UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMIZATION OF AIR-COOLING STRATEGIES FOR AN ELECTRIC FORMULA VARSITY BATTERY PACK

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ARMAN KUSHAIRY BIN ASWANDI

A thesis submitted
in fulfillment of the requirements for the degree of
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DEDICATION

This paper consist of the research of Optimization of air-cooling strategies for an electric formula varsity battery pack is sincerely dedicated to the unwavering support and guidance of my family, whose love and encouragement have been my constant motivation throughout this journey. Your belief in me has given me the strength to overcome challenges and reach this milestone.

To my esteemed supervisor, Ts. Dr. Nur Rashid Bin Mat Nuri @ Md Din, thank you for your invaluable mentorship and expertise. Your patience, constructive feedback, and commitment to my academic growth have shaped my research and enriched my understanding.

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This thesis is dedicated to all those who have played a part in my academic journey, and it is with immense gratitude that I acknowledge their contributions."

ABSTRACT

This project report delves into the fascinating world of electric vehicles technology, focusing specifically on the optimization of air-cooling strategies for an electric Formula Varsity battery pack. The main objective of this research is to thoroughly investigate and optimize various strategies for air-cooling to be applied for the Formula Varsity battery pack, with the aim of enhancing its thermal management system. This project involves designing an air-cooling system for the electric Formula Varsity battery pack. The incorporation of external airflow is designed to enhance the heat transfer through the air, expediting the cooling process. In this project, Arduino acting as both circuit controller and temperature monitor for the battery pack to serve as a temperature monitoring system, utilizing a sensor to measure ambient temperature. The final product that has been fabricated consists of an axial fan, air ducting and a steel plate to replace the current ai cooling strategies system. Steel plate was cut to fit perfectly onto the gap of the body chassis and the measurements were taken based on the current air-cooling system battery pack cover. After the steel plate is perfectly fit, holes are drilled onto the battery pack cover to allow the fan to be mounted and also holes to hold down the plastic part that has been sealed with the ducting. The plastic part and ducting were then connected to the side part of the Formula Varsity to allow only clean fresh air to enter the battery pack. The experimental was simulated in three conditions which is the time taken to cooldown the battery pack of the Formula Varsity from 60°C to 30°C. The result of testing reveals that the application of innovative cooling tactics significantly reduces cooldown time. When a low-speed fan is placed at the front of the vehicle to mimic airflow during motion, the cooldown time decreases from 690 seconds (current method) to 210 seconds. Further when a high-speed fan is employed, the cooldown time is reduced to 120 seconds. Other than that, the results show the current air-cooling strategies took 750 seconds to cooldown the battery pack when in static, while the new air-cooling strategies manage to cut down the time by half which is approximately 330 seconds. Next is the ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when light usage of battery such as vehicle electrical appliances and slow speed driving). The data obtained revealed that the application of newly developed cooling strategies managed to maintain the battery pack in optimal working temperature. However, the current air-cooling strategy failed to maintain the battery pack in its optimal working temperature (35°C to 45°C) when continuous heat applied to the battery pack, thus the heat supply has been forced to shut to make sure that the battery won't suffer any damage. The last condition is the ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when heavy usage such in Formula Varsity race) respectively. The results show only new air-cooling strategies which applied with high-speed fans at the front of the vehicle were managed to achieve a successful test. Results demonstrate the efficiency of the new air-cooling strategy compared to current air-cooling strategies. In conclusion, the inquiry of optimizing air-cooling plan for Electric Formula Varsity battery pack where extensive testing and inventive initiatives enhanced the cooling system's efficiency, addressing significant battery temperature concerns. Models from experiments shed light on procedures and the battery's capacity to sustain ideal temperatures.

ABSTRAK

Laporan projek ini meneroka dunia menarik teknologi kenderaan elektrik, dengan tumpuan khusus kepada pengoptimuman strategi penyejukan udara bagi satu pek bateri Formula Varsiti elektrik. Objektif utama penyelidikan ini adalah untuk menyiasat dan mengoptimumkan pelbagai strategi penyejukan udara yang boleh digunakan bagi pek bateri Formula Varsity, dengan matlamat meningkatkan sistem pengurusan termalnya. Projek ini melibatkan reka bentuk satu sistem penyejukan udara untuk pek bateri Formula Varsity elektrik. Penyertaan aliran udara luaran direka bentuk untuk meningkatkan pemindahan haba melalui udara, mempercepatkan proses penyejukan. Dalam projek ini, Arduino bertindak sebagai pengawal litar dan pemantau suhu bagi pek bateri untuk berfungsi sebagai sistem pemantauan suhu, menggunakan sensor untuk mengukur suhu sekitar. Produk akhir yang telah dibuat terdiri daripada kipas axial, pemanas udara dan kepingan keluli untuk menggantikan sistem strategi penyejukan udara semasa. Kepingan keluli dipotong untuk sesuai dengan sempurna pada celah badan kereta dan pengukuran diambil berdasarkan penutup bateri sistem penyejukan udara sedia ada. Selepas kepingan keluli dipasang dengan sempurna, lubang ditebuk pada penutup bateri untuk membenarkan kipas dipasang dan juga lubang untuk menahan bahagian plastik yang telah disambung dengan pemanas udara. Bahagian plastik dan pemanas udara kemudian disambungkan ke bahagian sisi Formula Varsity untuk membenarkan hanya udara segar yang bersih masuk ke dalam pek bateri. Eksperimen dijalankan dalam tiga keadaan iaitu masa yang diambil untuk menyejukkan semula pek bateri Formula Varsity dari 60°C ke 30°C. Hasil ujian menunjukkan bahawa penggunaan taktik penyejukan yang inovatif secara signifikan mengurangkan masa penyejukkan semula. Apabila kipas berkelajuan rendah diletakkan di hadapan kenderaan untuk meniru aliran udara semasa bergerak, masa penyejukkan semula berkurangan dari 690 saat (kaedah semasa) kepada 210 saat. Selanjutnya apabila kipas berkelajuan tinggi digunakan, masa penyejukkan berkurangan kepada 120 saat. Selain itu, hasil menunjukkan strategi penyejukan udara semasa mengambil masa 750 saat untuk menyejukkan semula pek bateri sedia ada dalam keadaan statik, manakala strategi penyejukan udara baru berjaya mengurangkan masa separuh iaitu kira-kira 330 saat. Seterusnya adalah keupayaan untuk menjaga pek bateri berfungsi dalam suhu kerja optimalnya (bekalan haba berterusan untuk mensimulasikan penolakan haba dari bateri semasa penggunaan ringan bateri seperti alat elektrik kenderaan dan pemanduan laju perlahan). Data yang diperoleh menunjukkan bahawa penggunaan strategi penyejukan yang baru diubahsuai berjaya mengekalkan pek bateri dalam suhu kerja optimal. Walau bagaimanapun, strategi penyejukan udara semasa gagal untuk mengekalkan pek bateri dalam suhu kerja optimalnya (35°C hingga 45°C) apabila haba berterusan dikenakan kepada pek bateri, oleh itu bekalan haba telah dipaksa untuk ditutup bagi memastikan bahawa bateri tidak mengalami sebarang kerosakan. Keadaan terakhir adalah keupayaan untuk mengekalkan pek bateri berfungsi dalam suhu kerja optimalnya (bekalan haba berterusan untuk mensimulasikan penolakan haba dari bateri semasa penggunaan berat seperti dalam perlumbaan Formula Varsity) masing-masing. Hasil menunjukkan hanya strategi penyejukan udara baru yang dilengkapi dengan kipas berkelajuan tinggi di hadapan kenderaan berjaya mencapai ujian yang berjaya. Hasil menunjukkan kecekapan strategi penyejukan udara baru berbanding dengan strategi penyejukan udara semasa. Kesimpulannya, penyiasatan pengoptimuman rancangan penyejukan udara untuk pek bateri Formula Varsity Elektrik di mana ujian yang luas dan inisiatif-inisiatif yang kreatif meningkatkan kecekapan sistem penyejukan, menangani kebimbangan suhu bateri yang signifikan. Model dari eksperimen menerangkan prosedur dan keupayaan bateri untuk mengekalkan suhu yang ideal.

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TABLE OF CONTENTS

PAGE

CHAPTER 3 METHODOLOGY 24

CHAPTER 4 RESULTS AND DISCUSSION 40

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

BTMS	-	Battery Thermal Management System
EV’s	-	Electric Vehicle’s
HEV’s	-	Hybrid Electric Vehicle’s
CFD	-	Computational Fluid Dynamics
NiMH	-	Nickel–Metal Hydride Rechargeable Batteries
s	-	Seconds
mm	-	Millimeter
°C	-	Celsius
IoT	-	Internet of Things
GPIO	-	General Purpose Input/Output
RAM	-	Random-Access Memory
V	-	Volt/Voltage
W	-	Wattage
RPM	-	Revolutions Per Minute
IDE	-	Integrated Development Environment
VR	-	Virtual Reality
K	-	Kelvin
DC	-	Direct Current
AC	-	Alternate Current
KG	-	Kilograms
LCD	-	Liquid Crystal Display
CFM	-	Cubic feet per minute

LIST OF APPENDICES

APPENDIX **TITLE** **PAGE**

CHAPTER 1

INTRODUCTION

1.1 Background

The battery pack in a Formula Varsity Car is the main energy storage system that supplies power to the electric motors and other components. Mainly consists of multiple lithium-ion battery cells in the arrangement of series and parallel configurations which to deliver the required voltage and capacity to supply powers to the Formula Varsity Car. Usually, the battery pack have been controlled by sophisticated battery management systems to monitor the state of the battery so adjustment could be applied the Formula Varsity Car accordingly to maximize it speed while managing it energy efficiency so it could last the entire race.

The battery pack used in Formula Varsity Car were normally designed to be lightweight, compact, and able to withstand the rigors of racing. It is typically located in specially designed compartment in the car's floor pan or behind the driver's seat within the car chassis to ensure weight distributed evenly, optimized handling, and for safety purposes. The battery car pack can be quite large and heavy. Normally, all Formula Varsity Car battery packs are designed to be high-performance and reliable to ensure the car performs at its best on the track.

Battery pack of a Formula Varsity Car is an essentially critical component that need to be taken care of, as it directly affects the car's performance and range. The energy capacity and power output of the battery pack will determine how far and fast the car can go before it needs to be recharged. Therefore, it needed to be able to deliver high levels of power and energy consistently, while also able to withstand the intense demands of racing, including the vibrations that channels throughout the surface of the roads and the intense of high temperature. As a result, the design and construction of the battery pack is important to the safety features and the performance of the Formula Varsity Car, and it is a part of the major area of focus for Formula Varsity Car teams and manufacturers.

1.2 Problem Statement

As for the findings that has been go through, a Lithium-ion batteries which commonly used in electric vehicle including the ones in the Formula Varsity Car, can be degraded and lose their efficiency if they have been exposed to high temperatures which due to the battery pack to work exceeds its optimal working temperature for a prolonged period of times. Therefore, it is critical to keep the battery pack at a consistent and optimal temperature range during operation.

Project aims to identify and create the most efficient and effective air-cooling strategy that can maintain the battery pack at its required working temperature at the best affordable cost that could be manage. The goal is to optimize the cooling system to minimize energy consumption while ensuring that the battery pack remains within its optimal working temperature range to improve overall performance and extend the life of the battery pack. As research has been done a battery pack should be at a range temperature of a minimum of 35 °C to 45°C maximum to ensure it works at its best performance, provide longevity of life of the battery pack and to make sure the battery pack is safe from high temperature which in worst case it could the battery to explode.

1.3 Research Objective

The aim of this research is identifying and developing the optimal air-cooling strategy that can be applied to a Formula Varsity Car battery pack to improve their performance, safety, and lifespan. Specifically, the objectives are as follows:

a) To analyze and assess the current air-cooling strategy for the battery pack and the need for the new air-cooling system.

b) To design optimize air-cooling strategies system for the battery pack by utilizing natural and forced air convection cooling

c) To evaluate overall performance of the new air-cooling system under experimental test of simulated heat.

1.4 Scope of Research

The scope of this research are as follows:

- The study of thermal characteristics of battery cells, including its heat generation and dissipation properties within the battery pack, the current existing air-cooling approach used by the Formula Varsity battery pack and the necessities for a new approach of the air-cooling strategies for the Formula Varsity battery pack.

- Discover various approaches of the design of cooling system which the placement of the battery pack, placement, and the size of fans, and ducting. Research purposes are to optimize design to maximize air flow and cooling efficiency while minimizing cost of the system.

- To run performance evaluation, optimization, and validation of the new air-cooling strategies which to run through numbers of practical experiments by simulate the heat rejection from a battery pack by using a heat gun on a real Formula Varsity battery pack. Tests are run to investigate the temperature of the battery pack after applying the new approach of air-cooling strategies. The experimental data is then analyzed to assess the total overall performance of the new approach of air-cooling strategy for the battery pack and to identify for further improvement in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The target of this literature review which to optimize air-cooling strategies for the existing electric formula varsity battery pack is to present a summary of the most recent findings that significantly related in the field of air-cooling Battery Thermal Management Systems (BTMS) for electric vehicles. The review focuses on the study of efficient air-cooling techniques for BTMS. Effective air-cooling BTMS might dissipate extra heat within the battery pack, regulate the maximum operation temperature below a specified value, and preserve the maximum temperature differences. A robust and efficient BTMS is essential for the battery packs of Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) to achieve optimal performance and maintain a long service life. Both excessive heat buildup and the risk of thermal runaway must be minimized. Lithium-ion batteries generate heat both inside the cells and where the cells are connected while charging and discharging, which results in an excessive rise in the battery's internal temperature and temperature anomalies. As a result, research was done by reading numerous publications and articles to learn how to optimize air cooling for the battery pack. Based on the literature, this paper provides a thorough analysis of how to best keep the battery pack of the Formula Varsity Car cool. It first investigates the strategy that can be used to optimized air-cooled for the battery pack of a for the Formula Varsity Car, location of the duct Inlet/Outlet Position for Battery Pack/Fan Placement, microcontroller that can be used to control the fan, type of fans, and type of thermal sensors and other electrical appliances.

2.2 Air-cooled strategies for the battery pack of vehicle

Since it is lightweight, simple to manufacture and maintain, and inexpensive, pure air cooling is preferred by practical applications in EVs. As the name suggests, air cooling makes use of air as a cooling medium The air cooling could be classified as passive or active depending on whether an external fan is used [1]. Different businesses preferred to use different strategies. The Nissan Leaf and the Volkswagen E-Golf both use passive cooling [2]. In the interim, popular EVs like the Pirus and Zoe 40 tended to use active air cooling. Despite the method's extensive application in the finished product, a number of air-cooling problems remain. The temperature homogeneity between battery cells is the main problem with air cooling because of the limited thermal conductivity of air. Summary of previous developments in air-cooling from the configuration, design, and optimization perspectives by Akinlabi et al[3]. The researcher has divided these newly developed technologies into three different groups which are the fan location or operation, airflow channel configuration, and battery layout configuration.

Based on some classifying, several improvements have been made to this method's cooling issues from the following four angles which is inlets and outlets are followed by flow pathways, flow strategy, and flow state in that order. A large, air-cooled battery pack's unique shortcut computing approach was created by Liu et al. [4]and was based on a model that combined a transient heat transfer model with a flow resistance network model. Based on forced-air convection, the model was able to quickly predict the cooling performance of the planned BTMS. Experimental testing of the battery pack was done by Saw et al. [5] at various rates of discharging, and the findings supported those of CFD.

A point has been made that CFD might offer a simple and affordable technique to gauge a particular BTMS's forced-air convection-based cooling performance. To determine the velocity and pressure of cooling channels as well as the relationship between the electrode and current density, Sun et al. [6] took advantage of the three-dimensional pack flow sub-model and the transient one-dimensional battery pack network sub-model. The temperature distribution within cells might then be calculated using the battery cell's thermal sub-model. Based on the calculations, it concluded by applying aluminum corrugation properly, the cooling effectiveness of the air-forced convection could increase to about 93% and the maximum temperature would decrease by around 4 °C.

2.2.1 Passive Methods of Air Cooling (Natural air-cooling Convection)

As thermal and electrical devices become smaller, it is becoming more challenging to design efficient cooling systems for them. One of the best ways to cool these devices is through natural convection, which involves using finned surfaces. The great thing about natural convection is that it does not rely on any moving parts like fans or pumps, which can be expensive and prone to failure. Instead, it takes advantage of the buoyancy forces created by the heat transfer from the finned surface to the surrounding air, causing a difference in temperature and creating a flow of air over the fins [7].

As an example, battery cells inside the battery pack are routinely aligned in a lithium-ion battery passive air-cooling BTMS. By means of the relative movement of the air through the battery pack, outside air enters inlet vents on one side of the vehicle battery pack. Then it travels through spaces between cells, and then emerges through the outlet’s vents. The air flow transported away the heat that was produced. The passive air conditioning BTMS may not be adequate when the car is moving slowly, or the ambient temperature is rather high[8].

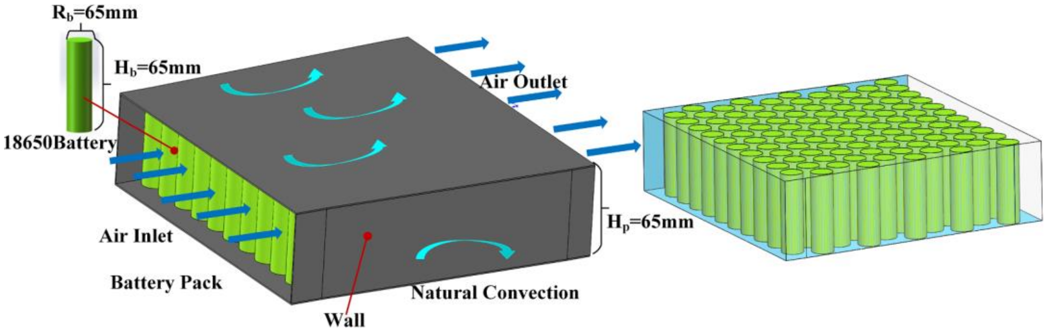


Figure 2.1 Diagram of the battery pack under natural air convection cooling [9].

2.2.2 Active Methods of Air Cooling (Force air-cooling Convection)

According to Lechner, "mechanical equipment to satisfy the needs of cooling within a building not provided by nature" is what constitutes active cooling systems. Power sources for active procedures mostly include heat and electricity. The 'new' cooling solution that designers of portable electronic devices favor is forced convection cooling which is because of a variety of elements, such as price, dependability, power consumption, footprint size, and profile height [10]. To set an example, distributing cabin air to the battery pack is a widely used technique (direct cabin air blow) for battery active cooling and heating in electric vehicles (such as the HEVs of the Honda Insight and Toyota Prius, which were NiMH-based)[11]. This approach, despite being straightforward, wastes an excessive amount of energy when cabin air is vented into the atmosphere. Additionally, the cabin's air connection to the battery container raises the risk to human safety in the event of a fire or explosion. Forced convection, in contrast to phase change materials [12], can effectively remove heat over a long period of time. Since air conditioning is presently used extensively in industry, there aren't many costs associated with its deployment. Finally, if the device has a small enough footprint and profile, heat can be dispersed directly at the source along a path with little thermal resistance, which lowers the temperature of all other parts and surfaces.

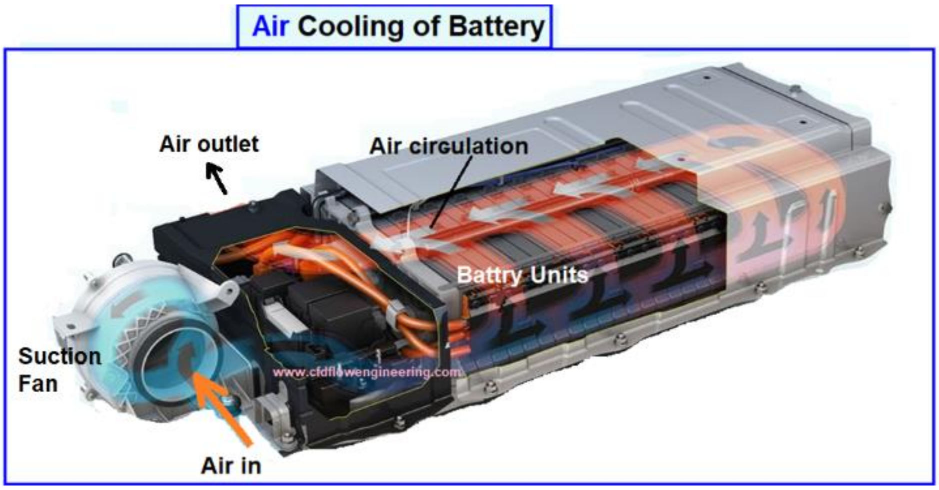


Figure 2.2 Diagram of the battery pack under forced air convection cooling [13]

2.3 Flow of air inlet and outlet from Battery Pack/Fan Placement

By determining the ideal location for the inlet and outlet air vents, it is possible to reduce the amount of power needed to circulate the air in the air flow channels in forced-air cooled BTMS. According to Wang et al. (2015), the optimal temperature range for forced-air cooling BTMS is roughly between 20 degrees Celsius and 35 degrees Celsius. Additionally, it has been found that when the fan is mounted on top of the module, the outermost cells experience the highest temperatures due to the slow airflow around the borders. An indication that regions with ambient temperatures below 20 degrees Celsius do not require forced-air cool BTMS, but forced-air cool BTMS was recommended if significant discharge rates are needed.[14]

Jiaqiang et al. (2018) changed the relative placements of the inlet and output air vents to influence the thermal properties of the 60 cylindrical cells module. A CFD model has been created to do the experiment. A viewed at how air vents on different sides of the module performed better at cooling than vents on the top and bottom or the same side. Finally, a demonstration of a novel design that included baffle plates inside the module created to improve airflow.[15]

Chen et al. (2020) numerically investigated the impact of asymmetric air flow in 5 BTMS designs and verified findings through practical experiments. Additionally, a creation of a symmetrical air flow models by improving the input and output air vents and hypothesized that these models performed better at cooling. For symmetrical air flow models, the maximum temperature differential between cells was less than 3.0 K. Energy usage and the maximum cell temperature differential were both lowered by at least 43% and 33%, respectively, in symmetrical air flow models. [16]

Advantages and challenges of Air-Cooled BTMS [17]

Advantages:

- Easy maintenance and implementation
- Safety and dependability during use
- Simple construction

Challenges:

- Air has a lower heat transfer coefficient and lower specific heat capacity than a liquid cooling medium. This is because battery modules that dense have a high capacity and are suited for EVs that capabilities for long-distance which generate a lot of heat and have close-packed cells, using them for highly dense battery modules results in a reduction in cooling performance for this BTMS.
- Passive air-cooled BTMS are appropriate for low-capacity battery modules, they have very limited cooling capacity for dense battery modules, which can lead to concerns with thermal runaway and passenger comfort. By introducing forced air, boosting air volume, or preconditioning air, air-cooled BTMS for dense battery modules can be optimized, but these methods demand too much power and are hence unsuitable.

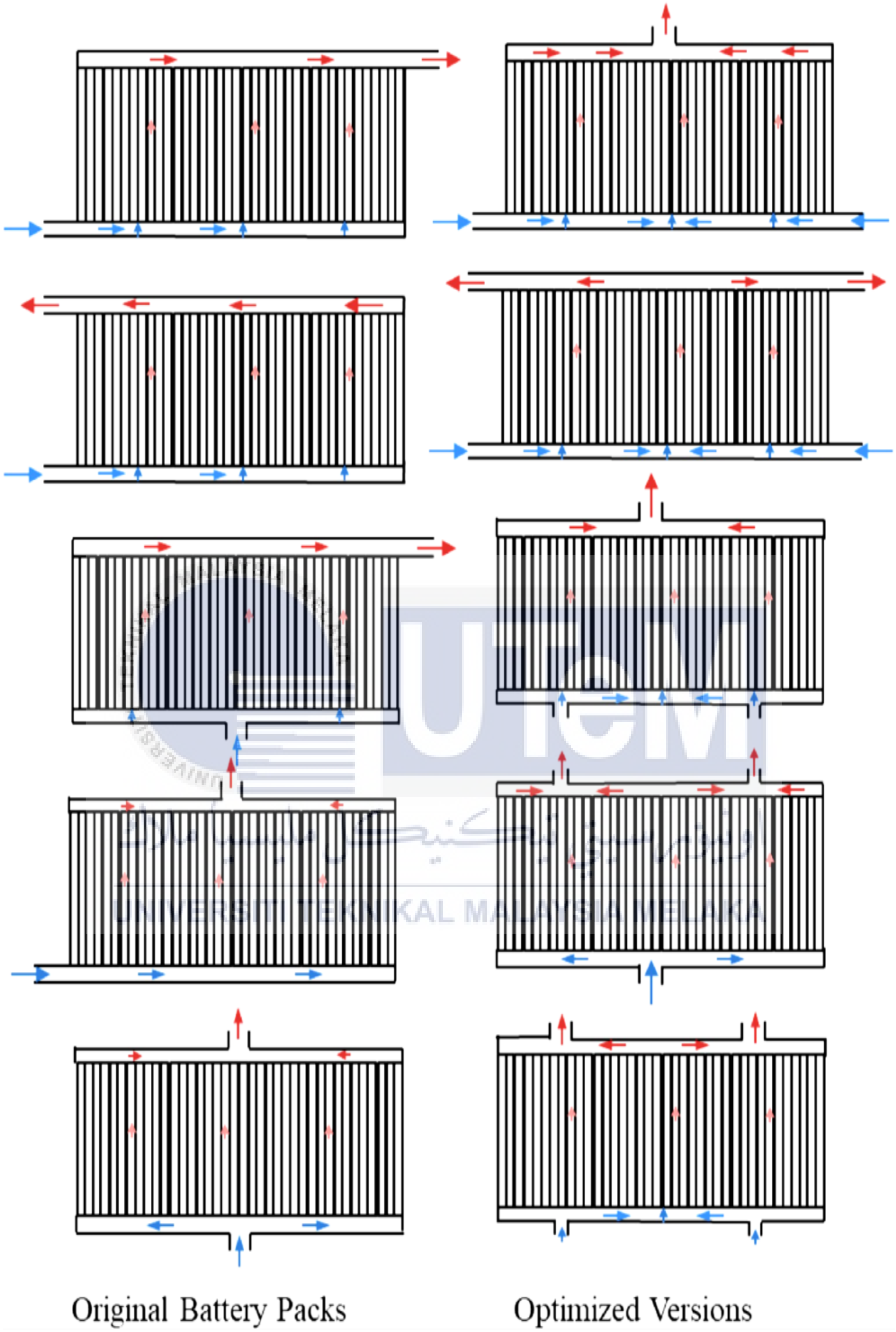


Figure 2.3 Examples arrangement of inlet and outlet of the duct and flow of air. [15]

2.4 Types of cooling fans for air cooling

Integration of active and passive approaches is a typical practice. In contrast to basic BTMS, hybrid BTMS places more of an emphasis on integrating and merging. The article primarily focuses on various techniques employed by researchers to improve battery performance and pack efficiency by lowering temperature and other losses. For forced air convection BTMS, a higher airflow rate is needed to provide cooling performance comparable to that of a liquid based BTMS. Due to the battery pack's decreased heat capacity, the forced-air cooling system leads to an uneven distribution of temperature inside it, which is a serious problem that needs to be fixed.[18]

In a study on air-cooled batteries, Fan et al. [19]discovered that raising the air intake velocity improves cooling efficiency. Raising the air inlet temperature also makes the temperature more uniform. A Battery Thermal Management System (BTMS) with reciprocating airflow was created by Mahamud et al. [20]. The maximum temperature within the battery module and the maximum temperature differential were both reduced by 1.5°C and 4°C, respectively, when the reciprocating period was set to 120 s. He and colleagues [21] carried out computational and experimental research on air cooling in a Li-ion battery module with eight inline battery cells. They discovered that increasing air velocity reduces the greatest temperature rise and leads to a more uniform temperature distribution through wind tunnel testing and computational simulations of turbulent flow.

2.4.1 Axial Flow Fan

An axial-flow fan is commonly used as a for outdoor units cooling fan. Compared to a centrifugal fan, the flow pattern of an axial-flow fan creates is more intricate. This complexity necessitates consideration of additional design parameters that impact the fan's flow and noise performance. These parameters include the geometry of the airfoil (such as the camber line and thickness), sectional pitch angles, solidity, tip geometry, and the shape of the shroud or orifice.[22]

Axial flow fans are utilized extensively in numerous engineering applications. Its adaptability has led to its incorporation into large-scale systems, such as industrial dryers and air conditioning units, as well as automotive engine cooling and in-cabin air recirculation systems. Due to the need for compact designs, the advantage of employing axial flow fans to improve heat transfer is particularly apparent in the automotive industry. The pervasive use of axial flow fans for fluid movement and heat transfer has prompted extensive research into the performance characteristics of a variety of designs [23][24].There have been numerical studies conducted to quantify the efficacy and flow characteristics of axial fans [25],[26].In terms of understanding flow characteristics and heat transfer, however, the practical implementation of cooling with an axial flow fan has garnered more interest [29]The main objective is to address the problem of heat generation and uneven cooling in cylindrical cells by modifying the configuration of a basic battery pack with axial airflow. The adjustment of outlet dimensions and the shape of the control volume aims can make better airflow convergence and faster movement into the latter part of the battery pack, thereby eliminating stagnant airflow areas behind the cells. Additionally, the altered geometry of the control volume acts as a nozzle, increasing the flow velocity in that region and providing additional cooling to the cells in the middle section. [30]

2.4.2 Centrifugal Flow Fan

On the basis of flow direction, there are two primary categories of fans which an axial flow fan and a radial flow fan, also known as centrifugal fans. Centrifugal fans increase air pressure by utilizing the centrifugal force generated by the impeller's rotation. Centrifugal fan impellers include backward inclination, backward curved, forward curved, radial tip blades, radial blades, and aero foil blade impellers, among others.

Widespread use of high-speed centrifugal fans in engineering for ventilation, refrigeration, and numerous other applications, among others. Highly valued for their ability to generate high-pressure air, these fans are in high demand. The airfoil-sectioned impellers on centrifugal fans are referred to as high efficiency impellers among the six distinct types of airfoil blades. Blades with a single thickness and a reverse incline, blades with a reverse or forward curve, blades with radial ends, and radial blades.[31]

Centrifugal fans consist of an impeller enclosed in a casing with a spirally curved shape. Air is injected axially into the impeller and evacuated at the outer perimeter of the impeller. The direction of the airflow is centrifugal (or radial). Fans with radial flow are another term for centrifugal fans. Centrifugal fans are capable of producing relatively high pressures. Unlike axial flow fans, they are suitable for high-pressure applications.

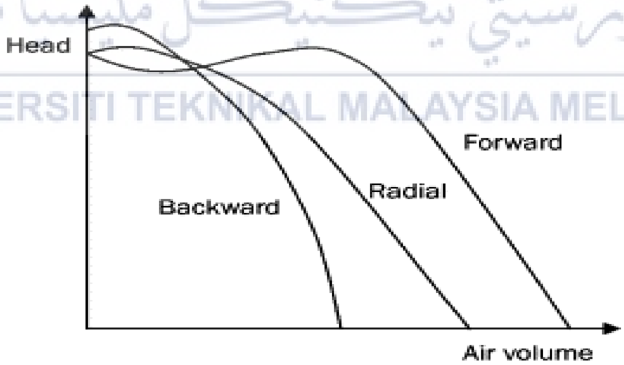


Figure 2.4 Displays characteristic curves for different types of centrifugal fans.[32]

2.5 Fans controller by using microcontroller.

The lithium-ion battery pack in a vehicle utilizes a passive air-cooling system known as BTMS, wherein the battery cells are regularly arranged. This system operates by facilitating the movement of air within the battery pack. External air is drawn in through inlet vents on a specific side of the pack and subsequently flows through the gaps between the individual cells. Finally, it exits through outlet vents, effectively carrying away the generated heat. However, it is important to note that this passive air conditioning BTMS may not be sufficient under certain conditions. For instance, when the vehicle is moving at a slow pace or when the surrounding temperature is considerably high, the passive air-cooling system may struggle to adequately regulate the temperature of the battery pack.

Today, home automation systems have been developed. A procedure that follows pre-determined sequential phases with little or no human effort is referred to as automation. The use of numerous sensors suited to observe the production processes provides automation actuators and various tools and methods.[33]

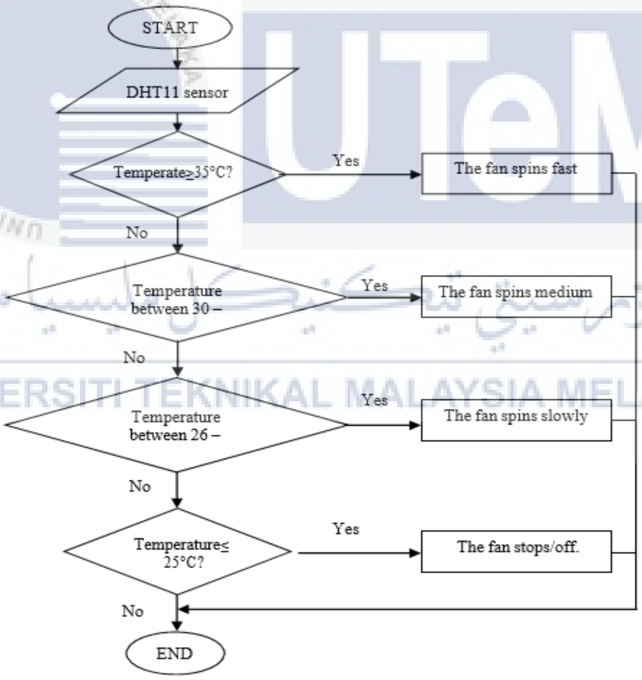


Figure 2.5 Example of a flowchart system automatic fan.[33]

2.5.1 Microcontroller

A microcontroller, also known as a computer control system on a single chip, is a remarkable technological invention. It incorporates a multitude of intricate electronic circuits capable of interpreting written instructions and converting them into precise electrical impulses. This compact device acts as the central processing unit for various electronic systems, efficiently orchestrating their functions. An interesting example of its application is the control of fan speed based on room temperature. By employing sensors, the microcontroller accurately measures the temperature and autonomously adjusts the fan's speed, accordingly, enhancing comfort and convenience. There was a diverse range of microcontrollers available such as an Arduino Uno, Raspberry Pie and the NodeMcu.[34]

2.5.2 Arduino Uno Act as Microcontroller

Microcontrollers are highly appreciated for their ability to be reused, cost-effectiveness, and reliability. Although there are various options available for creating microcontrollers, Arduino has emerged as the most efficient choice. Arduino, an open-source company, and community focused on hardware and software, has been producing Arduino boards based on microcontrollers since 2005. These development boards, commonly referred to as Arduino Modules, are ideal for microcontroller development. Arduino is particularly well-suited for individuals who have an affinity for languages like C, simplified C++, and Processing, such as hobbyists, students, and amateur innovators. It offers a straightforward and user-friendly syntax that is easy to comprehend and use. [35]

Arduino can be considered as a combination of a microcontroller and essential components like crystal, on-board power supply pins, and a bootloader. These elements are indispensable for effectively creating functional programs within the Arduino IDE.[36]

The following details the special attributes of the Arduino: [36]

- Arduino technology is inexpensive compared to other microcontrollers. The basic board, suitable for various projects and users like students, hobbyists, and microcontroller enthusiasts. This affordability has contributed to its widespread acceptance worldwide.
- Arduino Boards stand out from other boards because they possess cross-platform compatibility, supporting Windows, Linux (in all its variations), and even MAC OS. Unlike their counterparts, which are limited to Windows, Arduino Boards offer functionality across multiple operating systems.
- Arduino belongs to the category of open-source hardware, allowing different manufacturers to create their own customized boards based on the technology.
- Arduino Technology provides a simple and user-friendly programming environment through Arduino Software (IDE). The IDE is easy to comprehend, flexible, and robust, catering to the needs of various users. It also includes built-in examples that can be readily utilized for different interactions with the board.
- Arduino is compatible with the C++ programming language, enabling the utilization of various C++ libraries. These libraries can be extended to virtual reality (VR) applications and directly integrated into main programs.

2.6 Air-cooling strategies towards battery pack of Formula Varsity

Studies and research have demonstrated how important it is to monitor battery temperature and operate them within the correct range. According to research, the optimal temperature range for using a Li-ion battery is between 15°C and 50°C. [37]. According to Zhao et al. [38], a one-degree increase in temperature will reduce the battery's lifespan by two months. In order to promote battery balancing and uniform charging throughout the cycle, the maximum temperature difference of a battery pack should be maintained below

5°C [39]. In addition, recent studies have demonstrated that increasing the temperature of Li-ion cells as a result of a higher charge/discharge rate reduces battery life by between 65% and 95%. (Depends on the chemistry of the cell) [40].

2.6.1 Horizontal position configuration for cylindrical batteries.

To forecast temperature changes inside the battery's cells, computational fluid dynamics (CFD) simulations are used to determine the local convective heat transfer coefficients. The transient model depicts the electric drivetrain's dynamic behavior, which is typical of racing. The creation of such a numerical model and its application to the thermal control of a Formula Student electric vehicle battery pack with forced air conditioning constitute the study's primary contribution.

The analysis and design of an air-based battery temperature management system were conducted using a new mathematical model. The authors' numerical analytical method, which makes use of a heat transfer model, considers both the dynamic behavior of an electric car on a racecourse (Hockenheim ring, Germany), as well as the horizontal arrangement of the battery cells in the battery pack.

The cooling capability of the analyzed system was evaluated using CFD simulations, and the cells were divided into five segments so that local heat transfer coefficient measurements could be obtained. On the basis of these coefficients, a sectioned mathematical model is proposed in which thermal conduction between sections is also considered and each battery cell section transfers heat to the coolant (air) separately. At each entrance to the housing, where the cross-section of the flow abruptly increases, the air velocity increases, resulting in increased turbulence. These turbulences aid in the process of static extraction. The vertical orientation of cylindrical battery cells, however, makes this model the most suitable. This research examines the thermal characteristics of a horizontally oriented cylindrical battery cell using a new mathematical model that considers interactions between distinct cell sections rather than the battery cell as a whole.[41]

2.6.1.1 Summary of Horizontal position configuration for cylindrical batteries.

Based on the research of horizontal position configuration for cylindrical batteries. It is said that the horizontal position configuration for this instance, the temperature of the chilled surfaces and the flow parameters affect how much the air is heated after passing close to each cell segment. It is noted that utilizing the initially predicted air flow, it is not possible to maintain the cells' core temperature below the intended level of 50°C, with the last module's highest temperature reaching 51.7°C. For batteries positioned vertically, this might also be of interest, but for those positioned horizontally, as in this study, further analysis could be done addressing the placement of the positive electrode with respect to the direction of air flow. In these circumstances, the axial heat conduction and battery cell division may be of higher relevance.[41]

2.6.2 Aluminum plates as a heat spreader

The aluminum plates appear to be a crucial component of the pack's thermal dissipation, but they also substantially increase the pack's overall weight. If the battery pack can maintain its thermal performance without them, it would be advantageous to eliminate them. The second question is how much air must be blown into the accumulator container to maintain discharge temperatures below 55 °C, which is appropriate for cell chemistry [42].

The track model has provided us with the pack's current draw. By numerically performing this integration, we get that the total temperature for an endurance race is 75°C. We will likely need to air cool the entire pack because a 75°C climb exceeded outside the cells acceptable operating temperature range. It is necessary to calculate the mass flow needed to maintain the pack's thermal equilibrium is also helpful.

Only a portion of the heat produced by the pack is lost; the remainder is retained as thermal energy in the cell [43]. Heat exits the cell in four main ways such as through the tabs, the top and bottom of the cells, the faces of the cells, and the sides of the cells. Plots of the cooling model with and without the aluminum heat spreaders incorporated into the heat transfer routes are shown in Figure 2.5.

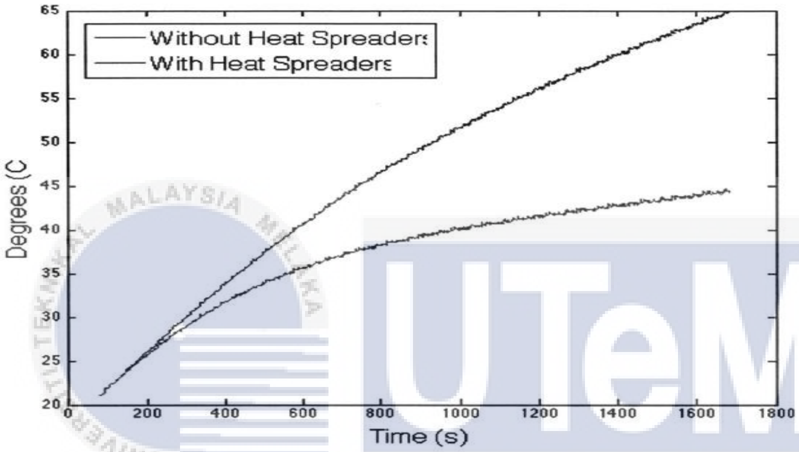


Figure 2.5 The rise temperature of battery pack with and without heat spreaders.[44]

This graph demonstrates that heat spreaders are necessary to maintain the operational temperature range of the pack, which is below 55°C. When the heat spreaders were removed, the overall temperature rose by 20°C, resulting in a significant decrease in thermal performance. This clarifies our primary concern initially which according to Figure 2.5 The rise temperature of battery pack with and without heat spreaders.[44], the heat spreaders are essential to the functionality of our pack design. The second question the thermal model was intended to answer was how much heat must be evacuated from the pack using forced air cooling. As this heat removal is accomplished by fans, the more important design consideration for the pack is the requisite CFM (cubic feet per minute) of airflow. Initial calculations indicated that approximately 120 CFM of air would be required to cool the burden. However, with our transient solver and cooling model, we can refine this number and eradicate the best-case temperature difference assumption required by the original model. The complete heat transfer from the air to the battery pack is depicted in Figure **2.6**.[44]

Figure **2.6** Fan cooling performance desire.**[44]**

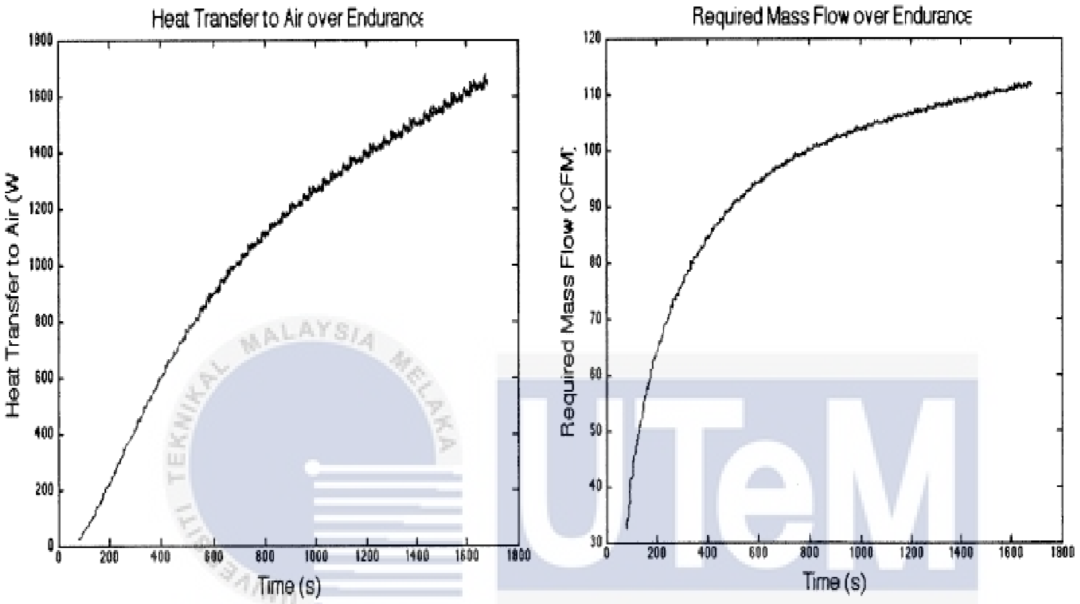


Figure 2.6 Fan cooling performance desire.[44]

In addition, this heat transfer and the transient temperature of the load can be used to calculate the required airflow in CFM. This information will be used to compute fan speeds, which correspond to energy demands on the racecar's low voltage supply. In order to determine the size of the low voltage battery required to power the fans and electronics, it is crucial to accurately model these loads. This worries due to the power that required to power the fans will increase the load usage of the batteries and hence increase the heat generation of the batteries.[44]

2.6.2.1 Summary of air-cooling strategies for battery pack of Formula Varsity

By comparing this two research, a finding has been made which both researches has stated out the optimal working temperature of a battery pack of a Formula Varsity Car. The optimal working temperature for the battery pack is being said that it is withing 20°C -50°C. The battery pack shouldn't exceed 50°C which is the battery max working temperature for safety purposes and to make sure the battery is longevity, prevent it from degrading and the efficiency of the battery is at its peak. Other than that, there were numerous designs and implementations of maintaining the battery at its optimal working temperature such as the aluminum plate as a heat spreader and the positioning of the battery in the battery pack. The research that has been done has its benefits and downsides.

2.7 Summary of Literature Review

This literature review delves into the enhancements of air-cooling methodologies for Formula Varsity battery packs, emphasizing their crucial role in ensuring optimal performance, durability, and safety in high-performance electric vehicles. It explores diverse air-cooling approaches, such as natural and forced convection, evaluating their merits, drawbacks, and applicability to Formula Varsity battery packs.

The assessment places particular importance on thermal management, acknowledging its profound impact on battery performance, capacity, and cycle life. Factors like air flow rate, cooling channel design, and thermal interface materials are scrutinized for their influence on cooling efficiency. This comprehensive exploration enables an understanding of heat transfer mechanisms, temperature distributions, and various air circulation configurations.

In summary, the literature review underscores the necessity for effective air-cooling strategies in electric Formula Varsity battery packs, offering insights into existing research, challenges, and optimization opportunities. Its findings serve as a valuable guide for future research endeavors and the development of enhanced cooling systems for high-performance electric vehicles. Implementing efficient cooling strategies has the potential to uphold optimal operating temperatures, thereby elevating overall performance and extending battery life for Formula Varsity vehicles.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In essence, the development of an electric vehicle hinges on addressing the pivotal challenges of thermal efficiency and the reliability of its battery pack. Managing excessive heat becomes paramount as it can significantly influence the battery's performance, lifespan, and overall safety. The adoption of air-cooling methods emerges as a widely favored solution in dissipating heat from electric vehicle battery packs, primarily due to its simplicity and cost-effectiveness. However, the effectiveness of these air-cooling strategies is subject to various design parameters, including everyday usage, high-load scenarios, and even racing conditions. Variables such as cooling airflow rate, fan placement, ducting, and the overall system architecture contribute to the strategy's efficiency. Strategic optimization of these factors not only promises enhanced cooling performance but also translates to prolonged battery life, heightened overall vehicle efficiency, improved performance, and bolstered safety measures.

This chapter intricately outlines all the requisites and methodologies crucial for the successful completion of the project. Employing a systematic approach to optimize air-cooling strategies for the Electric Formula Varsity Car's battery pack, the project endeavors to elevate thermal efficiency, performance, and reliability. The focus is on identifying the most effective cooling configuration tailored to the Electric Formula Varsity Car, considering additional considerations such as aerodynamics, weight constraints, and packaging requirements.

3.1.1 Flow Chart

Several stages have been taken in order to complete this research. This project progress has been done approximately two semesters to complete it fully. The project process is depicted in Figure **3**.**1**.

The intricately designed flow chart elegantly captures each nuanced step of the process. Commencing with a meticulous exploration and in-depth research into air conditioning systems, the initial stage involves discerning and selecting suitable methods and components. Subsequently, the fabrication of the new battery pack cover for the fan takes center stage, accompanied by rigorous testing to ensure seamless integration of the ducting mount and the new battery pack cover. This phase is marked by precision and scrutiny to guarantee flawless installation.

Moving forward, the process delves into the integration of hardware control for the novel air-cooling systems. This involves a series of simulations and Arduino designs, with multiple trials undertaken to identify the optimal configuration that ensures the system functions precisely as intended. Once the validation process is successfully navigated, the various components are seamlessly incorporated into the car.

The final stage of the process entails a comprehensive assessment of the system's functionality and performance. Every facet is scrutinized to ensure that the implemented air-cooling strategy enhances the vehicle's thermal performance and reliability. This meticulously outlined flowchart provides a comprehensive and systematic approach to achieving superior thermal efficiency and dependability through the implementation of an effective air-cooling system.

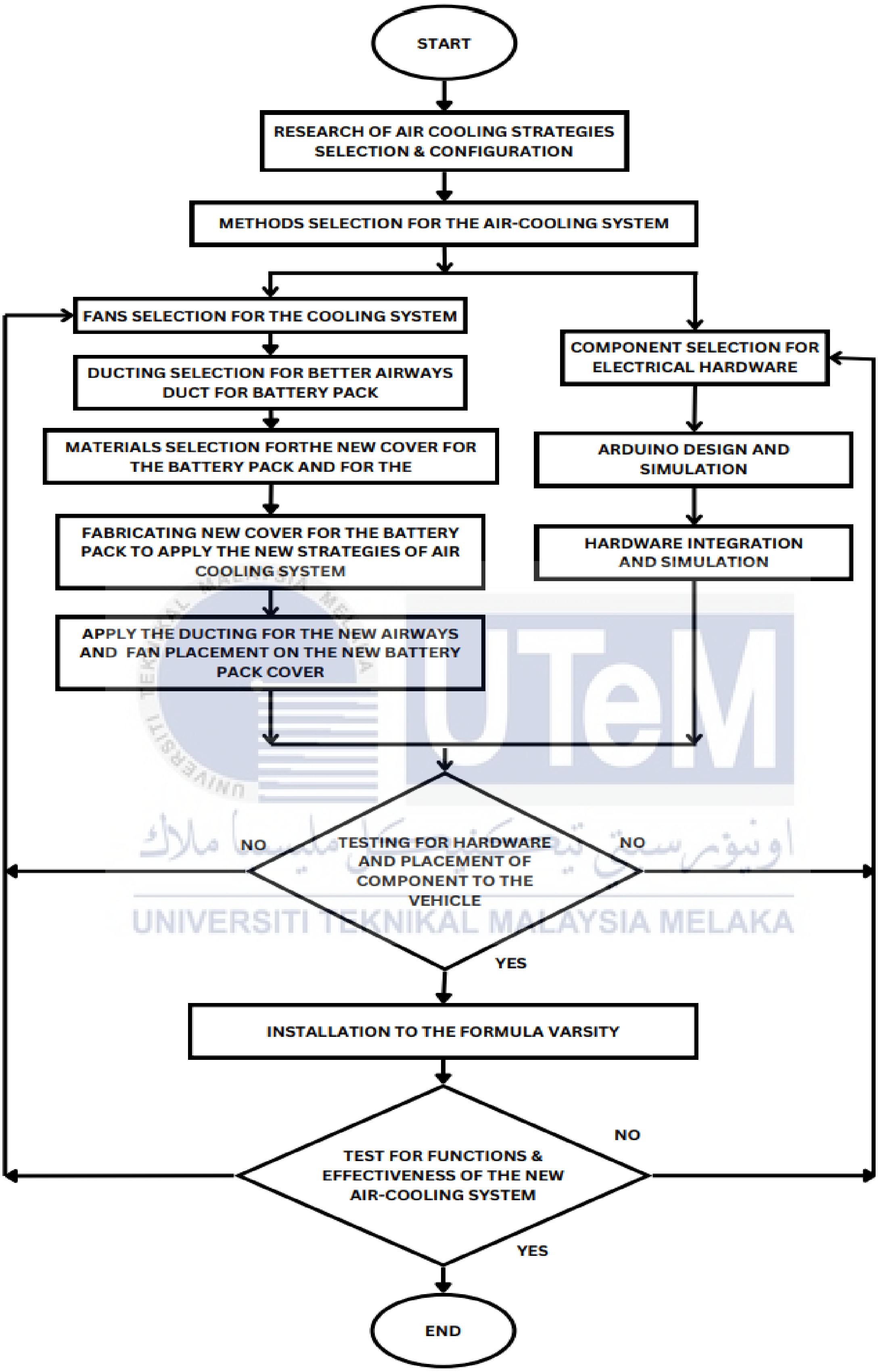


Figure 3.1 An overview flow Chart of this project.

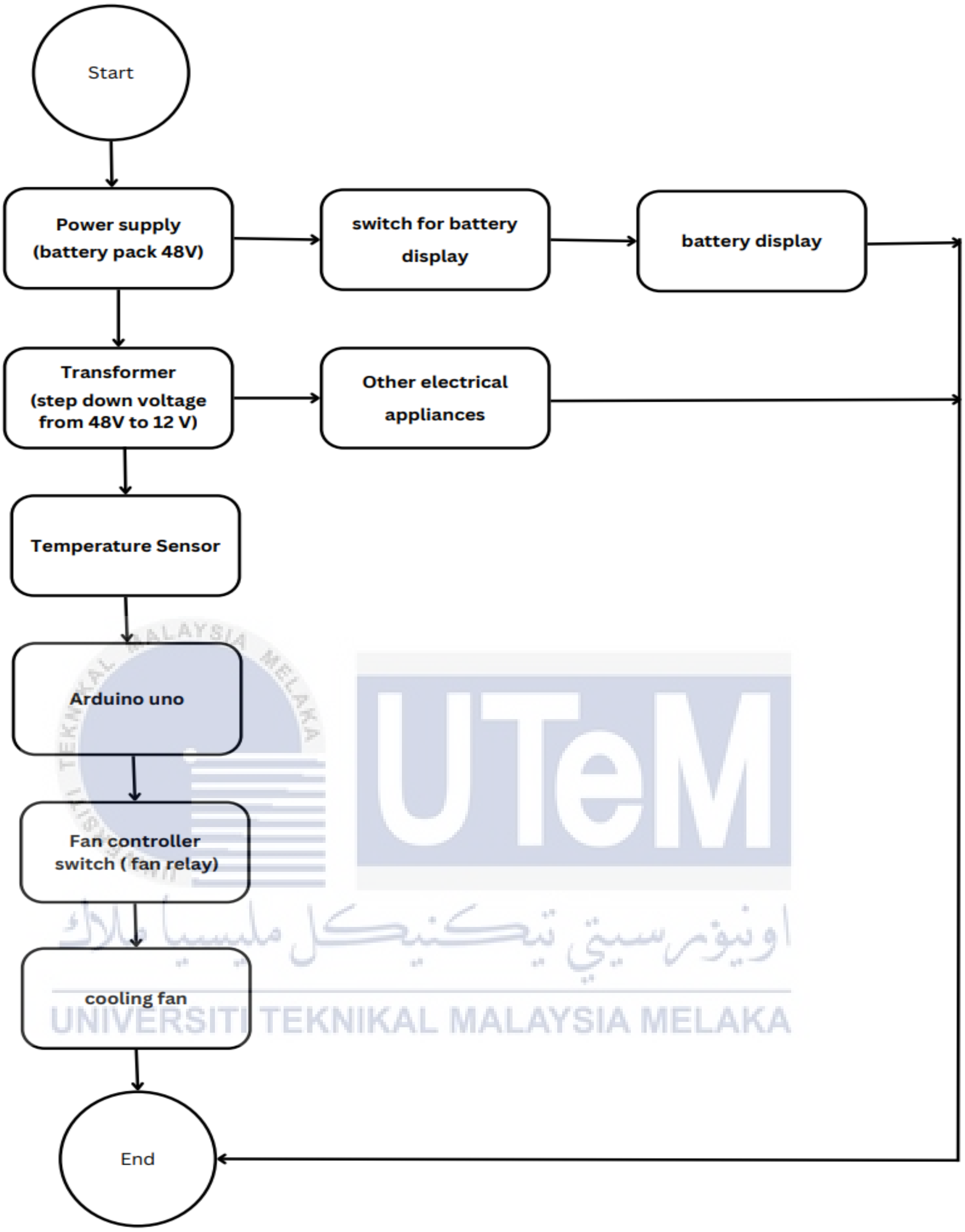


Figure 3.2 An overview of the air-cooling strategies that will be applied.

This project exclusively utilizes Arduino Uno, renowned for its versatility and user-friendly interface, it has gained popularity among the engineers. With its compact design, integrated memory, and extensive code library, the Arduino Uno empowers individuals to explore programming and electronic circuitry, fostering innovation.

3.2 Methodology for Air Cooling Towards Battery Pack

Employing a harmonious fusion of forced and natural convection air-cooling techniques constitutes the innovative approach adopted in this experiment for cooling the Formula Varsity battery pack. These sophisticated methods leverage the orchestrated movement of air to efficiently dissipate heat, ensuring the battery pack operates seamlessly within its optimal temperature range, delivering peak performance.

3.2.1 Forced Convection Air-Cooling methods.

Optimal battery pack temperatures are achieved through the implementation of forced convection air-cooling techniques. Utilizing an axial fan as an external airflow source ensures efficient circulation within the battery pack, expelling excess heat. The incorporation of external airflow is designed to enhance heat transfer through the air, expediting the cooling process. Forced convection, superior in heat transfer to natural convection, becomes essential only when the battery exceeds its optimal temperature. Thus, a synergistic blend of natural and forced convection is employed for precise temperature regulation. The use of forced air convection allows targeted cooling of specific battery pack regions, ensuring effective temperature control. In this context, the selection of an axial fan as the forced convection method compensates for the absence of natural airflow, contributing to the overall effectiveness of the cooling process.

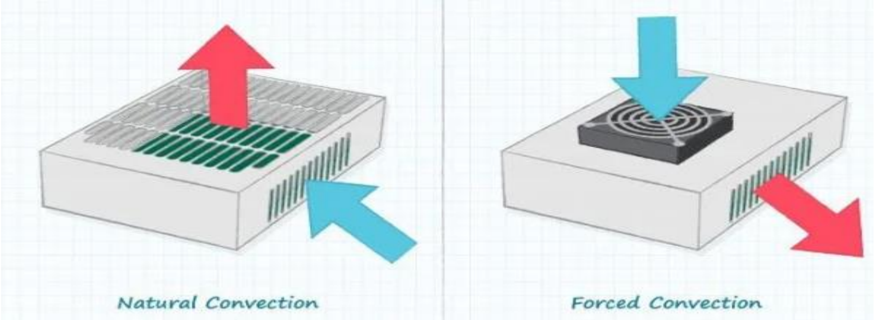


Figure 3.3 Difference working principle of natural and force convection.

3.2.1.1 Axial Fan

Figure 3.4 The axial fan that used for this project.

Within the realm of the automotive industry, axial fans emerge as stalwart components employed for cooling radiators and various engine surfaces. Their operational mechanism involves directing air parallel to their axis, facilitated by a compact body design housing impellers with blades surrounding a central hub. Noteworthy for their energy efficiency, considerable airflow capacity, adaptable size and configuration, and minimal noise production, axial fans find applications in diverse sectors, including automotive, electronic cooling, and ventilation systems. The advantages offered by axial fans align seamlessly with the requirements of this project. The deliberate exclusion of centrifugal fans from consideration stems from their tendency to generate excessive pressure, create unwarranted commotion, and prove unsuitable for the project's specific needs. Hence, a judicious selection has been made, employing a 12V axial fan boasting a 7" diameter and a circulation rate of 2100 RPM. For a comprehensive understanding of the fan's attributes, Table **3.1** Attributes of an axial fan.outlines the key features of the axial fan utilized in this project.

Table 3.1 Attributes of an axial fan.

Attribute	Value
Supply voltage	12V
AC or DC operation	DC
Fan Speed	2100 RPM
Air flow of fan (CFM)	297.92 CFM
Material	ABS plastic
Fan Weight	1.35KG
Size	7” Inch
Power	80W

3.2.2 Natural Convection Air-Cooling Methods.

Natural convection air-cooling harnesses the inherent airflow driven by buoyancy forces to cool battery systems, utilizing temperature differentials to induce the upward movement of warmer air. This method proves energy-efficient, cost-effective, and reliable, particularly when the battery operates within its optimal temperature range. In contrast to forced convection, which relies on external airflow sources like fans, natural convection is less prone to mechanical failure. The dynamic control and seamless transition between forced and natural convection cooling systems necessitate the integration of electrical and electronic components such as Arduino. This approach optimizes cooling efficiency based on the battery's temperature, ensuring it remains within the safe operating range. Strategic utilization of natural convection air-cooling when appropriate not only enhances cooling effectiveness but also minimizes energy consumption and associated costs.

For enhanced efficacy in natural convection air-cooling, an air ducting system is integrated into the new battery pack cover. This strategic addition facilitates the influx of cool air from the surroundings into the battery pack, optimizing the exchange between the heat-rejected hot air within the battery pack and the incoming cool air via the mounted ducting. This meticulous integration ensures an efficient cooling process while maintaining energy efficiency.

3.2.2.1 Air Ducting

Figure 3.5 Air Ducting that install and used in this project.

Fully leveraging the advantages of natural convection air cooling presents an array of benefits, notably in reducing electrical power consumption and minimizing the reliance on additional fans. By turning off the fan when it's unnecessary, such as when the battery is operating within its optimal temperature range, this method effectively curtails the heat rejection from the battery, contributing to overall energy efficiency.

In order to maximize the efficiency of natural convection, the implementation of an air ducting system becomes paramount. This addition enhances the role of natural convection in maintaining optimal battery temperatures. The air ducting system acts as a channel, facilitating the entrance of cool air from the surroundings into the battery pack. This strategic integration not only aids in effective heat dissipation but also ensures that only clean air, free from debris, contaminants, and external heat sources like the motor and controller, enters the battery compartment.

Within the Formula Varsity battery pack, the air ducting system is meticulously engineered to address various challenges. The system serves as a protective barrier, safeguarding the battery from external elements and mitigating the impact of heat-producing components, particularly the controller. Filters and screens embedded in the air ducting system play a crucial role in maintaining a pristine environment within the battery compartment, preventing dust and contaminants from compromising performance. This thoughtful design not only extends the operational life of the battery but also contributes to the overall efficiency and health of the electric vehicle.

3.3 Arduino Uno

Figure 3.6 Arduino Uno

In this project, the Arduino plays a dual role, acting as both a circuit controller and a temperature monitor for the battery pack. Functioning as a circuit controller, it orchestrates fan operations based on preset temperature thresholds through a dedicated circuit. Simultaneously, Arduino serves as a temperature monitoring system, utilizing a sensor to measure ambient temperature. This data can be transmitted to a computer or showcased on an LCD screen for real-time monitoring. This integration not only automates fan control but also provides a visual representation of temperature readings, enhancing cooling efficiency and ensuring safe battery pack operation. By continuously monitoring and controlling ventilation, Arduino safeguards against overheating and potential damage, ultimately optimizing cooling performance and reinforcing system reliability.

3.3.1 Arduino act as Circuit Control and Temperature Measurement

The Arduino serves as an advanced temperature-controlled ventilation system for the Formula Varsity Controller, utilizing a dynamic process loop to regulate the fan circuit based on preset temperature thresholds. This ensures energy-efficient and effective cooling tailored to specific temperature conditions, enhancing stability, and minimizing energy consumption and fan wear. The integrated DHT22 temperature sensor and relay, synchronized with the Arduino, provide precise temperature measurements, displaying relevant data on an LCD screen for efficient air-cooling optimization.

Incorporating the DHT22 temperature sensor and relay into the Arduino setup not only aids in air-cooling optimization evaluation but also offers a visual representation of fan status and temperature data. This comprehensive configuration contributes to efficient energy usage and extended fan lifespan. Arduino's capability to collect and display temperature data on the LCD screen is crucial for understanding system heat behavior, facilitating the evaluation of cooling methods and making informed decisions for system design and optimization. The combination of the DHT22 sensor, relay, LCD display, and Arduino ensures continuous monitoring and control of the Formula Varsity Battery Pack's blowers, ensuring efficient cooling.

3.4 Circuit and Component Designed of Air-Cooling System Arduino

Arduino, combined with a temperature sensor and a fan control circuit, transforms into a sophisticated temperature-controlled fan system that autonomously regulates the Formula Varsity battery pack cooling. This intelligent controller continuously monitors temperature variations and dynamically activates or deactivates the fan circuit based on predetermined thresholds, ensuring optimal cooling efficiency. In the schematic representation created using Tinker CAD software in Figure **3.7**, essential components are featured: the Arduino Uno microcontroller (1), the DHT22 temperature and humidity sensor (2), and an I2C-enabled LCD (3). This LCD provides critical real-time information, including the battery pack temperature and the status of the fan, showcasing the system's autonomous and responsive nature.

Within the circuit diagram as shown in Figure **3.7** , the DC fan symbolizes the actual axial fan used in the project. The 5V relay (5) serves a crucial role, orchestrating the high-voltage circuit from the battery through a smaller voltage circuit from the Arduino, contributing to the overall safety and functionality of the setup. The power source (6), providing the necessary 12V for the axial fan, ensures the effective operation of the cooling system. This comprehensive represents the practical implementation of an intelligent temperature-controlled fan system.

This innovative system, with Arduino at its core, showcases a cohesive approach to temperature control, offering a seamless interplay of components for efficient fan operation and optimal cooling. The visual representation, while symbolic in nature, accurately portrays the autonomous and responsive features of the system. The integration of Arduino, temperature sensors, relay, and LCD display aligns with practical considerations, providing a reliable platform for real-time temperature data measurement, monitoring, and analysis in the dynamic context of the Formula Varsity Controller.

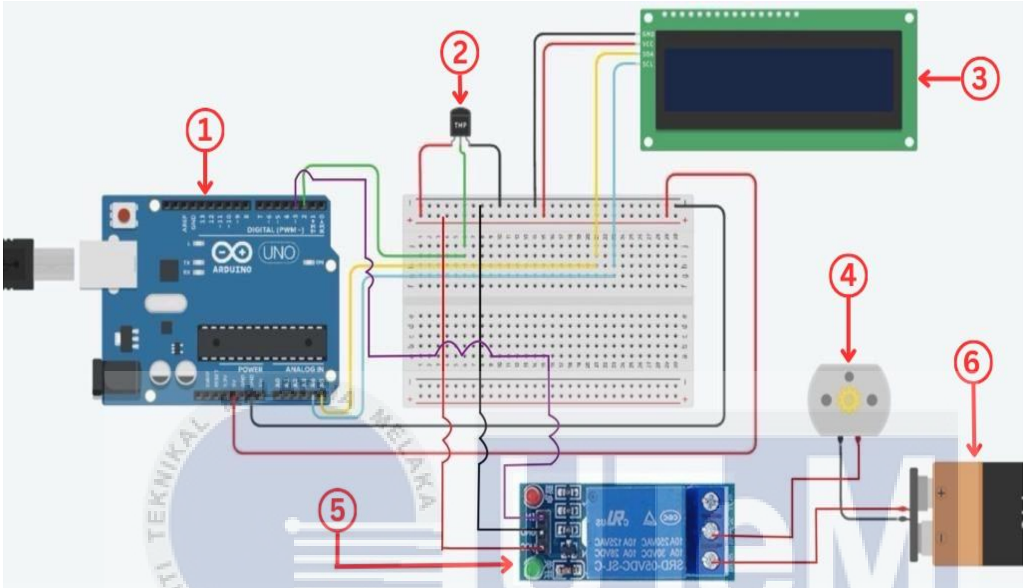


Figure 3.7 Circuit diagram for Microcontroller of the battery pack cooling system.

3.5 Design Coding of Arduino as Temperature Measurement Instrument and Data Collection

The Arduino code for the Formula Varsity air cooling system serves as the backbone for temperature measurement and data collection. Programmed to interact with the DHT22 temperature sensor and control the fan circuit, Arduino employs a dynamic loop to continually monitor temperature conditions. It utilizes predetermined thresholds to trigger fan activation or deactivation, ensuring efficient cooling. The code also integrates with an LCD display, providing a real-time visual representation of temperature data and fan status. This design coding facilitates accurate temperature measurement, automated fan control, and seamless data collection, contributing to the optimization of the air-cooling system's performance for the Formula Varsity battery pack.

In this design that was shown in the APPENDIX D Design Coding of Arduino as Temperature Measurement Instrument and Data Collection., the Arduino code acts as a smart controller, orchestrating the interplay between temperature sensors, the fan control circuit, and the display module. The modular and versatile nature of the code enables the system to adapt to varying temperature conditions, offering a robust solution for maintaining the optimal working temperature of the battery pack. The structured coding ensures reliable and responsive temperature control, making it an essential component for effective air cooling in the challenging environment of Formula Varsity races.

3.6 Final Product Designed of Air-Cooling System for the Electric Formula Varsity Battery Pack

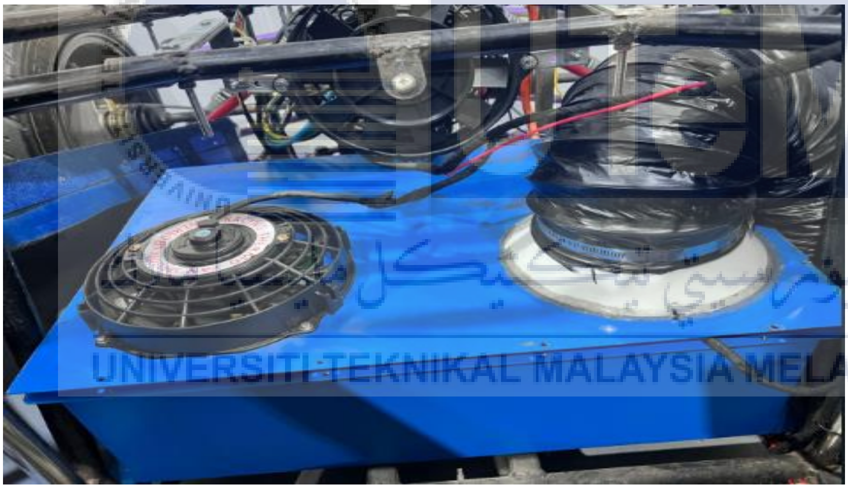


Figure 3.8 Final Product Designed of Air-Cooling System for the Electric Formula Varsity Battery Pack.

Figure 3.8 shows the final product design of the new air-cooling system that has been invented for the battery pack of the Formula Varsity. The final product that has been fabricated are consists of a fan, ducting and also a steel plate that has been fabricated to replace the current air-cooling strategies system. The steel plate was cut to fit perfectly onto the gap of the body chassis and the measurements were taken based on the current air-cooling system battery pack cover. After the steel plate is perfectly fit, holes are drilled onto the battery pack cover to allow the fan to be mounted and also holes to hold down the plastic part that has been sealed with the ducting. The plastic part and ducting were then connected to the side part of the Formula Varsity to allow only clean fresh air to enter the battery pack.

3.7 Experimental simulated testing on the Formula Varsity Battery Pack

Experimental testing plays a pivotal role in the Formula Varsity Battery Pack project, providing essential data pre and post air-cooling strategy implementation. The aim is to assess the necessity and gauge the performance of the cooling system before and after its installation. Simulating heat rejection using a heat gun allows for a comprehensive evaluation of the air-cooling systems' efficacy, both with and without the cooling system. Comparative analysis serves to identify the cooling strategy's necessity and effectiveness. The outcomes of these performance tests become instrumental in affirming the development of reliable and efficient cooling system for the Formula Varsity Battery Pack.

1. Time Taken to Cooldown the Battery Pack of The Formula Varsity From 60°C to 30°C.

Assessing the air-cooling system's efficacy is vital, particularly in cooling the battery pack beyond its optimal working temperature of 60°C, risking long-term damage. A comparison of cooldown times before and after installing the new air-cooling system highlights the performance gap between current and innovative strategies. The experimental test, simulating heat rejection with a heat gun, provides essential data for evaluating the current system's performance and gauging the new air-cooling strategies' optimization needs, functionality, efficiency, and overall effectiveness. The focus of this simulation is to determine the time required for both current and new strategies to cool the battery pack from 60°C (the upper limit) to 35°C (the minimum optimal working temperature).

2. Ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when light usage of battery such as vehicle electrical appliances and low speed driving)

Evaluating how well the air-cooling system keeps the battery at its ideal temperature also includes mild usage situations like travelling at a slow speed or utilizing the electrical appliances in the car. In these situations, maintaining temperature equilibrium is difficult but essential for system dependability. Tests conducted with low utilization levels shed light on how well both old and modern air-cooling techniques work. The duration required for the battery pack to reach its ideal temperature, which ensures effectiveness in a variety of operating scenarios and improves overall system reliability, is the primary evaluation criterion.

3. Ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when heavy usage such as in Formula Varsity race)

Maintaining the battery pack within the ideal temperature range is crucial, especially during continuous heavy usage, which leads to increased heat rejection. High-speed travel or uphill terrain intensifies the load on the battery pack, impacting its overall temperature. Conducting a series of tests is essential to evaluate both current and new air-cooling strategies, confirming their needs, functionality, efficiency, and performance. These tests expose the limitations of the current strategies in sustaining the battery's optimal working temperature, while the innovative air-cooling system's capabilities are scrutinized under continuous heat supply conditions. The focus is on observing the time taken for the air-cooling strategies to effectively cool down the battery pack to its optimal working temperature.

3.8 Summary

This final year project aims to optimize air-cooling strategies for an electric Formula Varsity battery pack. The methodology consists of three phases: research and analysis, design and fabrication, and performance evaluation. During the research phase, a comprehensive study is conducted to define the research design, while the design phase involves simulations and the implementation of air-cooling strategies. The performance evaluation phase focuses on testing and analyzing the effectiveness of the strategies. The methodology chapter provides a comprehensive overview of the research approach, including experimental methods, design considerations, and data analysis techniques, serving as a guide for achieving the project's goal of optimizing air-cooling strategies for Formula Varsity battery packs.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter emphasizes the significance of effective cooling systems for the performance and safety of battery packs. This chapter will describe and answer the project's research queries and hypothesis, as well as the structure of the results and discussion. The objective of this section is to analyze and interpret the experimental testing for the system performance and the functionality of the simulation design for the Arduino. In general, it will evaluate the efficiency of the implemented air-cooling strategies. Overall, a concise summary of the objectives and methodology will be proven by providing the groundwork for the subsequent analysis and interpretation of the findings regarding the optimized air-cooling strategies for the Formula Varsity battery pack.

Other than that, balance has to take precedence over energy efficiency, cooling performance, and design limitations. Further studies will provide a thorough understanding of air-cooling optimization for the Formula Varsity Battery Pack by improving experimental setups, looking into other cooling techniques, and analyzing more variables. The goal of this study is to improve the Formula Varsity Controller's cooling system's performance.

4.2 Time Taken to Cooldown the Battery Pack of The Formula Varsity From 60°C to 30°C.

The purpose of this experimental investigation is to determine the duration that it takes for the Formula Varsity battery pack to cool down from an increased temperature of 60°C to an ideal working temperature of 30°C. The battery pack was being heated by using a heat gun to imitate the heat rejection that comes from the battery pack when it been used. For this experiment, the battery pack are heated to a safe max limit temperature of 60°C and this is to make sure that the battery is not affected because the battery will be affected when it is exposed to high heat (50°C and above) for a long period of time.

The setting for the experiment started with setting of the heat gun at a fixed rate which is medium speed blow and medium heat settings. Then, time was taken and recorded from the moment the heat been stop supply to the battery pack which when the internal temperature of the battery pack reach 60°C, until it reaches the ambient room temperature 30°C. The ambient temperature of the room was measured before the experiment started to determine the temperature it should be when the battery stopped supply load to the system.

This experiment was done with three different settings: vehicle in static, low speed of fan at the front of vehicle and high speed of fan at the front of the vehicle. The settings for the low and high speed of fan at the front of the vehicle was to imitate the movement of the vehicle which the speed of fan imitates the air flows that run throughout the body of the vehicle, and this been done because an air flow which go through the vehicle when it moves can help in the aid of cooling down the battery pack of the vehicle. Two setting of the fan are used in this experiment which the low settings of the fan speed have an air volume of $214m^3/min$ while the high setting of the fan speed has an air volume of $270m^3/min$.

4.2.1 Vehicles in static

The duration of the experiment process involves recording and observing the time it takes for the battery pack to cool down from 60°C to 30°C while the vehicle is stationary. After data was collected, it was examined, organized in a table, and a graph was created.

Table 4.1 Duration for the Battery Pack to Cooldown From 60°C to 30°C When the Vehicle in Static.

Vehicle in Static		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	60.00	60.00
30	56.40	52.20
60	52.70	49.50
90	49.90	44.40
120	47.20	40.70
150	45.00	38.60
180	43.20	34.80
210	41.50	33.20
240	40.20	32.40
270	38.90	31.50
300	37.80	30.70
330	36.90	30.00
360	36.10	
390	35.40	
420	34.80	
450	34.20	
480	33.80	
510	33.30	
540	32.90	
570	32.60	
600	32.00	
630	31.60	
660	31.20	
690	30.90	
720	30.60	
750	30.00	

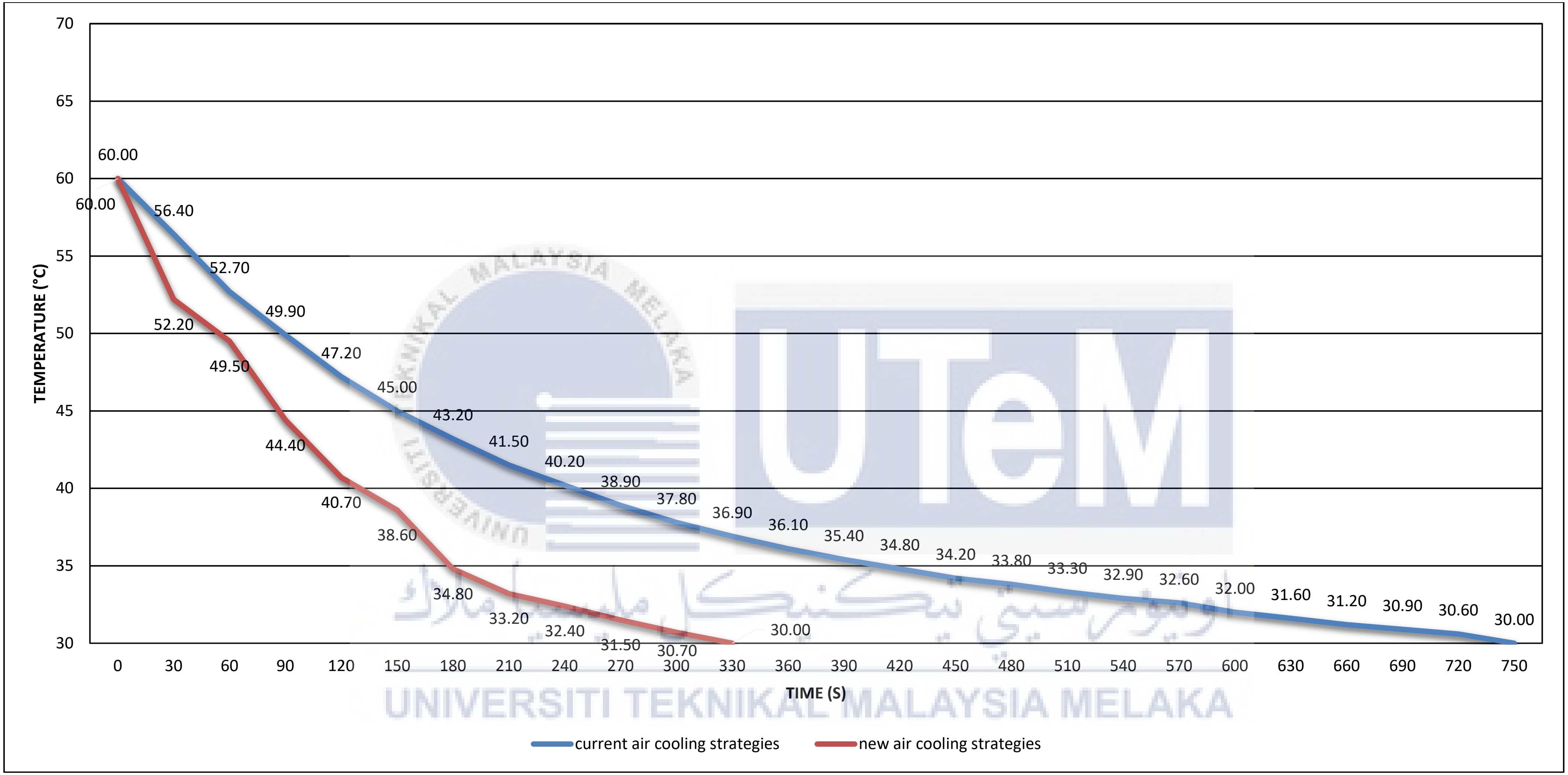


Figure 4.1 Temperature vs Time of duration for the Battery Pack to Cooldown from 60°C to 30°C when the vehicle in static.

Table 4.1 and figure 4.1, shows time that has been taken to cooldown the Formula Varsity battery pack from 60°C to 30°C C when the vehicle is in static. From the graph, a comparison of data was shown for the two types of air-cooling strategy: current air-cooling strategies (blue line) and the new air-cooling strategies that have been invented (red line).

The overall results that were presented show that using new air-cooling techniques significantly improves cooling times. The application of the innovative cooling tactics dramatically shortens this time to cooldown the battery pack to approximately 330 seconds, while the existing air-cooling approach takes 750 seconds to accomplish the requisite temperature reduction. This significant decrease in cooldown time indicates a significant improvement in the cooling system's efficiency. This enhancement has led to a discovery to bring benefits to the safety of the battery because this advancement can lead to improved battery pack performance and longevity as well as enhanced thermal management capabilities.

This difference of results data are obvious to be seen because the enhancement of the new air cooling strategies were applied with both natural and forced convection air cooling method in which the air ducting provide cooling through the ducting which allows cold air to enter the battery pack, allowing the cold air that are more dense than hot air to replace the hot air in the battery pack through natural fluid motion that occurs by buoyancy. Besides that, the aids of the forced convection strategies which consist of the fan also help by pulling more cold air into the battery pack through the ducting and this effort has allows more volume of cold air to be pull into the battery pack to cooldown the internal temperature of the battery pack.

4.2.2 Vehicle Applied with a Low Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at low speed)

In this experiment procedure, a fan been setup in front of the vehicle and low setting of fan speed has been applied and this is to simulate the movement of vehicle at low speed which the airflows run throughout the vehicle body aids in cooling down the battery pack. Following analysis, the data were compiled into a table, and a graph was created.

Table 4.2 Time Taken to Cooldown the Battery Pack From 60°C to 30°C With Low Speed of Fan Applied at Front of Vehicle (simulate vehicle at low speed).

vehicle static (low fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	60.00	60.00
30	56.40	50.80
60	52.50	41.90
90	49.30	37.60
120	47.00	34.80
150	44.60	32.00
180	42.90	30.80
210	41.80	30.00
240	40.30	
270	39.40	
300	38.20	
330	37.30	
360	36.00	
390	35.40	
420	34.60	
450	34.10	
480	33.70	
510	33.40	
540	33.00	
570	32.30	
600	31.70	
630	31.20	
660	30.60	
690	30.00	
720		
750		

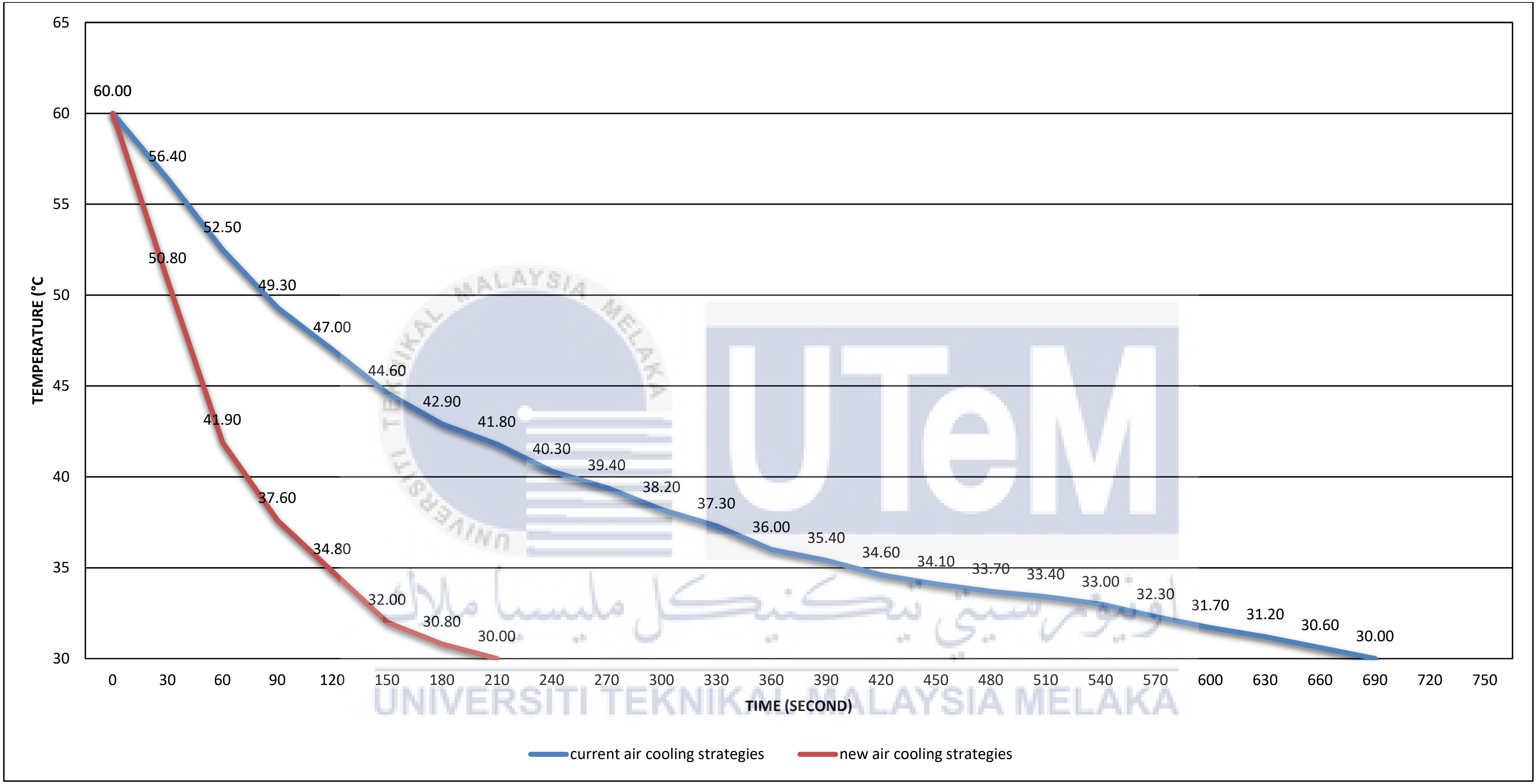


Figure 4.2 Temperature vs Time of Duration for the Battery Pack to Cooldown from 60°C to 30°C When Vehicle applied with a Low Setting of Fan Speed at the Front of the Vehicle.

Table 4.2 and Figure 4.2 graph temperature vs time shows time that has been taken to cooldown the Formula Varsity battery pack from 60°C to 30°C C when vehicle was applied with a low setting of fan speed at the front of the vehicle. The fan was set up to imitate the air flows that occur around the car body when it moves which helps in cooling down the battery pack. A comparison of data for the two types of air-cooling strategies: the newly developed air-cooling strategies (red line) and the existing air-cooling strategies (blue line) was displayed in the graph.

The total findings demonstrate that new air-cooling methods lead to significant improvements in cooling times. The duration of both air conditioning procedures was shortened for this experiment, which involved placing a low-speed fan at the front of the car. While the current air-cooling strategy takes 690 seconds to accomplish the necessary temperature drop, the implementation of the new cooling tactics substantially shortens this time to cooldown the battery pack to roughly 210 seconds. The cooling system's efficiency has significantly improved, as evidenced by this notable reduction in cooldown time.

Figure 4.2 graph shows both air cooling strategy conditions shorten the cooling time than the results that shown in Figure 4.1, which the results of the battery pack to cooldown while vehicle in static. This points to the assistance of the fan. The fan was positioned in front of the car at a low speed in an attempt to replicate the airflows that circulate throughout the vehicle and cool the battery pack. The current air-cooling strategies manages to reduce the duration to cooldown the battery pack by 60 seconds while substantial improvement shows with the new air-cooling strategies which the data shows that it reduces the time taken to cooldown the battery pack by 120seconds.

4.2.3 Vehicle applied with a High Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at high speed)

In this experiment, a fan is placed in front of the car and its speed is adjusted to a low setting to replicate the vehicle moving at a slow speed. The airflows created by the fan throughout the car's body help to cool the battery pack. A graph was created from the data collection after the data was examined, organized, and placed in a table.

Table 4.3 Time Taken to Cooldown the Battery Pack From 60°C to 30°C With High speed of Fan Applied at Front of Vehicle (simulate vehicle at High speed).

vehicle static (high fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	60.00	60.00
30	55.60	46.40
60	51.20	37.70
90	48.70	32.80
120	46.50	30.00
150	44.20	
180	42.90	
210	40.50	
240	39.80	
270	38.50	
300	37.60	
330	36.30	
360	35.20	
390	34.50	
420	33.80	
450	33.10	
480	32.50	
510	31.90	
540	31.20	
570	30.70	
600	30.30	
630	30.00	
660		
690		
720		
750		

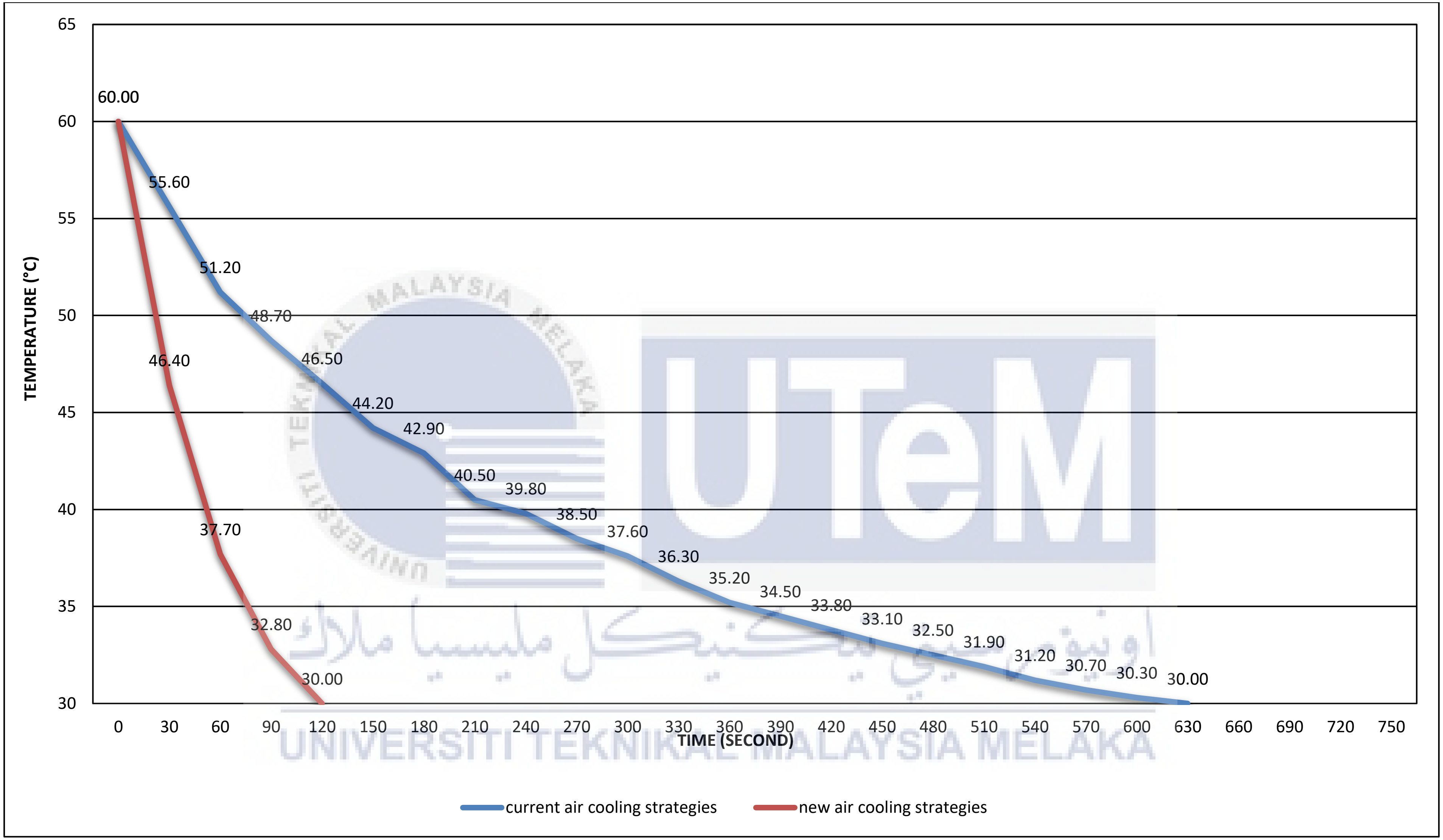


Figure 4.3 Temperature vs Time of Duration for the Battery Pack to Cooldown from 70°C to 30°C When Vehicle Applied with a High Setting of Fan Speed at the Front of Vehicle.

The temperature and time required to cool the Formula Varsity battery pack from 60°C to 30°C are displayed in Table 4.3 and Figure 4.3, respectively, while the front of the vehicle is applied with a fan that been set it speed set to a high setting. The fan was designed to replicate the airflows that surround the moving automobile body, assisting in the battery pack's cooling. A comparison of data for the two types of air-cooling strategies: the newly developed air-cooling strategies (red line) and the current air-cooling strategies (blue line) was displayed in the graph.

Overall results show that significant improvements in cooling times can be achieved using new air-cooling techniques. For this experiment, in which a high-speed setting of fan has been placed at the front of the vehicle, the duration of both air-cooling strategies to cool down was decreased. Using the new cooling techniques greatly reduces the amount of time needed to cool the battery pack, which the time taken was 210 seconds, compared to the present air-cooling strategy which manages to complete in 630 seconds.

Figure 4.3 graph shows both air cooling strategy conditions improve to shorten the cooling time than the results that shown in Figure 4.1 and figure 4.2. This difference was due to the fan speed being set at the highest speed which the fan that was positioned in front of the vehicle and this is to replicate the airflows circulate throughout the vehicle and cooldown the battery pack. The new and current air-cooling strategies that were applied with high speed of fan at the front of the vehicle manages to reduce the duration to cooldown the battery pack greatly by 120 seconds. The new air-cooling systems with the application of high-speed fan significant reduction in comparison to the application of a low-speed fan is due to the ducting that controls the amount of airflow into the battery pack system. As a result, there are only noticeable differences in the amount of time it takes for the battery pack to cool down when the fan is applied at the front of the vehicle at a high speed versus a low speed.

4.2.4 Summary of Time Taken to Cooldown the Battery Pack of The Formula Varsity From 60°C to 30°C.

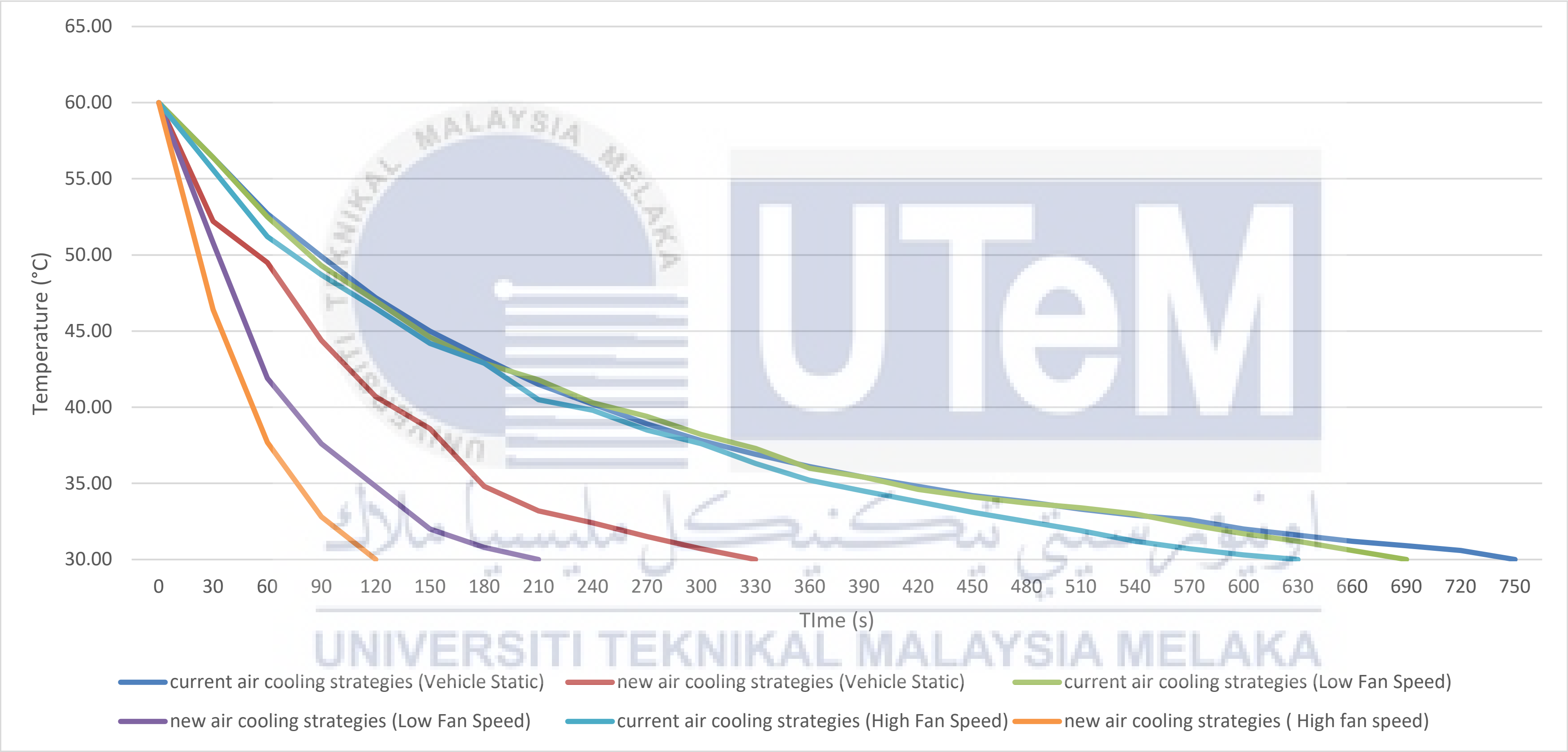


Figure 4.4 Summary of Time Taken to Cooldown the Battery Pack of The Formula Varsity From 60°C to 30°C.

The presented results compare the performance of newly developed air-cooling strategies with current air-cooling methods in cooling the Formula Varsity battery pack from 60°C to 30°C under different fan speed conditions. The data consistently reveals that the application of innovative cooling tactics significantly reduces cooldown times. When a low-speed fan is placed at the front of the vehicle to mimic airflow during motion, the new strategies decrease the cooldown time from 690 seconds (current method) to 210 seconds. Further, when a high-speed fan is employed, the cooldown time is reduced to 120 seconds compared to 630 seconds with the current strategy. Other than that, the graph also shows when the vehicle is in static the current air-cooling strategies took 750 seconds to cooldown the battery pack while the new air-cooling strategies manage to cut down the time by half which is approximately 330 seconds. This is due to the forced air suction from the axial fan manage to pull cold air from the ducting to flow to the battery pack, while when the current air-cooling strategies does not allow air to escape which it been concealed safely to keep air from escaping from the battery pack making the battery hard to cooldown.

This marked improvement suggests enhanced cooling system efficiency, crucial for the safety and longevity of the battery. The findings highlight how fan speed affects cooldown times, with high-speed fans showing more notable decreases because of better airflow control via the ducting system. All things considered, these results demonstrate the encouraging developments in battery cooling technology and point to the possibility of improved longevity and performance in challenging situations like Formula Varsity races.

4.3 Ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when light usage of battery such as vehicle electrical appliances and low speed driving)

In this experiment, heat rejection was simulated in light-load situations, like a vehicle electrical appliances and low speed driving, in order to evaluate a battery pack's capacity to maintain its ideal operating temperature under constant heat delivery. In order to simulate the thermal stress, the battery pack experiences under normal heat operating circumstances, the experiment entails exposing it to a continuous low heat source. This is to assess the efficiency of heat dissipation methods and guarantee that the battery pack stays within its designated temperature range for long-term performance by closely monitoring temperature variations.

For this experiment, the Formula Varsity battery pack was run with three different settings of experiments while the settings of the continuous heat supply were kept at the same settings which were low speed of blower and low settings of heat. There were three different settings of the condition of the vehicle: vehicle in static, imitating the vehicle movement in slow speed by setting up a fan with low setting of fan speed, and imitating the vehicle movement in high speed by setting up a fan with high setting of fan speed. Fans were being set up at the front of the vehicle to imitate the movements of air flows when the car moves. In this experiment, two fan speed settings are used: the low setting has an air volume of 214 m^3/min, while the high setting has an air volume of 270 m^3/min. In this experiment, An Arduino microcontroller, attuned to the battery's temperature, will activates the fan at 45°C, sustaining its operation until the temperature descends to 35°C. This intricate will loop repeats also showcasing the new strategy's efficiency in consistently maintaining the battery within the ideal working temperature range.

4.3.1 Vehicle in static.

In this experiment, the ability to keep the battery pack working in its optimal working temperature while the car is stationary is being assessed, monitored, and recorded. After data gathering, analysis, and table arrangement, a graph was created. After the data was inspected, arranged, and put in a table, a graph was produced from the data gathering.

Table 4.4 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle in Static.

Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	33.00	32.60
20	35.40	34.80
30	38.10	36.60
40	40.40	40.60
50	43.20	44.20
60	45.80	46.50
70	48.10	45.00
80	52.30	42.70
90	55.70	40.80
100	59.20	38.90
110	62.40	37.20
120	65.30	35.90
130	68.90	34.80
140	70.00	35.00
150	69.40	37.20
160	68.60	39.50
170	67.30	41.90
180	66.40	43.80
190	65.90	46.00
200	64.60	44.90
210	63.20	42.60
220	62.30	40.80
230	61.10	38.90

240	60.60	37.20
250	60.00	36.20
260	59.70	35.00
270	59.10	34.40
280	58.30	35.10
290	57.20	38.00
300	56.30	41.60
310	55.40	46.00
320	54.60	47.60
330	53.40	47.10
340	52.70	44.80
350	51.90	42.40
360	50.80	41.20
370	49.70	40.50
380	49.10	39.80
390	48.40	39.00
400	47.70	37.80
410	46.90	37.00
420	46.10	36.40
430	45.60	35.80
440	45.00	35.00

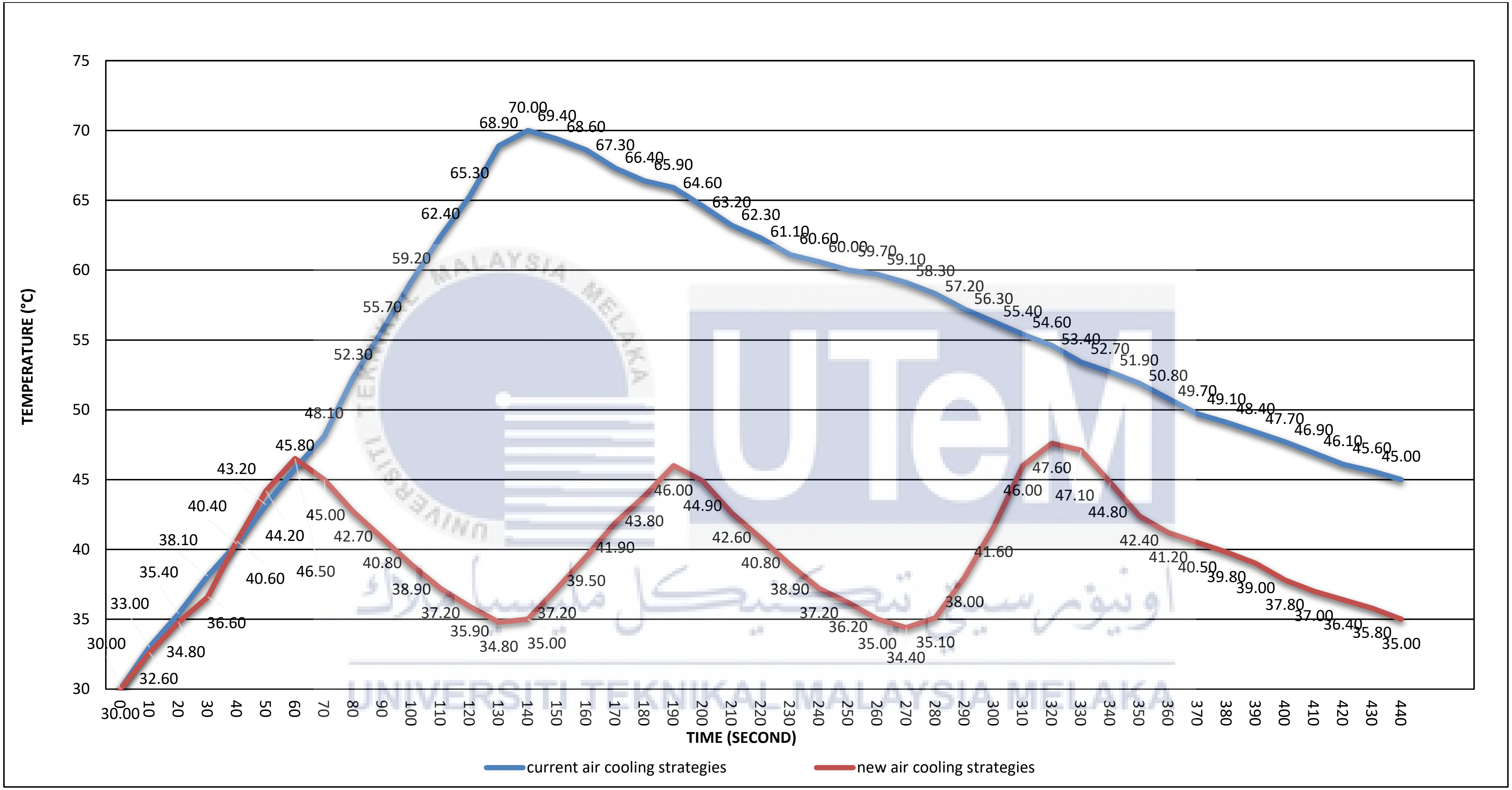


Figure 4.5 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle in Static.

The ability to maintain the battery pack's ideal operating temperature (between 35°C and 45°C) while the vehicle is in a static position is shown by the data and graph of temperature vs. time in Table 4.4 and Figure 4.5, respectively. A comparison is provided between the current air-cooling techniques (blue line) and the newly designed air-cooling strategies (red line). Overall, the results show that newly developed air-cooling technologies significantly increase the capacity to maintain the battery pack's ideal operating temperature (35°C to 45°C) when the vehicle is stationary.

In the illustration presented in Figure 4.5, the existing air-cooling techniques (shown by the blue line) cool down elegantly as the temperature hits 70°C at 140 seconds. This reaction is a result of shortcomings of the strategies currently in use, which find it difficult to maintain the battery pack's temperature within the ideal range while a continuous heat source is present. As a result, the heat sources been cut off quickly around 60°C to 70°C, allowing the battery to drop to a safe level. The cooldown period spans 300 seconds, concluding at 45°C, the upper threshold of the experiment's optimal working temperature.

On the contrary hand, Figure 4.5, shows how well-suited modern air-cooling methods are for keeping the battery pack between the ideal operating temperature range, even when the vehicle is stationary and exposed to a constant heat source (represented by the red line). This accomplishment is made possible by the newly developed air-cooling technique's deliberate use of a fan, which forms a forced convection system. Cool air is drawn through the ducting causes natural convection cooling which cools down the battery pack and heated air from the battery pack to drawn out by the fan. The battery's optimal working temperature range of 35°C to 45°C is maintained through a complicated loop that repeats three times in 440 seconds, showcasing the efficiency of the new air-cooling tactics.

4.3.2 Vehicle Applied with a Low Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at low speed)

In this experiment, the ability to maintain the battery pack's ideal operating temperature is being evaluated, tracked, and documented in this experiment. A fan is placed in front of the car, and its speed is adjusted to a low setting to replicate the vehicle moving at a slow speed while the airflows circulate throughout the body of the car, helping to cool the battery pack. Following the data's examination, organization, and placement in a table, a graph was produced from the data gathering.

Table 4.5 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) With Low speed of fan Applied at Front of Vehicle (simulate vehicle at Low speed).

(continuous heat) (heater set at low-speed low heat) (min fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	32.50	31.90
20	34.90	33.20
30	36.60	35.80
40	38.70	37.50
50	41.90	39.80
60	43.60	41.40
70	45.00	43.70
80	48.50	45.80
90	51.60	44.20
100	54.30	42.40
110	57.80	39.90
120	60.90	37.50
130	64.30	35.10
140	67.70	34.60
150	69.90	35.90
160	70.80	37.10

170	69.50	39.70
180	67.10	41.50
190	65.80	42.80
200	63.80	44.30
210	61.90	45.20
220	60.50	43.60
230	59.20	41.50
240	57.70	39.90
250	56.30	37.70
260	55.40	36.10
270	54.30	34.90
280	53.60	34.60
290	52.10	35.80
300	51.40	37.30
310	50.80	39.70
320	49.50	40.90
330	48.60	42.00
340	47.80	43.30
350	46.90	44.70
360	46.00	45.60
370	45.40	43.80
380	44.70	41.60
390	44.10	40.20
400	43.50	38.50
410	42.40	37.70
420	41.60	36.10
430	41.10	35.00
440	40.70	34.60

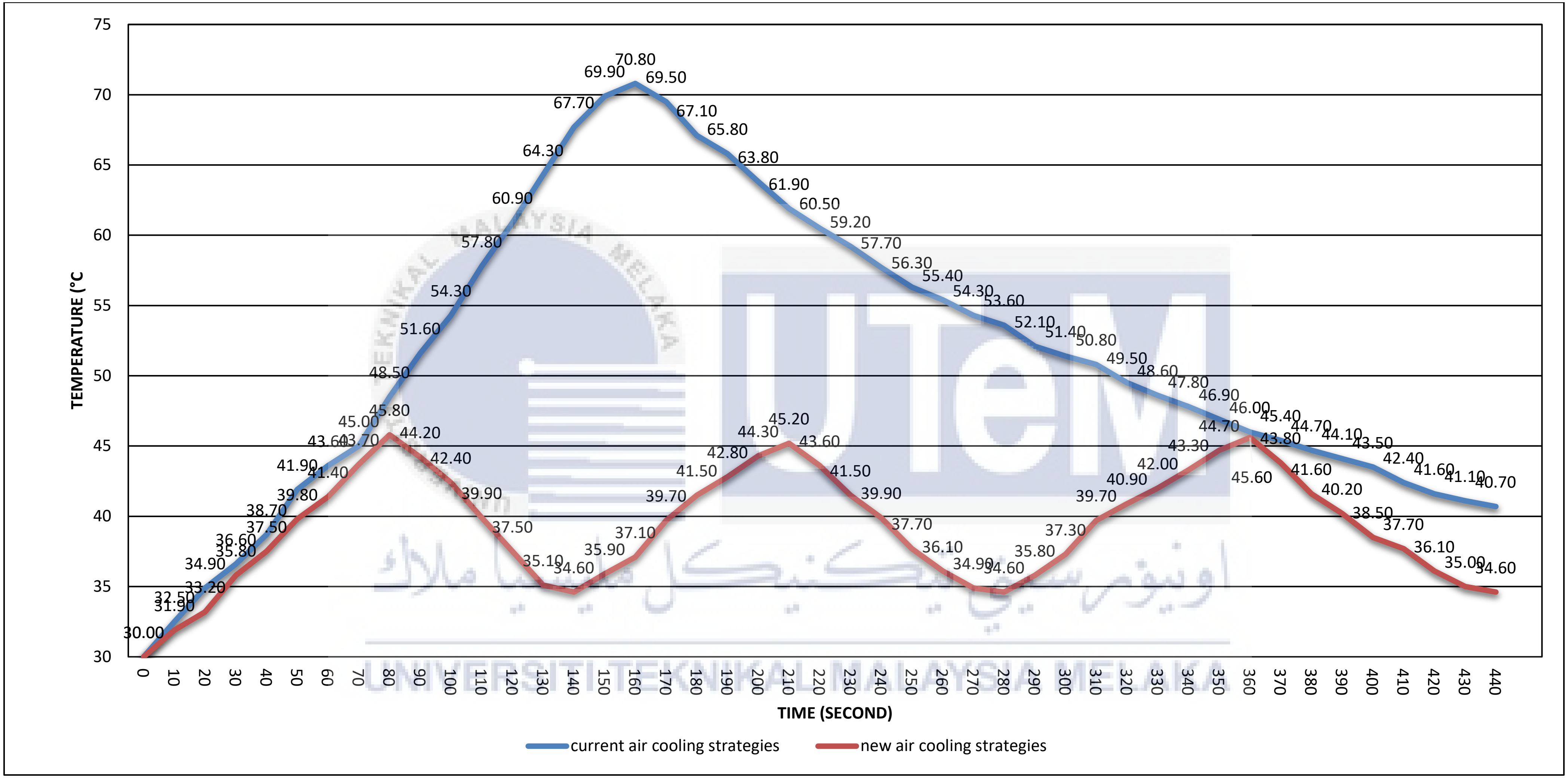


Figure 4.6 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle Applied with a Low Setting of Fan Speed at the Front of Vehicle.

The battery pack's ability to maintain its ideal working temperature (between 35°C and 45°C) when the Low Setting of Fan speed is positioned at the front of the vehicle to simulate the vehicle driving at a slow pace is demonstrated by the statistics in Table 4.5 and Figure 4.6, respectively. The newly created air-cooling strategies (red line) and the existing air-cooling processes (blue line) are contrasted. Overall, the results show that recently developed air-cooling technology has greatly improved the ability to sustain the battery pack's optimal operating temperature (35°C to 45°C) while the vehicle is applied with Low Setting of Fan Speed placed at the Front of Vehicle to simulate the vehicle moving at a slow speed.

In Figure 4.6, depicts how the blue line, representing the existing air-cooling approaches, gracefully cools down when the temperature reaches 70°C after being heated for 160 seconds. The inabiliy of the currently employed tactics to keep the battery pack's temperature within the optimal range while a constant heat source is present is what causes this reaction. Because of this, the heat sources were rapidly turned off between 60 and 70 degrees Celsius, allowing the battery to discharge heat to a safe level. The 210-second cooling phase ends at 45°C, which is the upper limit of the experiment's ideal operating temperature.

Figure 4.6, shows how the battery pack is carefully kept within its ideal temperature range by new air-cooling techniques. This accomplishment is made possible by the creative air-cooling method's addition of a fan (forced convection air cooling). The fan controls the ducting's natural convection cooling process, which pushes heated air out and naturally cools the battery pack. This intricate loop, which cycles three times in 440 seconds, maintains the battery's ideal working temperature range of 35°C to 45°C, demonstrating the effectiveness of the newly developed air-cooling strategies.

4.3.3 Vehicle Applied with a High Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at high speed)

The ability to keep the battery pack at its optimal working temperature is being assessed, monitored, and recorded in this experiment. The vehicle is equipped with a fan in front that is turned up to a high speed to simulate it on a high-speed travelling. The fan's airflows cool the battery pack by circulating air throughout the car's body. After the information was gathered, it was analyzed, arranged, and put in a table to create a graph.

Table 4.6 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) With High speed of fan Applied at Front of Vehicle (simulate vehicle at High speed).

(continuous heat) (heater set at low-speed low heat) (max fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	31.80	31.20
20	34.00	32.60
30	35.90	34.40
40	38.10	35.90
50	41.30	37.40
60	42.70	39.50
70	44.20	40.90
80	46.80	42.70
90	49.10	44.80
100	53.60	45.50
110	56.10	42.20
120	58.90	39.80
130	61.50	37.70
140	62.90	35.20
150	63.70	34.10
160	64.80	34.90
170	66.50	35.30
180	68.70	35.70

190	69.60	36.60
200	70.20	37.40
210	69.10	38.20
220	66.50	39.00
230	65.20	40.50
240	63.20	41.40
250	61.60	42.80
260	60.50	44.50
270	58.70	45.30
280	56.40	42.30
290	54.90	40.10
300	53.70	38.00
310	52.30	36.50
320	50.60	35.00
330	48.60	33.90
340	47.10	34.50
350	45.80	35.20
360	44.30	35.90
370	43.10	36.70
380	42.50	37.10
390	41.70	38.20
400	40.40	39.30
410	39.60	40.70
420	38.90	42.00
430	37.50	43.20
440	36.80	44.80

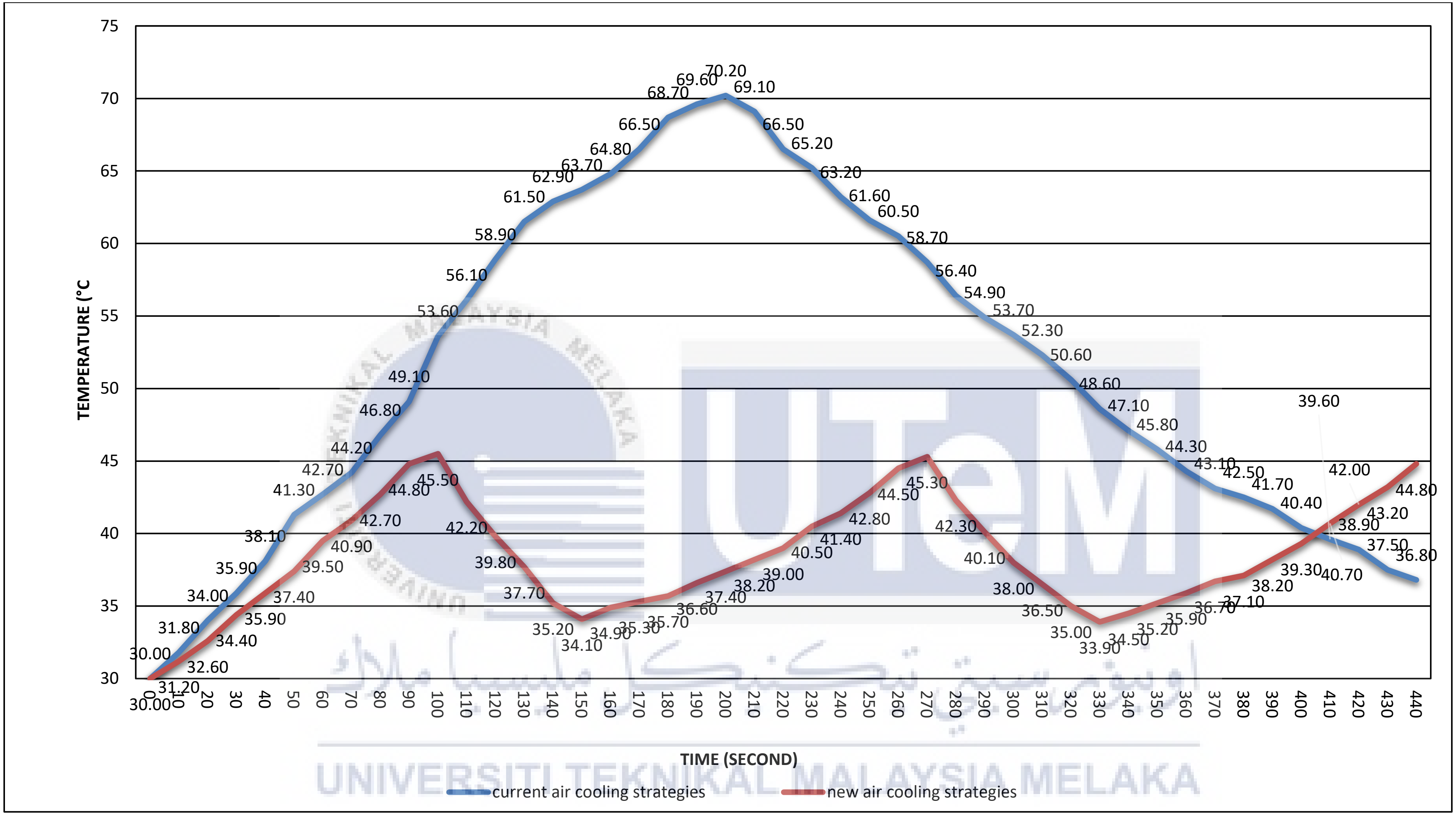


Figure 4.7 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle Applied with a High Setting of Fan Speed at the Front of Vehicle.

The figures in Figure 4.7 and Table 4.6, respectively, show how the battery pack can keep its optimal working temperature (between 35°C and 45°C) when the high setting of fan speed is placed in front of the car in order to simulate the car moving at a high speed. This comparison shows the differences between the newly developed air-cooling techniques (red line) and the current air-cooling procedures (blue line). The ability of the battery pack to maintain its ideal operating temperature (between 35°C and 45°C) when the vehicle is operated at a high setting of fan speed, which is placed at the front of the vehicle to simulate high speed, has been significantly enhanced by recently developed air-cooling technology, according to the overall results.

As the temperature rises to 70°C after 200 seconds of heating, the blue line Figure 4.7, which represents the current air-cooling technique, elegantly cools down. This response is brought on by the current strategies' failure to maintain the battery pack's temperature within the ideal range in the presence of a continuous heat source. As a result, between 60°C and 70°C, the heat sources were quickly turned off, enabling the battery to discharge heat to a safe level. The 150-second cooling phase ends at 45°C, which is the upper limit of the experiment's ideal operating temperature.

In Figure 4.7, the new air-cooling techniques ensure the battery pack remains in its optimal temperature range. This success is attributed to the inventive air-cooling approach, featuring the integration of a fan for forced convection air cooling. The fan manages the natural convection cooling within the ducting, expelling heated air and facilitating the natural cooling of the battery pack. This complex loop, which completes only two cycles in 440 seconds, due to the battery pack's increasing heat is lessened by the fan's rapid speed, thus demonstrates how well the innovative air-cooling solutions when the vehicles run at high speed while keeping the battery within its ideal working temperature range of 35°C to 45°C.

4.3.4 Summary of Ability to keep the battery pack working in its optimal working temperature. (continuous heat supply to simulate the heat rejection from battery when light usage of battery such as vehicle electrical appliances and low speed driving)

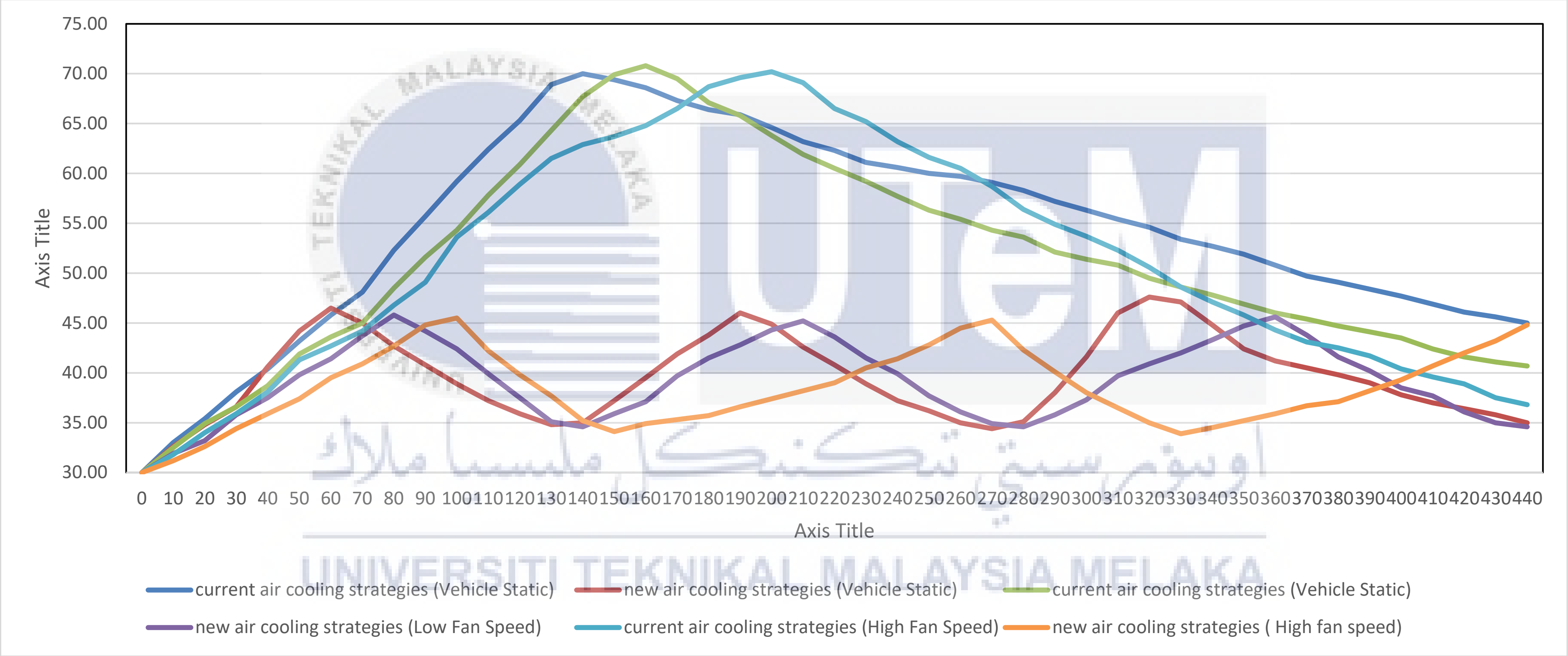


Figure 4.8 Summary of Ability to keep the battery pack working in its optimal working temperature. (continuous heat supply to simulate the heat rejection from battery when light usage of battery such as vehicle electrical appliances and low speed driving)

The presented results compare the performance of newly developed air-cooling strategies with current air-cooling methods ability to keep the battery pack working in its optimal working temperature which undergone different setup for certain condition. Experimental testing was done when the vehicle was in static and in certain conditions which under different fan speed at the front of vehicle. Data reveals that the application of the newly developed cooling strategies managed to maintain the battery pack in optimal working temperature. However, the current air-cooling strategy failed to maintain the battery pack in its optimal working temperature (35°C to 45°C) when continuous heat applied to the battery pack, thus the heat supply was been forced to shut to make sure that the battery won't suffer any damage.

When a low-speed fan and a high-speed fan is placed at the front of the vehicle to mimic airflow during motion, the new strategies manage to control the battery pack temperature. All the graph shows when a speed fan is applied to the front of the vehicle, the battery pack temperatures are gradually increasing when the system are off, while when the system are activated, the temperature decreases rapidly indicates the success of the new air-cooling strategies. Even though the vehicle in static the new air-cooling strategy system still manage to cool down the battery pack to its optimal working temperature, but the current air-cooling system failed in all conditions.

These findings highlight how fan speed affects cooldown times and heated duration of battery pack, with high-speed fans showing more notable increases for cooldown times and decreases of duration of the battery to exceed its optimal working temperature because of better airflow control via the ducting system. From the overall data, as the speed of the fan increases, the time it takes to cool down the battery decreases and the time of the battery to reach it upper limit of optimal working temperature increases. Results demonstrate the efficiency of the new air-cooling strategy compared to current air-cooling strategies.

4.4 Ability to keep the battery pack working in its optimal working temperature (continuous heat supply to simulate the heat rejection from battery when heavy usage of battery such as in Formula Varsity race)

In this experiment, we assess a battery pack's ability to sustain its ideal operating temperature under continuous heat delivery by simulating the heat rejection experienced in high-load scenarios, like a Formula Varsity race. The experiment involves subjecting the battery pack to a constant high heat source in order to replicate the thermal stress that it encounters under high operating conditions. This is to analyze the efficiency of heat dissipation mechanisms and ensure that the battery pack stays within its prescribed temperature range for long-term performance by closely monitoring temperature variations.

For this experiment, the Formula Varsity battery pack was run with three different settings of experiments while the settings of the continuous heat supply were kept at the same settings which were high speed of blower settings and high settings of heat. There were three different settings of the condition of the vehicle: vehicle in static, imitating the vehicle movement in slow speed by setting up a fan with low setting of fan speed, and imitating the vehicle movement in high speed by setting up a fan with high setting of fan speed. Fans were being set up at the front of the vehicle to imitate the movements of air flows when the car moves. In this experiment, two fan speed settings are used: the low setting has an air volume of 214 m^3/min, while the high setting has an air volume of 270 m^3/min. In this experiment, an Arduino microcontroller activates the fan at 45°C, running until the temperature hits 35°C. This loop highlights the efficiency of the new strategy in consistently keeping the battery within the ideal working temperature range.

4.4.1 Vehicle in static.

The ability to maintain the battery pack's ideal operating temperature while the car is immobile is being evaluated, tracked, and documented in this experiment. A graph was made following the collection, processing, and arranging of the data in tables. A graph was created from the data collection after the information was examined, organized, and placed on a table.

Table 4.7 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle in Static.

vehicle static (continuous heat) (heater set at high-speed high heat)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	35.00	34.60
20	38.40	37.90
30	42.20	40.50
40	45.60	44.20
50	49.10	47.50
60	53.50	49.30
70	58.40	50.90
80	61.90	51.50
90	66.60	52.00
100	70.80	52.40
110	69.90	53.00
120	69.20	54.50
130	68.60	55.30
140	67.80	55.90
150	67.10	56.50
160	66.70	57.60
170	66.20	58.90
180	65.80	59.70
190	65.30	60.60
200	64.90	61.10
210	64.30	61.80

220	63.70	62.70
230	63.00	63.30
240	62.40	63.90
250	61.80	64.20
260	61.10	65.00
270	60.70	65.30
280	60.10	65.60
290	59.60	65.40
300	59.00	65.30
310	58.30	65.40
320	57.90	65.60
330	57.10	65.80
340	56.90	66.00
350	55.90	65.80
360	55.20	65.60
370	54.40	65.70
380	53.70	65.90
390	53.00	66.10
400	52.30	66.30
410	51.50	66.50
420	50.80	66.40
430	49.90	66.50
440	48.80	66.50

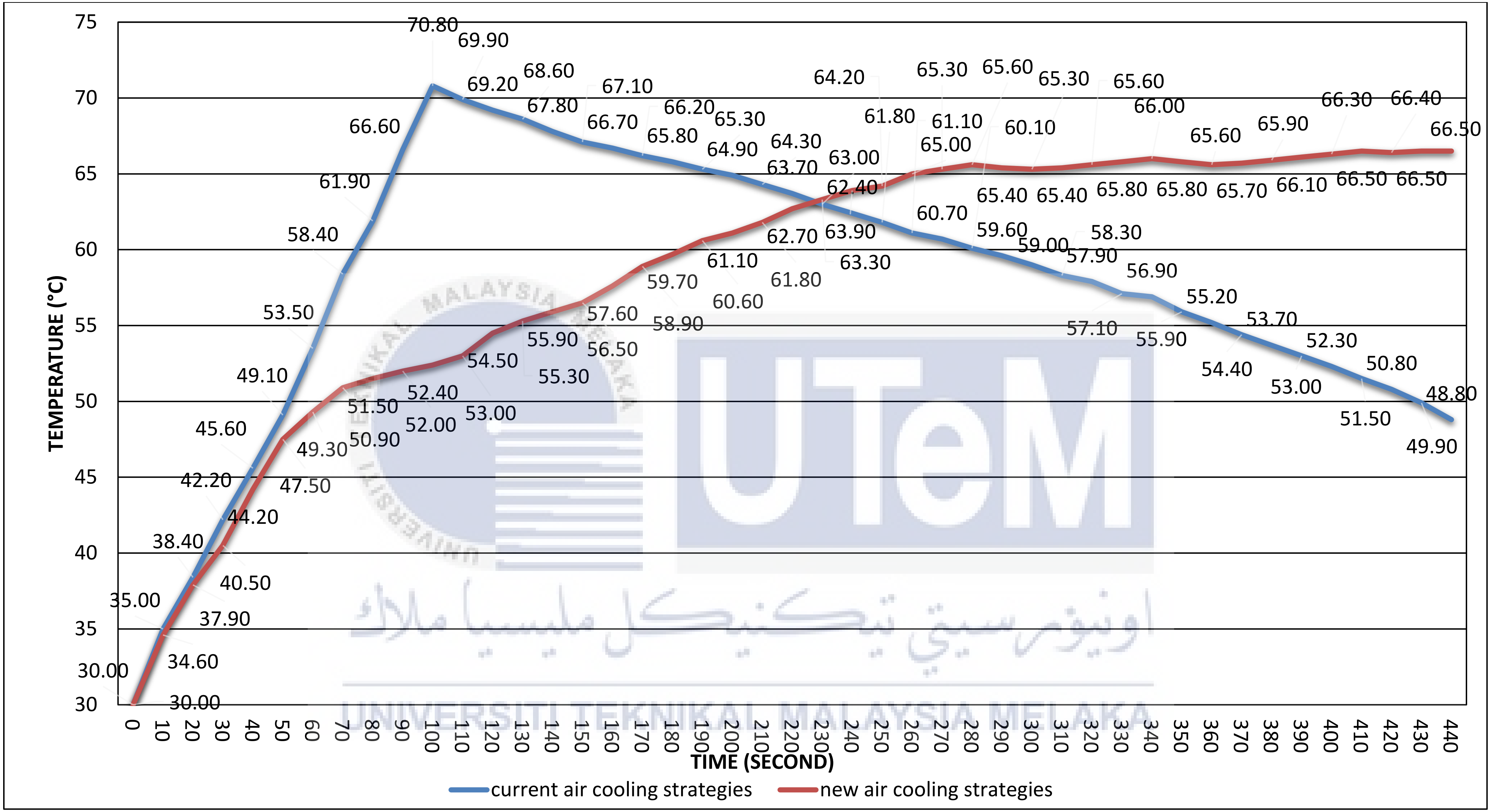


Figure 4.9 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle in Static.

The statistics in Figure 4.9 and Table 4.7, respectively, illustrate the battery pack's ability to maintain its ideal operating temperature (between 35°C and 45°C) when the vehicle is in a static posture. The newly developed air-cooling strategies (red line) and the existing air-cooling procedures (blue line) are compared. This analysis shows the inability to sustain the battery pack's optimal operating temperature (35°C to 45°C) while the vehicle is stationary.

As the temperature reaches 70°C at 100 seconds in the figure provided in Figure 4.9, the current air-cooling techniques been let gradually cool down. The inability of the air-cooling methods to keep battery pack's temperature within the optimal range while a constant heat source is present, causes this reaction. The heat sources were rapidly turned off between 60 and 70 degrees Celsius, allowing the battery to cool to a safe level. Because it takes longer to drop down to 45°C than 440 seconds, data when it reaches the required temperature is not captured.

Figure 4.9, also illustrates new air-cooling methods failed to maintain the battery pack within the optimal operating temperature when the vehicle is in static. The new air-cooling method is unable to handle the constant high heat that has been delivered. Statistics and graphs demonstrate that as the system is turned on, the new air-cooling system is able to slow down and regulate the rapidly rising temperature. This is due to the fan of the system increasing the air volume intake of the ducting, allowing air to cool the battery pack more efficiently.

At the end of this experiment, evidence shows that the battery pack was not adequately cooled by the new or existing air-cooling procedures. The heat that was projected, however, was illogical because, in a static vehicle, a battery with minimal utilization does not have a high heat rejection capability because it has not been fully utilized.

4.4.2 Vehicle Applied with a Low Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at low speed)

The ability to keep the battery pack at its optimal working temperature is being assessed, monitored, and recorded in this experiment. In order to simulate the automobile moving slowly and to assist cool the battery pack, a fan is mounted in front of the vehicle and its speed is set to a low setting. Airflows from the fan circulate throughout the car's body. After the information was gathered, it was analyzed, arranged, and stored in a table to create a graph.

Table 4.8 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Low High speed of Fan Applied at Front of Vehicle (simulate vehicle at Low speed).

vehicle static (continuous heat) (heater set at high-speed blower and high heat) (Low fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	34.40	33.80
20	37.80	37.50
30	41.60	40.10
40	45.00	43.30
50	48.70	46.60
60	52.90	48.20
70	56.20	50.40
80	58.80	51.20
90	62.70	51.70
100	64.30	52.00
110	67.50	52.90
120	69.10	53.60
130	70.30	54.70
140	69.40	55.50
150	68.80	56.20

160	68.00	57.10
170	67.30	58.00
180	66.50	58.80
190	65.60	59.50
200	64.90	60.30
210	64.00	61.10
220	63.20	61.90
230	62.70	62.50
240	61.80	63.30
250	60.90	64.10
260	59.80	64.80
270	59.00	65.10
280	58.20	65.30
290	57.30	65.50
300	56.40	65.60
310	55.40	65.40
320	54.80	65.30
330	54.10	65.50
340	53.70	65.50
350	53.00	65.60
360	52.40	65.70
370	51.60	65.80
380	50.80	65.60
390	49.50	65.50
400	48.60	65.70
410	47.90	65.90
420	47.10	66.20
430	46.50	66.10
440	45.80	66.20

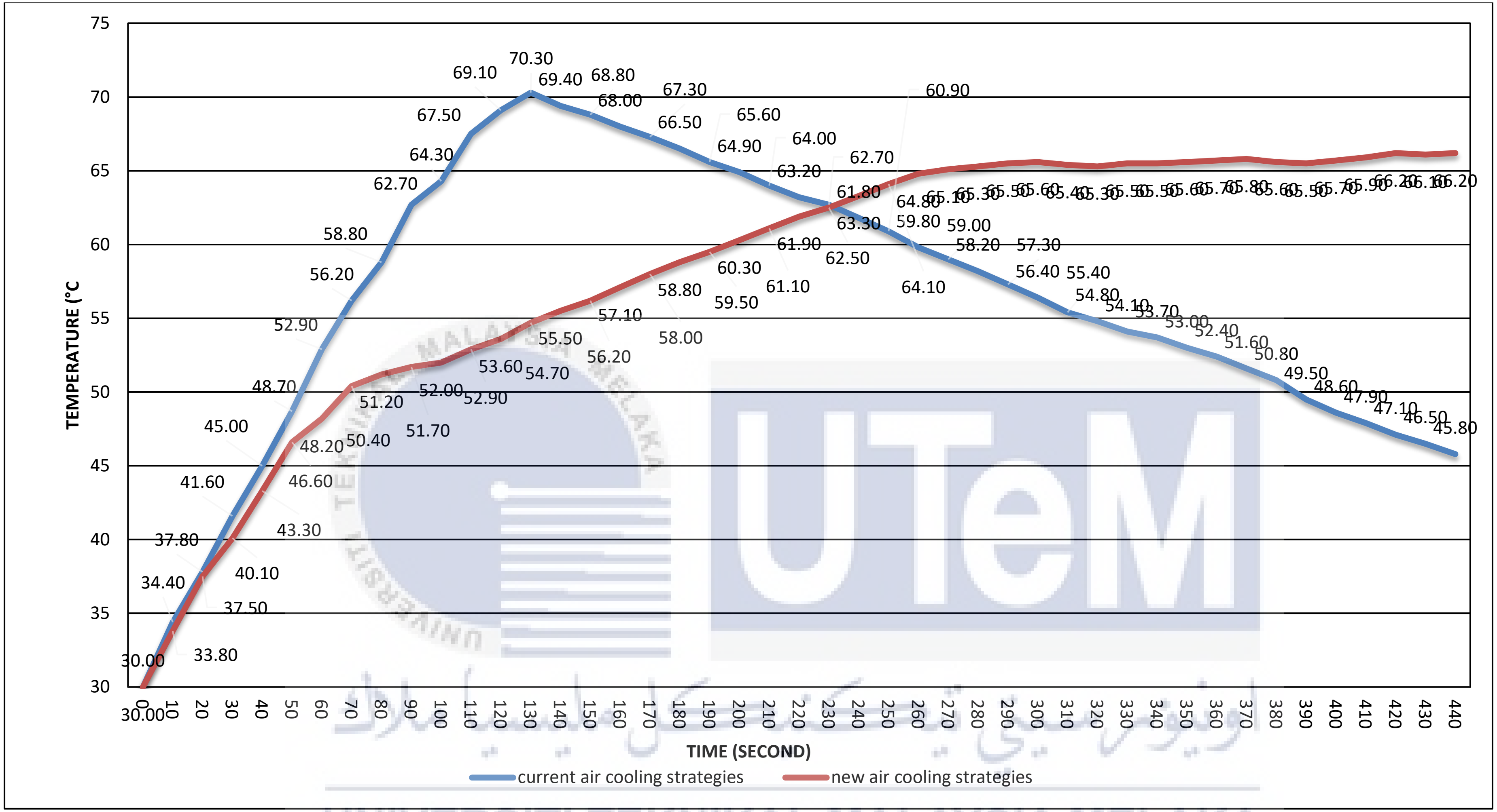


Figure 4.10 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle Applied with a Low Setting of Fan Speed at the Front of Vehicle.

The battery pack's capacity to sustain its optimal working temperature (between 35°C and 45°C) while the car is applied with a low setting of fan speed at the front is demonstrated by the Figure 4.10 and Table 4.8, respectively. The newly created air-cooling strategies (red line) and the existing air-cooling processes (blue line) are contrasted. The investigation demonstrates that the battery pack cannot be kept at its ideal working temperature of between 35°C and 45°C even when vehicle applied with a low setting of fan speed at the front of vehicle to imitate the vehicle cruising at low speed.

As seen in Figure 4.10, the temperature reaches 70°C at 130 seconds, at which point the existing air-cooling mechanisms are allowed to cool down gradually. This reaction is brought on by the air-cooling techniques' incapacity to maintain the battery pack's temperature within the ideal range in the presence of a continuous heat source. Between 60 and 70 degrees Celsius, the heat sources were quickly shut off to allow the battery to cool to a safe temperature. Since it takes longer than 440 seconds to drop to 45°C, data is not recorded when the temperature reaches the necessary level. For this scenario, the time taken to reaches 70°C increase than the data of Figure 4.10 and this is because of the aids of the low speed of fan to allow the heat to increasing slowly than increasing rapidly in data of Figure 4.10.

Additionally, Figure 4.10 shows that while the vehicle is applied with a low setting of fan speed at the front of vehicle, the battery pack is not kept within the ideal operating temperature range by the current air-cooling techniques. The continuously high heat that has been supplied is too much for the new air-cooling technique to handle. The statistics and graph, however, reveal that as soon as the system is turned on, the new air-cooling system is still able to slow down and regulate the fast-rising temperature. This is because the system's fan increases the ducting's air volume intake, which makes it possible for air to cool the battery pack more effectively.

The results of this experiment demonstrate the battery pack was not sufficiently cooled using either the new or old air-cooling techniques. However, the heat that was projected was nonsensical because a battery with little utilization in a cruising speed of vehicle does not have a strong heat rejection capability because it is not completely utilized.

4.4.3 Vehicle Applied with a High Setting of Fan Speed at the Front of Vehicle (to simulate vehicle moves at High speed)

The ability to maintain the battery pack at its ideal working temperature is being evaluated, tracked, and documented. A fan is placed in front of the car and has a high-speed setting on it to help cool the battery pack and imitate the car moving at a fast pace as in the Formula Varsity Race. The car's body is circulated by airflows from the fan. After the data was collected, a graph was made by analyzing, organizing, and storing it in a table.

Table 4.9 Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When High speed of Fan Applied at Front of Vehicle (simulate vehicle at High speed).

vehicle static (continuous heat) (heater set at high-speed blower and high heat) (High fan speed)		
Time (seconds)	Temperature (°C)	
	current air-cooling strategies	new air-cooling strategies
0	30.00	30.00
10	33.20	32.50
20	36.60	34.80
30	39.90	36.50
40	41.60	38.90
50	43.50	41.30

60	46.80	43.50
70	49.70	45.40
80	52.90	46.10
90	54.90	45.80
100	57.60	44.60
110	60.70	43.90
120	62.50	43.10
130	64.10	42.40
140	66.50	41.60
150	68.70	41.00
160	70.50	40.50
170	68.90	39.90
180	67.80	39.50
190	66.40	38.90
200	64.00	38.20
210	63.10	37.60
220	61.90	37.00
230	60.80	36.50
240	59.70	36.10
250	58.40	35.70
260	57.00	35.40
270	56.50	35.10
280	55.20	34.80
290	54.10	34.60
300	53.70	34.90
310	52.60	35.20
320	51.50	36.40
330	50.10	37.80
340	48.20	40.20
350	47.30	42.10
360	46.40	44.40
370	45.10	45.70
380	44.40	46.00
390	43.60	45.70
400	42.70	44.60
410	41.90	43.80
420	41.10	42.90
430	40.70	41.70
440	39.80	41.00

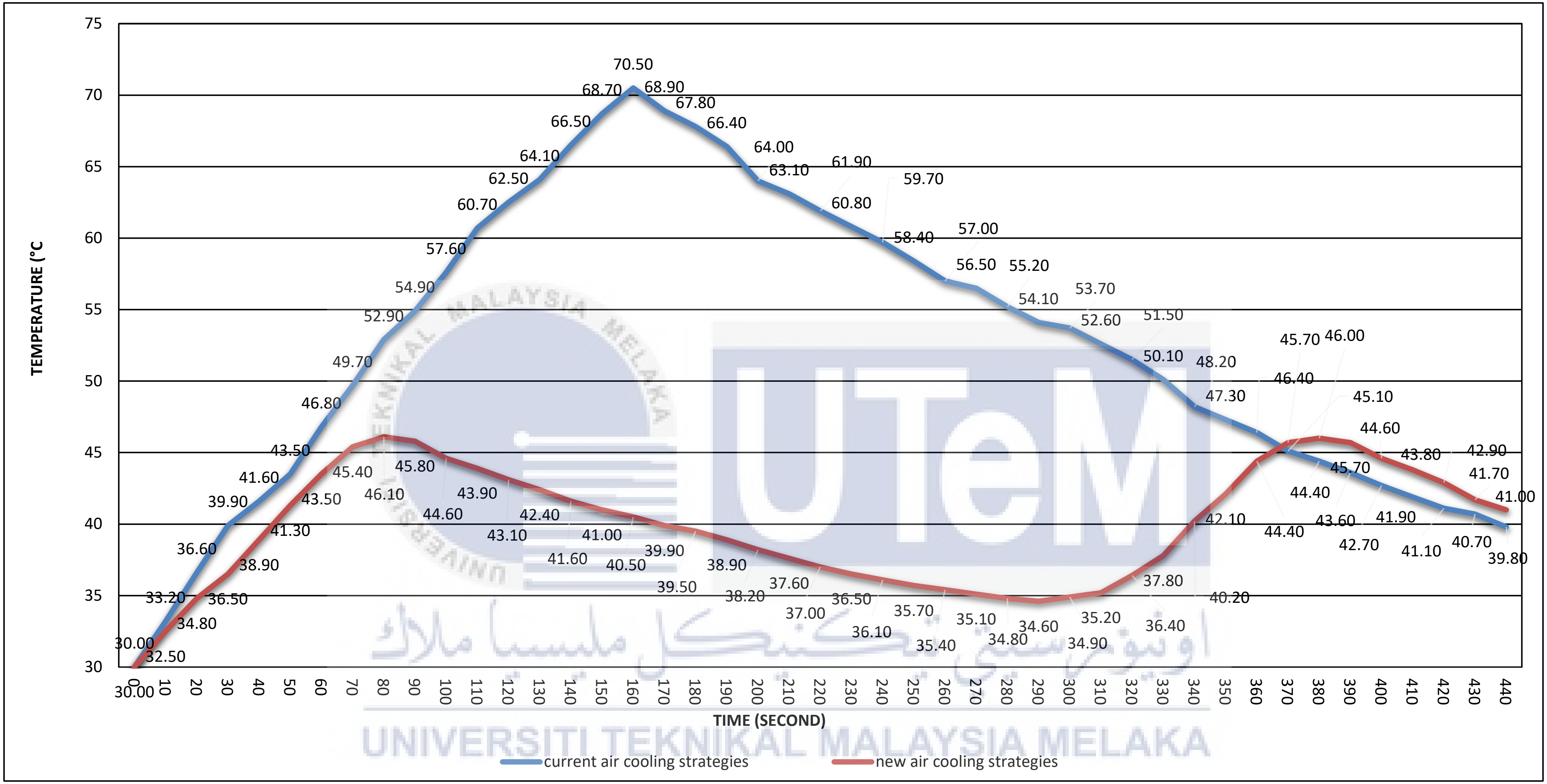


Figure 4.11 Temperature vs Time of Data for the Ability to Keep the Battery Pack Working in its Optimal Working Temperature (35°C - 45°C) When Vehicle Applied with a High Setting of Fan Speed at the Front of Vehicle.

Figure 4.11 and Table 4.9, respectively, show how long the battery pack can maintain its ideal operating temperature (between 35°C and 45°C) when the automobile is stationary. There is a comparison between the recently developed air-cooling techniques (red line) and the current air-cooling procedures (blue line). The experiment reveals that the battery pack cannot be retained at its ideal working temperature of between 35°C and 45°C even when vehicle applied with a low setting of fan speed at the front of vehicle to imitate the vehicle travelling at low speed.

As seen in Figure 4.10, the current air-cooling methods are allowed to progressively cool down after 160 seconds, when the temperature hits 70°C. This is because the battery pack's temperature cannot be kept within the optimal range in the presence of a constant heat source, the air-cooling strategies fail to prevent this reaction. To ensure that the battery cooled to a safe temperature, the heat sources were promptly turned off between 60°C and 70°C. The time as it reaches the optimal working temperature of battery is 380 seconds and this is due to the fan high speed which aids in the cooling down the battery pack. For this scenario, the time taken to reaches 70°C increase than the data of Figure 4.10 and this is due to the aids of the high speed of fan to allow the heat to increasing slowly than increasing rapidly as appeared in the graph of Figure 4.10.

Figure 4.11 elegantly illustrates that, with the vehicle's front fan set to high speed, the new air-cooling methods effectively maintain the battery pack within its optimal temperature range, even under constant high heat. Despite the 230 seconds required for the battery to cool to the lower limit of the optimal working temperature, this experiment validates the success of the new air-cooling strategies. These strategies demonstrate their efficiency by ensuring the battery pack remains at its optimal working temperature despite the application of high heat, mimicking the intense usage of the battery pack. Additionally, the results indicate that the battery takes a longer time to heat up beyond the optimal working temperature, attributed to increased air volume flowing into the battery pack ducting during high-speed vehicle movement or when a high-speed fan is placed at the front.

The overall result of this experiment not only highlights how well the newly developed air-cooling strategies protect the battery pack's ideal operating temperature under demanding circumstances, but it also points to a possible path towards extended battery life. The robustness and efficiency of these innovative cooling methods are highlighted by their capacity to withstand extended periods of high heat and their carefully calibrated cooldown periods. Essentially, this experiment confirms the effectiveness of the new air-cooling methods while also raising the possibility that they could be used to improve battery systems' endurance and sustained efficiency in harsh conditions

4.4.4 Summary of Ability to keep the battery pack working in its optimal working temperature. (continuous heat supply to simulate the heat rejection from battery when heavy usage of battery such as in Formula Varsity race).

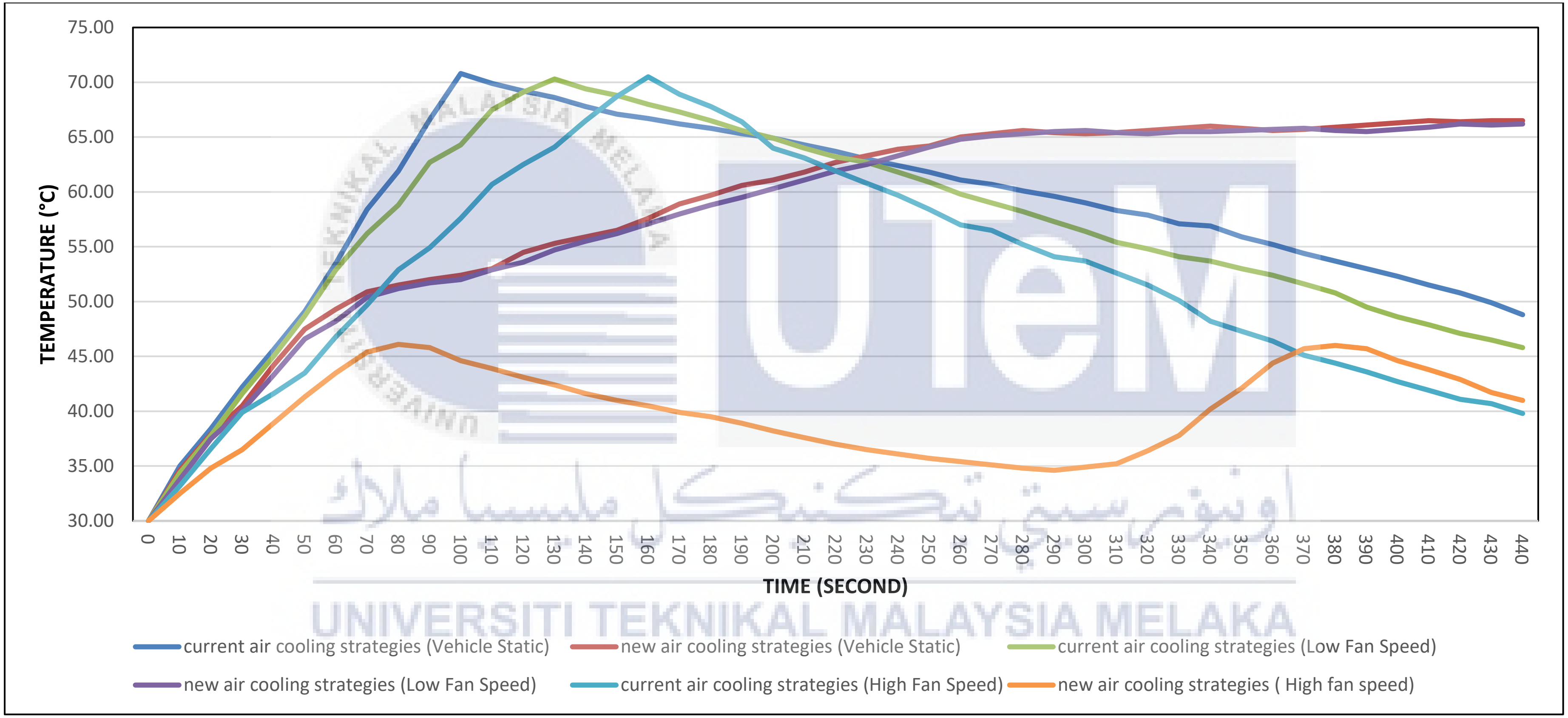


Figure 4.12 Summary of Ability to keep the battery pack working in its optimal working temperature. (continuous heat supply to simulate the heat rejection from battery when heavy usage of battery such as in Formula Varsity race).

The presented results compare the performance of newly developed air-cooling strategies with current air-cooling methods ability to keep the battery pack working in its optimal working temperature which undergone different setup for certain condition. Experimental testing was done when the vehicle was in static and in certain conditions which under different fan speed at the front of vehicle. Data reveals that the application of the newly developed cooling and current air-cooling strategy failed to maintain the battery pack in its optimal working temperature (35°C to 45°C) when continuous heat applied to the battery pack, thus the heat supply was been forced to shut to make sure that the battery won't suffer any damage.

The graph shows only new air-cooling strategies which applied with high-speed fans at the front of the vehicle were managed to achieve a successful test. This is due to the test that been run were tough for other conditions to adapt which it is illogical because battery will only generate high heat rejection when it's been fully utilized which when the vehicle moves at a fast pace.

These findings highlight how fan speed affects cooldown times and heated duration of battery pack, high-speed fans causing better airflow control via the ducting system and with the aids of the new air-cooling systems it manages to maintain the battery pack in its optimal working temperature. Results demonstrate the efficiency of the new air-cooling strategy compared to current air-cooling strategies.

4.5 Summary of Results Data Analysis of The Performance of The Current and New Air-Cooling Strategies for The Electric Formula Varsity Battery Pack

According to a comprehensive examination of the data pertaining to the new air-cooling method, the system effectively maintains the battery pack within its optimal working temperature range under all trial scenarios. However, under some irrational settings, such as excessive battery heat when the car is stationary and mimicking cruising speed, the system was unable to effectively cool the battery pack to keep it at the ideal operating temperature. This can be explained by the fact that the experiment's settings such as applying intense heat to a stationary vehicle were not appropriate for the situation.

In contrast, a meticulous analysis of the data unveils a notable deficiency in the current air-cooling strategies. Unlike their innovative counterparts, the existing cooling methods falter when confronted with irrational settings, particularly scenarios involving excessive battery heat during stationary periods or attempts to emulate cruising speed. In such instances, the current system struggles to efficiently cool the battery pack, leading to an inability to sustain the ideal operating temperature. This shortfall can be attributed to the mismatch between the experiment's settings, particularly the application of intense heat to a stationary vehicle, and the adaptability limitations of the current air-cooling strategies, highlighting a critical area for improvement in addressing unconventional conditions.

The first conditions of experimental which time taken to cooldown the battery pack of the formula varsity from 60°C to 30°C provide a comparison analysis between the current and the new air-cooling strategy. The time that was taken for the battery pack to cooldown from 60°C to 30°C by using the new air-cooling strategy shows a substantial advancement compared with the current air-cooling strategy. The experimental data that has been obtained shows that the new air-cooling strategy managed to cooldown the battery pack approximately more than the half of the time that is needed for the current air-cooling strategy to cooldown the battery pack. The outcomes demonstrated a noteworthy enhancement in performance subsequent to implementation, with the air-cooling system proving to be effective in delaying the time required to attain critical temperatures. Therefore, this shows how important this approach of advancement towards the battery pack.

The cooling capacity of the battery pack and its ability to keep battery pack in its optimal operating temperature emerged as a pivotal performance benchmark, and the results underscored the significance of advanced cooling methodologies. Employing intricate strategies, including precision-targeted airflow and optimized fan speeds, the new air-cooling system demonstrated remarkable efficiency in rapidly lowering the battery pack's temperature under duress and regulate the battery pack temperature to be in its optimal temperature of operating. The incorporation of precision control mechanisms and real-time monitoring ensured consistent maintenance of the battery pack within its ideal operating temperature range. Conversely, the current air-cooling strategy, as revealed by the data, fell short in delivering adequate cooling, especially during moments of heightened stress. This deficiency extended to both providing efficient cooling and sustaining the battery pack within its optimal operating temperature, even under light usage scenarios, such as utilizing electrical appliances or cruising at slow speeds. This disparity highlights a crucial area for enhancement in the current air-cooling strategy's adaptability to varying operational demands.

Furthermore, the new air-cooling approach is a symphony that plays out as it skillfully directs and synchronizes the battery pack's temperature regulation, even during the peak of high battery usage that brings about greater heat rejection. With the exception of a few nonsensical situations, the new approach handles every difficult note with grace in this elegant performance. These include the contradictory situations where the battery overheats when it is stationary and when it is cruising at a moderate pace and very little air enters the ducting to effectively cool the battery pack, which is struggling to reject a lot of heat. The new air-cooling approach falters in these contradictory chapters.

In conclusion, the investigation shows that the new air-cooling method works well to keep the battery pack within the ideal temperature range, even in the face of nonsensical settings. On the other hand, the existing air-cooling techniques are not flexible enough to handle non-standard situations. The comparison highlights the new method's major improvements, most notably its ability to cut the cooldown time from 60°C to 30°C. The benchmark demonstrates the advantages of improved cooling techniques; under stress, the new system exhibits efficiency while the conventional approach fails. Even with difficulties in absurd circumstances, the new method exhibits elegance. The experimental trip comes to an end with a clear indication of the potential of the novel air-cooling approach and the necessity of continuous improvement to meet operational demands. The successful application of the new air-cooling system for the Electric Formula Varsity battery pack represents a significant leap forward in electric vehicle technology. By effectively managing and maintaining the battery pack within its optimal working temperature range, the air-cooling system has not only improved immediate performance but has also contributed to the long-term reliability and efficiency of the electric vehicle.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Chapter 5 concludes the investigation into optimizing the air-cooling strategy for the Electric Formula Varsity battery pack. This study unveiled results and challenges encountered during project execution, emphasizing the significance of both current and new air-cooling strategies in overall performance assessment.

Through testing, analysis, and creative efforts, advancements were achieved, enhancing the cooling systems, and tackling critical battery temperature regulation. Experimental simulations provided key insights into both methodologies, particularly the battery pack's ability to maintain its ideal operating temperature under diverse usage conditions. Challenges arose in obtaining real-world data, necessitating various vehicle settings during experimental simulations. The acquired data is limited to the simulation and doesn't directly apply to real-world scenarios involving actual driving conditions.

The inquiry of optimizing air-cooling plan for Electric Formula Varsity battery pack comes to an end. Extensive testing and inventive initiatives enhanced the cooling system's efficiency, addressing significant battery temperature concerns. Models from experiments shed light on procedures and the battery's capacity to sustain ideal temperature. It is acknowledged that real-world data is difficult to get, and that the data obtained is only applicable to simulations and not immediately applicable to real-world driving circumstances. The development of electric vehicles is aided by this research.

5.2 Potential for Commercialization

The conclusion of the Electric Formula Varsity battery pack air-cooling optimization marks a significant stride in electric vehicle (EV) technology. Rigorous testing and innovative solutions have notably improved cooling system efficiency, addressing vital battery temperature concerns. Positioned at the forefront of the EV industry, this research offers a commercially viable solution, enhancing both battery performance and longevity. Experimental simulations provide key insights, paving the way for reliable EVs under diverse usage conditions.

As the research edges towards potential commercialization, the optimized air-cooling strategy holds promise to revolutionize the electric vehicle market. Meeting current demands and laying the groundwork for future sustainable transportation, this technology sets a new standard. Investors, manufacturers, and EV stakeholders stand to benefit, as the findings contribute significantly to global EV development.

In conclusion, the journey to optimize the Electric Formula Varsity battery pack's air-cooling plan is pivotal for a commercially viable and sustainable future in the expanding EV market. Positioned as a catalyst for the next era of efficient transportation, this research underscores a commitment to innovation and holds immense potential for industry transformation.

5.3 Recommendations for future development

Examining the outcomes closely reveals that the existing dataset and analysis are not applicable in the real world. The collected data, limited to simulations, is not flexible enough to be directly applied to the dynamic and uncertain driving environments found in real life. This restriction emphasizes the necessity of exercising caution in interpreting the results and considering their wider ramifications as well as their applicability in real-world driving situations. For future work, collaborate with authorities or stakeholders to establish a controlled testing environment meeting regulatory standards such as running the vehicle with the system in a wind tunnel which provides more detailed and accurate data. By exploring partnerships with testing facilities or regulatory bodies to safely operate the vehicle for comprehensive assessments. Consider advancements in simulation technologies for realistic evaluations without physical vehicle operation. Strive for a balance between technical precision and logistical feasibility in designing testing protocols.

To address the challenges posed by the battery pack's spatial constraints and regulatory limitations, future work should explore collaborative efforts with regulatory authorities to establish a framework for assessing and potentially modifying the battery pack. Engaging in open dialogue and seeking approval for necessary alterations to the battery pack's layout could pave the way for a more comprehensive evaluation. Additionally, considering alternative design approaches that work within existing regulatory boundaries while optimizing air-cooling efficiency is crucial. Exploring technological advancements and innovations that align with regulatory requirements would be instrumental in overcoming these limitations and ensuring the successful completion of the project in a timely manner.

5.4 Limitations.

This project encounters a constraint in testing the newly fabricated air-cooling system due to the inability to run the vehicle for an overall assessment of both the new and current air-cooling strategies. The intricate nature of the testing environment poses a challenge in executing a comprehensive evaluation of the system's functionality and performance. The constraints are not only technical but also logistical, requiring a balance between experimental rigor and practical considerations. Despite this limitation, the project emphasizes the significance of the simulated testing conducted, providing valuable insights and foundational data that pave the way for future testing under more extensive and realistic conditions.

Due to limitations on the battery pack's spatial layout, another limitation was encountered which a major challenge in thoroughly assessing the battery pack. Changes to the pack were further impeded by regulatory constraints imposed by the authorities. Despite these obstacles, the determination to investigate new methods within the current legal framework to maximize the efficiency of the air-cooling system remains in place in order to finish this project as soon as possible.

REFERENCES

[1] Qin, P., Sun, J., Yang, X., Wang, Q., Battery thermal management system based on the forced-air convection: A review, eTransportation, https://doi.org/10.1016/j.etran.2020.100097.

[2] Liu Y, Zhang J. Design a J-type air-based battery thermal management system through surrogate-based optimization. Applied Energy. 2019;252:113426.

[3] Akinlabi AAH, Solyali D. Configuration, design, and optimization of air-cooled battery thermal management system for electric vehicles: A review. Renewable and Sustainable Energy Reviews. 2020;125:109815.

[4] Liu Z, Wang Y, Zhang J, Liu Z. Shortcut computation for the thermal management of a large air-cooled battery pack. Applied Thermal Engineering. 2014;66:445-52

[5] Saw LH, Ye Y, Tay AAO, Chong WT, Kuan SH, Yew MC. Computational fluid dynamic and thermal analysis of Lithium-ion battery pack with air cooling. Applied Energy. 2016;177:783-92.

[6] Zhao C, Cao W, Dong T, Jiang F. Thermal behavior study of discharging/charging cylindrical lithium-ion battery module cooled by channeled liquid flow. International journal of heat and mass transfer. 2018;120:751-62.

[7] Wu, W., Xie, S., Zhang, W., Wang, C., Yang, J., & Rao, Z. (2022). Role of natural convection and battery arrangement for phase change material based battery thermal management unit. Journal of Energy Storage, 52, 104820. https://doi.org/10.1016/j.est.2022.104820

[8] Ranjbaran, Y. S., Shojaeefard, M., & Molaeimanesh, G. (2023). Thermal performance enhancement of a passive battery thermal management system based on phase change material using cold air passageways for lithium batteries. Journal of Energy Storage, 68, 107744. https://doi.org/10.1016/j.est.2023.107744

[9] Qian, X., Xuan, D., Zhao, X., & Zhuangfei, S. (2019). Heat dissipation optimization of lithium-ion battery pack based on neural networks. Applied Thermal Engineering, 162, 114289. https://doi.org/10.1016/j.applthermaleng.2019.114289

[10] Oropeza-Perez, I., & Østergaard, P. A. (2018). Active and passive cooling methods for dwellings: A review. Renewable & Sustainable Energy Reviews, 82, 531–544. https://doi.org/10.1016/j.rser.2017.09.059

[11] Kelly KJ, Mihalic M, Zolot M. Battery usage and thermal performance of the Toyota Prius and Honda Insight for various chassis dynamometer test procedures. In: 17th Annual Battery Conference, Long Beach, California, US January 14e18, 2002.

[12] Zhang, X., Kong, X. Y., Li, G., & Li, J. (2014). Thermodynamic assessment of active cooling/heating methods for lithium-ion batteries of electric vehicles in extreme conditions. Energy, 64, 1092–1101. https://doi.org/10.1016/j.energy.2013.10.088

[13] Rana, S., Kumar, R., & Bharj, R. S. (2022). Lithium-Ion Battery Thermal Management Techniques and Their Current Readiness Level. Energy Technology, 11(1), 2200873. https://doi.org/10.1002/ente.202200873

[14] Wang, T., Tseng, K. J., & Zhao, J. (2015). Development of efficient air-cooling strategies for lithium-ion battery module based on empirical heat source model. Applied Thermal Engineering, 90, 521–529.

[15] Jiaqiang, E., Yue, M., Chen, J., Zhu, H., Deng, Y., Zhu, Y., … Kang, S. (2018). Effects of the different air cooling strategies on cooling performance of a lithium-ion battery module with baffle. Applied Thermal Engineering.

[16] Chen, K., Chen, Y., She, Y., Song, M., Wang, S., & Chen, L. (2019). Construction of effective symmetrical air-cooled system for battery thermal management. Applied Thermal Engineering, 114679.

[17] Muddasar, M. Optimization, Modelling and Analysis of Air-Cooled Battery Thermal Management System for Electric Vehicles. Preprints.org 2022, 2022010051. https://doi.org/10.20944/preprints202201.0051.v1

[18] Chen, K., Li, Z., Chen, Y., Long, S., Hou, J., Song, M., & Wang, S. (2017). Design of Parallel Air-Cooled Battery Thermal Management System through Numerical Study. Energies, 10(10), 1677. https://doi.org/10.3390/en10101677

[19] Fan, L.; Khodadadi, J.M.; Pesaran, A.A. A parametric study on thermal management of an air-cooled lithium-ion battery module for plug-in hybrid electric vehicles. J. Power Sources 2013, 238, 301–312.

[20] Mahamud, R.; Park, C. Reciprocating air flow for Li-ion battery thermal management to improve temperature uniformity. J. Power Sources 2011, 196, 5685–5696.

[21] He, F., X, Li, Ma, L., 2014. Combined experimental and numerical study of thermal management of battery module consisting of multiple Li-ion cells. Int. J. Heat Mass Transfer 72, 622–629. https://doi.org/10.1016/j.ijheatmasstransfer.2014.01.038.

[22] Ryu, S., Cheong, C., Kim, J. W., Park, B. I., & Park, S. M. (2023). Numerical and experimental investigation into effects of winglet shape on flow and noise performances of axial-flow fans for outdoor unit of air conditioner. Numerical and Experimental Investigation Into Effects of Winglet Shape on Flow and Noise Performances of Axial-flow Fans for Outdoor Unit of Air Conditioner. https://doi.org/10.1016/j.ijrefrig.2023.02.003

[23] K. Duvenhage, J. A. Vermeulen, C. J. Meyer, and D. G. Kroger, “Flow Distortions at the Fan Inlet of Forced-Draught Air-Cooled Heat Exchanger,” in Applied Thermal Engineering, Vol. 16, Nos. 8/9, pp. 741–752, 1996.

[24] F. W. Yu and K.T. Chan, “Modelling of a Condenser-Fan Control for an Air-Cooled Centrifugal Chiller,” in Applied Energy Vol. 84, pp. 1117–1135, 2007.

[25] E. H. Twizell and N. J. Bright, “Numerical Modelling of Fan Performance,” in Applied Mathematical Modelling, Vol. 5, 1981.

[26] J. R. Bredell, D. G. Kroger, and G. D. Thiart, “Numerical Investigation of Fan Performance in a Forced Draft Air-Cooled Steam Condenser,” in Applied Thermal Engineering, Vol. 26, pp. 846–852, 2005.

[27] J. Stafford, E. Walsh, V. Egan, and R. Grimes, “Flat Plate Heat Transfer With Impinging Axial Fan Flows,” in International Journal of Heat and Mass Transfer, Vol. 53, pp. 5629–5638, 2010.

[28] J. Stafford, E. Walsh, and V. Egan, “Local Heat Transfer Performance and Exit Flow Characteristics of a Miniature Axial Fan,” in International Journal of Heat and Fluid Flow, Vol. 31, pp. 952–960, 2010.

[29] S. H. Ho, L. Rosario, and M. M. Rahman, “Thermal Comfort Enhancement by Using a Ceiling Fan,” in Applied Thermal Engineering, Vol. 29, pp. 1648–1656, 2009.

[30] Franzke, R., Sebben, S., Bark, T., Willeson, E., & Broniewicz, A. (2019). Evaluation of the Multiple Reference Frame Approach for the Modelling of an Axial Cooling Fan. Energies, 12(15), 2934. https://doi.org/10.3390/en12152934

[31] Wang, J., Liu, X., Chenye, T., & Xi, G. (2023). Aerodynamic performance improvement and noise control for the multi-blade centrifugal fan by using bio-inspired blades. Energy, 263, 125829. https://doi.org/10.1016/j.energy.2022.125829

[32] Yu, J., Zhang, T., & Qian, J. (2011c). Classification: electric motors, pumps, fans. In Elsevier eBooks (pp. 11–172). https://doi.org/10.1533/9780857093813.11

[33] Widyaningrum, V. T., & Pramudita, Y. D. (2018b). Automatic Lamp and Fan Control Based on Microcontroller. Journal of Physics, 953, 012146. https://doi.org/10.1088/1742-6596/953/1/012146

[34] Oyebola B. O. and Odueso V. T. (2017), LM35 Based Digital Room Temperature Meter: A Simple Demonstration. Equatorial Journal of Computational and Theoretical Science, 2 (1): 6-15

[35] P. Roy, J. Saha, N. Dutta and S. Chandra, "Microcontroller based automated room light and fan controller," 2018 Emerging Trends in Electronic Devices and Computational Techniques (EDCT), Kolkata, India, 2018, pp. 1-4, doi: 10.1109/EDCT.2018.8405090.

[36] A. Nayyar and V. Puri, "A review of Arduino board's, Lilypad's & Arduino shields," 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), New Delhi, India, 2016, pp. 1485-1492.

[37] Chen, M.; Zhang, S.; Wang, G.; Weng, J.; Ouyang, D.; Wu, X.; Zhao, L.; Wang, J. Experimental Analysis on the Thermal Management of Lithium-Ion Batteries Based on Phase Change Materials. Appl. Sci. 2020, 10, 7354.

[38] Zhao, R.; Gu, J.; Liu, J. An experimental study of heat pipe thermal management system with wet cooling method for lithium ion batteries. J. Power Sources 2015, 273, 1089–1097. [CrossRef]

[39] Pesaran, A.A. Battery thermal models for hybrid vehicle simulations. J. Power Sources 2002, 110, 3377–3382. [CrossRef]

[40] Spitthoff, L.; Shearing, P.R.; Burheim, O.S. Temperature, Ageing and Thermal Management of Lithium-Ion Batteries. Energies 2021, 14, 1248. [CrossRef]

[41] Buidin, T. I. C., & Mariasiu, F. (2021). Modeling Approach of an Air-Based Battery Thermal Management System for an Electric Vehicle. Applied Sciences, 11(15), 7089. https://doi.org/10.3390/app11157089

[42] A123 Systems datasheet for Lithium Ion Prismatic Pouch Cell AMP20M1HD-A, 2011.

[43] "Rapidly Charging Battery Systems," L. Rodgers, P. Karplus, R. Gogoana, M. Narwot, 2010, ASME 2010 International Design Engineering Technical Conference. From url: https://www2.lirmm.fr/lirmm/internLBIBLI/CDROM/ROB/2010/DETC2010/data/pdfs/trk-6/DETC2010-29226.pdf

[44] General Hosoi, A. (2013). Design and analysis of a battery for a formula electric car. https://dspace.mit.edu/handle/1721.1/83741

APPENDICES

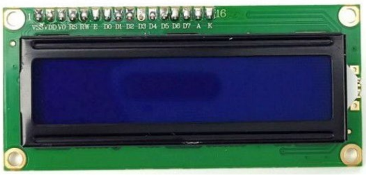
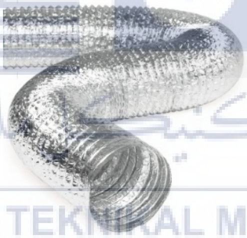
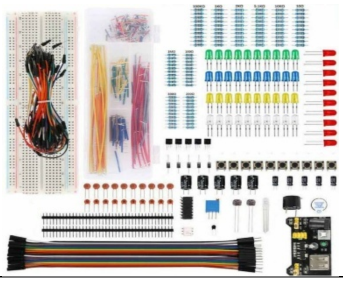
BDP1	**WEEK**													
PROGRESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
BDP 1 briefing by JK PSM, FTKMP	■													
Discussion and verification of the project title		■												
Submit the selected topic to Supervisor		■												
Identify the problem statement and objective			■											
Problem statement and objective review by Supervisor			■	■										
Report Writing: Chapter 1 (introduction, Problem statement, Objective, Scope)			■	■	■									
Finding journals and articles that related to the topic				■	■	■	■	■	■					
PSM 1 Progress 1 Submission						■								
Literature Review and Methodology briefing by Professor Madya Ts. Dr. Muhammad Zahir bin Hassan							■							
Report Writing: Chapter 2(Literature Review)					■	■	■	■						
Researching on designing of air-cooling system for battery pack of the Formula Varsity						■	■	■	■					
choosing a cooling system and its data monitoring and its control system									■	■	■			
Report Writing: Chapter 3 (Methodology)										■	■	■		
PSM 1 Progress 2 Submission												■		
Correction for Chapter 1, 2 and 3												■	■	
Finalize the PSM 1 Report												■	■	
Construct PSM 1 Presentation Slide												■	■	■
BDP 1 PRESENTATION AND ASSESSMENTS														■

APPENDIX A Gantt Chart of PSM 1.

BDP2	**WEEK**													
PROGRESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Meeting supervisor, discussion, overview and inspection of the project vehicle.	■	■												
Troubleshoot and repairing.		■	■	■	■									
Fabricate control panel for the battery panel temperature data monitoring		■												
Troubleshoot, installation of control panel and wiring.			■	■										
Construct temperature monitoring system circuit and programming				■	■									
Measuring necessary dimensions for air-cooling system battery pack installation.					■	■								
Installation of air-cooling system battery pack and test run.					■	■								
Drafting for PSM 2 report and updating chapter 3 - methodology						■	■							
Experimental conduct, data collection and observation.							■	■	■	■				
Consulting with supervisor for PSM2 thesis content and writing								■	■					
Data analysis and calculation and completing thesis writing									■	■	■	■		
Finalize thesis writing and submission to supervisor for checking and correction.										■	■			
Correction of thesis writing - chapter 4 and chapter 5											■	■	■	
Completing and finalize weekly logbook, PSM poster and thesis summary												■	■	
PSM2 thesis submission to supervisor, panel 1 and panel 2.													■	■
Presentation and evaluation.														■

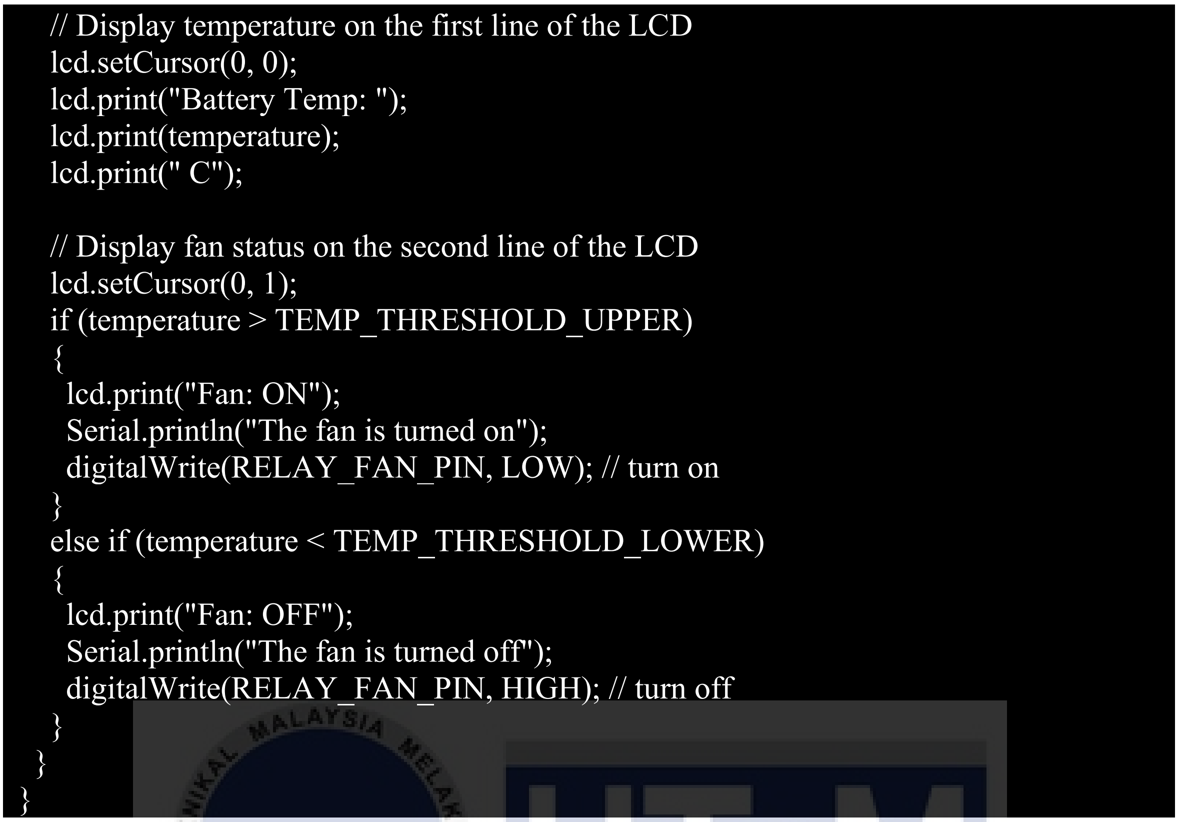
APPENDIX B Gantt Chart of PSM 2.

NO.	COMPONENTS	QUANTITY	COST
1	Axial Fan 	2	RM 60.00
2	Arduino UNO R3 	1	RM 25.00
3	LM35 Temperature Sensor 	2	RM 5.00
4	48V to 5V Converter 	1	RM 100.00

5	I2C 1602 LCD 	1	RM 15.00
6	12V to 5V Converter 	1	RM 15.00
7	Aluminum air flow hose 	2	RM25.00
8	Other Electrical Components 	1	RM150.00
	TOTAL		RM460.00

APPENDIX C Bills of Material.

```
#include "DHT.h"
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

#define RELAY_FAN_PIN 3  // Arduino pin connected to relay which is connected to
the fan
#define DHTPIN 2         // Arduino pin connected to relay which is connected to the
DHT sensor
#define DHTTYPE DHT22

const float TEMP_THRESHOLD_UPPER = 45.0; // upper threshold of temperature,
change to your desired value
const float TEMP_THRESHOLD_LOWER = 34.0; // lower threshold of temperature,
change to your desired value

DHT dht(DHTPIN, DHTTYPE);
LiquidCrystal_I2C lcd(0x27, 16, 2);  // I2C address 0x27, 16 column and 2 rows

float temperature; // temperature in Celsius

void setup()
{
  Serial.begin(9600);          // initialize serial
  dht.begin();                 // initialize the sensor
  pinMode(RELAY_FAN_PIN, OUTPUT); // initialize digital pin as an output

  lcd.begin(16, 2);  // initialize the LCD with 16 columns and 2 rows
  lcd.backlight();   // turn on the backlight
}

void loop()
{
  // wait a few seconds between measurements.
  delay(2000);

  temperature = dht.readTemperature(); // read temperature in Celsius

  if (isnan(temperature))
  {
    Serial.println("Failed to read from DHT sensor!");
  }
  else
  {
    Serial.print("Cotroller Temp: ");
    Serial.print(temperature);
    Serial.println(" °C");

    lcd.clear();  // clear the LCD display
```



```
    // Display temperature on the first line of the LCD
    lcd.setCursor(0, 0);
    lcd.print("Battery Temp: ");
    lcd.print(temperature);
    lcd.print(" C");

    // Display fan status on the second line of the LCD
    lcd.setCursor(0, 1);
    if (temperature > TEMP_THRESHOLD_UPPER)
    {
      lcd.print("Fan: ON");
      Serial.println("The fan is turned on");
      digitalWrite(RELAY_FAN_PIN, LOW); // turn on
    }
    else if (temperature < TEMP_THRESHOLD_LOWER)
    {
      lcd.print("Fan: OFF");
      Serial.println("The fan is turned off");
      digitalWrite(RELAY_FAN_PIN, HIGH); // turn off
    }
  }
}
```

APPENDIX D Design Coding of Arduino as Temperature Measurement Instrument and Data Collection.