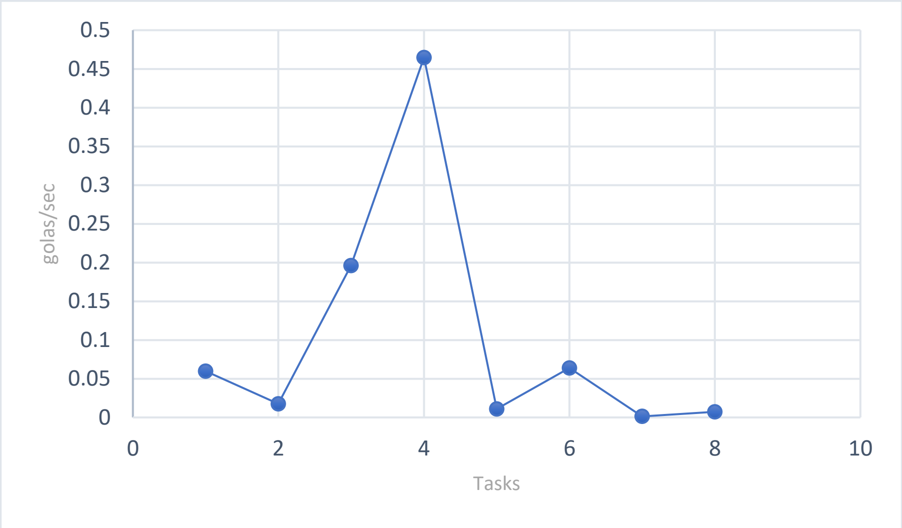

Figure 10 Time-based efficiency

4.1.3 Satisfaction

4.1.3.1 Post-task satisfaction

Single Ease Question (SEQ) is used to evaluate the post-task satisfaction which is a 7-point rating scale with 1 representing "Very Difficult" and 7 representing "Very Easy". Fig. 11 and Fig. 12 show the average SEQ score for each task and the average SEQ score for each task based on nationality respectively. We can see that the users were least satisfied with task 7. Other than tasks 1 and 4, satisfaction levels for the remaining tasks are below 4 as per Fig. 11 which shows that the users were not very happy with the UI. Additionally, as per Fig. 12, the average SEQ scores for each nationality is found to be almost the same for every task which indicates that the satisfaction levels of all three nationalities pretty much match with each other despite the differences in familiarity with using such systems.

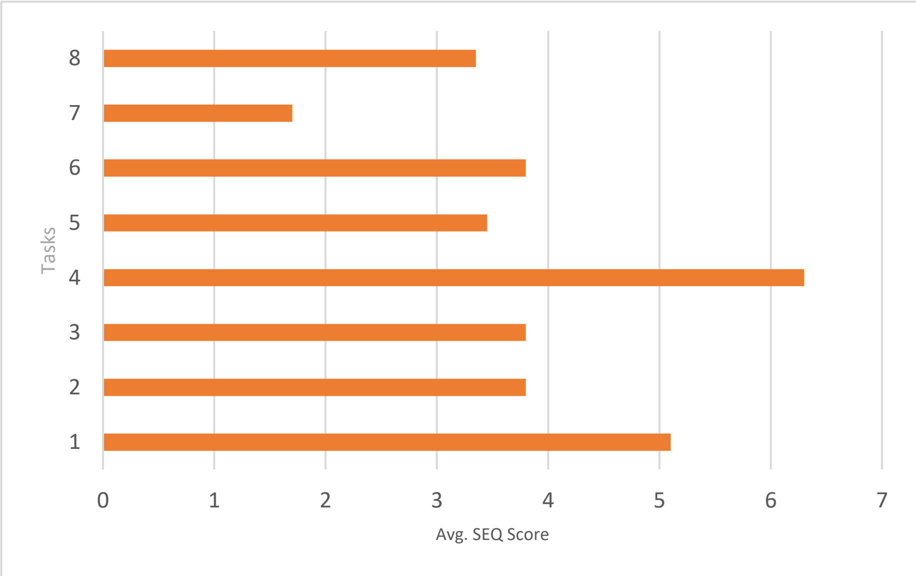

Figure 11 The SEQ Score

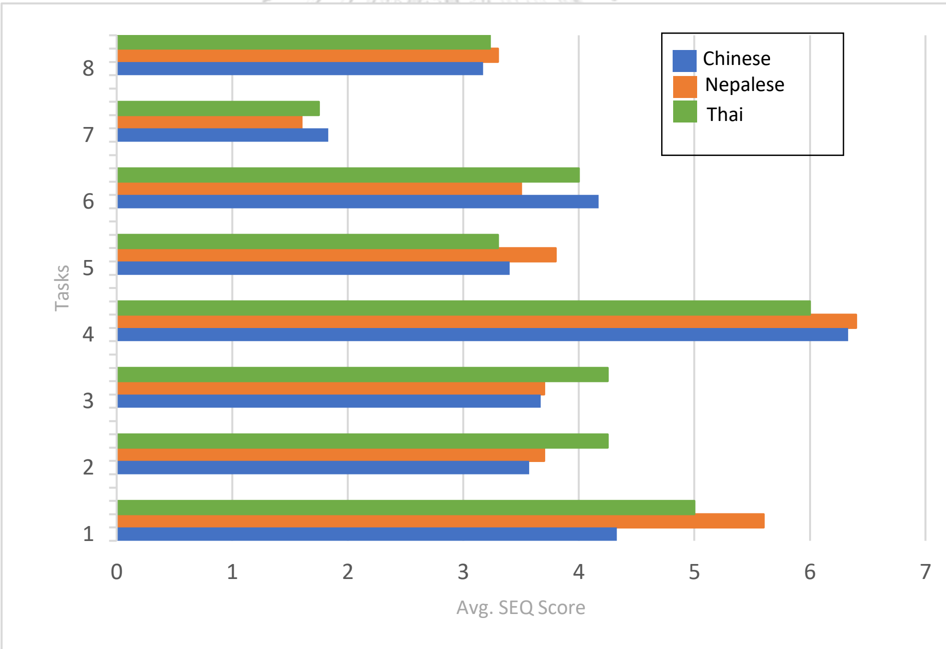

Figure 12 SEQ Score grouped by nationality

4.1.3.2 Post-experiment satisfaction

System Usability Scale (SUS) is used to measure the post-experiment satisfaction. Fig. 13 shows the SUS score of each participant. We can see that the lowest SUS score is 20 which indicates a very poor UI. SUS score that is below 50 is deemed to be unacceptable [23]. The average SUS score among 20 participants is approximately 49 which again indicates poor UI and that there are major issues with the current design.

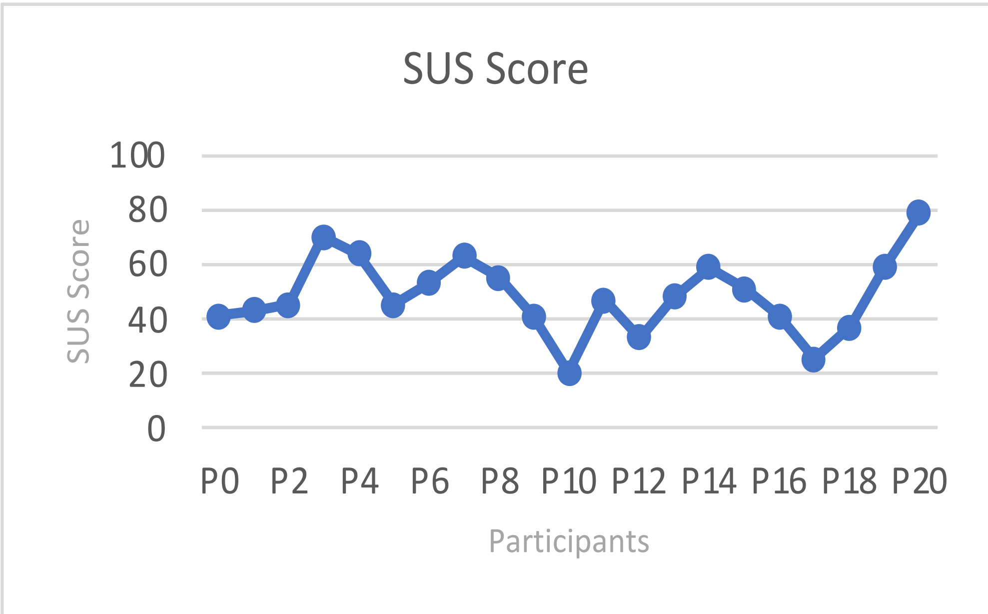

Figure 13 The SUS Score

The quantitative evaluation based on all three categories shows problems in the UI, mostly the UIs related to tasks 2,7, and 8 and task 5 to some extent. Quantitative analysis mostly is only capable of showing whether a system has a problem or not. It is not possible to find out the root cause of the usability problem with only quantitative analysis which is why qualitative analysis is required which is shown in the following section.

4.2 Qualitative Evaluation

Qualitative evaluation in this study is done by asking follow-up questions to the participants based on what they do during the task. The think-aloud approach is heavily used in between performing the task to get as much information from the participants as possible. A lot of insight was gained from the participants with the help of post-task questionnaire. The findings from post-task questionnaire were used to compare it against the ten heuristics designed by Jakob Nielsen for User Interface Design [25] to see if the current UI violates any heuristic and suggest a better design based on it. A few examples of post-task questionnaire are shown in Table 3. The problems encountered by participants is analyzed by dividing into 3 categories based on difficulty level of each task. Tables 4, 5 and 6 provide a summary of problems, causes, violated heuristics, and suggestions/solutions in each level of the task. Elaboration on each problem is provided in dedicated sections for Easy, Medium, and Difficult tasks, offering a more in-depth exploration of the identified challenges.

Table 4 Summary of problems, causes and violated heuristics for Easy-level Tasks

Problems	**Causes**	**Violated Heuristic**	**Suggestions/Solutions**
Confusion among users due to usage of abbreviations such as “Temp and Hum"	Usage of jargon terms and unfamiliar abbreviations.	Match between System and Real World	Avoid the usage of jargon terms as much as possible. If necessary to use jargon/unfamiliar terms, provide tooltips or hover hover-over explanation for the terms ensuring users have clear definition and context within the UI
Diffifulty in understanding meanings of terms shown.	Lack of clear explanations or pop-up text for unfamiliar terms and UI elements.	Help and Documentation	
Users not able to view data in the graph based on a certain date range	Lack of personalized functionalities for the users.	Flexibility and Efficiency of Use	Provide user control and personalization by introducing functionalities that allow users to set and customize data for proper visualization.

Table 5 Summary of problems, causes and violated heuristics for Medium-level Tasks

Problems	**Causes**	**Violated Heuristic**	**Suggestions/Solutions**
Difficulty in navigating to the correct page for finding answers.	The static landing page provided insufficient information or guidance for users, leaving them unsure about their next steps.	Visibility of System Status	Utilize the Overview Report page as the landing page instead of employing a static landing page with no user interactivity.

<table>
<tr><td>Difficulty in understanding the overview report of the dashboard</td><td>Inconsistent placement of headings within the user interface.</td><td>Consistency and Standards</td><td rowspan="2">Group the headings/titles logically and place them consistently to create a visual heirarchy. Standardize the format of titles across the UI by encorporating visual elements such as color-coding or using bold text.</td></tr>
<tr><td>Users mistook a UI element for a button.</td><td>Elements resembling buttons used for titles</td><td>Match between System and Real World</td></tr>
</table>

Table 6 Summary of problems, causes and violated heuristics for Difficult-level Tasks

Problems	**Causes**	**Violated Heuristic**	**Suggestions/Solutions**
Difficulty in understanding the values represented by 0 and 1 in the graph.	Lack of proper graph labeling	Visibility of System Status	Improve the graph interpretability by clearly labeling the axes. Provide a legend or context to explain the significance of the terms used in the graph.
Difficulty in viewing and using the zoom functionality.	The zoom functionality didn't match real-world expectations, leading to increased memory load.	Match between System and Real World	Provide a more intuitive and user-friendly interface matching the real-world scenario for zoom funtionality that minimizes cognitive load that might include using a familiar magnifying glass symbol which is a widely recognized visual cue.
Uncertain about the representations of the dropdowns.	Lack of clear explanations or guidance for dropdown options.	Help and Documentation	Provide tooltips or information icon next to the dropdown that users can hover over for information about each.
No options to cancel actions before sending the final inquiry	Lack of a user-friendly mechanism for users to redo their actions.	User Control and Freedom	Provide user-friendly mechanism to allow users to undo actions before finalizing inquiries giving the users flexibility to backtrack and make adjustments before confirming their actions.

4.2.1 Easy (Tasks 1,2,3,4)

Fig. 14 shows the interfaces related to tasks 1,2,3, and 4 out of which the one on the upper part is the landing page when the users' login to the dashboard. One of the most common problems that participants from all three nationalities found difficult was navigating to the correct page where they can find the answer. Most of them were found to have spent quite a bit of time on the landing page. Participants from all nationalities were found to have this problem but the issue was particularly pronounced among Nepalese participants, who lingered on the static page for an extended duration. Upon asking them about this, they expressed confusion, anticipating an interactive dashboard upon login but encountering a non-responsive page. While Chinese and Thai participants also faced delays on the static page, it was not as prolonged as observed with Nepalese participants. Notably, Chinese participants spontaneously vocalized this concern during the think-aloud approach, underscoring the importance of avoiding static pages. Participants across nationalities expected immediate task resolution upon landing, highlighting the limitation of a static landing page. This also violates the first heuristic of UI Design as defined by Jakob Nielsen which is related to "Visibility of system status". According to this heuristic that the UI should clearly indicate and keep the users informed about what is going on in the interface. But since the landing page itself is a static page, it might make the users not able figure out what action to be taken next. To enhance user experience, a preferable design would involve utilizing the overview report shown on the below part of Fig. 14 as the dynamic landing page.

Another part that caused a problem for some participants during the initial tasks was improper and inconsistent use of titles. The headings in some parts of the UI were in the top whereas some were at the bottom. For example, on the below interface shown on Fig. 14, the title "Classroom 202 Overview" is at the top while the title for "Average Room Temp & Hum" is at the bottom. This also violates the fourth heuristic which is "Consistency and standards". As per this heuristic, UIs should follow the same convention so that it meets users' expectation. Although Task 2 falls under the easy category, participants were found to have problem, again due to inconsistent use of defining titles. Users got confused in this task as "Power Consumption" in Fig. 14 looked more like a button than a title which led them to clicking it multiple times. This behavior was noticed not only in participants of a particular nationality but all of them. The participants were seen hovering and clicking on "Power consumption" at least once. Upon asking them about it, all of them had the same answer saying that they mistook it for a button leading them to click on it. This violates another heuristic which is the second one which is "Match between system and real world". As per this heuristic, interface should be designed in such a way that it follows real-world conventions so that users understand without having to look up somewhere for the definition. A better design would be to simply place the titles on top and standardize the format used for titles across the UI rather than using something that looks like a button.

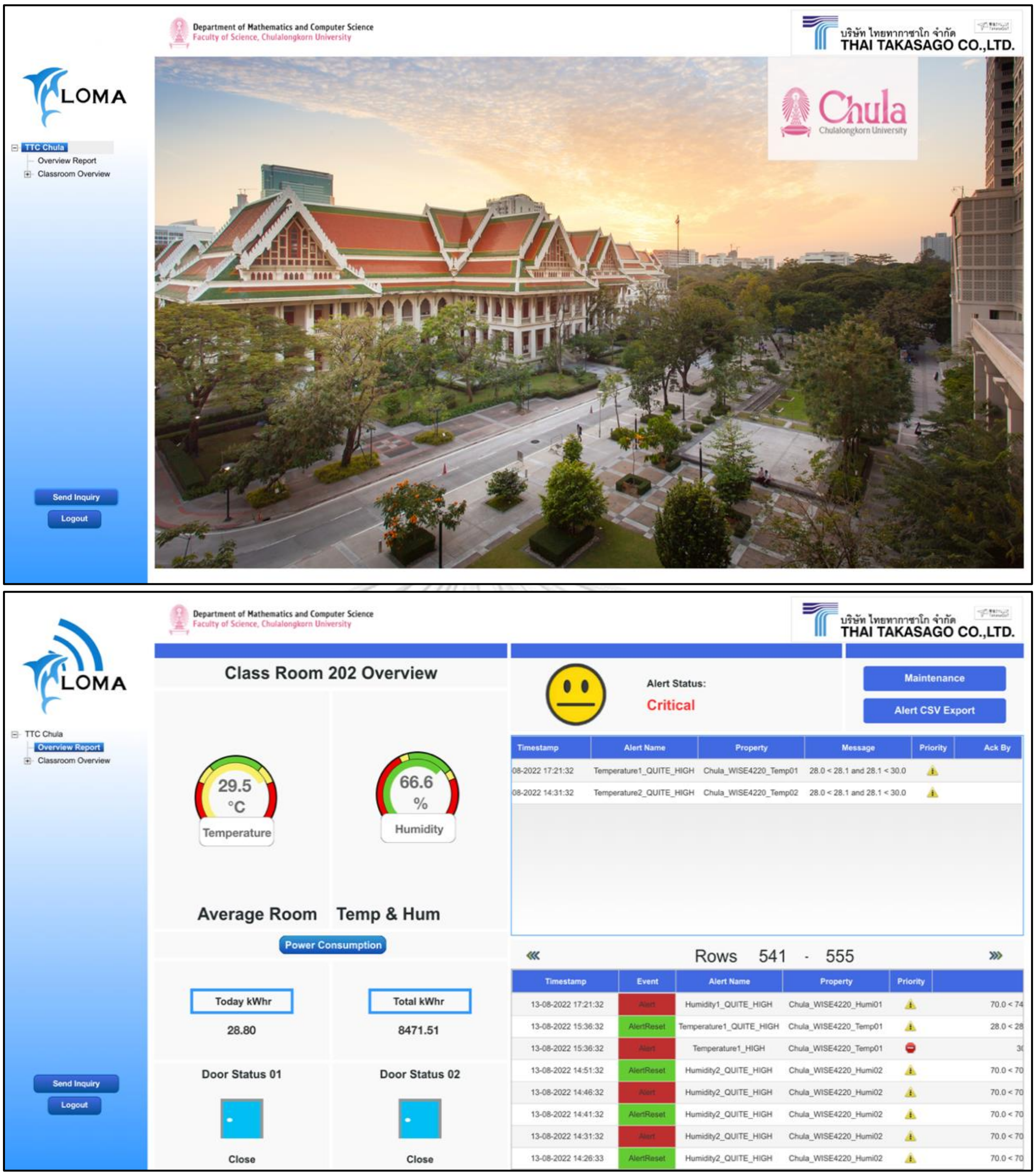

Figure 14 Interfaces related to "easy" level task

4.2.2 Medium (Tasks 5, 6)

Fig. 15 shows the interfaces related to tasks 5 and 6. Although more than 50% of the participants were able to successfully complete tasks 5 and 6, there were some problems identified. One of the problems identified was the usage of abbreviations like “Temp and Hum”. This was a complaint from participants from almost all nationalities. Thai and Nepalese participants were the ones specifically who were not able to understand the meaning of it. Out of the 6 Chinese participants, 5 of them were able to understand the meaning of it but they expressed their dissatisfaction on the usage of abbreviation like that. Additionally, users were also unable to figure out what the "Online" which represented the status of the sensor next to the "Export" button in the second interface in Fig. 15. These violate the second heuristic "Match between system and real world" and the tenth heuristic "Help and documentation". As per the second heuristic, jargon terms should be avoided where "Temp and Hum" used as short form might be a jargon for some users. The tenth heuristic says that whenever required, users should be presented with help but since there are no explanations for what the term "Online" represented, it led to confusion. A better design would be to avoid using short forms until and unless it is something generic that everybody understands and provide a small pop-up text to define what a certain thing stands for. For example, for "Online", when users hover over it, it could show a pop-up text defining it stands for the status of the sensor.

Another problem the participants had with the dashboard was not being able to filter the temperature and humidity graph by date. The dashboard only shows the temperature and humidity for a particular range which was found to be a problem for many users, specifically the Chinese participants. Most of them were found to ask the question "Is there a way I can filter this graph other than just by Min and Max temperature? I was looking to filter by date". This is a feature that maybe not all users need but some might want it. As per the seventh heuristic "Flexibility and efficiency of use", it is a good design to provide personalization by tailoring certain functionalities for individual user so that users can pick whatever suits them.

In task 6, participants took longer to finish the task due to the discrepancy in the count shown when hovered in the chart and the count shown on the left-hand side of the second chart in the 3rd interface of Fig. 15. The users got confused as they were not sure whether door count shown on the interface was the average count for the date range specified or the door count for today which violates the sixth heuristic "Recognition rather than recall" which states that the UI should have enough information required such as field labels for the users to use the design. If it was labelled properly in the UI whether the door count was the average or today door count, it wouldn't have caused confusion for the users. This was one of the tasks where Chinese participants were able to finish the task earlier than the participants from Nepal and Thailand. Participants from Nepal and Thailand struggled in the task due to the discrepancy specified earlier but the Chinese participants were found to not struggle very much in this one as they said that they did not even take a look at the count shown of the left panel and just hovered the graph to find out the answer, while participants from Nepal and Thailand were found to pay more attention to the nitty gritty details since they are relatively newer to using such interfaces causing more confusion among them. So, keeping in mind about all various kinds of users, it is very important to show important information as much as possible rather than neglecting them to increase user experience and make it usable for both familiar and unfamiliar users.

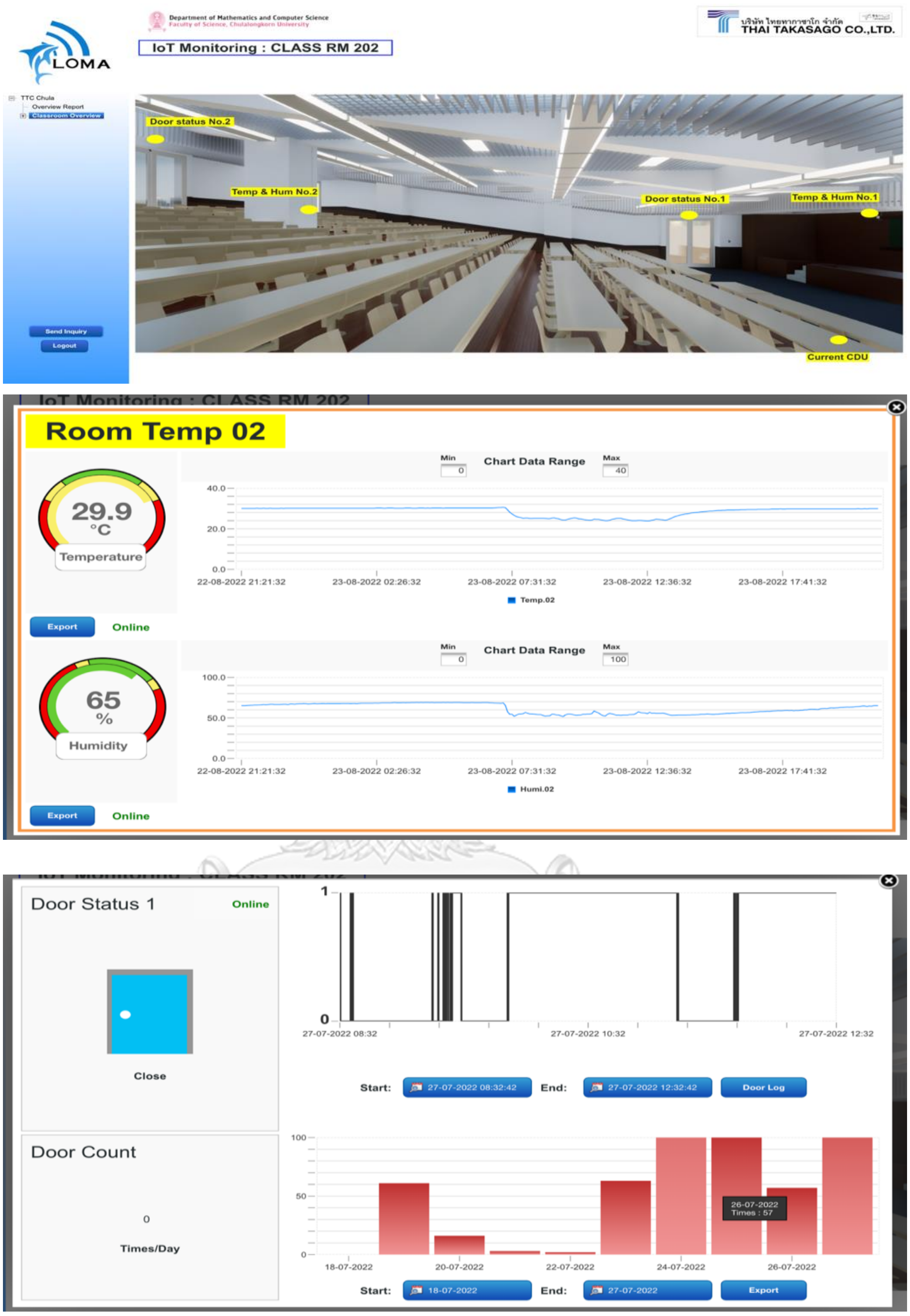

Figure 15 Interfaces related to "medium" level tasks

4.2.3 Difficult (Tasks 7, 8)

Fig. 16 represents the interfaces related to tasks 7 and 8. These were the tasks that users had the most problems with. One of the most common problems faced by almost all users was the lack of graph labeling on y-axis for the upper graph shown on the first interface of Fig. 16. Users were not able to understand what 0 and 1 stood for. None of the participants were able to understand the meaning of these values. This again violates the sixth heuristic. To enhance the UI, the graph should be labelled on both axes and for vague information such as values 0 and 1, a proper index should be provided so that the users are able to understand the meaning of each value represented correctly.

In some cases, the graph showing the door status could be very compact based on the time range selected because of which it might be difficult for the users to view the graph properly. Compactness was not the problem, but the problem was that users did not know that the graph could be zoomed in by selecting a portion of the graph as there was no proper instruction about it. None of the participants knew that the graph could be zoomed in unless told. Users were also not satisfied with the zooming way of the graph which is by selecting a portion of the graph like how a screenshot is taken. This violates three of the heuristics which are the second, sixth, and tenth heuristic where firstly, the zoom functionality does not match the real world secondly, with the current functionality users would have memorize how to zoom in increasing users' memory load and finally, even if the current zoom functionality is to be kept, there is no help or documentation that the users could refer to as a demo for using the functionality. A better design would be to make the functionality to be more like real world cases, maybe indicated by a magnifying glass.

A lot of users also had trouble sending an inquiry as they were unsure about what "Category" and "Incident level" represented even after opening those dropdowns which again violates the tenth heuristic. Most users had a problem while uploading files when sending inquiry. Users were unsure whether to select "Choose File" or "Upload" button. The users who were successfully able to upload a file did not have the option to cancel the uploaded file if any wrong file was uploaded by mistake before sending in the final inquiry. This violates the third heuristic "User control and freedom" which states that users can perform certain actions by mistake because of which UIs should be designed in a way where user actions can be reversed. As per the suggestion from the participants, the UI should be modified in a way such that when a file is uploaded, they should have the option to revert the action. Furthermore, Chinese participants provided additional feedback, suggesting the avoidance of buttons or button names that either sound or appear to serve the same purpose. They recommended using a single button to mitigate potential confusion among all users.

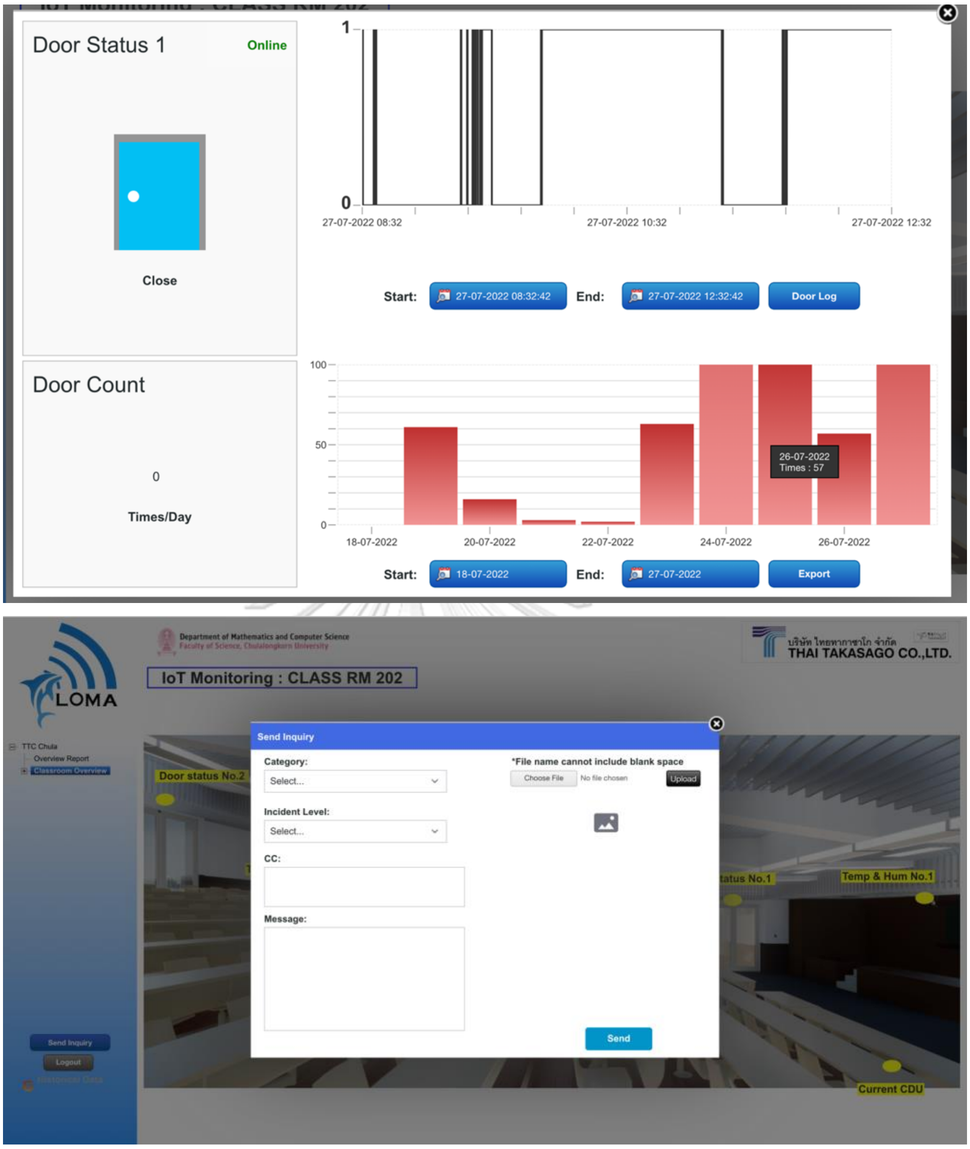

Figure 16 Interfaces related to "difficult" level task

Among the various issues uncovered in the qualitative evaluation, these highlighted problems were prevalent. Despite the greater familiarity of Chinese and Thai participants with smart systems compared to Nepalese individuals, they encountered numerous challenges while completing tasks, primarily attributed to the user interface. One thing noticed when conducting the qualitative evaluation is that similar kind of problems were found among all participants regardless of their experience. Similar problems were detected even on the trial experiment that was conducted for validation. Regardless of the familiarity in using such systems, participants from all nationalities faced similar kind of issues in the interface suggesting that there need to some changes made. Interestingly, Chinese participants, possessing more experience with similar systems, played a significant role in identifying several interface problems during the follow-up questionnaire phase. Their insights not only underscored the existing challenges but also contributed valuable suggestions for enhancing the design of the interface.

Chapter 5

Suggestions/Solutions with Mock-Up Interface

This section aims to offer recommendations by presenting a mocked-up interface addressing issues identified through participant interviews. The primary goal is to propose suggestions that enhance usability and user experience without necessitating a complete revamp of the interface. Notably, modifications designed to improve usability are highlighted in red.

Problems (Refer to 2nd interface in Fig. 14 for old interface):

- Difficulty in understanding the overview report of the dashboard due to inconsistent placement of headings.
- Users UI element referring to a title as a button.

Suggestions/Solutions:

- Group the headings/titles logically and place them consistently to create a visual heirarchy.
- Standardize the format of titles across the UI by encorporating visual elements such as color-coding or using bold text.

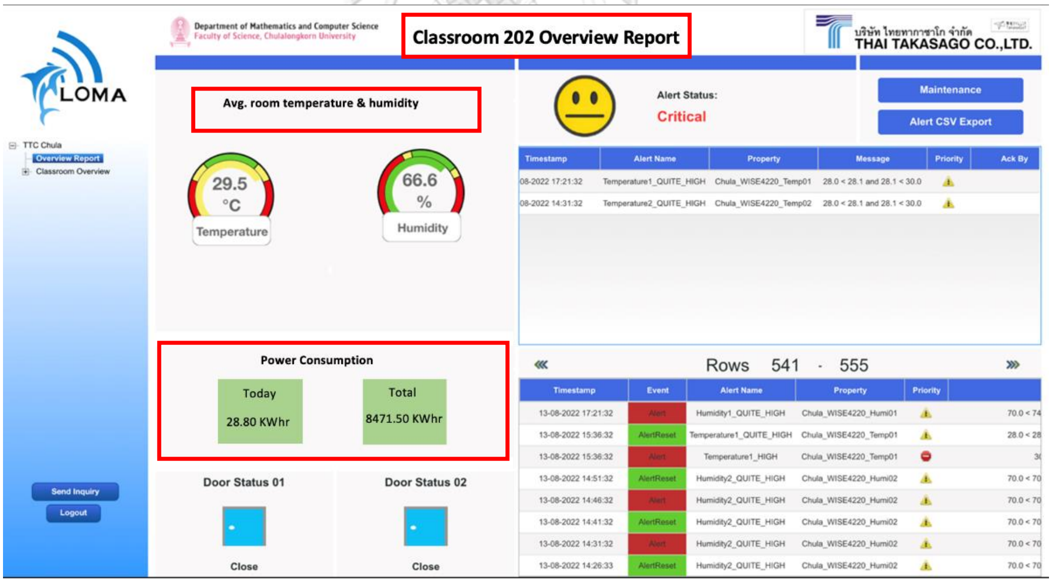

Figure 17 Mock-up Interface 1

The alterations implemented in this mock-up pertain to the placement and styles of titles. Consistency has been achieved by standardizing the font size and style across the page for both main titles and subtitles.

Problems (Refer to 2nd interface in Fig. 15 for old interface):

- Diffifulty in understanding meanings of terms shown.
- Users not able to view data in the graph based on a certain date range.

Suggestions/Solutions:

- If necessary to use jargon/unfamiliar terms, provide tooltips or hover hover-over explanation for the terms ensuring users have clear definition and context within the UI.
- Provide user control and personalization by introducing funtionalities that allow users to set and customize data for proper visualization.

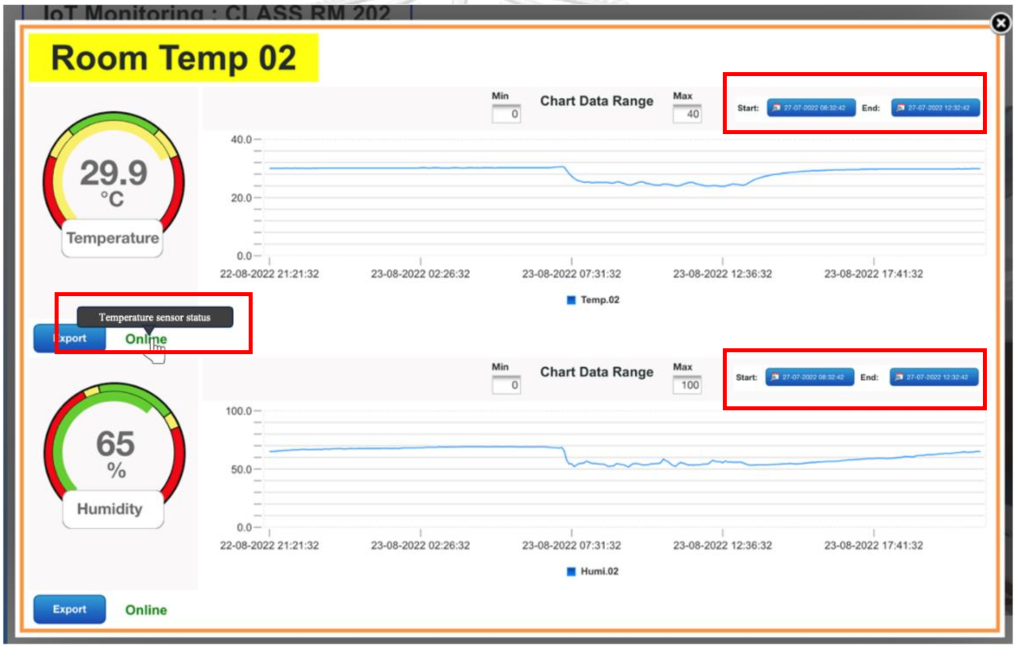

Figure 18 Mock-up Interface 2

In the provided mock-up interface, tooltip has been added when users hover over term “Online” showing that it stands for the status of the sensor. Additionally, filter option by date has been added providing more flexibility to the users.

Problems:

- Difficulty in understanding the values represented by 0 and 1 in the graph.

- Difficulty in viewing and using the zoom functionality.

Suggestions/Solutions:

- Improve the graph interpretability by clearly labeling the axes.
- Provide a legend or context to explain the significance of the terms used in the graph.

- Provide a more intuitive and user-friendly interface matching the real world scenario for zoom funtionality that minimizes cognitive load that might include using a familiar magnifying glass symbol which is a widely recognized visual cue.

Figure 19 Mock-up Interface 3

In the provided mock-up interface, a legend has been provided explaining what 0 and 1 means in the graph and to adhere to the match between real world and system, a magnifying glass symbol with "+" and "-" have been added to represent the zoom functionalities.

Problems (Refer to 2nd interface in Fig. 16 for the old interface):

- Uncertain about the representations of the dropdowns.
- No options to cancel actions before sending the final inquiry.

Suggestions/Solutions:

- Provide tooltips or information icon next to the dropdown that users can hover over for information about each.
- Provide user-friendly mechanism to allow users to undo actions before finalizing inquiries giving the users flexibility to backtrack and make adjustments before confirming their actions.

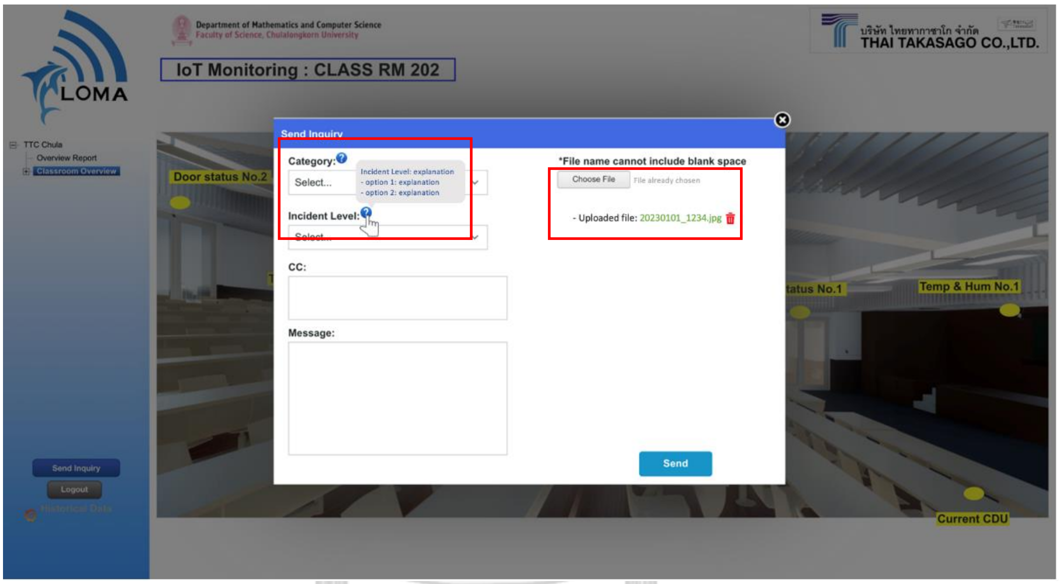

Figure 20 Mock-up Interface 4

In the provided mock-up interface, an information icon has been provided next to the dropdowns which when hovered shows information about the dropdown and the options available to avoid user confusion. Additionally, to allow users to revert their action, a delete icon has been added so that users are free to delete the uploaded file and re-upload before their final action. Moreover, based on feedback from Chinese participants, it was recommended to avoid having two distinct buttons that might appear to perform the same action. Consequently, the "Upload" button has been eliminated, leaving only the option "Choose File" for file uploads.

CHAPTER 6
CONCLUSION

In conclusion, this study conducted a usability evaluation of a smart HVAC dashboard interface, aiming to identify usability problems and assess the user experience through quantitative and qualitative analysis. The quantitative evaluation focused on effectiveness, efficiency, and user satisfaction. The results indicated that participants faced challenges and had the most difficulty with tasks 2, 7, and 8, suggesting usability issues with the interface. The efficiency analysis revealed that participants took longer than the benchmark times for tasks 2, 5, 7, and 8, indicating usability problems. Furthermore, both the post-task satisfaction and post-experiment satisfaction scores indicated low user satisfaction with the current interface design. These findings highlight the need for improvements in the usability of the smart HVAC dashboard.

The qualitative evaluation, including participant feedback and comparison against UI design heuristics, provided further insights into usability issues. The identified problems revolved around system status visibility, consistency, real-world match, and the lack of helpful information. Based on the findings, several recommendations for improving the interface were suggested, such as enhancing the landing page, using consistent titles, avoiding jargon, providing explanatory tooltips, and implementing better data filtering options. These improvements aim to enhance user experience, improve task efficiency, and address the usability challenges observed in the study. The findings from the qualitative evaluation emphasized the importance of addressing these issues to enhance the usability of the smart HVAC dashboard.

The results of this usability evaluation emphasize the importance of considering users' diverse backgrounds and technical expertise when designing smart HVAC dashboards. The study included participants from Nepal, China, and Thailand, representing different levels of familiarity with smart systems. Surprisingly, even participants from technologically advanced backgrounds faced usability difficulties, indicating that the current interface design fell short in terms of userfriendliness and intuitiveness. To ensure broader adoption and ease of use, it is crucial to develop interfaces that cater to both familiar and unfamiliar users, providing clear instructions and minimizing the learning curve.

In summary, this study identified several usability problems in the smart HVAC dashboard interface. The quantitative analysis revealed challenges in effectiveness, efficiency, and user satisfaction, while the qualitative evaluation provided deeper insights into the specific issues faced by users. Based on these findings, it is evident that improvements are necessary to enhance the usability of the interface. Addressing issues such as navigation, consistency, clarity of titles, and providing adequate explanations and help documentation can contribute to a more user-friendly smart HVAC dashboard. As the number of smart homes and smart HVAC systems continues to grow, ensuring a seamless user experience becomes increasingly vital. Future research should focus on implementing the suggested improvements and conducting further usability tests to validate the effectiveness of interface modifications. Ultimately, by prioritizing usability, smart HVAC systems can achieve their energy efficiency goals while providing users with enhanced control and comfort in their indoor environments.

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PUBLICATION	Rubina S., and Nagul C., "Cross Cultural Usability Evaluation Of IoT Based Smart HVAC Dashboard", The 7th International Conference on Information Technology (InCIT2023), Pp. 299-304, 2023