Faculty of Engineering

SMART AIR-CONDITIONER CONTROLLER FOR EFFECTIVE ENERGY AND COST MANAGEMENT

‘Aini ‘Afiyah Binti Gas @ Mohammad Hafiz

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

UNIVERSITI MALAYSIA SARAWAK

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SMART AIR-CONDITIONER CONTROLLER FOR EFFECTIVE ENERGY AND COST MANAGEMENT

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A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
Electrical and Electronics Engineering with Honours

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DEDICATION

I dedicate this dissertation wholeheartedly to my parents, who have provided me with necessary means to learn and continuously supported me in my pursuit of excellence.

I would like to thank my siblings, friends, classmates, mentors, and lecturers who were always there to provide advice, encouragement, and support during the difficult times this project was being completed.

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ABSTRACT

The utilization of Air-Conditioners (Air-Conds) nowadays has increased significantly ever since the Movement Control Order (MCO) has been issued. This is mainly because most people are working from home. The increase in the number of Air-Cond usage especially without proper energy management among dwellers increases electricity demand in residential areas. However, most Air-Cond owners are ignorant of how much energy is consumed by their Air-Cond which leads to an increase in the utility bill. Thus, this project is conducted to design a smart Air-Cond system to resolve this issue, as well as to investigate the effectiveness of a Smart Air-Cond system in decreasing the energy usage of Air-Cond and the electric costs. "The Smart Air-Conditioner Controller for Effective Energy and Cost Management" is a system that comprises of Smart Air-Cond Socket and Smart Air-Cond Controller. The Smart Air-Cond Socket is used to check and monitor energy consumption. Meanwhile, the Smart Air-Cond Controller can be further divided into the "ON and OFF" Controller and the Temperature Regulator Controller. The "ON and OFF" Controller is used to remotely switching ON and OFF the Air-Cond, meanwhile, the Temperature Regulator Controller is used to regulate the room temperature according to Malaysian thermal comfort standards which are 24°C - 26°C with 26°C as the optimum temperature. The energy consumption is then used to calculate the electricity bill based on the Sarawak Energy Berhad's tariff. In this study, two experiments were conducted, with the presence of a Smart Air-Cond Controller as the manipulated variable. Then, the data from the experiments are compared. From the experiments, it is shown that the temperature of the Air-Cond without the Smart Controller will stay constant, and the room temperature kept on falling until it stays below the thermal comfort standard. Meanwhile, the temperature of the Air-Cond with the Smart Controller will change according to the room ambient temperature. These temperature changes kept the surrounding temperature within the thermal comfort standard. Another valuable finding from this project is that the Smart Air-Cond Controller can reduce the average energy consumption and average electricity bills by 0.1% and RM 0.11 respectively.

ABSTRAK

Penggunaan Alat Penghawa Dingin (penyaman udara) pada masa kini telah meningkat dengan ketara sejak Perintah Kawalan Pergerakan (PKP) dikeluarkan. Ini terutamanya kerana kebanyakan orang bekerja dari rumah. Peningkatan bilangan penggunaan penyaman udara terutamanya tanpa pengurusan tenaga yang betul dalam kalangan penghuni meningkatkan permintaan elektrik di kawasan kediaman. Walau bagaimanapun, kebanyakan pemilik penyaman udara tidak mengetahui berapa banyak tenaga yang digunakan oleh penyaman udara mereka yang membawa kepada peningkatan dalam bil utiliti. Oleh itu, projek ini dijalankan untuk mereka bentuk sistem penyaman udara pintar untuk menyelesaikan isu-isu ini, serta untuk menyiasat keberkesanan sistem penyaman udara Pintar dalam mengurangkan penggunaan tenaga penyaman udara dan kos elektrik. "Pengawal Penghawa Dingin Pintar untuk Pengurusan Tenaga dan Kos Berkesan" ialah sistem yang terdiri daripada Soket Penghawa Dingin Pintar dan Pengawal Penghawa Dingin Pintar. Soket penyaman udara Pintar digunakan untuk menyemak dan memantau penggunaan tenaga. Sementara itu, Pengawal penyaman udara Pintar boleh dibahagikan lagi kepada ON dan OFF Pengawal dan Pengawal Pengatur Suhu. Pengawal ON dan OFF digunakan untuk menghidupkan dan mematikan penyaman udara dari jauh, sementara itu, Pengawal Pengatur Suhu digunakan untuk mengawal suhu bilik mengikut piawaian keselesaan terma Malaysia iaitu 24°C - 26°C dengan 26° C sebagai suhu optimum. Penggunaan tenaga kemudiannya digunakan untuk mengira bil elektrik berdasarkan tarif SEB. Dalam kajian ini, dua eksperimen dijalankan, dengan kehadiran Pengawal penyaman udara Pintar sebagai pembolehubah dimanipulasi. Kemudian, data daripada eksperimen dibandingkan. Daripada eksperimen, ia menunjukkan bahawa suhu Penyaman Udara tanpa Pengawal Pintar akan kekal malar, dan suhu bilik terus menurun sehingga ia kekal di bawah standard keselesaan terma. Sementara itu, suhu penyaman udara dengan Pengawal Pintar akan berubah mengikut suhu persekitaran bilik. Perubahan suhu ini mengekalkan suhu sekeliling dalam standard keselesaan terma. Akhir sekali, kajian ini, menunjukkan bahawa menggunakan Pengawal penyaman udara Pintar boleh mengurangkan purata penggunaan tenaga dan purata bil elektrik masing-masing sebanyak 0.1% dan RM 0.11.

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CO_2	-	Carbon Dioxide
CH_4	-	Methane
N_2O	-	Nitrogen Oxide
O_3	-	Ozone
ASEAN	-	Association of Southeast Asian Nations
Air-Cond	-	Air-Conditioner
COVID-19	-	Coronavirus disease 2019
WFH	-	Work-From-Home
FWAs	-	Flexible Work Arrangements
IR 4.0	-	Fourth Industrial Revolution
IoT	-	Internet of Things
SEB	-	Sarawak Energy Berhad
IR	-	Infrared
Blynk App	-	Blynk Application
TNB	-	Tenaga Nasional Berhad
SESB	-	Sabah Electricity Sdn. Bhd.
HVAC	-	Heating, Ventilation, and Air-Conditioning
WHO	-	World Health Organization
MCO	-	Movement Control Order
WFO	-	Work From Office
MILP	-	Mixed-Integer Linear Programming
PV	-	Photovoltaic
RF	-	Radio Frequency

SSR	-	Solid State Relay
Arduino IDE	-	Arduino Integrated Development Environment
PCB	-	Printed Circuit Board
Smart Life App	-	Smart Life Application

CHAPTER 1

INTRODUCTION

1.1 Background

Approximately 152 out of the 195 nations that have ever existed today are undergoing development [1]. Although undergoing development brings a lot of benefits, these countries suffer high energy consumption as its side effects. The rise of a nation like Malaysia will inevitably lead to high energy consumption because it will stimulate economic growth [2]. According to Figure 1.1, there is a projected increase of 32.7 million people in this nation's population from 32.6 million in 2020, which resulted in an increased demand for power in residential areas of the country [3]. In addition, this country's urban population increased from 71.61% in 2011 to 77.70% in 2021, as shown in Figure 1.2. Malaysia's population in 2023 is estimated at 33.4 million, an increase of 2.1% from 32.7 million in 2022. Citizens' population increased from 30.2 million in 2022 to 30.4 million in 2023, a marginal increase of 0.7% (2022: 0.6%) [4].

Year	Number ('000)			Annual Population Growth Rate (%)		
	Total	Citizens	Non Citizens	Total	Citizens	Non Citizens
2010	28,588.6	26,264.1	2,324.5	1.8	1.6	4.0
2011	29,062.0	26,616.9	2,445.1	1.6	1.3	5.1
2012	29,510.0	26,961.7	2,548.3	1.5	1.3	4.1
2013	30,213.7	27,325.6	2,888.0	2.4	1.3	12.5
2014	30,708.5	27,696.2	3,012.3	1.6	1.3	4.2
2015	31,186.1	28,060.0	3,126.1	1.5	1.3	3.0
2016	31,633.5	28,403.5	3,230.0	1.4	1.2	3.3
2017	32,022.6	28,735.1	3,287.5	1.2	1.2	1.8
2018	32,382.3	29,059.6	3,322.7	1.1	1.1	1.1
2019	32,523.0	29,382.7	3,140.4	0.4	1.1	(5.6)
2020	32,584.0	29,677.4	2,906.6	0.2	1.0	(7.7)
2021[e]	32,655.4	29,962.3	2,693.1	0.2	1.0	(7.6)

[e] Estimates

Figure 1.1: Population and annual population growth rate, Malaysia, 2010-2021 [3]

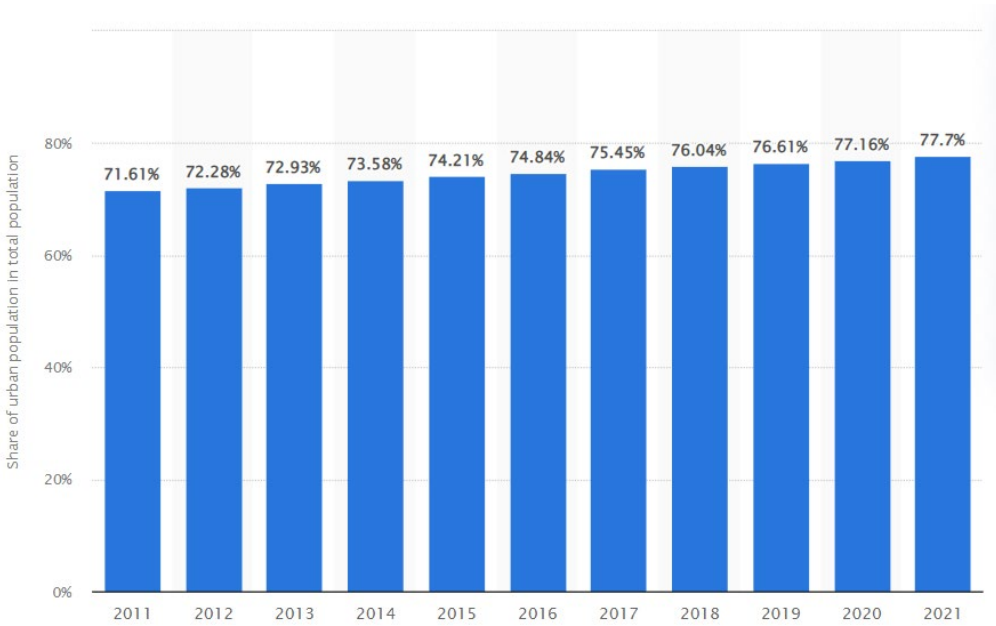

Figure 1.2: Urbanization in Malaysia from 2011 to 2021 [4]

Malaysia has an abundance of oil resources, but coal remains as Malaysia's primary source of energy generation, accounting for 51.25 % of consumption, followed by natural gas (49.24 %) and hydro (3.11 %) [5]. The constant need for electricity for industrial and economic purposes in this country leads to global warming which is caused by the emission of greenhouse gases such as methane (CH_4), nitrogen oxide (N_2O), and ozone (O_3) during the production of electricity. The combustion of fossil fuels produces carbon dioxide (CO_2) when thermal energy is converted into mechanical motion that has produce electricity [6]. As electricity demand rises, greenhouse gas emissions increase. According to recent reports [7], Malaysia is the fourth largest emitter of greenhouse gases in the Association of Southeast Asian Nations (ASEAN), contributing 0.52% of global carbon emissions.

As a result, countries that use fossil fuels as the source of electricity generation like Malaysia face heat-related issues. Following this, there has been a significant increase in the development of electrically powered cooling appliances designed to reduce heat build-up within buildings such as homes and businesses. The most common and widely used cooling devices are Air-Conds and fans. Air-Conds increase the occupancy rate of building spaces, resulting in a significant increase in energy usage [8]. Even though in 2021, the world has entered the endemic phase of Coronavirus disease 2019 (COVID-19) since the pandemic in 2020, the practice of working from home has continued in some companies, especially when facing certain situations such as COVID-19 outbreaks in the office or conducting online meetings instead of face-to-face meetings. In order to prevent the development of COVID-19 in the workplace, this practice is maintained to ensure the convenience and practicability of work in certain economic sectors and activities [9]. The frequent use of Air-Cond at home due to Work-From-Home (WFH) and Flexible Work Arrangements (FWAs) practices substantially increases domestic electricity consumption as many individuals rely on Air-Cond for a more comfortable and high-quality lifestyle [10].

Majority of households (particularly in equatorial nations) prefer Air-Cond for achieving thermal comfort, as evidenced by the fact that people employ it to create a more conducive environment for working or studying. However, most residents are inefficient with their Air-Cond usage, resulting in a substantial increase in their electricity bill. The practice of continually turning the appliances on and off in a conventional manner wastes energy due to uncontrolled use of Air-Cond. This consumes much energy, emphasising the need to manage electrical energy usage [11].

Today, due to the emergence of the Fourth Industrial Revolution (IR 4.0), it is usual for many people to use Internet of Things (IoT) devices including smartphones, computers, medical devices, and Tesla vehicles. Air-Conds are not exempted from this trend, as a wide range of Smart Air-Conds has been developed that enable customers to control the device settings from their mobile devices [12]. Although there are numerous smart system devices available that claimed to provide great reliability and assistance to buyers, the question is whether a smart system will be able to reduce a household's energy consumption and if it is necessary to switch to a Smart Air-Cond to improve energy efficiency [13].

Therefore, this project was designed to investigate a Smart Air-Cond System's performance in terms of energy management and the system's ability to reduce electricity expenditures. This project also intended to enable Air-Cond users to transform their existing Air-Cond into smart IoT Air-Cond to maintain the ambient room temperature without affecting their thermal comfort. It allowed users to automate the Air-Cond's on/off switching and maintain room temperatures between 24°C to 26°C, which is the thermal comfort range for Malaysians [14]. This feature allowed customers to monitor and manage their Air-Cond's energy consumption using smartphone applications. The electricity bills were computed using Sarawak Energy Berhad (SEB) tariff based on the measured amount of consumed energy.

The critical components for this system are Air-Cond, ESP32 Development Kit V1, Arduino UNO and Arduino Mega as the microcontrollers, DHT22 temperature sensor, and an I^2C LCD. The essential operation of this project was to develop a smart system that detects the room temperature via the DHT22 sensor and send an instruction to the Air-Cond unit via Infrared (IR) sensor to maintain the room temperature according to the temperature set by the user based on the Malaysian's thermal comfort.

1.2 Problem Statements

Thermal comfort can significantly impact a person's ability to work or study efficiently. Along with the continuation of WFH practice during this endemic and the new implementation of FWAs starting on September 1, 2022, workers tend to use Air-Conds more frequently to cope with the excessive heat from the surroundings due to environmental changes. An Air-Cond is a mechanical cooling device designed to draw heat energy from a room and exhaust it to the outside. However, there are several disadvantages of conventional Air-Cond usage. In addition to being ineffective in maintaining a comfortable indoor ambience, excessive air conditioning can also harm human health [14].

It is challenging to create a comfortable environment without appropriate Air-Cond management. For instance, if the room temperature is too low, a person's performance may suffer, especially when a person stays in the room for hours [15]. In addition, the conventional loading system requires a manual switching mechanism that necessitates human involvement, time waste, and power losses owing to switching and unnecessary load activation.

In addition, younger generation spends more time completing daily tasks on their smartphones. With a smart system that can be used to control household electrical appliances remotely, the homeowner can set up a schedule for the Air-Cond to run to cool their room before they arrive home, thereby saving a significant amount of time and preventing them from driving their system to its maximum capacity. The Air-Cond unit can also easily remotely be turned off, for instance, if the owner forgets to turn off the unit without being physically present [14].

Nowadays, most technological advances including IoT-based systems can be controlled via the Internet, a smartphone, or other networked devices. Home owners may now apply the convenient "Smart Home" concept since any device can be connected to a Wi-Fi network, allowing them to remotely control services such as lighting intensity, temperature, and humidity [17]. In addition to providing a safe and easy system design, smart home systems are touted to preserve energy by allowing users to control the operation of all electric equipment, including Air-Cond. The intelligent system provides automated switching features to devices, allowing them to work autonomously. Despite this, there have been no substantial studies relating to the power consumption efficiency of smart systems, especially in the field of Smart Air-Cond, including their economic feasibility.

As a result, a prototype of The Smart Air-Conditioner Controller for Effective Energy and Cost Management was developed to gather this evidence and analyse its implications. This device was used to automate the Air-Cond's switching ON and OFF function and regulate the room temperature according to Malaysian thermal comfort standards of 24°C - 26°C with 26°C as the optimum temperature. It also monitors Room temperature, Air-Cond temperature, energy consumption and calculated electric bills.

1.3 Objectives

The following were the main objectives of the project:

a) To develop a smart control and monitoring system for non-inverter Air-Cond to ease energy management and reduce utility costs.

   The remote control is used to manually control the home's installed conventional non-inverter Air-Cond system. In order to ease energy management and reduce electricity costs, the users' existing Air-Cond is fitted with the Smart Air-Cond System using IoT. This system enabled the users to remotely switch on and off the Air-Cond and regulate the temperature following Malaysian's standard thermal comfort range. The smart system was also portable and simple to operate.

b) To evaluate the implications of a smart system for Non-inverter Air-Cond in terms of energy and cost management.

This project was conducted to determine whether the application of a smart system can help to reduce energy consumption and electricity cost in a household. In order to achieve this objective, the user's existing Air-Cond was fitted with the Smart Air-Cond System. This system utilized the Arduino UNO microcontroller and Blynk Application (Blynk App) as a medium to control the activation of the Air-Cond with the help of the DHT22 (temperature) sensor and IR Sensor. This helped to prevent users from constantly switching on the Air-Cond at full blast for a short period to cool down the room.

c) To design an automated non-inverter Air-Cond system that will respond to the set temperature condition.

The non-inverter Air-Cond system that was fitted with the Smart Air-Cond Controller has a feature that could automate the switching on and off of the Air-Cond through a smartphone. Aside from that, to achieve the above objective, which was to measure and manage the energy consumption and electricity bill effectively, the existence of the Smart Air-Cond Controller was crucial in this project. It was used to regulate the room temperature between 24°C - 26°C, which was used as a mechanism to reduce the potential energy wastage to avoid an inefficient utilization of the Air-Cond.

1.4 Scope of Study

As Malaysia is close to the equator and has hot and humid weather throughout the year, inhabitants typically rely on Air-Cond for thermal comfort. A study conducted in [16] stated that the range of thermal comfort for Malaysian is between 24°C-26°C with an optimal temperature of 26°C, which is considered slightly cool and neutral. However, using the Air-Cond incorrectly could lead to excessive energy consumption and expensive utility costs.

In order to solve the problem, this project is developed to create a Smart Air-Cond System for existing non-inverter Air-Cond that allows users to control the machine using mobile devices remotely. This project covers one 156 square feet room area and applies explicitly to 1 horsepower non-inverter Air-Cond. The Smart Air-Cond System is divided into two parts which are the Smart Air-Cond Socket and Smart Air-Cond Controller.

Smart Air-Cond Socket is connected to the Air-Cond to measure and monitor the energy consumption. The electrical energy consumption that had been collected will then be used to calculate the cost of electricity.

Meanwhile, the main functions of the Smart-Air Cond Controller are to control the Air-Conds' on/off switching by using the ON and OFF Controller and maintain 24°C - 26°C temperatures in the room based on the thermal comfort of the users by using the Temperature Regulator Controller. This device will be developed as this Smart Air-Cond Controller aims to reduce the Air-Cond's energy consumption and electricity bill.

The process of developing this project can be divided into two stages; i) simulation and ii) testing and verification. The first stage, is an initial phase of the project where the initial schematic and breadboard designs of the system will be created using the Fritzing Software. This design acts as a reference to connect the components when doing the hardware part. By referring to the schematic and breadboard designs, the construction of the hardware will be conducted. Then, the process of developing the software using Arduino IDE concludes the first stage, the simulation phase.

After that, the second stage starts with testing the simulation system. If the simulation system is successful, the smart system will be directly tested on the Air-Cond. The data from the system will then be collected in Blynk App. The data will then be verified to ensure the project's objectives are achieved. The troubleshooting process will be conducted if the data is inaccurate until the desired result is achieved.

As one of the project's objectives is to evaluate the implication of the smart system for non-inverter Air-Cond in terms of energy and cost management, two experiments will be conducted, and the results will then be analysed to show the effectiveness of the Smart Air-Cond System. In these experiments, the constant variable is the presence of the Smart Air-Cond Socket, which is necessary to obtain electrical energy consumption and the electricity bill. A commercial made Smart Socket was used in this project. In the meantime, the manipulated variable is the presence of the Smart Air-Cond Controller. This smart controller will be developed in line with this project's name, Smart Air-Conditioner Controller for Effective Energy and Cost Management. It is expected that