EVALUATION OF A SOLAR POWERED VEHICLE VENTILATION SYSTEM USING FUZZY LOGIC CONTROLLER

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ABSTRACT

The temperature inside the vehicle cabin can rise quickly when the vehicle is parked under sunlight for a long period. This incident of temperature rising can lead to a risk of producing toxic gasses and cause to passenger discomfort and damage heat sensitive equipment and materials inside the vehicle cabin. In tropical countries such as Thailand, the cabin temperature of the vehicle increases up to 60°c to 70°c within few hours. In order to reduce temperature builds up inside the vehicle interior, the research study proposes a vehicle ventilation system using solar energy.

Temperature variation inside the vehicle interior due to solar irradiance, fuel consumption to reduce the temperature inside cabin and the temperature decrement using the ventilation system will be focused in this research study. Experiment results from the study will be used to identify the high-temperature zones and the temperature distribution inside the vehicle interior and the results will be used to build a ventilation system that helps to balance the temperature inside and outside the vehicle when the vehicle is parked in an unshaded area. Proposed ventilation system will be operated using solar power and additional battery to provide continuous power to the system when the solar energy is insufficient to operate the ventilation system.

This proposed car ventilation system can identify the temperature between the cabin interior and outside ambient temperature and controls the speed of exhaust fan to control the flow rate, which pumps the hot air inside the cabin to outside. The temperature of the inside air has a lower temperature than components of the vehicle interior because of the absorbing solar radiation which could not sense to the

temperature sensor. In order to minimize the effect which can affect the operation of the system, solar irradiation from the sun has been measured using a current sensor in addition to temperature sensors to identify the time to start the operation of the system using a fuzzy interface. This system can maintain the temperature difference around 6^{o}c at its peak performance. It can save 44ml fuel by reducing the AC load from a conventional car for the first 15minutes after parking. In this thesis, the importance and effectivity of using ventilation system will be discussed and in order to minimize the common issues that most of the car owners faced in their daily lives when they park the vehicles in outdoor.

ACKNOWLEDGEMENT

I take this opportunity to express the most appreciation and deepest gratitude to my NSTDA advisor, Dr. Kobsak Sriprapha from Solar Laboratory NSTDA-NECTEC, Thailand for the guidance and giving this idea for me to do as my final year project, which related to my field of study.

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I also want to express my thanks to Lab supervisors and staff members from NSTDA helping me during the entire period of the research study by verifying all the instruments, equipment and making them available for me and guidance to use equipment in the lab. In addition to that, I also want to thanks TAIST-Tokyo Tech staffs who coordinate my academic and research progress throughout this program.

Finally, yet importantly, my parents for directing me and issuing me the obliged good support in full filling the task. Without the contribution of many people, this thesis would not have been existed. It owes the existence to the supports and inspirations from many people.

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$\propto$	*Boltzman Constant*	$5.67 \times 10^{-8}\ W/m^2K^4$
π	*Pi*	3.14
R	*radius of the sun*	$696 \times 10^6 m$
D	*average distance from the sun to the earth*	$150 \times 10^9 m$
I_{SC}	*Solar Constant*	$1367\ W/m^2$
I_0	*Irrradiance on a plane perpendicular to the sun rays*	
n	*day number (starting from January 1)*	
θ_z	*Zenith angle*	
Ø	*Latitute*	
δ	*Solar Declination Angle*	
H	*hour angle which represent the solar radiation as the hour from midnight*	

CHAPTER 1

INTRODUCTION

1.1 Research Background

Heat accumulation inside a vehicle is an issue when the vehicle is parked in unshaded area with exposure to direct sunlight for a long time. The accumulated heat can cause to increase the cabin temperature and the high temperature can make the passenger feel discomfort, and damage the heat sensitive components and equipment inside the vehicle.

The importance of using a ventilation system, which can reduce the temperature built inside the cabin, will be discussed in this research study and implement a solution to reduce the overall temperature inside the cabin.

1.2 Objectives

- To design an experiment ventilation system for a vehicle to pump the hot air while the vehicle is parked.
- Improving the exhaust air flow using a ventilator to reduce the greenhouse effect inside the vehicle cabin.
- Compare the temperature difference between ambient and the cabin with the system and without the system.

1.3 Scope of the study

1.3.1 Research data collection

Study the issues, find solution and improve the quality of the product

Arrange the pros and cons of previous systems

1.3.2 Simulation to analyze the thermal behavior

Creating CAD model for the cabin

Identify the Thermal behavior under sunlight

Identify the better exhaust methods to pump the hot air out

1.3.3 Experimenting with a prototype

Implement the system with the prototype

Compare the thermal behavior with designed model

Identify and select the components for the exhaust system

Identify the solar output in time periods

1.3.4 Performance testing and analyzing the results

Specify the quality, efficiency, and performance

Effect for the fuel consumption

Discuss the importance of improved ventilation system

CHAPTER 2

LITERATURE REVIEW

2.1 Heat accumulation inside the vehicle

The temperature increment happens due to the greenhouse effect which happens by trapping partial heat radiation inside the vehicle cabin. All wavelength of spectrum hit the vehicle external surface and the surface either reflects or absorbs it. However, glass surface is transparent for short wavelength radiations. The light radiation is subsequently absorbed by interior components and light radiation is trapped inside the interior. Heat losses occurs due to the conduction combined with convective exchanges. All of the heat exchanges are strongly affected by climatic and weather conditions.

Under steady state conditions (with constant radiative input and fixed environmental conditions), the input heat per unit time should be equal to the heat loss.

$$S = C(T_C - T_0) \tag{2.1}$$

Where S is the total radiative power, T_C is temperature inside the cabin and T_0 is the outside temperature. The complex heat loss mechanisms collapse into a single heat loss transfer coefficient. Vehicle type, color and the ventilation state will be characterized into the coefficient. (Dadour IR, 2010)

2.2 Background of Solar Ventilators

There are many types of research and projects to overcome the thermal effect of the sun for the vehicle cabin, by using solar reflective paints and glazing, vehicle tint, cooling systems and ventilation systems. However, there are some issues with existing research studies such as fixing the time of the unit, mobility, fuel consumption, fuel emissions, performance and efficiency of the system.

In this paper, we will discuss a better technique and methods in order to minimize previous issues encountered by previous researchers. The National Renewable Energy Lab is one of the main laboratories that research about solar reflective techniques, which can reflect NIR-Near Infrared Rays from solar rays, which help to minimize the heating effect from the sunlight. (John P. Rugh, 2007) NREL Lab members focused on the glazing surface area, solar-powered car ventilation system, solar reflective paint. and how that effects to the actual car in reality. They analyzed many configurations for the system such as solar reflective windshield, solar reflective back lite, Solar reflective side lite and Solar reflective paint by doing thermal analysis and CFD. Greater than 50% of solar rays were reflected by using the glazing. The solar heat gain was reduced. Using the paint can reflect the IR portion and the overall solar heat gain was reduced. Dashboard and the windshield obtain a higher heat gain from inside and the highest one is the roof from outside. These techniques help to reduce 30% from cooling load and 26% reduction of AC fuel use of a vehicle to help the fuel efficiency of the vehicle.

Greenhouse inside car cabin effect helps to increase the cabin temperature to reach 60°C-70°C so that the durability of the accessories, panels and other instruments inside the cabin will decreased due to the exposure of the temperature for a longer period. Taiwan University has done intelligent solar powered ventilation system that can exhaust air from the cabin and suppress the greenhouse effect automatically. This system always monitors the temperature inside the vehicle to compare with outside temperature and after inside temperature exceeds the outside temperature, the exhaust air by a fan and open the inlet valve to pump the outside air to the vehicle cabin. (K. David Huang, 2004) A Malaysian group introduced an alternative design to car cooling system that is operated by solar and battery power and the important thing of this design is the mobility. Their product can pump the air up to 5m/s and at the same time, it provides water moisture by rotating a wet cloth. (M.F. Basar, 2013) More than using a solar cell, Peltier cell is also used to produce electricity, but practically that Peltier cell can produce only mili ampere current and it needs very high temperature difference to produce higher power output. However, they used alternative energy sources to minimize the main problem. This portable car cooling system can maintain the temperature between 25°C-30°C, while the car is under hot condition after developed successfully. Figure 2.1 shows their experimental results.

Another Malaysian group also did a research on this topic to overcome the same problem with a better way. An exciting solar ventilation system was modified by increasing the flow rate and minimize the steady state temperature. Generally, the solar panel does not produce stable electricity. So solar controller and a battery have been used to provide continuous power to the motor to drive at maximum speed. (R. Saidur, 2009) Insulation for the roof can cause to increase the cabin temperature because even though the roof was insulated solar heat transfer through the windshield and glasses, but that heat unable to reject through the roof from the vehicle cabin. (Robert B.

Farrington), supplying outside air into the cabin can help to minimize the air conditioning loads and most effective way is to recirculation the cabin air than treating from the outside air. In this study, they have found high-temperature zones by their analytical data to place the air inlet to exhaust the air quickly and effectively.

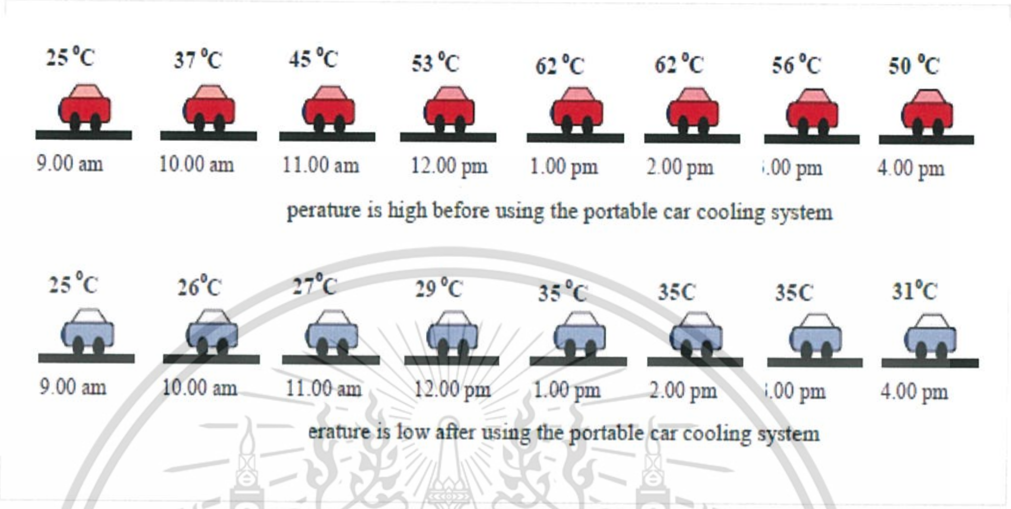


Figure 2.1 Comparison of temperatures without cooler and with cooler

Source: International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-3, Issue-3, August 2013

The fuel consumption of the Vehicle can be minimized by reducing climate control loads. For example, the peak load of climate controls around 6kW that is a significant value that can consume 3l of fuel for 100km. (Robert B. Farrington)

Toyota 3rd generation Prius also introduced a new solar ventilation system (Corporation, 2009) with this system, when the car is parked, the solar cells generate electricity to operate a fan and ventilate the inside of the vehicle and thus prevent the interior temperature from rising. The Toyota ventilation system will automatically turn on when the cabin temperature reaches 80 degrees. When it comes on, it will ventilate the vehicle using the outside air. Solar panels, neatly integrated into a sliding sunroof, power the electric air circulation fan. Running independently from the engine, it can cool cabin temperature down from 80 to 45°C, so there is less need for the air conditioning to be used to achieve a comfortable level when you return to the vehicle.

A research conducted (Rameshkumar.A, 2013) about a numerical model to study about temperature zones and air flow inside the car cabin using computational fluid dynamics(CFD) method with various human loads. Fluent CFD analysis tool is used to analyze and do the simulation. 8m/s for inlet air velocity of air vents and human body temperature of 298K and 30W/m^2 °C for heat transfer coefficient for outside of the car cabin was set analyze the temperature. Developed CFD model got closer value for experimented temperature value.

Another research (Walid Chakroun, 1997) to investigate the behavior of the air temperature inside the cabin of the car. And also effectiveness of using solar powered ventilating fan and using covering arrangements to windshields and side windows also investigated by this Kuwait university research group. This paper concluded that the Parking in the shady place is the most effective condition compared to other techniques. However, shady parking is not available every time so the next is solar powered fan it decreases inside temperature up to 10°C compared to without covering and exposing to the sun.

A research was conducted by (Rugh, 2000) to show the impact of fuel economy and tailpipe emissions and reduce the range of the electric vehicles. The authors have illustrated that current air condition systems can reduce fuel economy from high fuel economy vehicles by 50%. Reducing the Air conditioning loads has been discussed in this paper using Advanced glazing, air recirculation techniques. From the following figure, they have found when the % of circulated air increased, the required thermal power for cooling/heating is also reduced. Following figure shows that 1.5kW is needed to maintain the cabin temperature 30°C above ambient using 100% circulated air. 4.5kW is needed, if only outside air is used. 50W/K of vehicle skin heat transfer coefficient, 0.167kg/s (300cfm) air flow rate for climate control cooling 0.111kg/s (200cfm) for heating is used during observation.

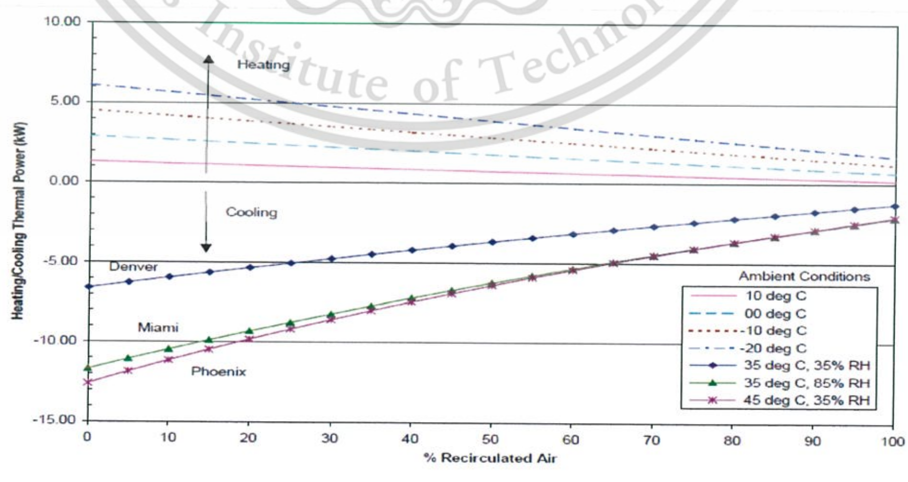


Figure 2.2 Thermal Power vs recirculated air and ambient conditions

Source: National Renwable Energy Laboratory 1617 Cole Blvd. Golden, CO, USA

From NREL, another research also conducted by (D. Bharathan, 2007) to improve and evaluate technologies that reduce the fuel use for air conditioning for vehicle and summarize fuel usage for air conditioning and use of reduction techniques and technologies last 10 years. The following figure shows the vehicle A/C fuel usage of analyze data from the ADVISOR(2) vehicle simulation software.

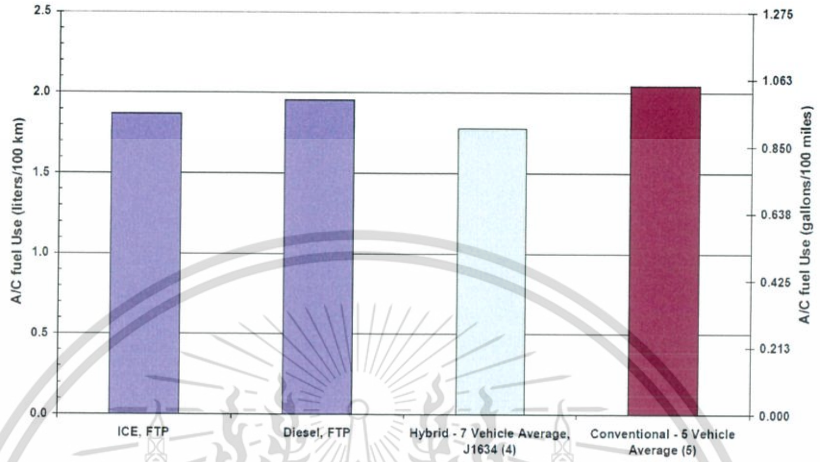


Figure 2.3 Vehicle A/C fuel use

Source: National Renewable Energy Laboratory, Center for Transportation Technologies and Systems, United States

So these researchers concerned about the ventilation technique for the vehicle and they used a Jeep Cherokee. Following figure shows how the cabin temperature varies with ventilation technique.

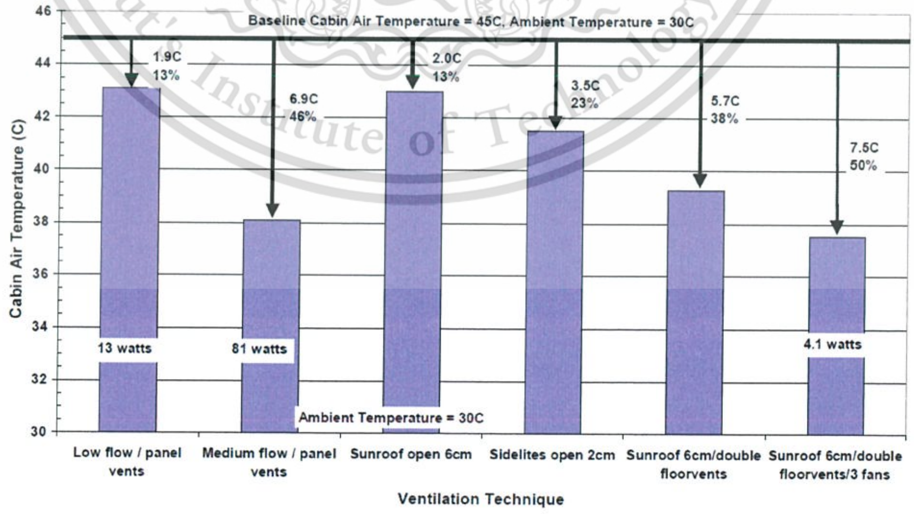


Figure 2.4 Parked car ventilation inside a Jeep

Source: National Renewable Energy Laboratory, Center for Transportation Technologies and Systems, United States

Research group from university of California (Anthony Flores, 2008) has done a research about benchmark product that named as AUTO COOL, this device can be placed on the side window of the vehicle and fan of that device pump outside air to inside to replace hot inside air from outside fresh air, and this unit is powered from solar panel. The appearance of that unit is as in the following figure.

Figure 2.5 AUTOCOOL benchmark product

Source: http://www.gadgetreview.com/auto-cool-a-solar-powered-air-conditioning-system-for-the-car

However, according to their result, this device cannot cool temperature up to significant value but they improve the ventilation system by power up the car blower from solar externally, so that technique improves the temperature reduction by 13.32°F as shown in following figure 2.6.

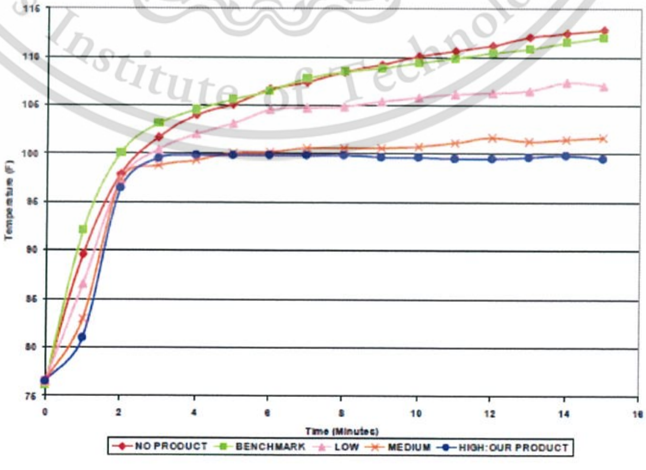


Figure 2.6 Comparison of the rising temperature inside the jeep

Source: June 6th, 2008 ME 153 – Team 18 , UCSB Department of Mechanical Engineering

A Group of Aswan University, Egypt (HASSANEIN, 2013) has conducted a research about greenhouse effect inside the car cabin, temperature inside the car has been measured at four different places inside the car cabin. That temperature variation had been measured during four days at the constant ambient temperatures in June. For measurement for daily hours the car had been parked faced towards to four main directions. Almost same conditions have been done with totally closed, lowering the driver's window by 1 cm, lowering the front two windows by 1 cm, lowering the four windows by 1 cm, lowering the four windows by 3 cm, and covering the front and rear glasses with a car sunshade in that experiment. Then the cabin temperature had been measured from the Front dashboard, rear board, front seat and rear seat and researchers were concerned about many orientation of the covering of front and rear glasses, parking directions and cracked windows.

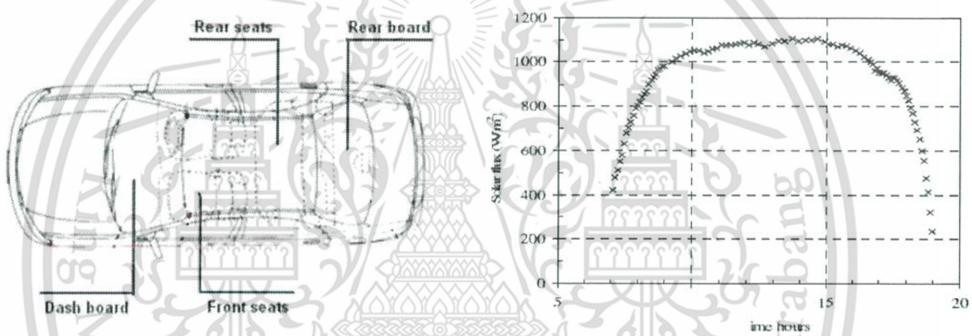


Figure 2.7 Thermometers locations and avg. solar radiation on horizontal surface

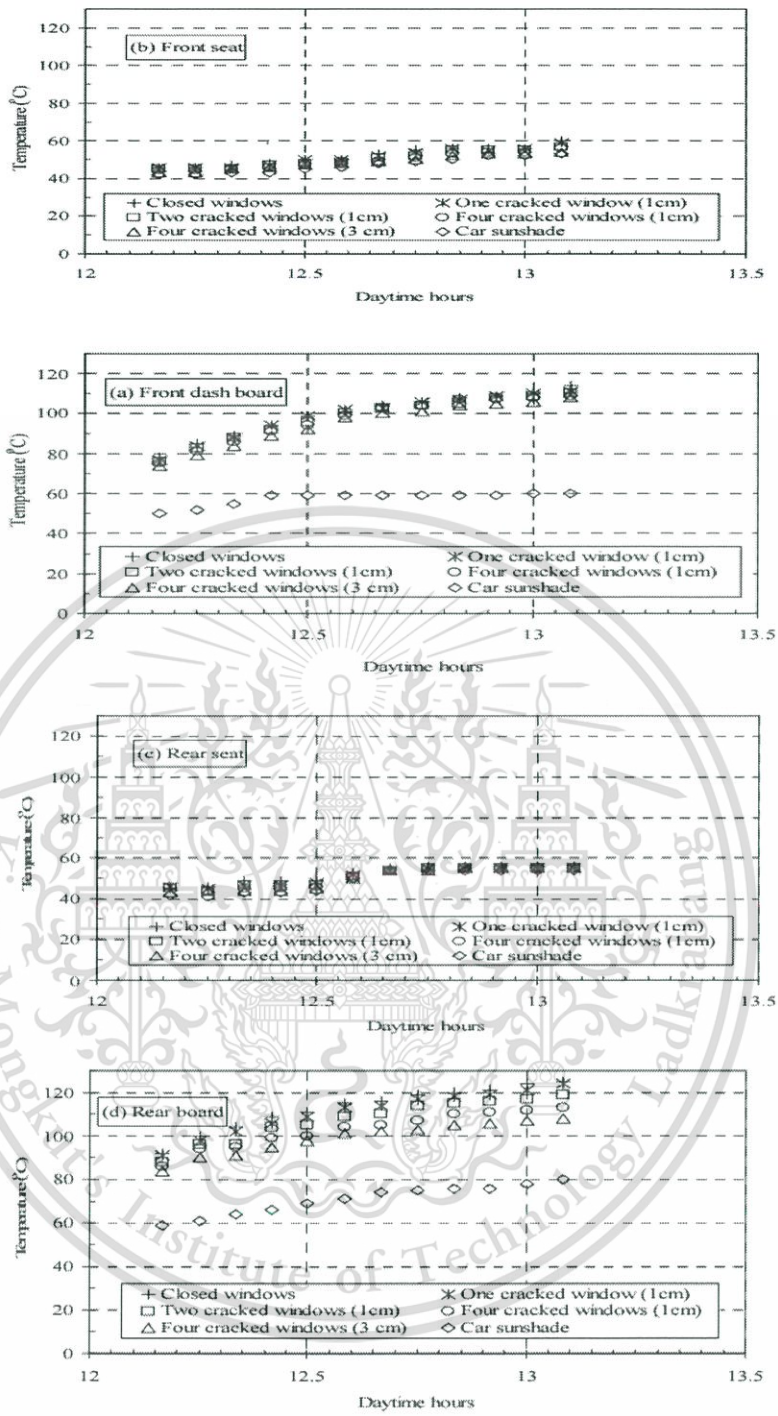


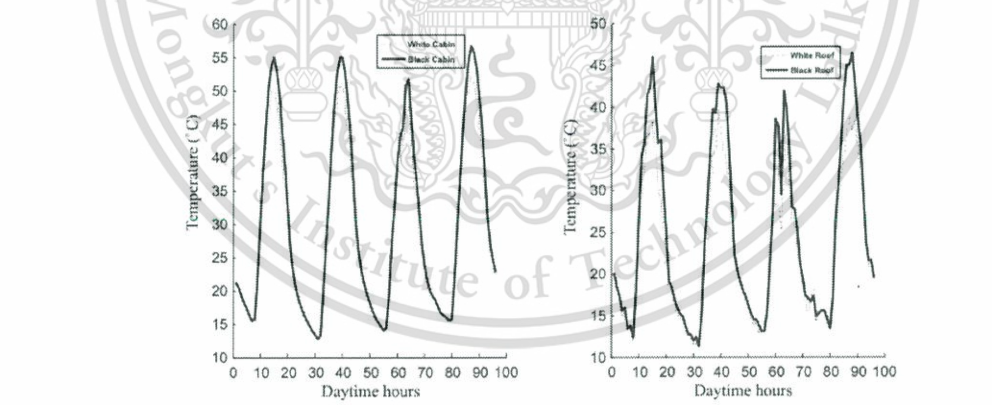
Figure 2.8 temperature distributions of locations during the orientations

Source: International Journal of Automobile Engineering, Research and Development (IJAuERD) ,

ISSN(P): 2277-4785; ISSN(E): 2278–9413, Vol. 4, Issue 5, Oct 2014, 29-34, © TJPRC Pvt. Ltd.

Researcher conclude that the maximum ambient temperature close to 40°C the maximum cabin temperature can rise up to 120°C. The maximum temperature can be recorded from front and rear boards because those places are the largest exposed areas under the glasses. Windows opening does not make any significant reduction of the cabin temperature because 1-3cm opened window failed to get sufficient fresh air because inside air velocity is negligible. Parked under shady places can reduce dashboard and rear board by 40ºC-60ºC.

From research study from (Dadour IR, 2010) focused on experimental records for summer seasons of 2005,2006 and 2008. The data were recorded from vehicles which were parked on an opened area at a intervals of 15minutes the rooftop, trunktop, headlevel of the passenger at back seat inside the cabin. Furthermore, research team focused on the color of the vehicle to black and white for experiment daytime hours of two weeks. The experimntal graph of their record were shown the temperature of the white color car has lower temperature value than black one as shown in the figure 9. More of the radiation from the sun is absorbed in the metal skin of the black vehicle than the white vehicle because of the relatively higher absorbtivity of the black surface. The effect of this is that the roof temperature of the black vehicle is significantly higher than that of the white vehicle during daylight hours. The reason of this experiment is to help determine the time of death of suicide and homicide victims inside vehicles and to investigate the serious threat to life of children or pets left in stationary vehicles on a hot summers day.



Left: cabin temperatures for white and black vehicles. Right: roof temperatures for white and black vehicles (black and white Ford sedan 2008a records).

Figure 2.9 Temperature difference between black and white

Source: Forensic science international 207(1-3):205-11 · November 2010

A research group from Malaysian University of PETRONAS (Hussain H. Al-Kayiem, 2010), has conducted a research study on numerical and experimental analyses on a car parked in an unshaded field. Six different cases had been investigated consisting of full windows closing case, four different windows opening settings and sun shade usage case. The temperature at 12 different locations inside the car had been recorded for many days and the mean values are used as initial and boundary conditions to run the 3-D computational simulation.

Table 2.1 Summary for the measurement cases

Test Case	Details
1	All windows are closed
2	Rear both windows were rolled 1cm
3	Rear both windows were rolled 2cm
4	Sunshade is placed under the front windshield
5	Both windows at front were rolled 1cm
6	Both windows at front were rolled 2cm

Table 2.2 Temperature measurement spots inside the vehicle

Measuring Location	Sensor Type
Dashboard	Surface
Space for leg near firewall (passenger side)	Air
Under roof	Surface
On left passenger seat	Surface
Front Windshield	Surface
Rear Windshield	Surface
On Back Seat	Surface
Front side (between driver and the passenger seat)	Air
Front Passenger's head rest	Surface
Left rear passenger's side window	Surface
Rear side (hanging at the center)	Air
Side Window (driver side)	Surface

Source: Include Solar Load in CFD Analysis of Temperature Distribution in a Car Passenger Compartment. Gothenburg

Another master's thesis from Sweden (Jonsson, 2007) had conducted for Volvo CFD center to analyses solar load using CFD analysis of temperature distributions in passenger compartment. The measurement has been collected from 200 air and surface thermal couples and most of those thermal sensors fixed for the cabin as shown in the Figure 2.10.

A team from Turkish University (KILIC, 2012) has performed a study using Computational Fluid Dynamics Method for a 3-D numerical analysis of temperature distribution in the automobile cabin. Ten points have been focused in this study as shown in the figure 2.11.

Outside roof
Instrument panel
Parcel shelf
Door panels (where the sun hits)
On seat cushion
On engine wall by feet (on the metal not on the carpet)
On the tunnel consol
On the canvas on the roofs inside

Figure 2.10 List of the position of the sensors used for the tunnel test

This allows to compares the simulation data with the tunnel test to understand the relationship between implemented CFD model and real car cabin.

The definition and the location of the measurement points

Points	Location
P1	Knee level (the left rear)
P2	Head level (the left rear)
P3	Knee level (the left front)
P4	Knee level (the right front)
P5	Shoulder level (the left front)
P6	Head level (Between two front seats)
P7	Head level (the left front)
P8	Head level (the right front)
P9	The point at the center console surface
P10	The point at the left side door inner surface

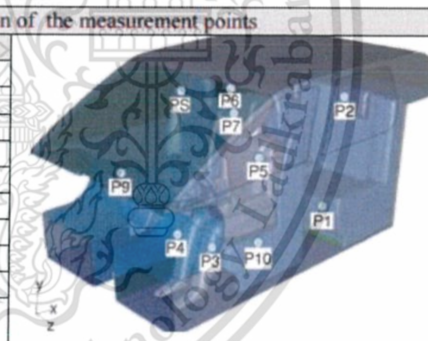


Figure 2.11 Location of the measuring points in the cabin of the test car

Source: Sevilgen, G., et al .: Three Dimensional Numerical Analysis of Temperature … THERMAL SCIENCE, Year 2012, Vol. 16, No. 1, pp. 321-326

Researchers concluded that the higher temperature values were calculated at the surfaces directly affected by the solar radiation in the automobile cabin, thus mean temperature of these surfaces was decreased slowly compared to the other surfaces during the cooling period.

A group from Taiwan University also performed a research using PCM material which covered the inner roof as shown in the figure.

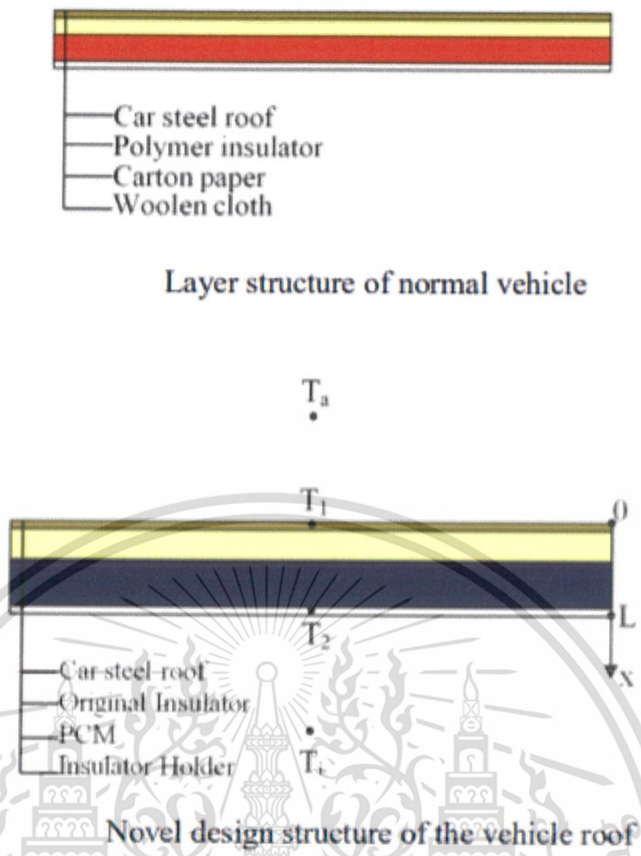


Figure 2.12 Cross-section of the roof of a car

Source: Lan, N. V., Chen, C. R., & Chou, H. M. (2012). The Use of PCM for Ameliorating Thermal Performance of Vehicle Cabin.

Research group has used PCM39D as a PCM material which has a 39degree Celsius melting temperature. Research experiment has been done for 8 hours to record the experimental data. The effectivity of different ambient temperatures was analyzed through their experiment but they found that the ambient air temperature is higher than the melting temperature of the pcm the stored heat unable to release the absorbed heat to ambient. (Lan, 2012)

Table 2.3 Effectivity of using PCM layers

Color	External wind	With PCM	Ambient temperature (°C)	ξ(%)
Grey	No	Yes	25*	40.03
Grey	No	Yes	35	38.13
Grey	No	Yes	45	32.04

Color	External wind	With PCM	Latent heat (kJ/kg)	Melting period (min)	ξ(%)
Grey	No	Yes	60	23	21.13
Grey	No	Yes	88*	40	40.03
Grey	No	Yes	120	66	62.04

Finally, research group concluded that PCM is very effective while some external wind is present. The design and selecting the PCM material can depend on the weather conditions and the country. Experimental Investigation of Thermal Performance in a Vehicle Cabin Test Setup with PCM in the Roof

Another research group from India confirmed that the importance of the air circulation and PCM under the roof panel.

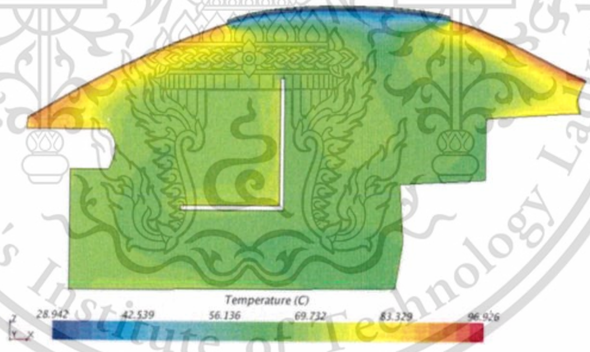


Figure 2.13 Temperature contour with a PCM layer

Figure 2.13 depicts temperature distribution after 1hour with a PCM layer. It was observed from 27°C to 67.96°C. A29 PCM is used for the layer which has a 29°C Melting point, 225kJ/kg latent heat and 2.15kJ/kgK heat capacity. (Purusothaman, 2016)

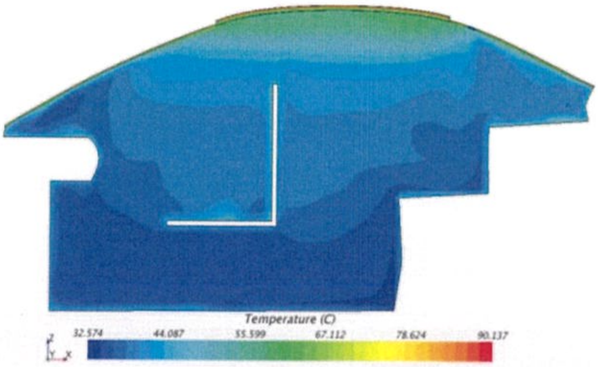


Figure 2.14 Temperature contour with a fan and without a PCM layer

As shown in the figure 2.14, using a fan without a PCM layer, the interior temperature is elevated from 27°C to 38.73°C. during 1hour simulation. Then group research the importance with combination of both. Finally, they found that the observed temperature is reduced from 27°C to 36.41°C as a summary Table 2.4 shows the results.

Table 2.4 Effectivity of using PCM layers

Analysis	Initial Temperature	Final Temperature
With normal roof	27^0 C	96.6^0 C
With PCM layer	27^0 C	67.96^0 C
Fan without PCM layer	27^0 C	38.73^0 C
Fan along with PCM layer	27^0 C	36.41^0 C

Source: Purusothaman, M., Valarmathi, T. N., & Mohammad, S. D. (2016, September). Computational Fluid Dynamic Analysis of Enhancing Passenger Cabin Comfort Using PCM. In IOP Conference Series: Materials Science and Engineering (Vol. 149, No. 1, p. 012197). IOP Publishing

2.3 Solar Radiation

Blue Line - Equator / **White Line** – the ecliptic (annual path of the Sun) / **Yellow Line** – Sun declination (Daily path of the Sun) the following figures show the orientation of the sun monthly at 12.00p.m. noon. These diagrams were taken from a solar motion simulator, which has done by The University of Nebraska-Lincoln astronomy education group.

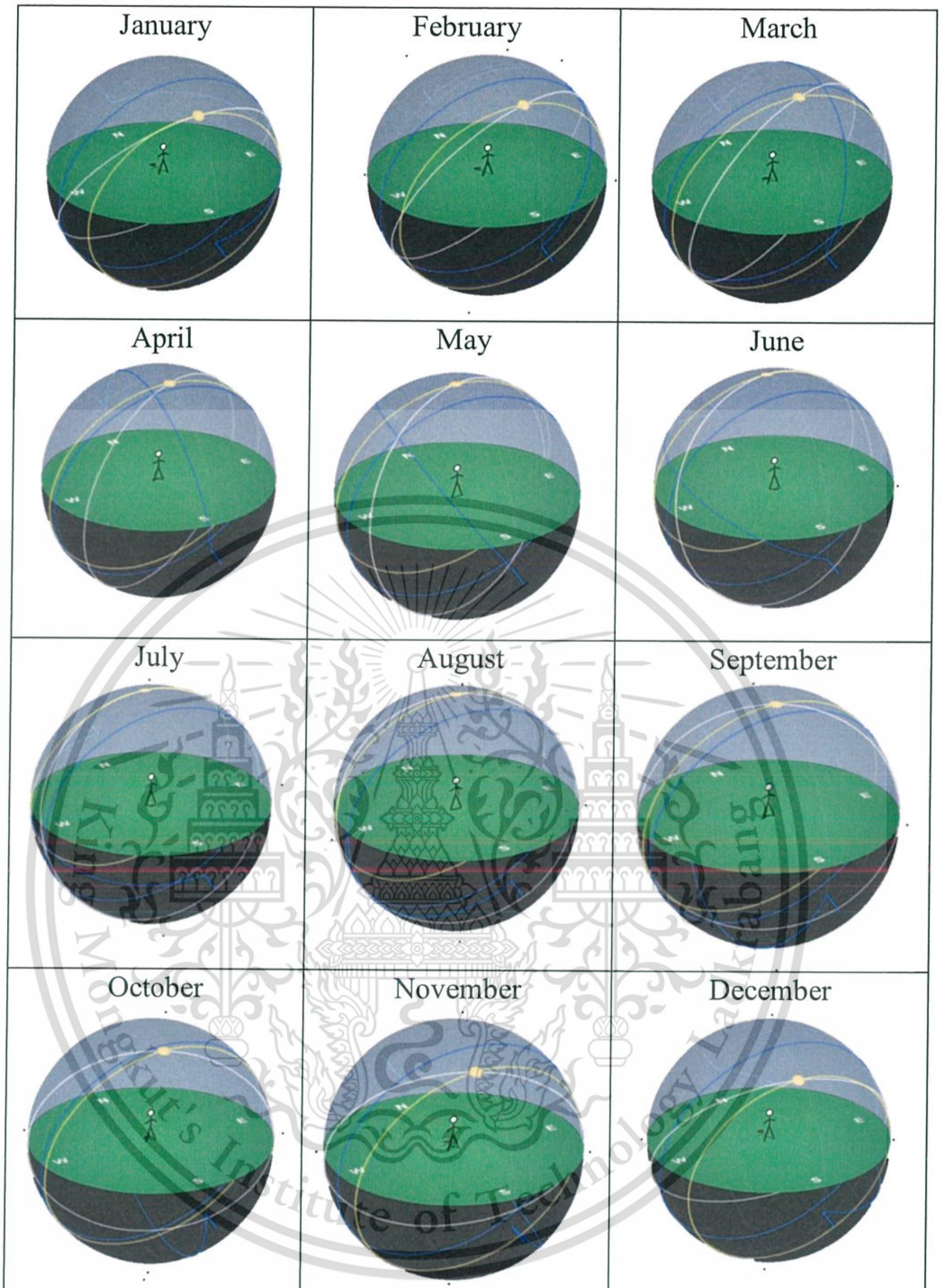


Figure 2.15 Orientation of the sun on 15th of each month at 12.00p.m. noon

Figure 2.16. Path of the Sun at 12p.m. on 15th each month

Above figure shows the orientation of the sun that varies to Pathumthani province (latitude 14 ° 01.0 'North and longitude 100 ° 32.0'-GPS Coordinate) Thailand at 12:00 noon each month.

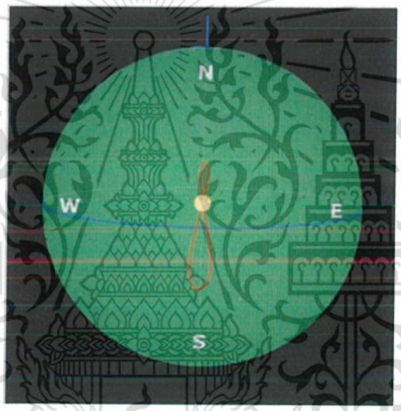


Figure 2.17 Annual Path of Sun

The solar position is very important to grab maximum solar irradiation by facing the solar panel and also reduces the thermal load by blocking the solar rays directly hit inside the vehicle.

Research Data collection has been done by Astronomical Society of Thailand-NECTEC at the position coordinate of latitude 14 ° 01.0 'North and longitude 100 ° 32.0' East to measure the behavior of sun rising and sun setting times for year 2016.

2.4 Heat Flux and Temperature

Heat flux is the thermal energy that crosses a unit area within unit time. Measuring the heat flux allows to quantify the energetic flow of the system. Temperature is a measure of the kinetic energy of the molecule substances with standard scaling system. For example, temperature is an objective measurement of how hot or cold an object is, so value of temperature can express how much heat energy is stored inside a system. But, note that temperature is different from heat, though the two concepts are linked. Temperature is a measure of the internal energy of the system, while heat is a measure of how energy is transferred from one system (or body) to another. When we consider the heat and temperature those are directly proportional to each other.

2.5 Solar Flux

Solar flux is the thermal energy from the sun rays that crosses a unit area within unit time. Solar flux is related to the heat flux and for the convenient for measuring and calculating solar irradiance has been used.

Amount of Solar Flux for a parked vehicle is dependent on many factors such as;

- Solar Irradiation
- Wind Speed
- Location
- Color and Surface
- Solar Irradiation

The heat energy from sun comes to earth by radiation but after it passes the atmosphere of the earth the thermal energy transfers through convection. Sun produces constant radiation of $6.33 \times 10^7 \frac{W}{m^2}$. but when we compare the distance between the sun and earth rays which spread from the sun becomes parallel.

$$G_{SC} = \propto T^4 \left(\frac{4\pi R}{4\pi D}\right)^2 = 1367\, {}^{W}/_{m^2} \qquad (2.2)$$

Where,

$\propto (Boltzmana\ Constant) = 5.67 \times 10^{-8}\, {}^{W}/_{m^2K^4}$

$R(radius\ of\ the\ sun) = 696 \times 10^6$

$D(average\ distance\ from\ the\ sun\ to\ the\ earth) = 150 \times 10^9$

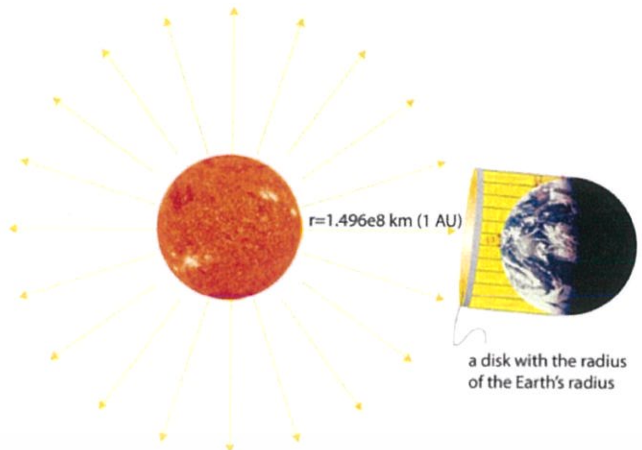


Figure 2.18 Spread of sun rays

As shown in the figure there's imagine surface that has a radius of the earth. So the solar constant is the average radiation intensity that hits this surface. The yearly average solar constant value is nearly 1367 $\frac{W}{m^2}$. But, it is not a perfect constant, and it can fluctuate by 6.9% during a year. So, the intensity can be expressed as in this equation.

Source: http://www.itacanet.org/the-sun-as-a-source-of-energy/part-2-solar-energy-reaching-the-earths-surface/

$$I_0 = I_{SC}(1 + 0.034\cos(2\pi \frac{n}{265.25})) \quad (2.3)$$

And also

$$I_0 \; can \; be \; represent \; for \; this \; formula$$

$$I_0 = I_{SC}(1 + 0.034\cos(\frac{360n}{365})) \quad (2.4)$$

Where:

I_0 = Irriadiance on a plane perpendicular to the sun rays

I_{SC} = the solar constant

n = day number (starting from January 1)

2.6 Cosine effect

The previous value is for the outside of the atmosphere. But, when it comes to earth surface, the irradiance is dependent on the location. To calculate the irradiance to an Imaginary surface on the Earth's surface, the solar constant will be reduced because of this cosine effect and the max amount of the solar irradiance, while the atmosphere did not absorb any radiation.

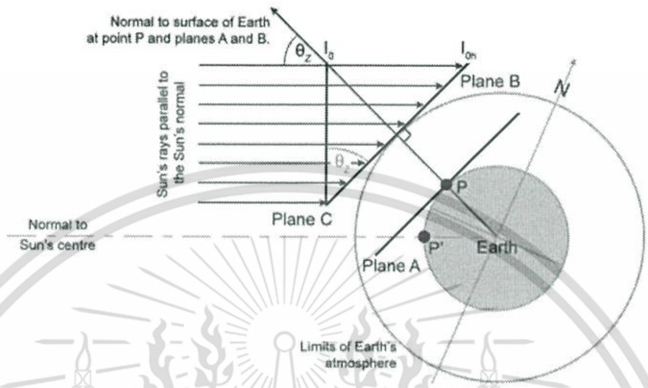


Figure 2.19 Angle of strike the Solar rays

As shown in the above figure, Plane A is the plane on the earth's surface at the point P, Plane B is the imaginary plane which is parallel to Plane A but on the atmosphere surface. Plane C is the surface which is perpendicular to the solar rays.

Following equation can be used to express the Irradiance intensity on the normal plane as a Rough Estimates of the Solar energy from radiation.

$$I_{0h} = I_0 \times cos\theta_z \quad (2.5)$$

$I_{SC} = 1367 \frac{W}{m^2}$ represent to an area of a disk. So it has to multiplied by πR^2 in order to get the power. And this value should be affect to the half of the earth's surface so the ${4\pi R^2}/_{2}$ So the value is 684 ${W}/_{m^2}$. The solar flux for a surface is 684 ${W}/_{m^2}$.

For example, the solar flux and the heat transfer from the solar radiance for the vehicle can be expressed like this,

For this calculation following assumptions have to considered:

- Total solar irradiance converts to heat energy.

- Earth is a precise sphere with a constant radius.
- No convection heat transfers for atmosphere.
- Direct Radiance of solar effect on the vehicle.
- Neglect the other metals body of the car except to roof, windscreen, rear screen and side windows.
- Constant heat flux from the sun and parallel to the roof of a vehicle.

2.7 Zenith Angle and Hour Angle

But when the solar radiation strikes the plane on the earth the position of the earth surface and the time is effected to the final heat flux.

So θ_z (Zenith Angle) is the angle from the zenith point which means the point directly overhead to the position of the sun

So the θ_z can be expressed using this equation:

$$\theta_z = \cos^{-1}(\sin\emptyset \sin\delta + \cos\emptyset \cos\delta \cos H) \tag{2.6}$$

$where, \emptyset\ is\ Latitude,$

δ is Solar Declination Angle

H is hour angle is the deviation of the suns angle from the south

H=15 (solar time-12) and this H value varies between -180 to 180, negative before the solar noon.

So, the radiation depends on above factors. The effect of the location also important. Latitude ($\emptyset$) is used to state the distance from the equator.

Following figure shows the measurement.

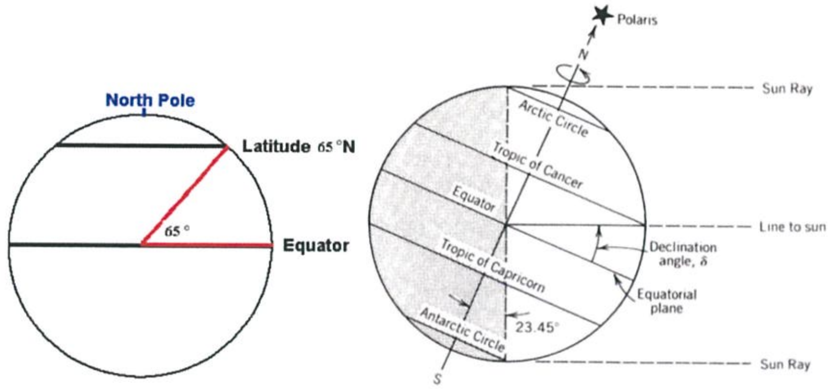


Figure 2.20 Value of latitude and Solar Declination Angle

δ*(Solar Declination Angle) is the angle between equator plane and the line to the su as shown in the following figure*

$\delta \approx 23.45 \sin\left(360\frac{284+n}{365}\right)$ where n can find from the following table (day numbers and STD mean day of the month.

Table 2.4 Declination angle for months

Month	n for i:th Day of Month	For the Average Day of the Month		
		Date	n, Day of Year	δ, Declination
January	i	17	17	-20.9°
February	31 + i	16	47	-13.0°
March	59 + i	16	75	-2.4°
April	90 + i	15	105	9.4°
May	120 + i	15	135	18.8°
June	151 + i	11	162	23.1°
July	181 + i	17	198	21.2°
August	212 + i	16	228	13.5°
September	243 + i	15	258	2.2°
October	273 + i	15	288	-9.6°
November	304 + i	14	318	-18.9°
December	334 + i	10	344	-23.0°

Source : http://www.labri.fr/perso/billaud/Helios2/resources/en03/Chapter_3_EN_final.pdf

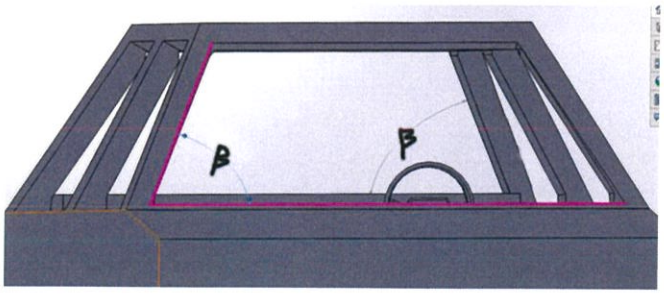


Figure 2.21 Angle for the glass surface from the horizontal surface

So amount of the peak solar flux the power transfer to the cabin can expressed as follows;

$$\text{Total Solar power} = Solar\ Flux * (Area\ of\ the\ roof + \cos angle\ (Area\ of\ windscreen) + \cos angle\ (Area\ of\ rear\ screen) + \cos angle\ (Area\ of\ sidescreens) \quad (2.7)$$

$$\text{Total Solar power} = Solar\ flux * (Area\ of\ the\ roof + \cos(\alpha_2)(Area\ of\ windscreen) + \cos(\alpha_1)(Area\ of\ rear\ screen) + cos\beta(Area\ of\ sidescreens) \quad (2.8)$$

Area of the roof	1.18125		
Area of the glasses	2.7744		Solar Radiance
			684
Solar power from the roof			807.975
Solar power from the glasses		1.351279881	924.2754388
total power			1732.250439

So according to that from the sun light at the peak time, it transfer about 809W to the vehicle cabin.

2.8 Temperature Control System

In the industry, PID and fuzzy logic use to control the temperature of system commonly but it depends on the situation of cooling or warming up or else quick response with minimum overshoot or undershoot. Theoretically, PID is commonly used to linear system to control the temperature, but it can be modified to an adaptive PID system or enhanced PID temperature control. However, fuzzy control is flexible to nonlinear system with some complex situations and imprecision situations. In the fuzzy systems, membership functions or rule base and the performance of the fuzzy controller can be adjusted according to the situation.

CHAPTER 3

RESEARCH METHODOLOGY

In this chapter shows the detail methodology of the research works and the project.

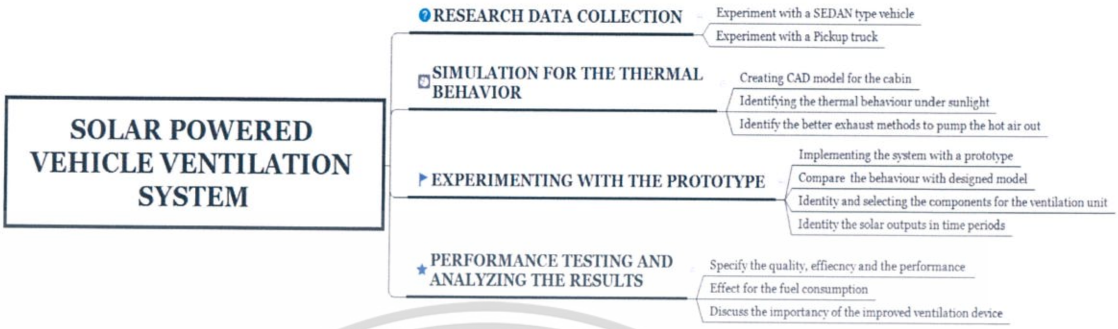


Figure 3.1. Overview of the Methodology

The overview of the proposed method is shown in the above figure.

3.1 Research Data Collection

First, temperature distribution inside the car cabin had been measured using several temperature sensors to identify the higher temperature zones due to solar radiations and greenhouse effect. Temperature sensors located 10 places inside car cabin and one temperature sensor to read ambient temperature. Expected locations of temperature sensors can be stated as follows;

1. under the windscreen (left/middle/ right) x 3
2. under the rear screen (left/middle/ right) x 3
3. four seats for passenger comfortability x 2
4. inside the cabin near to the roof x 2 because roof is the main component that exposes to the direct sunlight

Total thermocouples used = 3+3+2+2+1=11

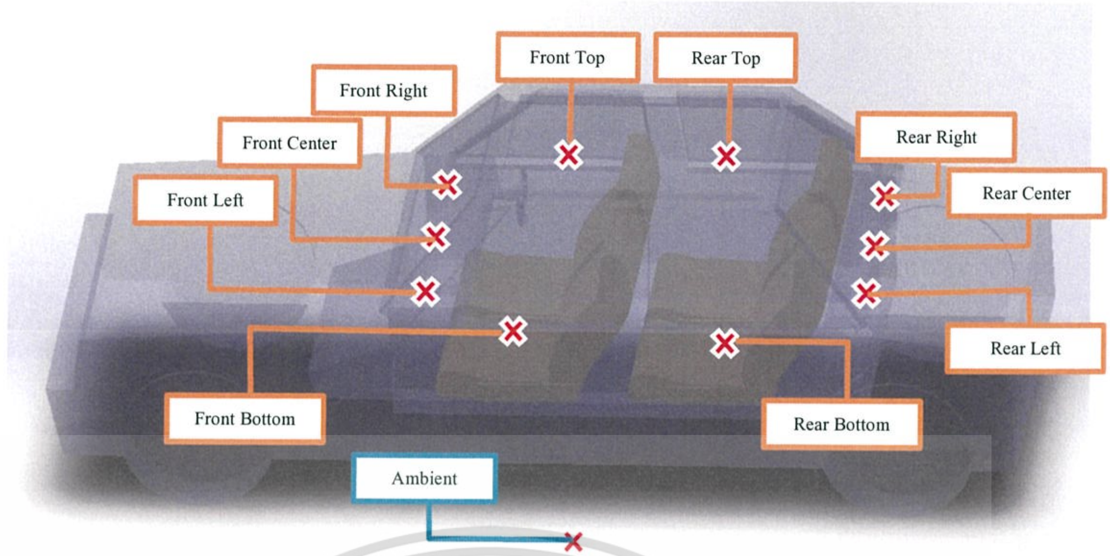


Figure 3.2a Location of the temperature sensors for SEDAN type vehicle

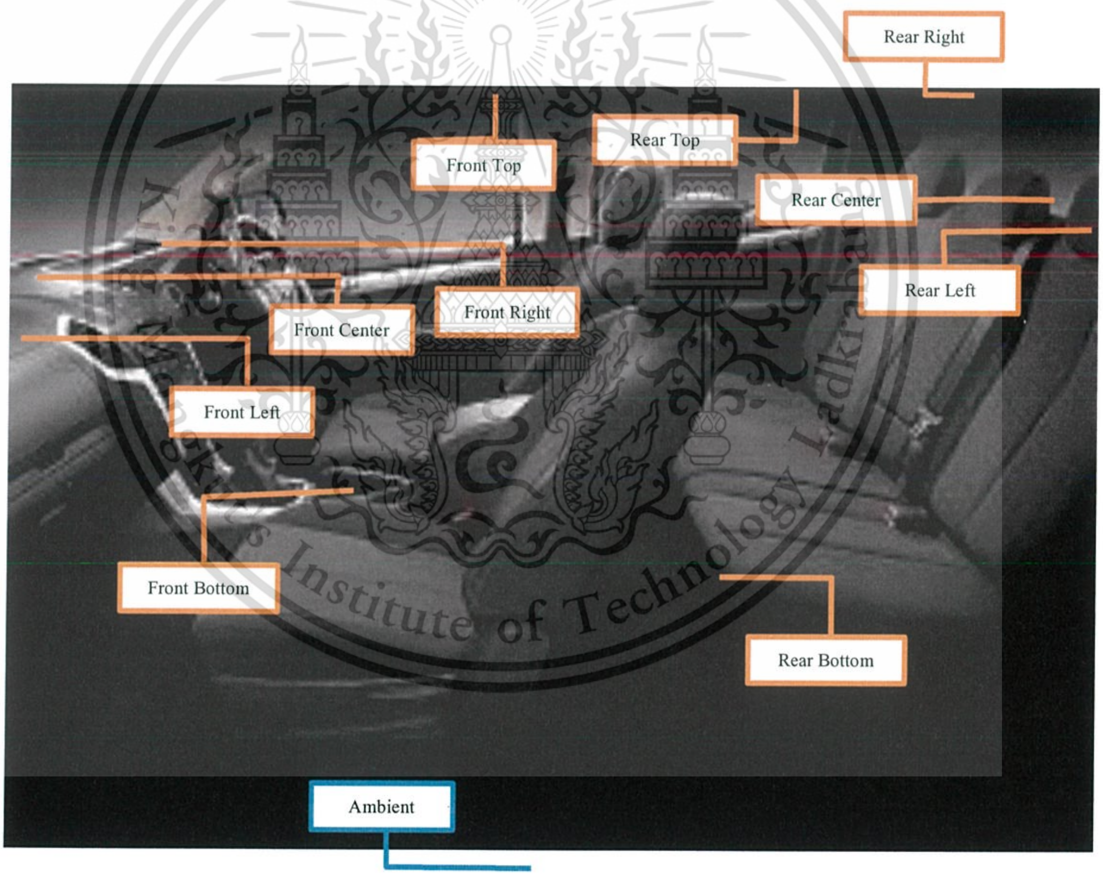


Figure 3.2b Location of the temperature sensors for pickup type vehicle

Temperature inside the vehicle was measured for several conditions to obtain the wide area of a data bundle. Whole experiment was carried out from 10.00a.m. to 4.00p.m. to analyze the behavior of temperature increment and identify the temperature zones of the vehicle. The temperature measurement was taken from two consecutive days in a raw to average the temperature value to improve the accuracy.

The experiment has been done for the two types of black color vehicles, sedan car and four doors pickup truck, closed window condition at the same place faced to the south direction with the same weather condition for two weeks. The summary of the experiment can be shown in the following chart. Research Data collection has been done by Thailand- NECTEC at the position coordinate of latitude 14 ° 01.0 'North and longitude 100 ° 32.0' East to measure the behavior in year 2016.

CASES:

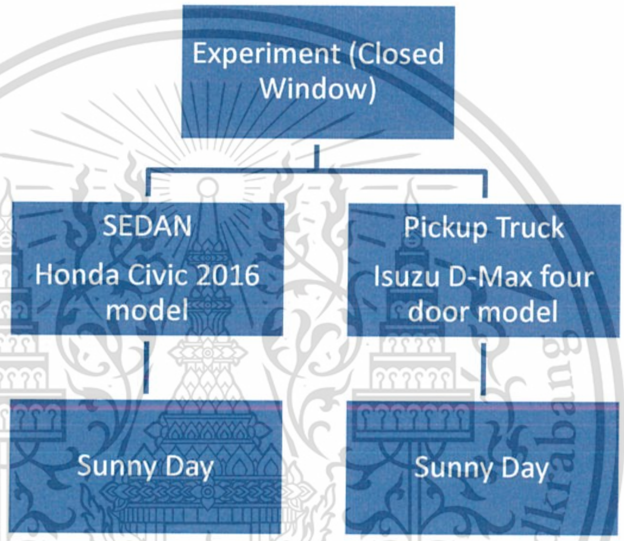


Figure 3.3 Experiment Procedure

From the research experiment, the temperature zones had been identified and a suitable place had been determined to locate the ventilator system and solar panel. So the effective and suitable place to fixed the exhaust fan to pump the hot air out can be identified from the results.

3.2 Simulation for the Thermal Behavior

Geometry of the vehicle CAD model is designed and created by using Solidworks 2016 CAD software. The interior and the exterior of the vehicle is made by using exact dimension of real world car but it's not fully detailed model. The complexity of the model can be effected to simulation time and research study was only concerned about the air trapped inside the vehicle interior.

Conventional Vehicle cabin is consisted with complicated components, shapes and material. But when simulation is focused only for the air trapped inside the cabin, simplified the model of extracted air volume is used because the complexity makes the tasks slower and require high processing power to compute the solution. According to that, the CAD model of car cabin had been simplified.

Following pictures will give a brief introduction about the simplification process.

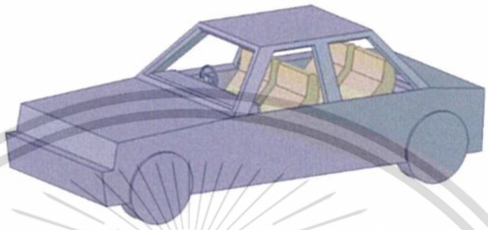


Figure 3.4 Whole CAD Model

Figure 3.5 Extracted Air volume and glass surfaces

This simulation focused about the accumulated heat inside the car cabin. The model has been simplified without steel surfaces as follows.

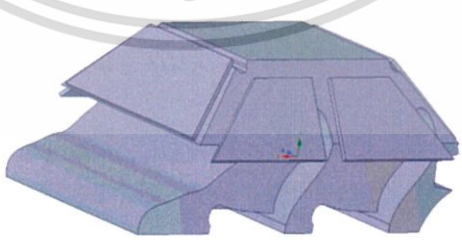


Figure 3.6 Extracted Air volume with fillets and non-important curves

Then the curves and fillets surfaces have been reduced to make more simplified as shown in the figure 3.6

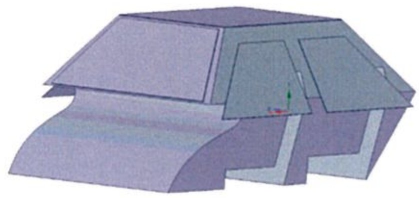


Figure 3.7 Extracted Air volume without fillets and non-important curves

Then the glass surfaces and metal shapes were added to the model to get results that are more accurate by transferring the heat through the glasses and the roof.

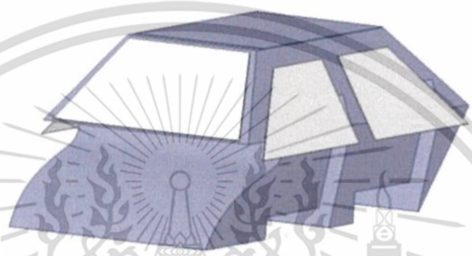


Figure 3.8 Simplified air volume with attached glasses

ANSYS fluent software is used to simulate the heat distribution and analyze the temperatures occurred which effects from solar radiation. ANSYS fluent consists with wide range of tool packages which are related to the simulations. In this study, Fluent with mesh package is used to simulate the heat transfer.

Solar Load Model is a tool which has been given by ANSYS Fluent to calculate the solar radiation which enter to computational domain. The solar load model of the FLUENT a solar calculator tool which is used to calculate the position of the sun by given locations (Longitude, Latitude) Day, Time of the observation. So this tool is very convenient tool to analyze the Automotive Climate control applications and human comfort modelling applications in buildings. Solar tracing algorithm has been used in this simulation in fair weather conditions as shown in following figure 3.9. As shown in the below image to improve the accuracy of the final result it consists with many parameters. Theoretical equations have been used according to the 2001 ASHRAE Handbook of Fundamentals book. So, after computing the radiation, Conditions of that day is visible with the radiation fluxes as shown in following figure.

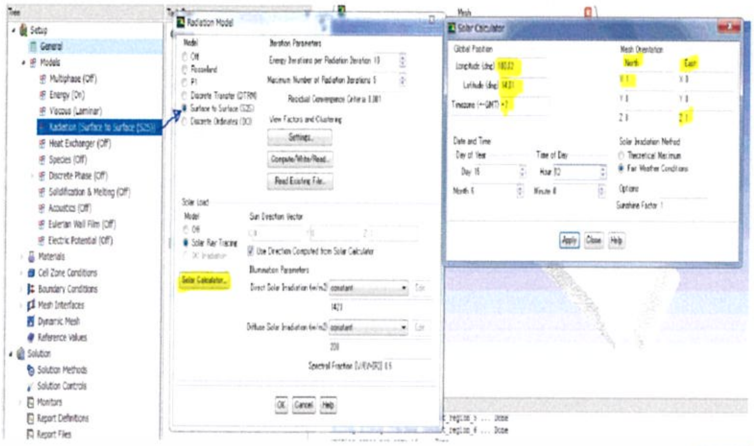


Figure 3.9 ANSYS Solar Calculator

```
Initialized VF Storage
Reading  View factors from file

Completed 25% reading of view factors

Completed 50% reading of view factors

Completed 75% reading of view factors

Completed 100% reading of view factors

Fair Weather Conditions:
  Sun Direction Vector:  X: 0.162347, Y: 0.983759, Z: 0.0765571
  Sunshine Fraction: 1
  Direct Normal Solar Irradiation (at Earth's surface) [W/m^2]: 887.426
  Diffuse Solar Irradiation - vertical surface: [W/m^2]: 74.5042
  Diffuse Solar Irradiation - horizontal surface [W/m^2]: 116.682
  Ground Reflected Solar Irradiation - vertical surface [W/m^2]: 98.9696
```

Figure 3.10 Conditions from ANSYS Solar Calculator

Only Direct irradiance of the sun light and default illumination parameters have been used for the calculation to minimize the solving time.

Material Assigning

The properties of the air have to enter to the setup to construct the model for the air inside the cabin.

Figure 3.11 Properties of Air

Properties of the steel and glass also enter to construct the roof, windscreen, rear glass and side glasses. For the insulation for the lower part of the cabin, insulation material has been used to obtain metabolic heat transfer from cabin to air.

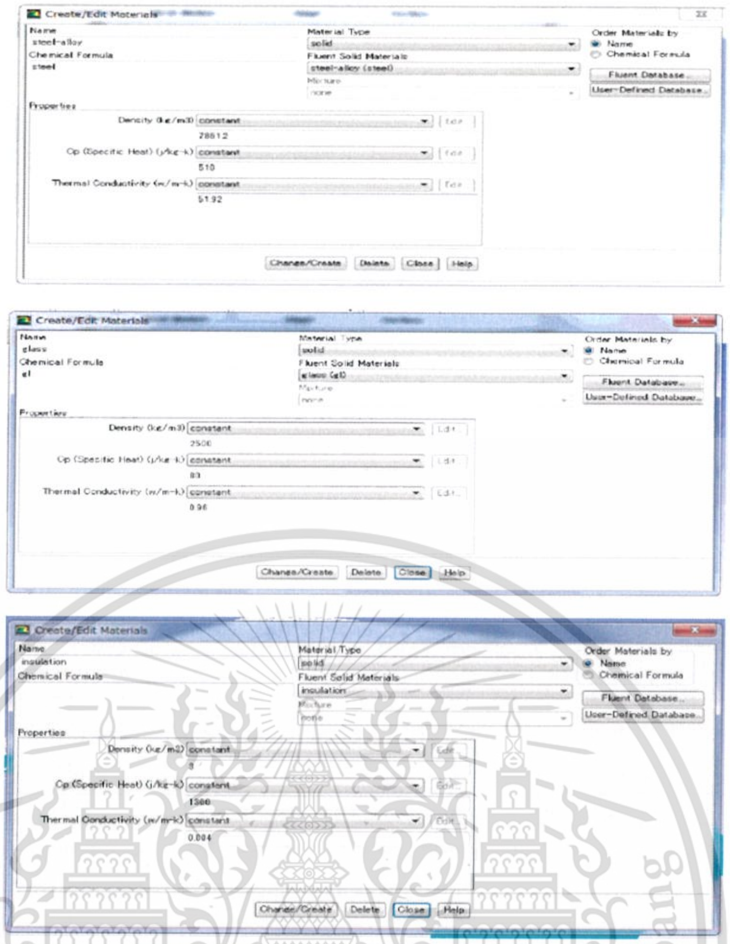


Figure 3.12 Properties of Solids (Glass, Steel and Insulations)

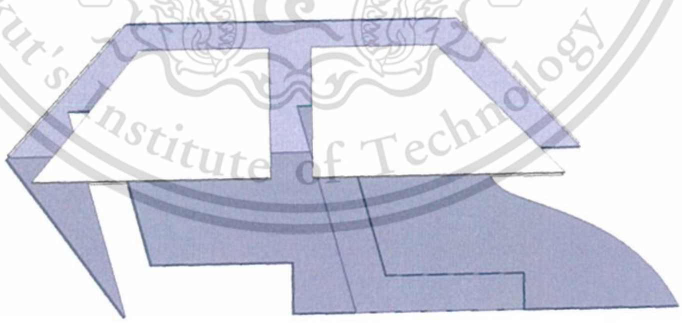


Figure 3.13 Side View of the CAD model

Direct solar radiation has been used over to the vehicle cabin which is normal to the roof as main energy source. The direct radiation values were automatically calculated from the solar model and other boundary conditions, such as properties of the heat transferring, material properties for the roof and the outer surface of the glasses have to input manually.

Defining contact bodies which are touched each other are shown in following figure.

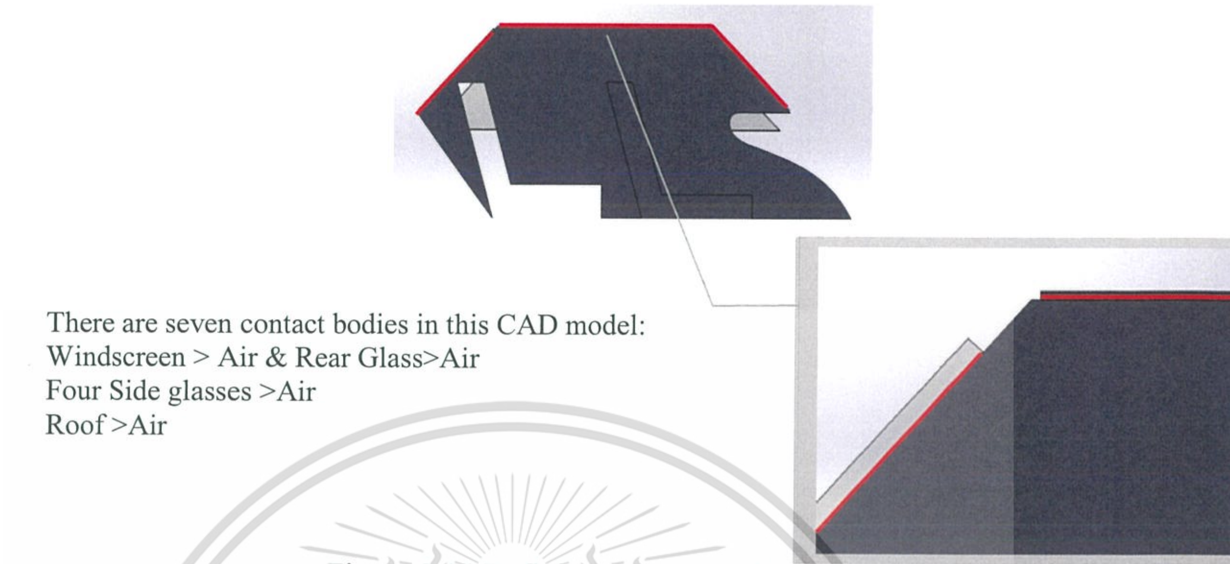


Figure 3.14 Defining contact surfaces

Contact bodies were coupled with surfaces for the meshing process. As shown in above figure the grey color inside the vehicle is consisted with air.

Table 3.1 Properties of the materials and boundary conditions

	Material	**Thickness(m)**	**Thermal conductivity** (W/mk)	**Density** (kg/m^3)	**Specific heat** (kJ/kgK)
Side Windows	Glass	0.003	0.96	2500	0.8
Front/Rear Glass	Glass	0.003	0.96	2500	0.8
Outer roof	Alloy	0.003	51.92	7861.2	0.51
Lower Cabin (insulation)	Insulation	0.004	0.004	3	1.3
Air	Air		0.0242	1.225	1.000

Following figures show the applied boundary conditions for the components inside the vehicle.

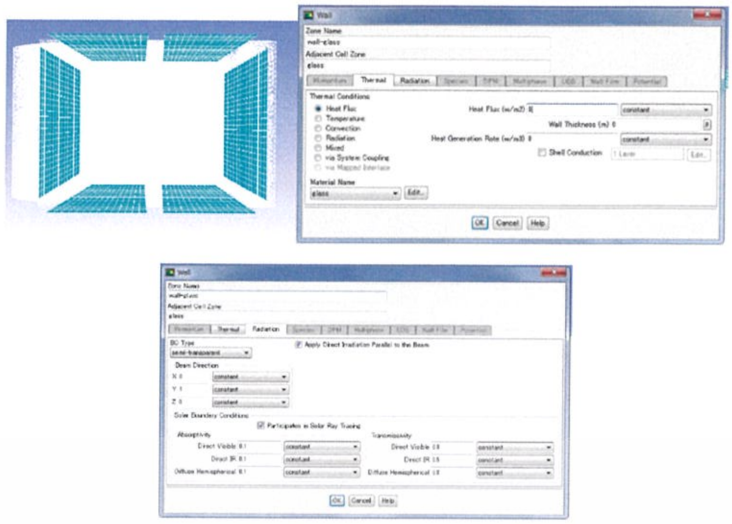


Figure 3.15 Defining boundary conditions for glasses

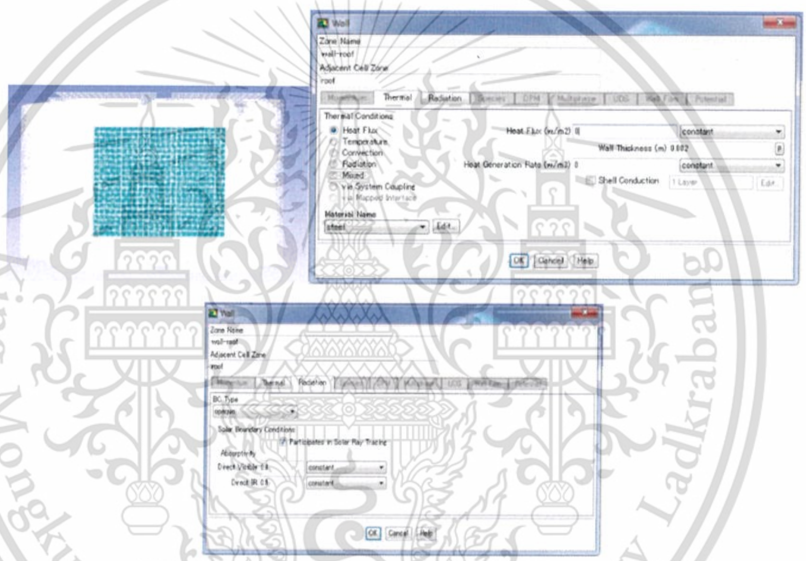


Figure 3.16 Defining boundary conditions for roof

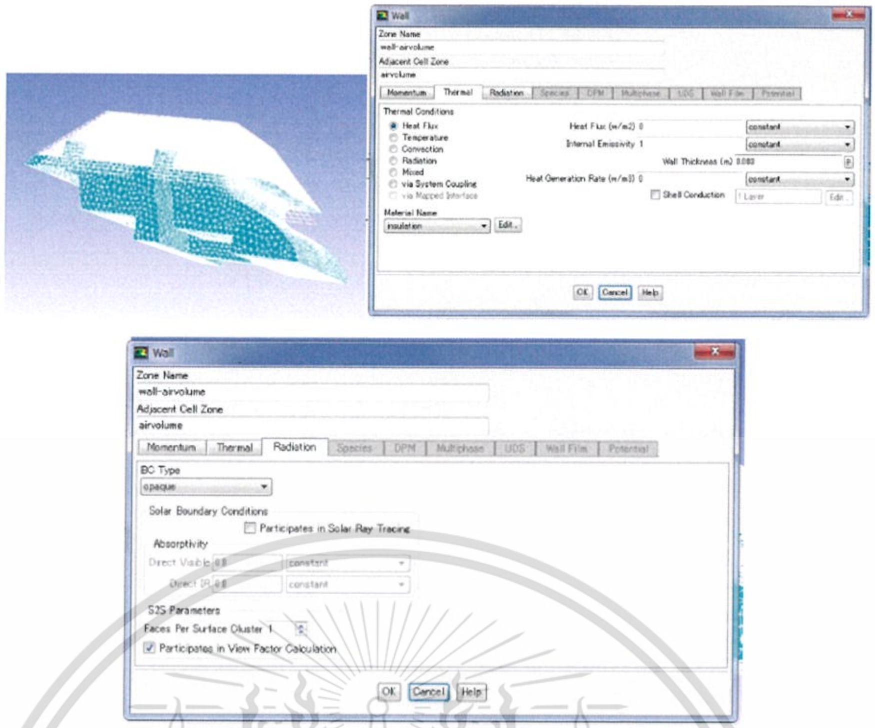


Figure 3.17 Defining boundary conditions for insulations

Simulation has been run for 5mins with 0.1s step times with 40 iterations for one-step. ANSYS Simulation was used to identify the thermal behavior which effect due to solar radiations. The higher and lower temperature zones were identified from the results to locate the ventilation system to increase the effectivity of pumping the hot air out.

From the simulation results the rate of increasing the temperature inside vehicle interior is measured and temperature incrementing rate is used to select the exhaust unit to pump the hot air out.

3.3 Experimenting with a prototype

Basic schematic view of this system is shown in figure fig:3.18. This unit can be easily attached to any kind of vehicle by a simple way and for the unit solar panel can be connected through wire connectors easily. The main reason of plug and use is very convenient to place this unit any location inside the vehicle cabin and foldable solar panel can be used to cover the windscreen, if you need to use or otherwise keep this one folded. And the exhaust piping system can be connected to the unit easily and extendable piping system to improve the mobility and user conveniently. After fixing this to the real vehicle, the system can minimize the temperature difference between vehicle cabin and outside ambient temperatures. Therefore, this leads to reducing the greenhouse effect inside vehicle cabin and it helps to improve the fuel economy by reducing the thermal load of air condition of a vehicle. Because of that, additional power from the engine is saved.

Arduino module has been used as the microcontroller because no advanced programming software and easy function will prefer and Arduino microcontroller is less in cost compared to other microcontrollers and the variety of the type of processor can be chosen for our requirements.

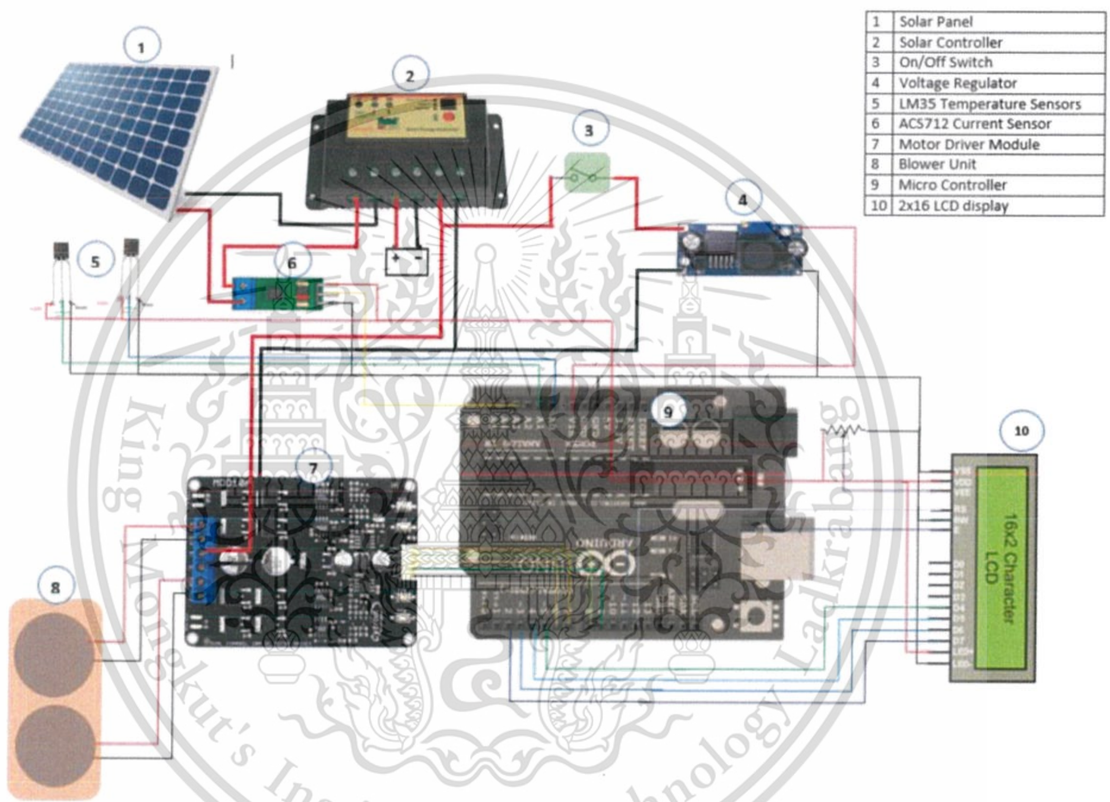


Figure 3.18 Schematic Design

Experimental results and simulation results were used to design a solution to reduce temperature inside the vehicle interior and determine a suitable place to locate the ventilator system and solar panel. So, the effective and suitable place to fixed the exhaust fan to pump the hot air out can be identified from the results.

The system is consisted with an Arduino microcontroller and two temperature sensors. The speed of exhaust fan control using the microcontroller that can operate different speed levels using PWM pulses to save some energy because the system has solar panels which can't expect continuous power output and low efficiency.

An experimental prototype will be implemented to compare the results between with ventilator and without a ventilator. From the experiment, the temperature zones had been identified and a suitable place been determined to locate the ventilator system and solar panel. So, the effective and suitable place to fixed the exhaust fan to pump the hot air out can be identified from the results.

Arduino micro-controller and temperature sensors will be used to check whether the temperature value is lower than the ambient temperature value, It means that tries to keep the cabin temperature value lower than the ambient temperature. If this is not satisfied exhaust system will be power on and pump the hot air out from the cabin. The speed of exhaust fan will be controlled by using a micro-controller that can operate at different speed levels using PWM pulses to save some energy by without operating at the maximum speed.

When PID is used the system, there will be an error occured for the present temperature value. For example, when cabin temperature is rising quickly, the PID calculates the PWM pulse to control the temperature from the present temperature and the temperature can be varied from the location of the temperature sensor but it takes time to bring the temperature into that certain temperature. While system is trying to stabilize at that temperature, the temperature can be changed again, PWM also changed, and there will be a time delay for the system. According the wide range of temperature difference inside the vehicle interior PID is not suitable and effective to reduce the temperature in the system. In this research, main focus was on energy saving to minimize the power consumption. The overall system is not linear and it's complex due to the two input parameters for the system. Due to that reason fuzzy algorithm is used to control the speed of the exhaust fan.

Solar panel and Battery are used to power up the system. In idle condition, battery is charging from the solar or else external charging methods also applicable in a case of insufficient, discontinuous charge from the solar panels. The actual air flow rate and power consumption of the system will be identified and behavior of producing solar energy at different time intervals also will be identified by this experiment.

Finally, this system will be tested with a real vehicle and the performance; efficiency will be compared with previous methods and techniques.

3.3.1 Fuzzy Logic Temperature Controlled System

Temperature control system is consisting with a closed loop feedback control system to obtain the measured temperature value to desired temperature inside the vehicle interior. Ventilation unit controls the temperature using the exhausting the hot air from the interior. The system controls the speed of the exhaust fans to decrease the temperature in the cabin. Fuzzy logic algorithm is used to control the speed of the motor. This control system automatically increases the speed of the fan, which is varied due to both solar irradiance and the temperature difference. Because the Solar irradiance is the main factor to increase the temperature in the cabin.

Following figure shows the rules of the logical thinking applied in the system.

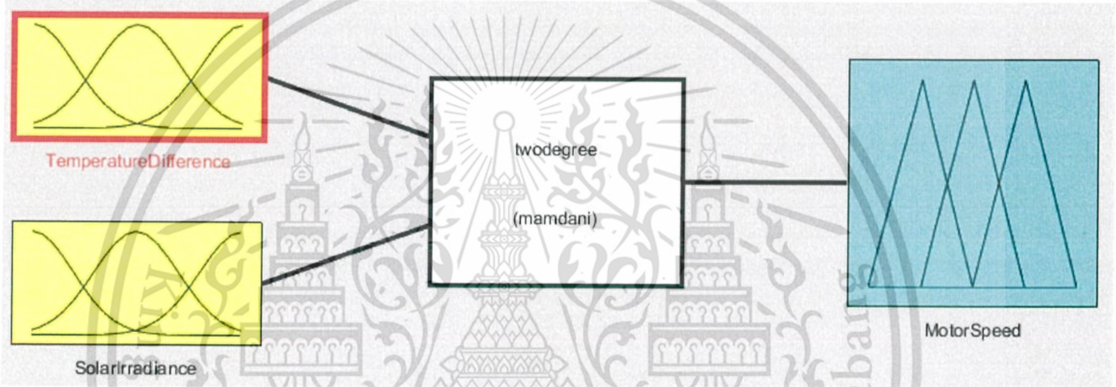


Figure 3.19 Fuzzy Control Diagram

Input of the fuzzy has two inputs, temperature difference which is the temperature difference of the ambient and interior temperature and the solar irradiation. Temperature difference is categorized into five states such as:

- very low temperature difference
- low temperature difference
- medium temperature difference
- high temperature difference
- very high temperature difference

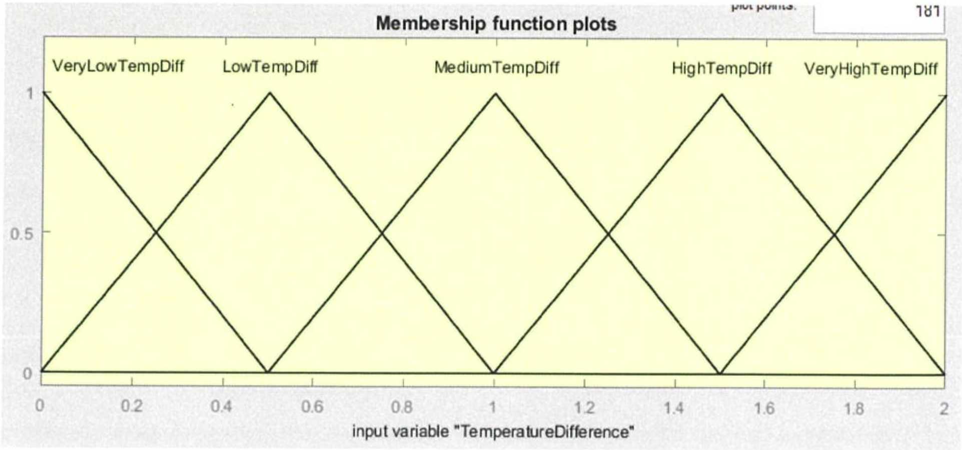


Figure 3.20 Membership function plot of the 2ºC temperature difference

In addition, the solar irradiation can be categorized into three states such like below:

- low solar irradiation
- medium solar irradiation
- high solar irradiation

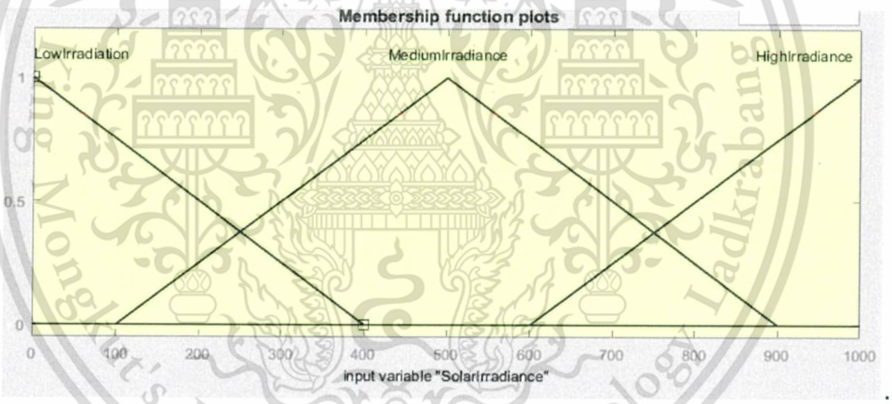


Figure 3.21 Membership function plot of the Solar Irradiance

According to these temperature differences from input, output motor speed is varied using Pulse width modulation (PWM). Moreover, the speed state of exhaust fan can be listed as follows:

- very low speed
- low speed
- medium speed
- high speed
- maximum speed

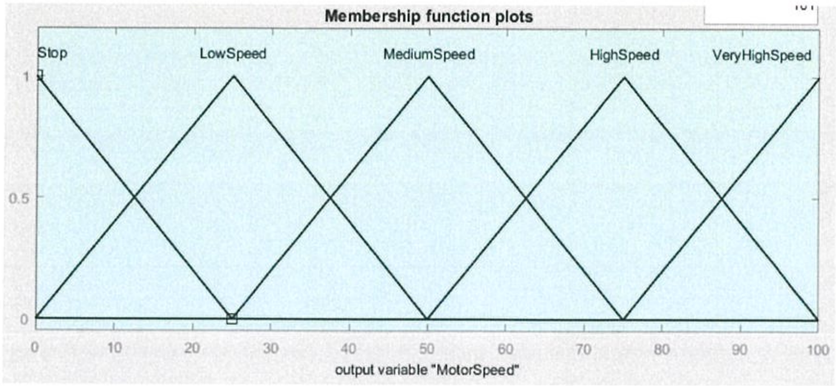


Figure 3.22 Membership function plot of the output (Speed of the ventilation unit)

Matlab fuzzy logic toolbox is used to design the control system for this system. Input used as temperature difference from 0°C to 2°C, 0°C to 5°C, 0°C to 10°C and the solar irradiation while the output is speed of the exhaust unit.

Table 3.2 Summary table (relationship for fuzzy rules)

CASE	If the temperature difference is		the solar irradiation is	Then the motor speed is
1	Very low	and	Low	Stop
2	Very low	and	Medium	Medium
3	Very low	and	High	High
4	Low	and	Low	Medium
5	Low	and	Medium	High
6	Low	and	High	Maximum
7	Medium	and	Low	Medium
8	Medium	and	Medium	High
9	Medium	and	High	Maximum
10	High	and	Low	Medium
11	High	and	Medium	High
12	High	and	High	Maximum
13	Very high	and	Low	Maximum
14	Very high	and	Medium	Maximum
15	Very high	and	High	Maximum

Figure 3.23 shows the behavior of the inputs and the output of the system. The system is not optimized because it takes time to do the research on optimization but for the easier of use control algorithm is applied for straight forward approach to given conditions for two degree Celsius change, for five degree Celsius change and for ten degree Celsius change. Solar irradiation is focused from 0-1000 W/m^2 in all conditions.

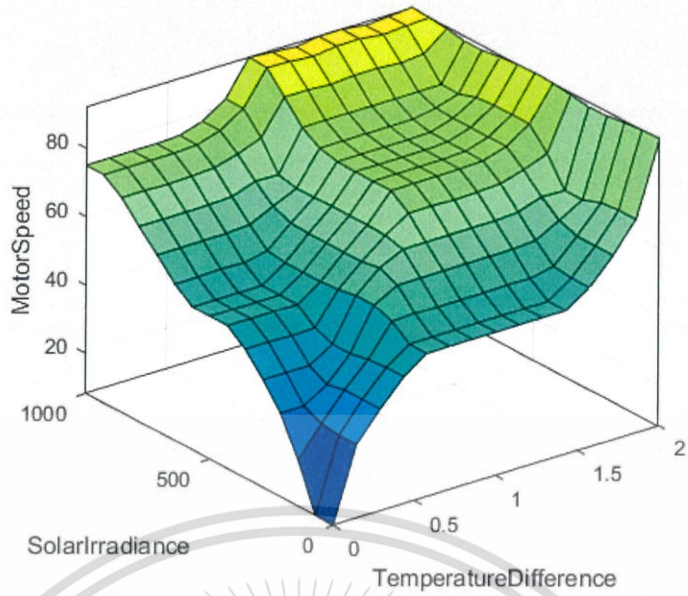


Figure 3.23 Relationship with Input and outputs in 2°C change

The table that have relationships between the input and out parameters are saved in the Arduino micro controller to get the output. Detailed programming flow will be discussed in section 3.4.

When fuzzy control is not used, simple mapping function is used to the temperature difference to control the blower. Speed of the blower varying from low temperature to high temperature. After exceeding the predefined temperature value, it operates at its maximum RPM.

3.3.2 Programming Flow

As mentioned in the section 3.3.1, system is designed fuzzy interface of triangular type membership functions so that the weight of the triangular shape is lower than the maximum value of the triangle end. Generated output values from the MATLAB after sampling is saved in Arduino as an array format to fetch according to the different solar irradiation and temperature levels. After exceeding the specified temperature value, the exhaust system operates at full speed using 255 PWM pulses.

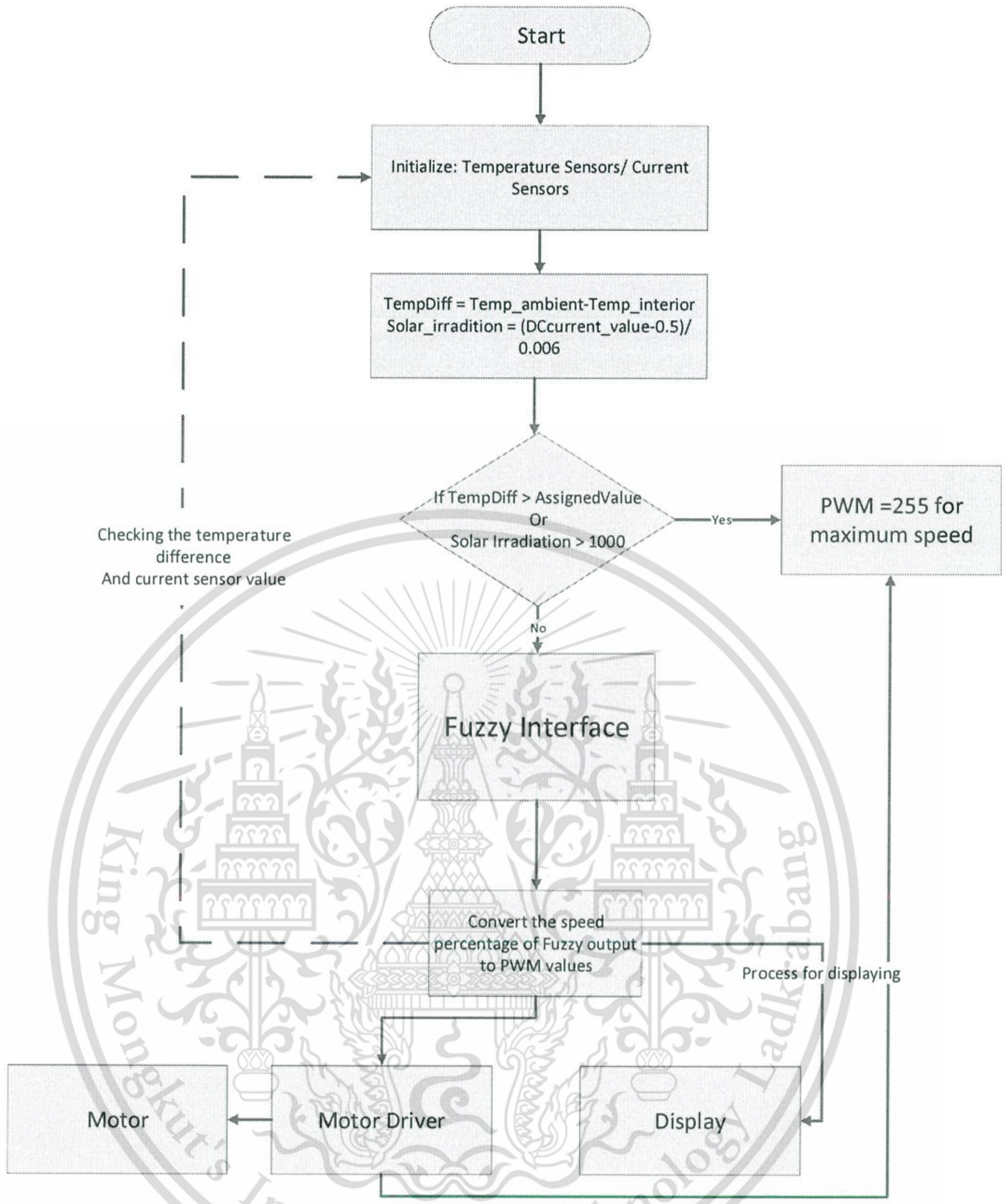


Figure 3.24 Programming flow of the Fuzzy system

Fuzzy Interface data for 2°C temperature difference and solar irradiation are shown in the table 3.3. For the 5°C and 10°C temperature difference fuzzy control algorithm also has almost the same relationship with the given temperature range. The detailed table is shown in the Appendix section A.

When the simple control algorithm is used, the system automatically adjusts speed from the lowest PWM value to the highest value by mapping predefined temperature range.

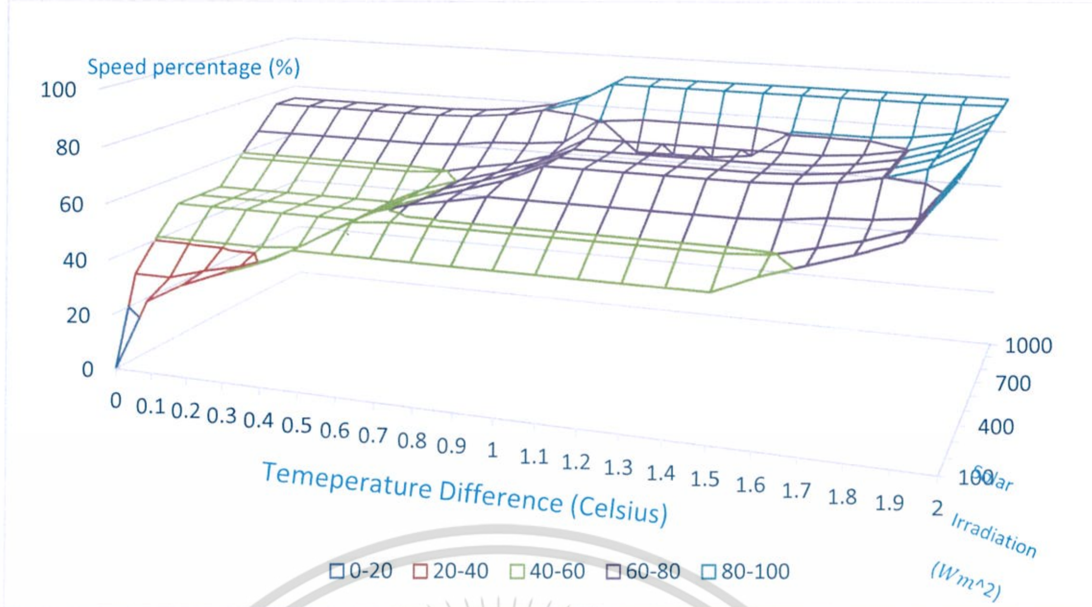


Figure 3.25a Input vs Output (0-2 Degree Fuzzy Interface in the Arduino)

3.3.3 Normal Control System

In this controlling system, current sensor reading is neglected. The speed of the blower unit is controlled only using the temperature differences. In this case also, 0-2, 0-5 and 0-10 has been considered to compare with the fuzzy controlled system. Figure 3.25b shows the linear relationship between the temperature difference and the blower speed.

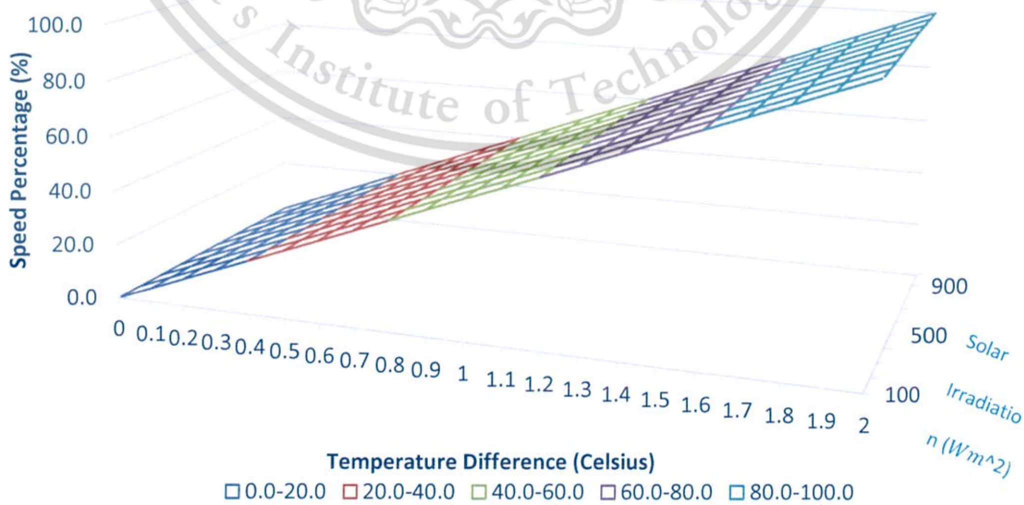


Figure 3.25b Input vs Output (0-2 Degree Normal control in the Arduino)

Arduino mapping function is used to calculate the speed at certain speed ranges.

3.3.4 Programming Code

The program is designed for the fuzzy algorithm by assigning array to the Arduino for each solar irradiance cases. There are 10 cases for solar irradiance from 0-1000W/m^2. But, if the values over that limit, blower will spin at its maximum RPM.

The program designed for linear controlling system used Arduino mapping function to get input output values.

3.4 Components, Sensors and Modules

3.4.1 Current Sensor module

ACS712 current sensor module is consist with a linear current sensor IC which measures the current using hall effect. The low resistance internal conductor allows for sensing up to 30 A continuous current. Providing typical output error of 1%.

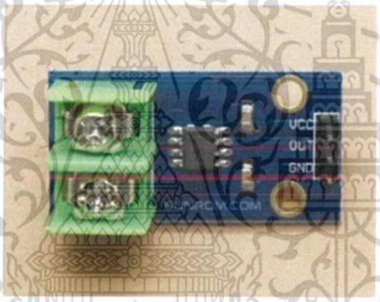


Figure 3.26 Current Sensor Module

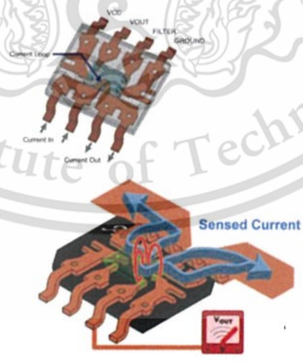


Figure 3.27 Hall Effect Sensor cross section

3.4.2 Temperature Sensor

Heat flux is a total energy measurement while the temperature gives the average kinetic energy of a molecule. LM35 temperature sensor is used to give the temperature.

I have used this sensor because of the following specifications of the temperature sensor.

As I mentioned in above sub section, heat flux is a total energy measurement, while the temperature gives the average kinetic energy of a molecule. LM35 temperature sensor is used to give the temperature. From this temperature sensor. I have used this sensor because of the following specifications of the temperature sensor.

- LM35 is an analog, linear temperature sensor that has an output voltage varies linearly with respect to temperature. (Linear + 10-mV/°C Scale Factor)
- It has a wide measurement of the temperature from-55 degree Celsius to +150 degree Celsius. Calibrated directly to Celsius (Less than 60-μA current use)
- LM35 temperature sensor is small and low power consumption

The schematic diagram of the system can be seen in following figure.

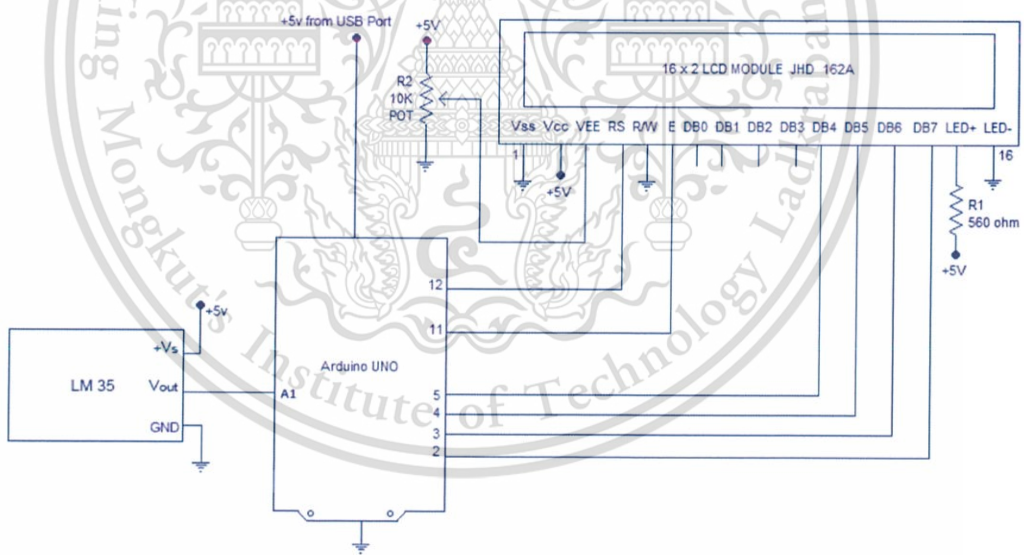


Figure 3.28 Schematic view for LM35 and LCD module

LM35 temperature is calibrated using a temperature measuring tool and ADT7410 temperature sensor.

3.4.3 Solar Panel

Solar panels are designed to produce 12v output voltage and the panel is consisting with foldable strips that seems like following picture and the whole solar panel can be used as a solar reflective panel for vehicle windscreen. This panel blocked the solar radiation to the front dashboard and produced the electricity.

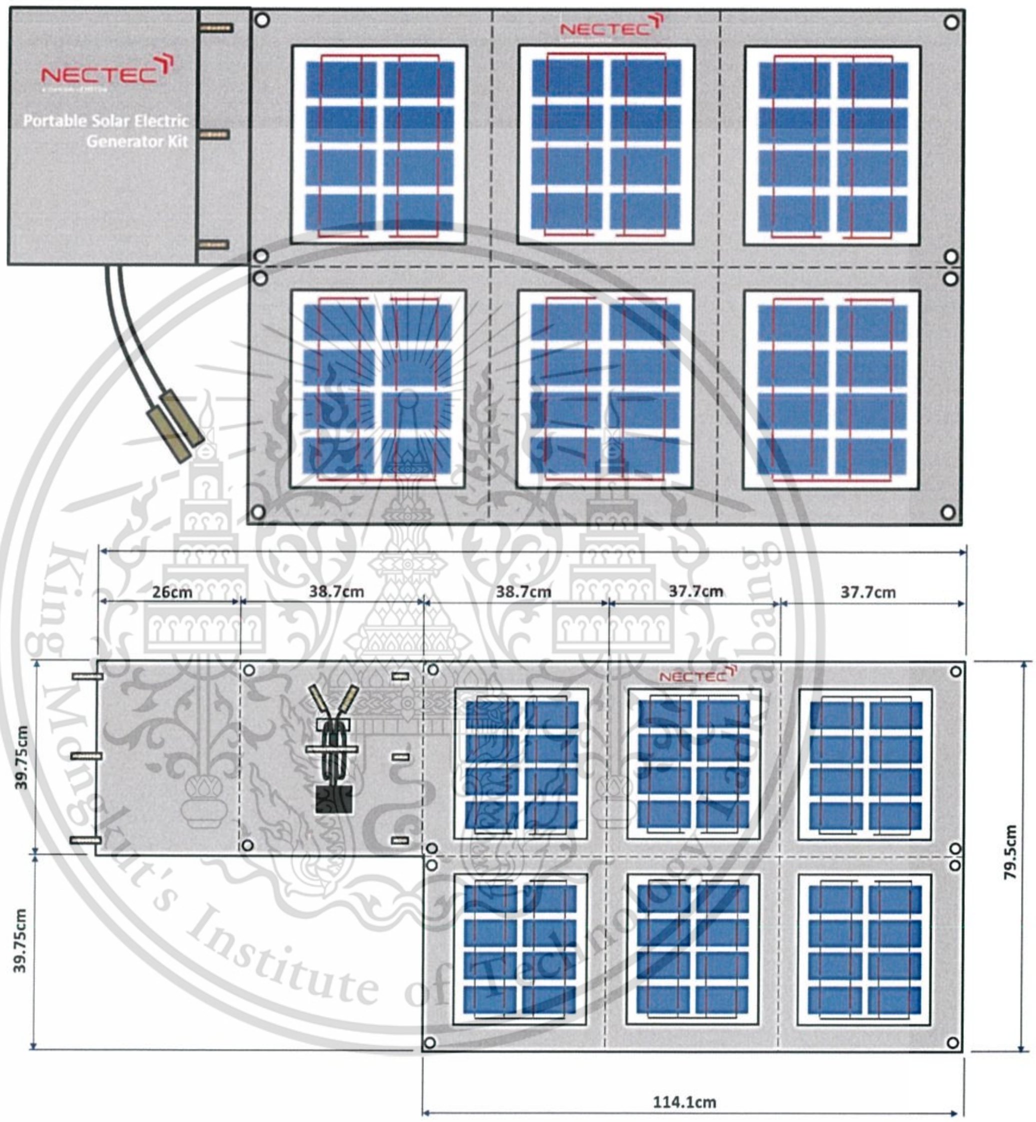


Figure 3.29 Type of the solar panel

3.4.4 Solar Controller

Landstar LS1024R/LS2024R PWM solar controller unit is used as the battery controller unit for the solar panel. Solar panel cannot be connected to the system due to the lack of continuous power/ voltage. Solar controller unit manage the power from the solar panel to charge the battery and supply it to the load.

3.4.5 Micro-controller (Arduino UNO R3)

Arduino Uno micro controller is used to control the motor speed according to the environment conditions. Arduino has analog 6 pins and 13 digital pins to works with sensors and actuators. System has three sensor inputs (current sensor, ambient temperature sensor and interior temperature) and PWM pins to control speed of the motor and to show the output in the 2×16 LCD module.

3.4.6 2×16 LCD module

LCD module is used to show the temperature difference and solar irradiation from the controller. If the temperature difference and solar irradiation value show in the LCD are displayed, the user can read and identify the how much it gets heated, rise of temperature and recognize, what is the solar irradiance value and the speed of the flow rate of the system. Figure 3.30 shows the output orientation of the system.

Figure 3.30 Sample output from the LCD

3.4.7 Motor Controller

Generally, Micro controller could not provide a high current to a motor directly due to that motor controller is used which can work with PWM -pulse width modulation signals. Motor can operate to the various speeds using the varies of input signals provided by the micro controller. Basically, the motor driver acts as an amplifier which amplifies both voltage and current (power) according to the signals from the micro controller.

3.4.8 Blower Unit - Motor specifications

System consists with two centrifugal blower unit to decrease the temperature inside the cabin by pumping the inside hot air to outside. The blower unit should satisfy the following requirements:

- High RPM - high flow rate
- Low Power Consumption - to pump the air continuously using the solar panel and the battery
- Small in size - to create a compact and portable device

It is very hard to find a blower fan that satisfies above requirements. As a consequence, an idea came to use a Brushless DC (BLDC) motor, which partially satisfies the requirements. In general, these fans are used in small volume cooling applications. But, this project contains two blower units. Each blower fan has a flow of 45.49 CFM at 5800-RPM maximum speed. both can provide a flow rate around $2.5 m^3/_{min}$.

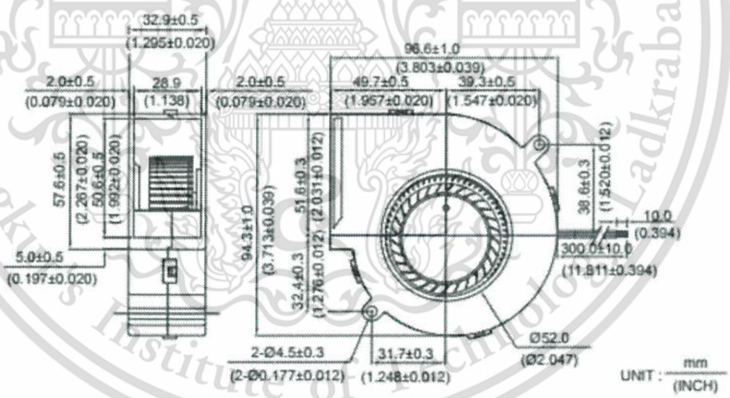


Figure 3.31 Dimensions of the Blower Fan

Source: http://www.delta.com.tw/product/cp/dcfans/download/pdf/BFB/BFB97x94x33mm.pdf

The speed of the blower unit is controlled by using PWM pulses. Unfortunately, BLDC does not consist with wide range of PWM, because it has an internal circuit to operate at a certain speed. It requires 220 PWM to start the motor spinning and 220 to 235 PWM range gives significant change in the rotations. After 240 PWM value, it reaches the maximum RPM. In practical BLDC cannot operate in low speed levels but for this research study, speed controlling used to control the flow rate and save the power consumption.

3.4.9 3-12v Step-Down Voltage Regulator

This system uses 5v input voltage for the LCD and for the Arduino micro controller. 3-12v variable voltage regulator used to convert the 12v supply from the solar controller to minimize in case of harmful voltage or current come to the system because it regulates the voltage at 5v and maximum 3A.

3.4.10 Battery

Designed system has a battery slot to plug 12v normal power pack using 3.5mm connections. So, if the battery does not have enough power user can charge easily using a conventional 3.5mm male adapter which has a rated voltage of 12v.

3.5 Performance Testing and Analyzing the Results

Final product of this research has two BLDC fans and the system can be attached to the vehicle on the rear side screen flat surface easily. This unit can be placed to seal the gap between door and the rear side window. The outer surface has an exhaust outlet that can blow the air to the outside of the car window.

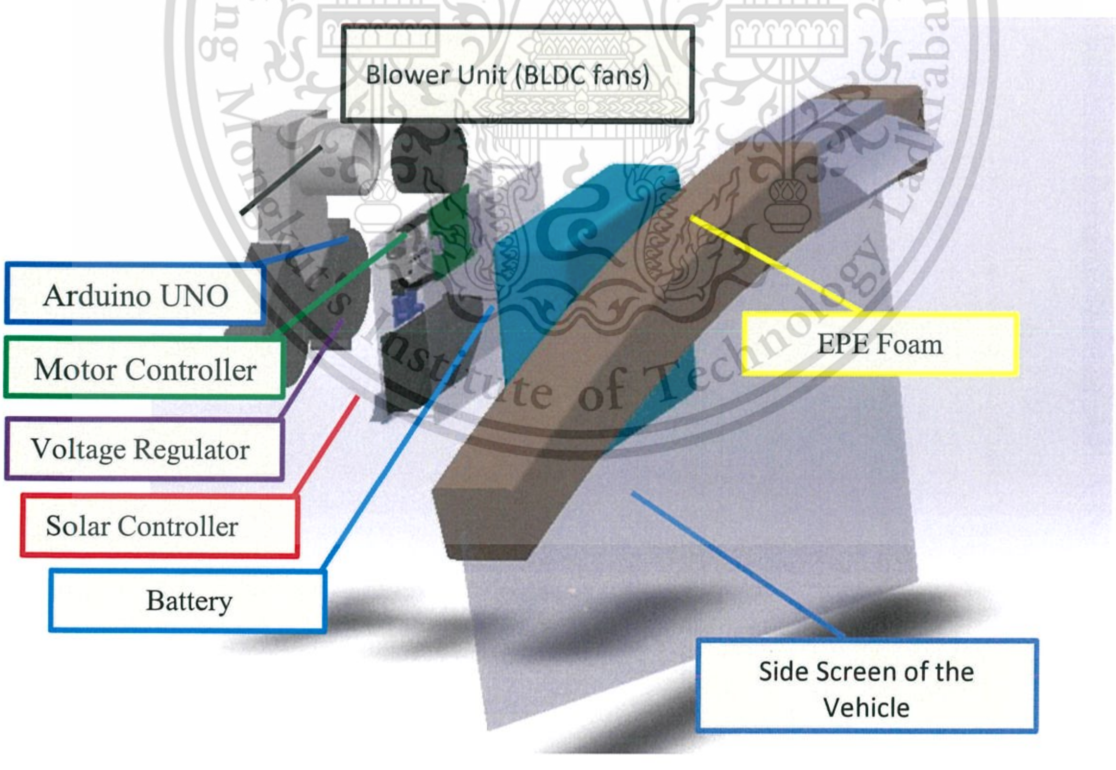


Figure 3.32 Components of the system

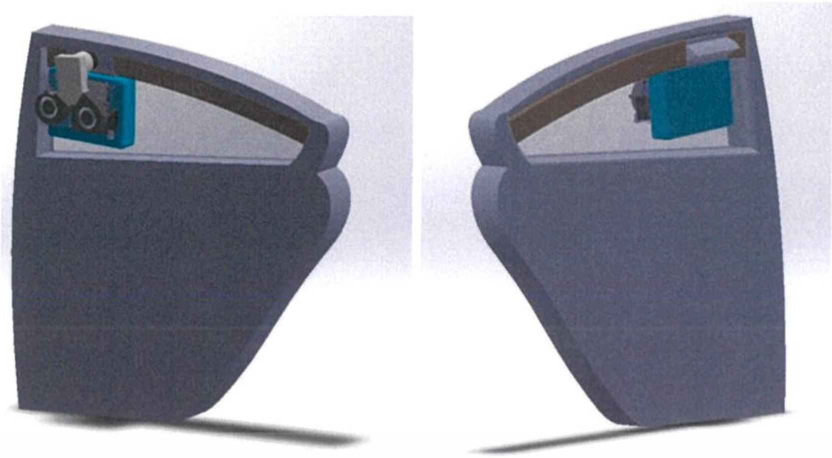


Figure 3.33 Location of the ventilation unit

After the ventilation unit was created, the several experiments have been done to measure the temperature variations inside the vehicle interior. List of experiments mentioned below:

- **Testing the System** - Temperature rising was measured in a vehicle under different conditions of ventilation system
  - Using fuzzy control system
  - Without using fuzzy control system (linear control system)
  - Without using a ventilation unit (No System)

In this experiment, control algorithm was changed in different conditions as follows. When using the fuzzy algorithm, the system adjusts the speed of the blower from 0 to predefined temperature value, such as 2 5 10 degree Celsius and solar irradiance. If not, the control system uses the fuzzy algorithm, simple mapping algorithm to control the speed of the blower from the same temperature range. Appendix A shows the detail value of the controlling value for fuzzy control algorithm.

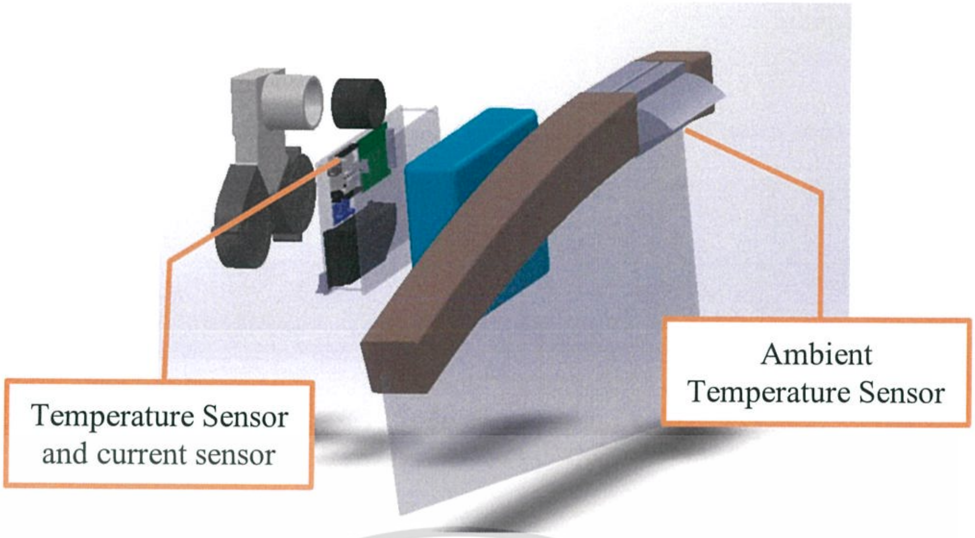


Figure 3.34 Location of the sensors

1. Fuzzy system 0-2°C control algorithm
2. Linear control 0-2°C control algorithm
3. Fuzzy system 0-5°C control algorithm
4. Linear control 0-5°C control algorithm
5. Fuzzy system 0-10°C control algorithm
6. Linear control 0-10°C control algorithm

As mentioned in 3.3.1, the fuzzy control system table was included in the controller to run the blower at different conditions. For this test, dark colored Honda accord vehicle was parked at the same location from 13/03/2018 to 18/03/2018. The car was parked facing to south direction and the solar panel was used to cover the front windshield as shown in the figure 3.35.

The measurement from 9a.m.to 4p.m. was taken within a time interval of 1 minute. Before starting the experiment all the doors were left open to balance the temperature difference between ambient and the interior. Then the system was installed to the vehicle side door as shown in the figure 3.36. Interior temperature and ambient temperature sensors are located as shown in the following figure. Ambient temperature sensor is not directly exposed to the sun light to increase the accuracy of data.

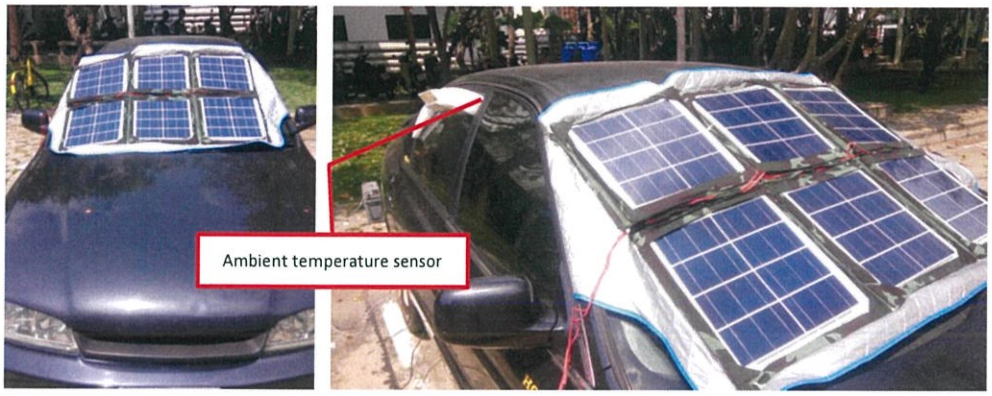


Figure 3.35 Solar panel covering the windshield

Figure 3.36 Installation of the system

- **Fuel consumption of the engine for AC** - In this experiment, the fuel consumption of the car was measured for 15 minutes after being exposed to sun light for few hours to reach it maximum average temperature for five thermos couples as previous. The experiment has been done in June 14-15. Then temperature changing has been recorded by using data logger within 1min intervals and the fuel consumption has measured using a portable OBD II tool.
- **Fuel consumption of the vehicle at idle stage** – this experiment also was done as the previous and without turning on the AC. So, the AC compressor was off in this experiment without measuring the temperature inside the interior.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, results of the experiments and output of the research methodology will be discussed. Experimental results have been conducted to analyze the performance of the system and research methodology.

4.1 Impact for the temperature accumulated inside the vehicle

Temperature distribution and Temperature rising inside the sedan type vehicle and pickup truck have been measured by using the 11 RTD type thermocouples as mentioned in the previous chapter. Temperature inside the vehicle can be summarized into following tables. The experiment has taken place at same location for the days where the experiment has carried out. the weather conditions almost the same for the week which we measured.

Day 01 – Honda Civic fully closed south faced (2016/06/11)

	Front_Right	Front_Center	Front_Left	Rear_Right	Rear_Center	Rear_Left	Front_Top	Front_Bottom	Rear_Top	Rear_Bottom	Ambient
Max temp	66.16	68.55	62.98	72.92	69.22	67.71	66.34	51.54	68.76	57.04	40.39
Avg. temp	60.86	61.97	58.45	66.32	63.11	61.62	60.85	46.76	63.36	52.30	36.31
Min temp	48.78	48.83	46.59	53.05	51.91	49.50	48.69	37.56	51.51	41.62	32.79
Max temp difference	17.4	19.7	16.4	19.9	17.3	18.2	17.7	14.0	17.2	15.4	7.6
Avg . % increment	67.6	70.6	61.0	82.6	73.8	69.7	67.6	28.8	74.5	44.0	0.0
Interior Average	59.6										

Figure 4.1 Experimental results 01

Day 02 – Honda Civic fully closed south faced (2016/06/12)

	Front_Right	Front_Center	Front_Left	Rear_Right	Rear_Center	Rear_Left	Front_Top	Front_Bottom	Rear_Top	Rear_Bottom	Ambient
Max temp	59.7	59.53	58.89	64.74	62.66	61.49	60.97	53.04	59.93	54.47	42.25
Avg. temp	55.76	56.54	55.37	60.17	58.68	57.62	57.28	50.15	56.31	51.07	40.55
Min temp	48.49	50.83	49.14	51.48	51.09	50.31	49.92	44.59	49.53	44.07	38.35
Max temp difference	11.21	8.7	9.75	13.26	11.57	11.18	11.05	8.45	10.4	10.4	3.9
Avg . % increment	37.5	39.4	36.6	48.4	44.7	42.1	41.3	23.7	38.9	25.9	0.0
Interior Average	55.9										

Figure 4.2 Experimental results 02

Day 03 – Isuzu D-Max fully closed south faced (2016/06/14)

	Front_Right	Front_Center	Front_Left	Rear_Right	Rear_Center	Rear_Left	Front_Top	Front_Bottom	Rear_Top	Rear_Bottom	Ambient
Max temp	54.20	54.90	55.00	49.70	50.30	49.70	44.60	43.90	44.60	44.60	36.00
Avg. temp	44.91	45.29	45.54	42.78	42.97	42.92	40.66	40.29	40.51	40.59	32.27
Min temp	38.80	39.30	39.30	37.90	38.00	38.00	36.00	35.20	35.70	35.80	30.50
Max temp difference	15.4	15.6	15.7	11.8	12.3	11.7	8.6	8.7	8.9	8.8	5.5
Avg . % increment	39.2	40.4	41.1	32.6	33.2	33.0	26.0	24.8	25.5	25.8	0.0
Interior Average	42.6										

Figure 4.3 Experimental results 03

Day 04 – Isuzu D-Max fully closed south faced (2016/06/15)

	Front_Right	Front_Center	Front_Left	Rear_Right	Rear_Center	Rear_Left	Front_Top	Front_Bottom	Rear_Top	Rear_Bottom	Ambient
Max temp	57.2	55.5	55.6	50.3	48.8	47.3	50.2	45.3	46.2	46.0	36.0
Avg. temp	47.4	45.9	46.1	43.3	41.7	40.8	45.7	41.6	42.0	41.9	32.2
Min temp	40.9	40.1	40.1	38.5	36.9	36.1	40.5	36.3	37.0	36.9	30.3
Max temp difference	16.2	15.4	15.5	11.8	11.9	11.1	9.7	9.0	9.2	9.1	5.7
Avg . % increment	46.9	42.3	43.0	34.4	29.4	26.6	41.9	29.0	30.2	29.9	0.0
Interior Average	43.6										

Figure 4.4 Experimental results 04

Detailed temperature rise with the temperature will be attached in the appendix. As shown in the above table, average temperature of a car cabin has a higher temperature than the pickup truck. When the car is parked and exposed to the sun light from 10.00a.m. to 04:00p.m. (6 hours), average temperature of the car is over 50 degrees Celsius, while the pickup truck has around 40 degrees Celsius. The temperature at the front rear dashboard and near the roof has higher temperature than average temperature inside the vehicle. The rear/front screens of Sedan car are inclined and has larger surface exposed to the direct sun can be the reason to increase the temperature inside the interior and the dash panels can absorb the heat radiations. After few minutes, the heat radiation emits from those components could not escape from the windows, because the wavelength of heat radiation is different from the wavelength of solar heat radiation. Due to that, most of the heat is trapped inside the vehicle and it causes gradual increment of the interior temperature of the vehicle. (University of California, Santa Barbara, n.d.)

Maximum/ Average/ Minimum temperature was calculated using the excel functions in each column for temperature. Maximum temperature difference recorded is the different between maximum temperature and the minimum temperature. Average percentage increment of the temperature can be calculated as follows;

$$Average\ percentage\ increment = \left(\frac{Avg.\ temperature - Avg.\ Ambient\ temperature}{Avg.\ Ambient\ temperature}\right) \times 100$$

Recorded temperature near the windscreen is relatively higher in both vehicles and the temperature near the rear screen high in the sedan car but in pickup truck it's not much higher like the sedan. Vertical rear screen and small dash panel may be the reason for the lower temperature in the pickup truck. Near the roof surface also has a higher temperature in both vehicles. Because roof is the largest area which exposed to the sunlight. Lowest recorded temperature is from the bottom area of the vehicle near the passenger seats because the sun light is not coming directly to those locations.

4.2 Simulation Results for the thermal behavior

The temperature inside the cabin has distributed as shown in the following figure. So in reality seats, plastic/leather coverings and dashboard absorb the significant percentage of thermal radiation and emit that heat as an extra heat emission from the cabin interior. The Simulation from ANSYS has been performed for 5mins from the step time of 0.1s in to 3000(10x60x5) with 40 iterations for one step for above boundary conditions. Within 5minutes with different conditions of solar radiation can cause temperature increment inside the vehicle.

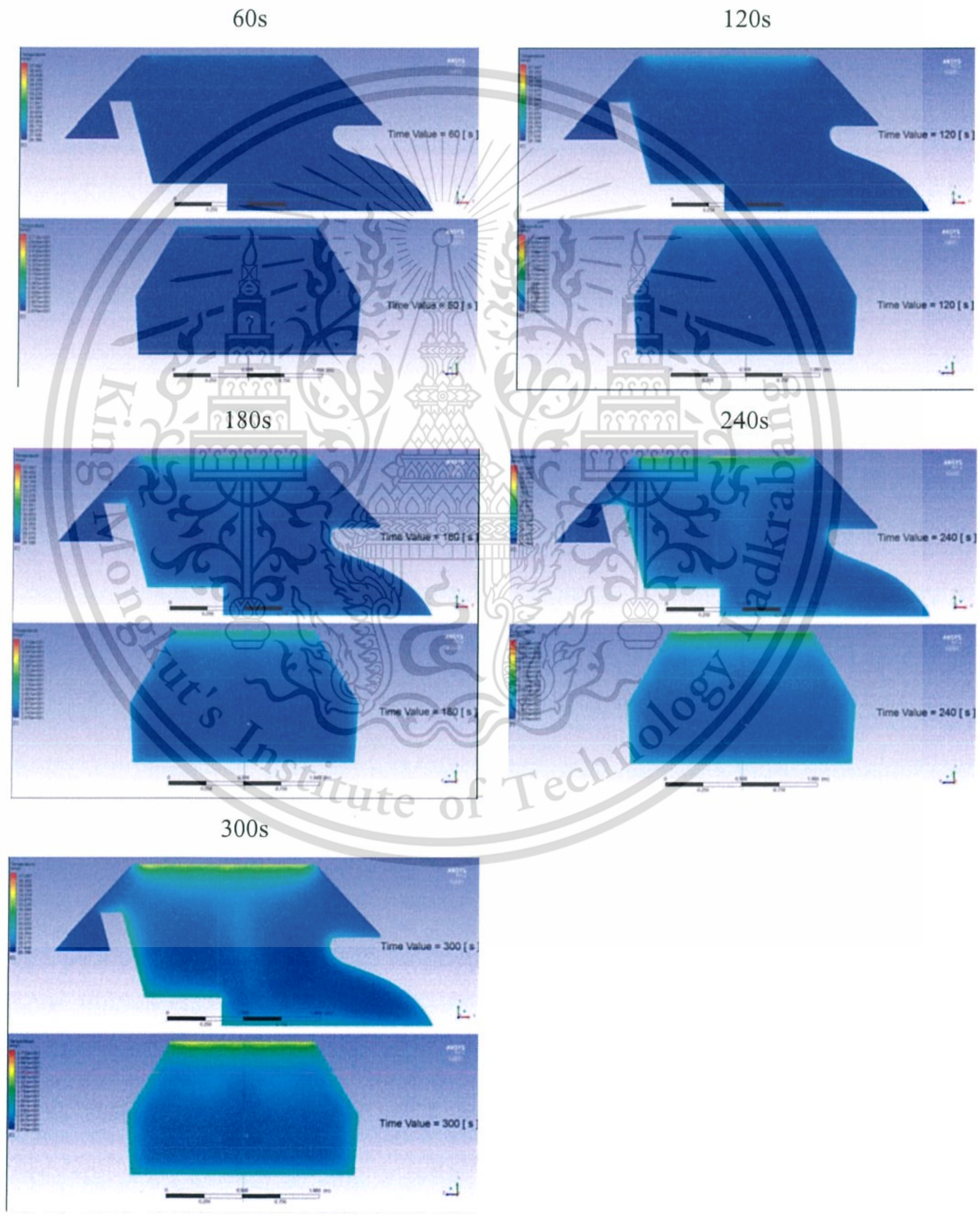


Figure 4.5: Simulation results at 400W/m^2 flux on the roof surface

The simulation has been run for 5minutes (300s) to identify the heat transfer inside the cabin and observe how fast the temperature is accumulated inside the cabin. (Note: The initial temperature is 26.85 °C (300K) and insulation of the inner roof is not applied)

Absorptivity of direct IR and visible for the glass used in the simulation is 0.1 and the transitivity of direct IR and visible for the glass is 0.5 and 0.8 used respectively. Due to that, higher percentage of solar radiation enters through the glass surfaces is directly affected to the interior and emits the radiation from the cabin interior.

Summary of the simulation results can be seen in the following figures with different heat flux levels over the roof surfaces.

Heat flux normal to roof (W/m^2)	Avg temperature inside the cabin(°C)	Max temperature recorded(°C)
100	27.75	29.44
200	28.56	31.99
300	29.84	34.55
400	30.08	37.10
600	31.79	41.26

Figure 4.6: Simulation results for difference heat fluxes on the roof surface

As shown in the above table the 600W/m^2 can cause 10°C difference within 5minutes for SEDAN type vehicle.

4.3 Experiments with the Prototype

As was mentioned in the section 3, each control measurement has two conditions such as using fuzzy algorithm and simple controlling algorithm. Those two conditions also contain three sub categories: 0-2°C controlling, 0-5°C controlling and 0-10°C controlling. Figure 4.7 shows the raw data of temperature difference between the ambient temperature and interior temperature. For easier to understand the sixth order polynomial trend will be discussed as shown in the figure 4.8. Raw data can be found in the Appendix B and C sections. Appendix B section shows the temperature variation along the cabin with multi points and Appendix C shows the temperature behaviors inside the vehicle for following results.

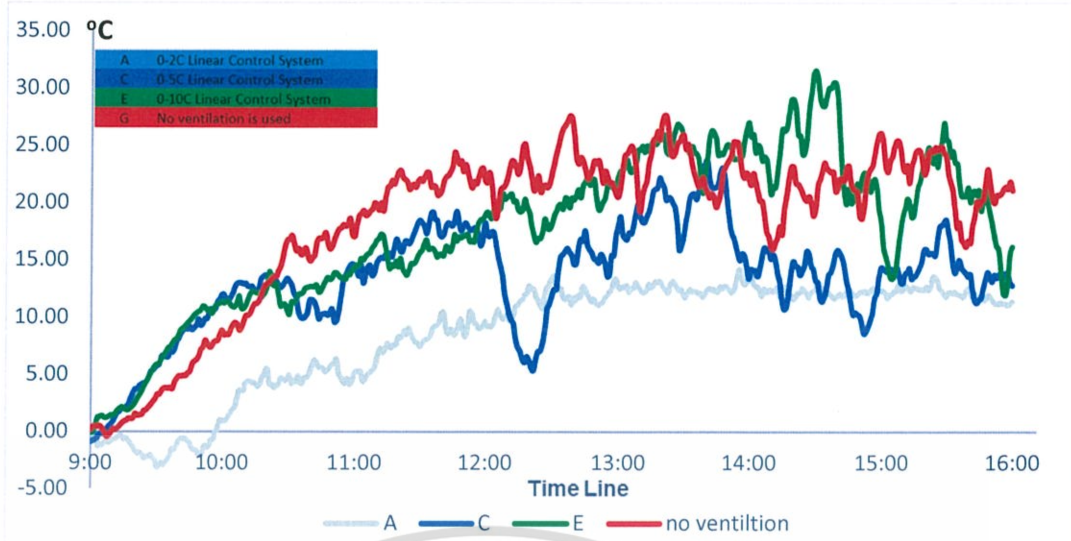


Figure 4.7: Raw data for temperature differences

In the figure 4.7 and 4.8, Simple mapping function is used to control the speed of the blower. Sixth order polynomial function of the raw data is shown in the following figure.

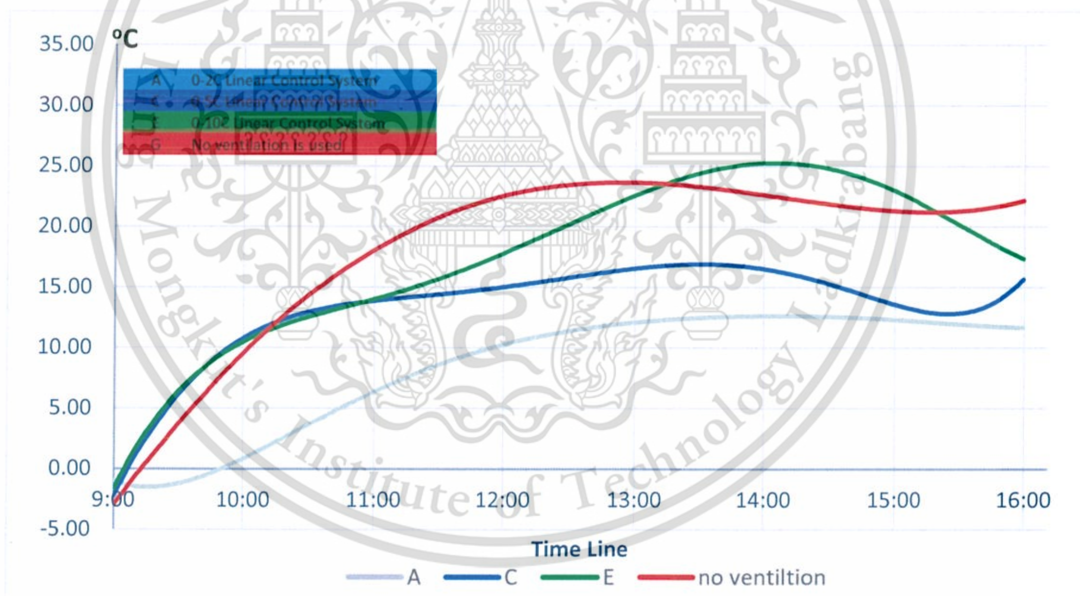


Figure 4.8: Smoothen data for temperature differences

Light blue color shows the temperature value of 0-2 Celsius mapping condition for controlling the blower. Blue color trend shows the temperature value of 0-5 Celsius mapping condition. Green color trend line shows the temperature value of 0-10 Celsius mapping condition, while the red trend line shows temperature difference of no ventilation method. March is a month that sun get closer to perpendicular angle of the earth surface in Thailand. So the solar irradiance also became higher and ambient temperature became higher. Due to that, interior temperature will rise rapidly. Within few minutes as shown in the figure 4.7 red trend line, temperature rises dramatically up to 10 Celsius. But, after few hours the temperature cannot be controlled using the using flow rate. If the controlling system has 0-2 range, it tries to maintain the temperature difference up to one hour. Other controlling temperature range is not effective to maintain the temperature difference due to the low performance at low temperature differences. However, after reaching high temperature difference, the system performance is insufficient to pump the hot air.

In addition to the normal controlling system , fuzzy control is added to improve the effectivity.

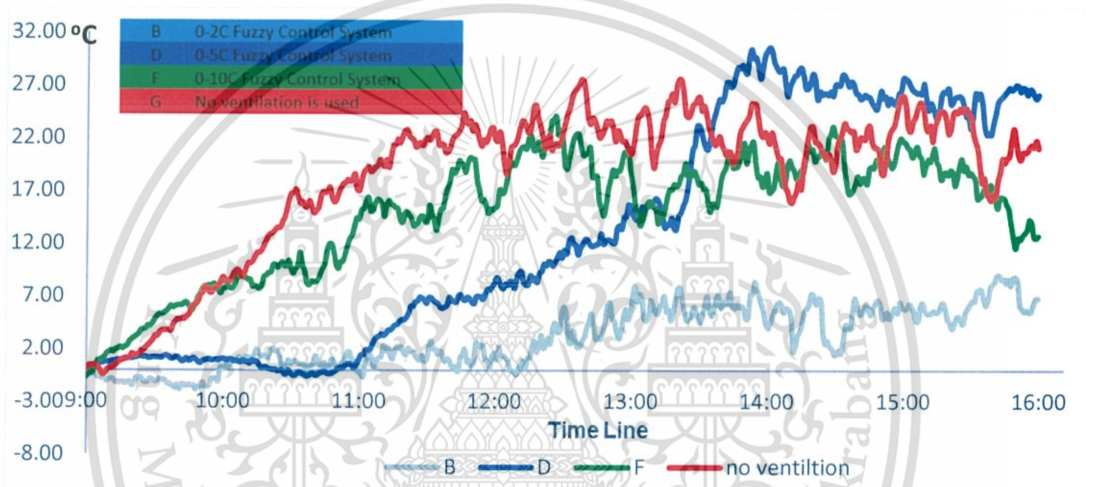


Figure 4.9: Raw data for temperature differences

In the figure 4.9 and 4.10, Fuzzy-controlling algorithm is used to control the speed of the blower. The low range of fuzzy controlling is much more efficient than normal controlling system because it increases the exhaust rate before the interior becomes warmer. But, after three hours the blower speed is not effective to maintain the temperature difference. But using fuzzy controlling algorithm is effective for few hours. Overall using fuzzy control system is effective for low range of temperature differences. Sixth order polynomial function of the raw data is shown in the following figure in order to filter the noise of the temperature readings.

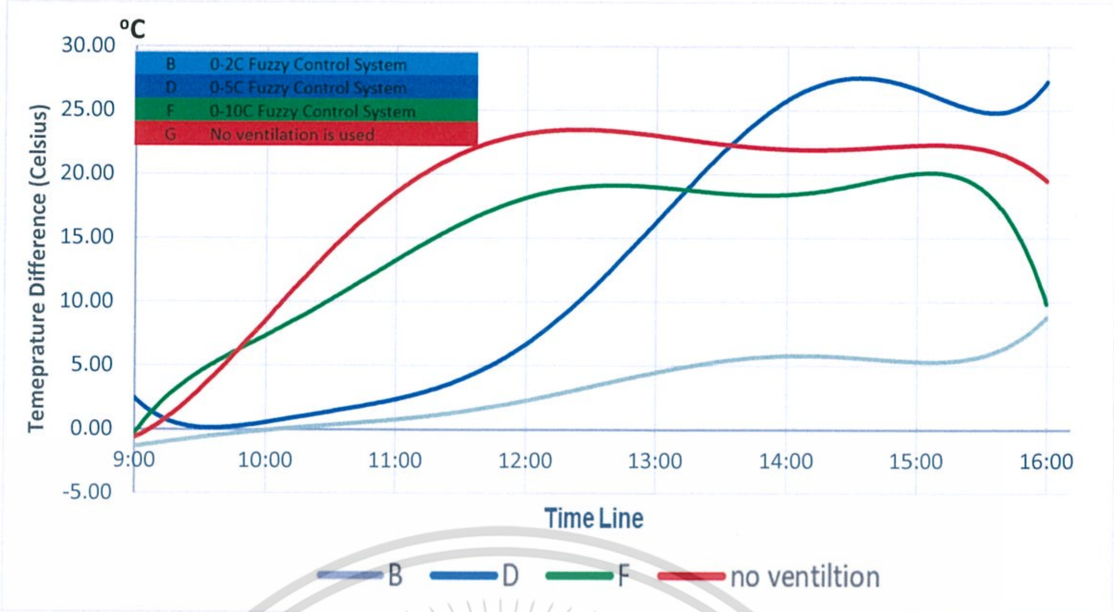


Figure 4.10: Smoothen data for temperature differences

Figure 4.10 shows how the system tries to maintain the temperature at the beginning for 0-2 and 0-5 Fuzzy controlling systems. 0-10 controlling technique is poor to pump the hot air and when it runs its maximum speed, it is too late for pumping.

The temperature difference got close to zero means the interior and the ambient temperatures are equal. That is the best fit to most effective trend in this research. Temperature difference is nearly zero means the system can maintain the temperature difference in effective way and it is effective. Now on the area under the curve will be discussed. Area under the curve is calculated using trapezium theory for each trend lines.

Heat Transfer Formula is used to measure the heat energy absorption, for the calculation; by using the heat equation,

$$Q = m_{air}C_{air}(\Delta T) \tag{4.1}$$

$$Q = (\rho_{air}v_{air})\, C_{air}\, (\Delta T) \tag{4.2}$$

Where, $Q = thermal\ energy$, $\rho_{air} = density\ of\ air$, $v_{air} = cabin\ air\ volume$
$C_{air} = heat\ capacity\ (J/_{kg.K})$, $(\Delta T) = temperature\ differencee$

Considering, $\rho_{air} = 1.225 kg/m^3$, $v_{air} = 2.5\ m^3$, $C_{air} = 1000(J/_{kg.K})$

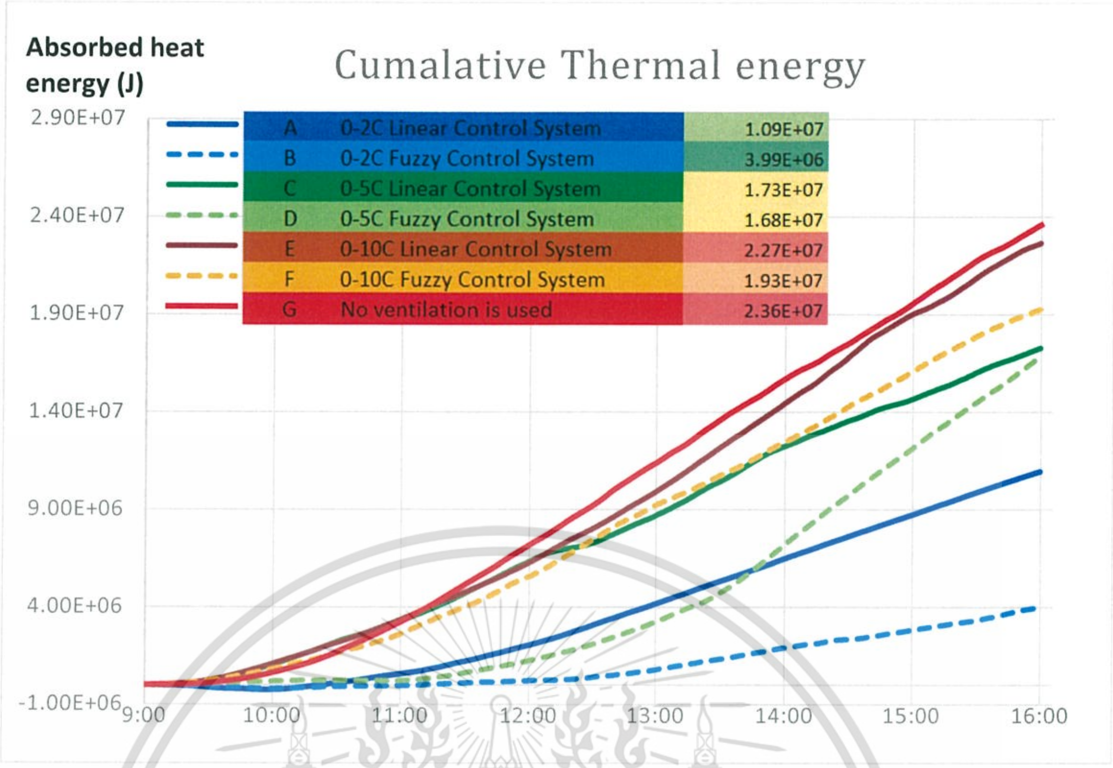


Figure 4.11: Cumulative Thermal Energy

The cumulative areas are calculated along the time as shown in the figure 4.11. the area of the each trend is given in the legend entry. As mentioned in the graph, highest area is obtained by no ventilation technique used. It obtains a value of 23600kJ. Using Fuzzy control system can help to reduce the temperature significant than linear controlling technique. If the blower is very powerful, this technique can balance the temperature between interior and the out.

Effect for the fuel consumption is measured as mentioned in the chapter 3. Due to the technical difficulties to connect the OBD tool to data logger, the fuel consumption is measured manually. Following figure shows the average temperature decrements by turning on the air conditioning system from the experiment.

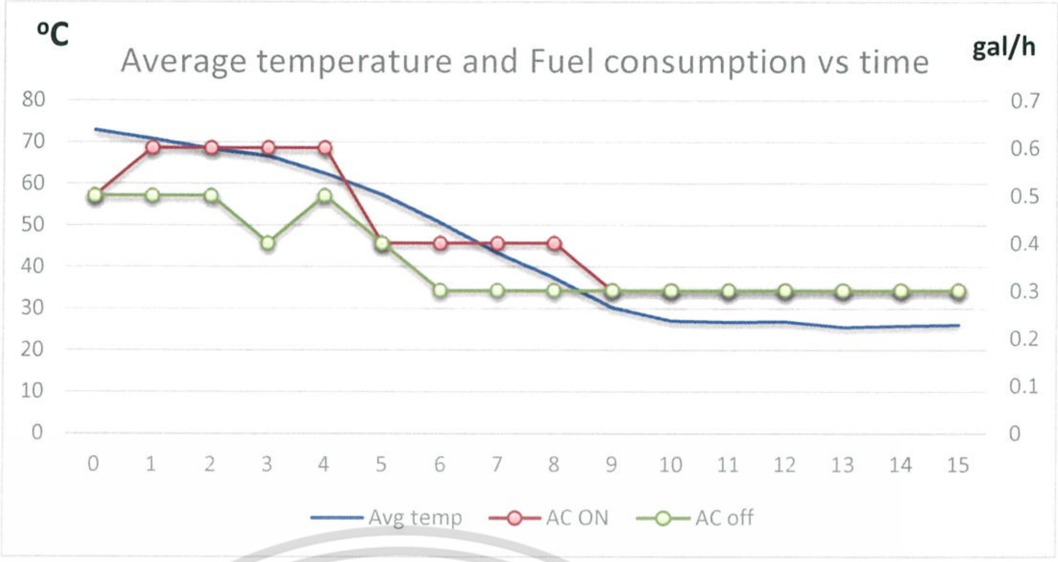


Figure 4.12 Effect for the Fuel Consumption and the Temperature

As shown in the graph when the AC compressor is ON fuel consumption is higher than idle condition without turning on the AC compressor until 8 minutes. After 8 minutes, the fuel consumption stays constant. The fuel usage is measured by using the following equations.

$$1\ {}^{gal}/_{h} = 1.0515\ {}^{ml}/_{s} \tag{4.3}$$

For example;

$$0.5\frac{gal}{h} = 0.5258\frac{ml}{s} \tag{4.4}$$

To calculate fuel usage for 1minute;

$$fuel\ consumption = 0.5258\frac{ml}{s} \times 60\ s$$
$$= 31.55ml$$

So, the total fuel consumption is calculated by summing all the fuel consumption along 15minutes measured time.

After adding the fuel consumptions for the turning on the AC compressor condition and the fuel consumption for the turning off the AC compressor. Following graph shows the cumulative fuel usage for 15minutes. So the system can save 50.47ml within this 15minutes.

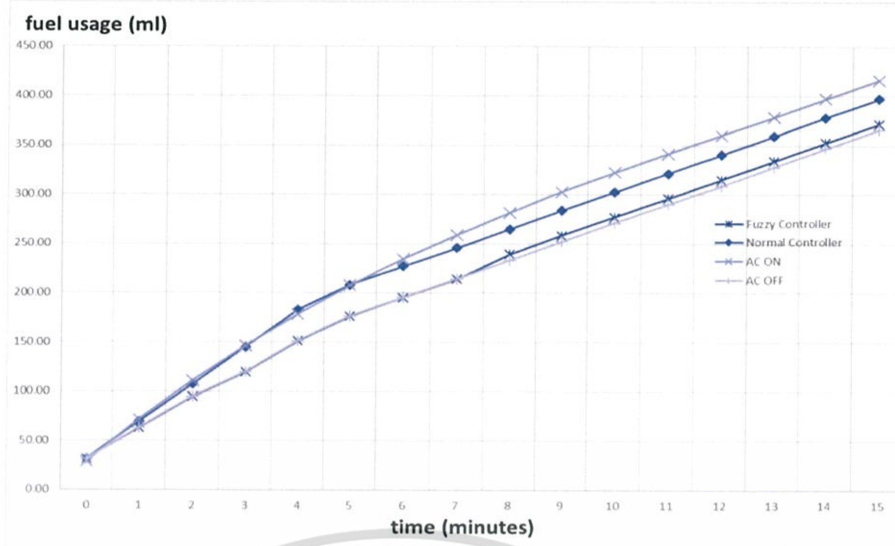


Figure 4.13 Fuel usage versus time

Cumulative fuel usage is shown in the figure 4.13. when the AC is off, the engine consumes 365.92ml and if the AC is on state, it consumes 416.25ml of fuel during this 15minutes. When the 0-2°C fuzzy system is used, it can reduce the temperature up to 41°C Celsius while the average ambient temperature is around 35° C. That means it consumes the fuel of 371.93ml to cool down from 70°C to 25°C. But, when the 0-2°C normal system is used, it can reduce the temperature up to 48°C which means it consumes the fuel of 397.20ml to cool the temperature from 70°C to 25°C.

The power of the system is varied with the speed as following figure at the idle condition system use 80mA current and rated peak current is 2.65A with the power of 31.8W.

PWM	m/s	CFM (40mm diameter)	Current (A)	Power (W)
0	0	0.0	0.08	0.96
220	2.6	6.9	0.37	4.44
223	4.6	12.2	0.49	5.88
225	6.7	17.8	1.74	20.88
227	9.9	26.4	1.87	22.44
230	18.2	48.5	1.95	23.4
233	18.2	48.5	2.38	28.56
235	18.3	48.7	2.36	28.32
240	18.6	49.5	2.48	29.76
245	18.7	49.8	2.5	30
250	19	50.6	2.55	30.6
253	20.1	53.5	2.5	30
255	21.1	56.2	2.65	31.8

Figure 4.14 Power Consumption of the system

CONCLUSIONS AND FURTHER DEVELOPMENTS

This chapter concludes the thesis and offers some improvements for further developments. This is a brief summary of my work and how this work can be improved in future to achieve efficient and robust system.

5.1 Conclusion

In tropical countries like Thailand, the temperature inside the car can rise up to 70°C, while the ambient temperature is around 40 °C. Circulating the cabin air help to minimize the temperature rising inside vehicle. So this thesis investigated the importance of using ventilation device inside a vehicle.

It has done a good comparison between a normal temperature control system and an improved control system for ventilation device. The normal ventilation systems are less effective, because the interior temperature has a higher value than the air temperature in the vehicle. So, this error can make a time delay to turn on the device and it can cause a lag and it is late to exhaust the hot air. However, if the system consists with an additional temperature predicting system, it can lead to pump the hot air much effectively. Using 0-2 degrees fuzzy controlling ventilation system tries to balance the temperature with the ambient temperature for three hours with 56CFM ventilation device. If the exhaust flow is higher than system which has 56CFM can perform much better than three hours, but on other hand, it consumes more power. Covering the windshield of the vehicle also depends on parking orientation with the orientation of the sun. This system can minimize temperature difference from 25 °C to 5 °C at its maximum performance with 0-2 °C fuzzy temperature controlling technique.

A 1800cc vehicle consumes about 416.4ml of fuel, while AC is ON, if the vehicle does not use AC, it consumes 365.9ml of fuel within first 15minutes. So, the AC compressor burnt around 50ml of fuel to cool down the cabin temperature after park the vehicle. Reduction of temperature can effects to improve the fuel efficiency.

Overall, this technique can reduce the temperature rising inside the vehicle cabin and it reduces the overall temperature inside the vehicle.

5.2 Further Improvements

Present system is focused on balancing the temperature difference between interior and the ambient. This cannot achieve a cooling technique. So if this research can be extended to work with air conditioning system with high power solar panel, it will be a great achievement because using solar energy is completely green and it is economical when someone parks the vehicle in outdoor open areas.

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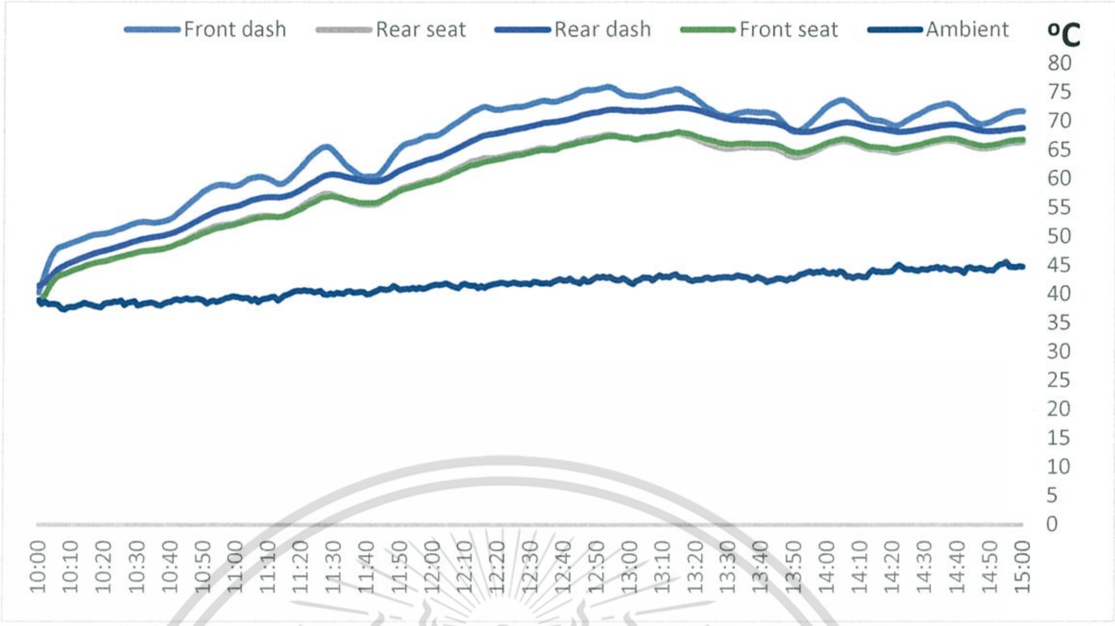
Solar Irradiation (W/m^2)			100	200	300	400	500	600	700	800	900	1000
Temp Diff (Celcius)												
0-2	0-5	0-10										
0	0	0	0.0	31.0	41.0	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.1	0.25	0.5	26.2	31.0	41.0	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.2	0.5	1	33.5	34.8	41.0	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.3	0.75	1.5	38.8	37.8	41.0	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.4	1	2	43.6	42.3	42.3	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.5	1.25	2.5	50.0	50.0	50.0	50.0	50.0	50.0	58.6	66.4	75.0	75.0
0.6	1.5	3	50.0	57.4	57.4	56.2	56.0	56.2	59.5	67.2	75.6	75.6
0.7	1.75	3.5	50.0	58.6	61.3	60.5	60.5	60.5	62.4	68.9	77.1	77.1
0.8	2	4	50.0	58.6	63.7	64.5	64.5	64.5	64.8	69.6	79.7	79.7
0.9	2.25	4.5	50.0	58.6	66.4	68.8	69.0	69.0	68.8	71.0	83.8	84.0
1	2.5	5	50.0	58.6	66.4	75.0	75.0	75.0	76.1	80.7	91.5	92.0
1.1	2.75	5.5	50.0	58.6	66.4	75.0	75.0	75.0	76.1	69.3	91.5	92.0
1.2	3	6	50.0	58.6	66.4	75.0	75.0	75.0	76.1	69.4	91.5	92.0
1.3	3.25	6.5	50.0	58.6	66.4	75.0	75.0	75.0	76.1	69.4	91.5	92.0
1.4	3.5	7	50.0	58.6	66.4	75.0	75.0	75.0	76.1	71.0	91.5	92.0
1.5	3.75	7.5	50.0	58.6	66.4	75.0	75.0	75.0	76.1	80.7	91.5	92.0
1.6	4	8	56.4	59.5	67.2	75.6	75.6	75.6	76.1	80.7	91.5	92.0
1.7	4.25	8.5	61.2	62.9	68.9	77.1	77.1	77.1	77.3	80.7	91.5	92.0
1.8	4.5	9	65.8	66.5	69.6	79.7	79.7	79.7	79.7	81.7	91.5	92.0
1.9	4.75	9.5	71.2	71.2	71.2	83.8	84.0	84.0	84.0	84.0	91.7	92.0
2	5	10	90.5	90.5	90.5	91.5	92.0	92.0	92.0	92.0	92.0	92.0

Defuzzication Table

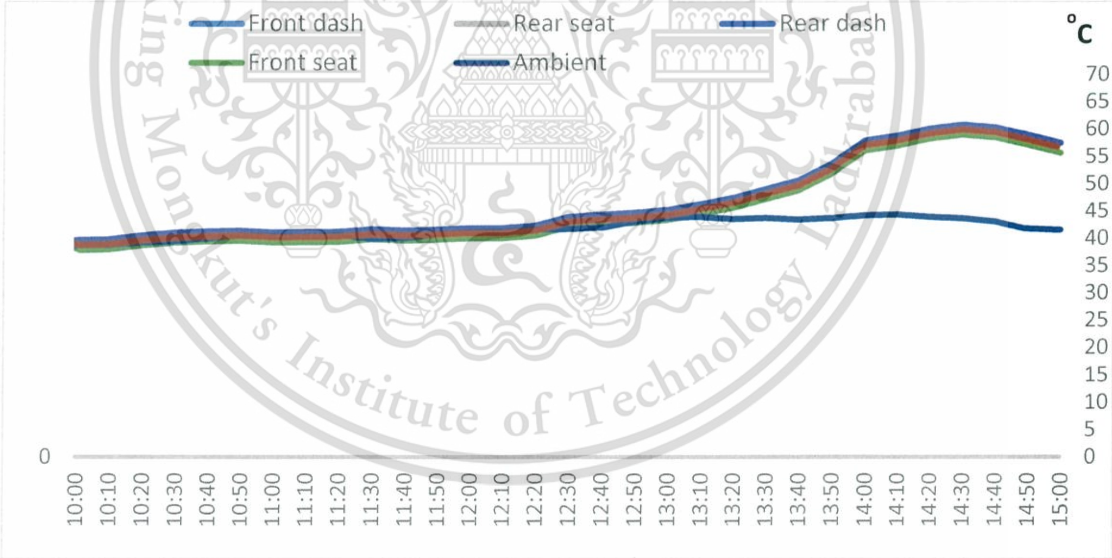
Solar Irradiation (W/m^2)			100	200	300	400	500	600	700	800	900	1000
Temp Diff (Celcius)												
0-2	0-5	0-10										
0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.25	0.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.2	0.5	1	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
0.3	0.75	1.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
0.4	1	2	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
0.5	1.25	2.5	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
0.6	1.5	3	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
0.7	1.75	3.5	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
0.8	2	4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
0.9	2.25	4.5	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
1	2.5	5	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
1.1	2.75	5.5	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
1.2	3	6	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
1.3	3.25	6.5	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
1.4	3.5	7	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
1.5	3.75	7.5	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
1.6	4	8	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
1.7	4.25	8.5	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
1.8	4.5	9	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.9	4.75	9.5	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
2	5	10	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Linear Input/output Table

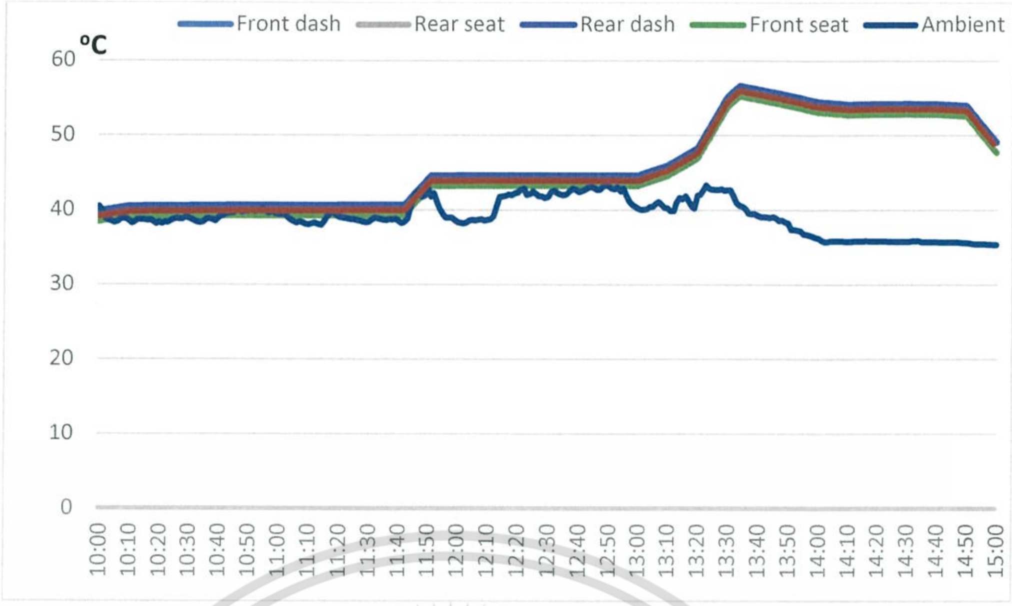
APPENDIX C



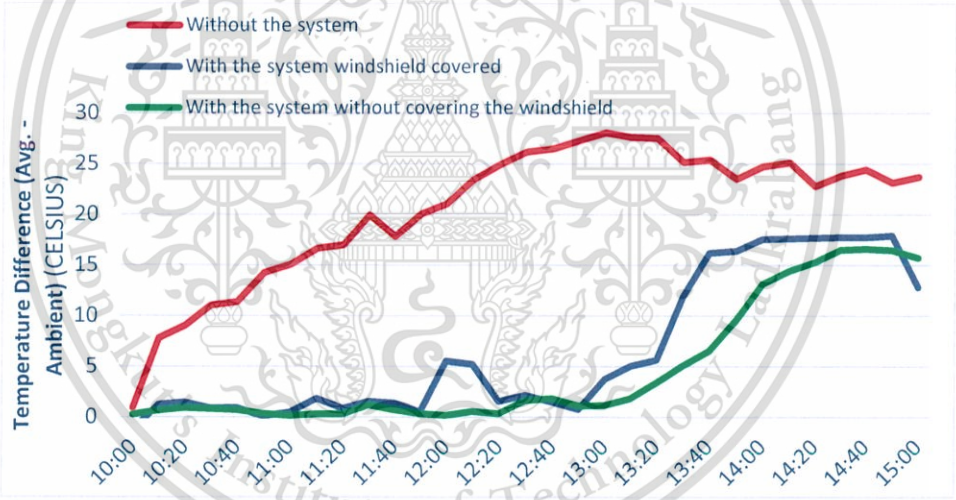
Temperature distribution inside the interior of SEDAN vehicle 1-2/05/2016 for the fully closed vehicle and without any ventilation method.



Temperature distribution inside the interior of SEDAN vehicle 04-05/05/2016

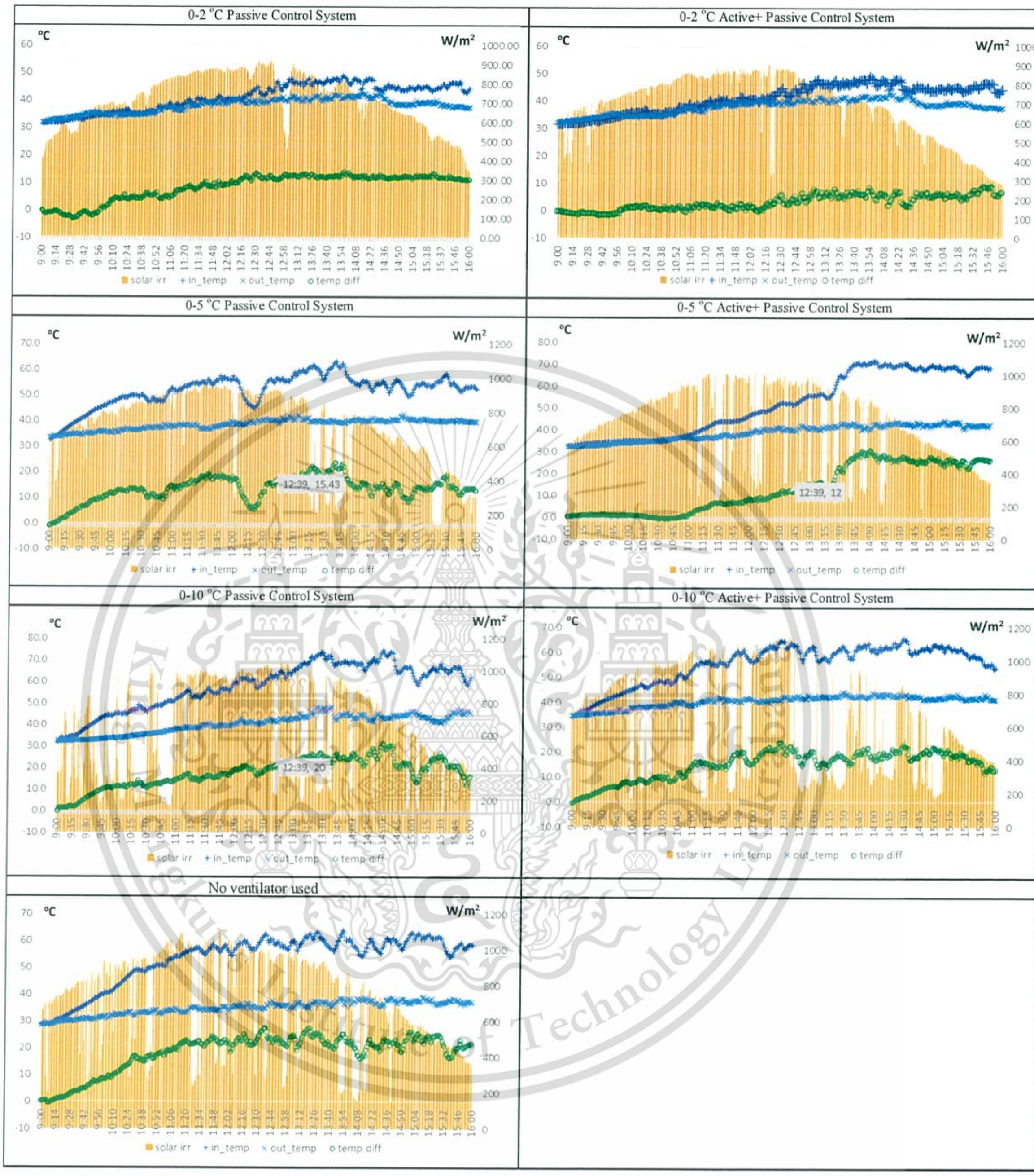


Temperature distribution inside the interior of SEDAN vehicle 10-11/05/2016 for the fully closed vehicle and with the ventilation device by covering the windshield.



Summary of the datasets

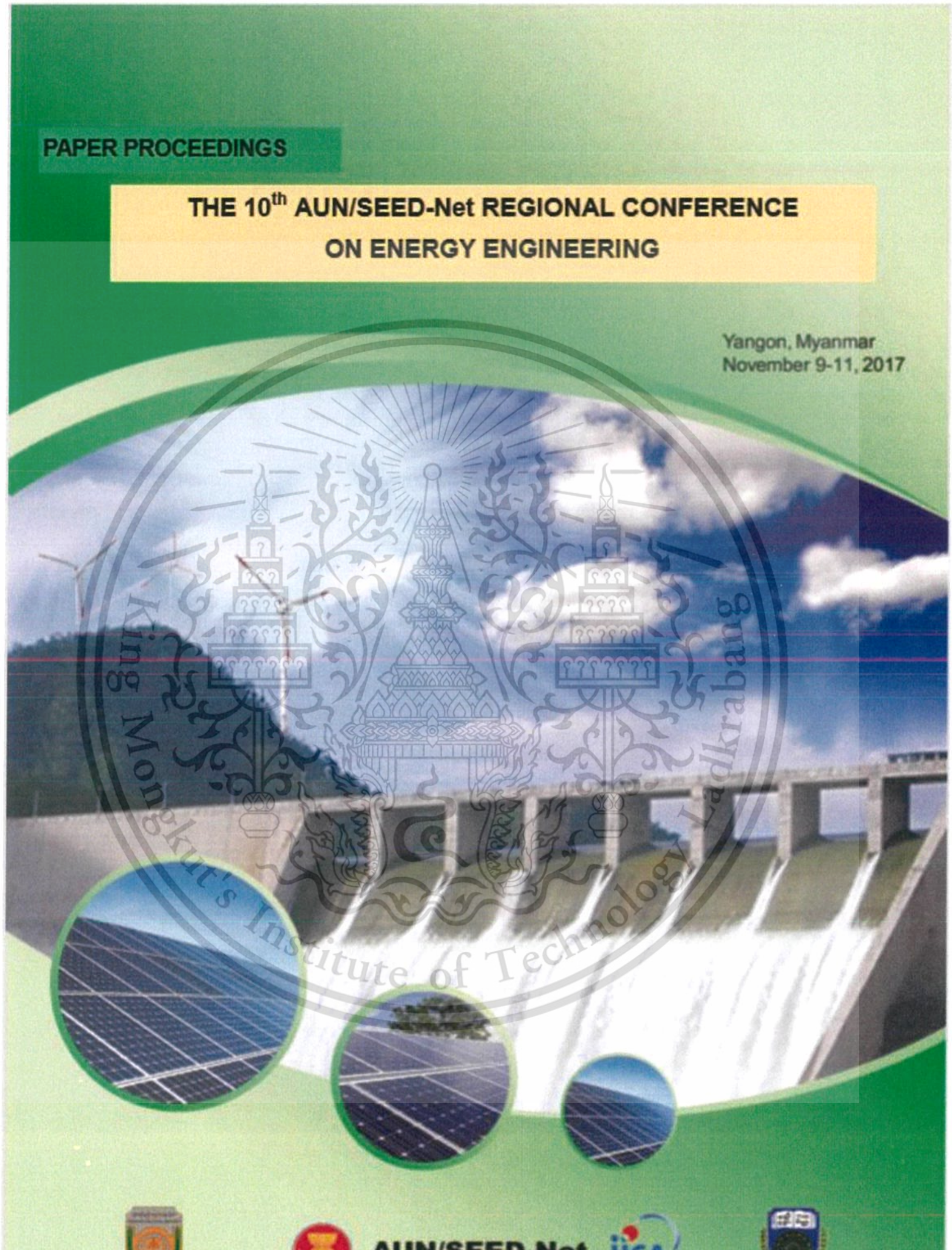
APPENDIX D



Experimental Results

APPENDIX E

PUBLICATION



DEVELOPMENT OF A SOLAR POWERED VEHICLE VENTILATION SYSTEM

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Abstract

The temperature inside the vehicle cabin can rise quickly when a vehicle is parked which is exposing to sunlight for a prolonged period. This scenario can cause passenger discomfort by emitting toxic gases as well as damage heat sensitive equipment and materials inside the vehicle cabin. In the summer, Thailand, the interior temperature of a vehicle could rise up to 60°C to 70°C by few hours. To reduce this effect, this research study proposes the importance of using a vehicle ventilation system which can use solar energy. This system can reduce the high temperature inside the vehicle by exhausting the hot air out from the vehicle interior. Temperature distribution inside the vehicle and the effect of using the ventilation system will be focused in this research study and also effect from the different heat flux was analyzed from a simulation using ANSYS fluent to identify the thermal accumulation inside the interior of the vehicle. Experimental results from the study will be used to identify the high-temperature zones and the temperature distribution inside the vehicle interior and the results will be used to place the ventilation system which helps to maintain the equality of the temperature inside and outside the vehicle when the vehicle is parked in an unshaded area. Proposed ventilation device will operate using solar power and an additional battery to provide continuous power to the system when the solar energy is insufficient to operate the ventilation system. This proposed car ventilation system can identify the temperature between the cabin interior and outside ambient temperature and controls the speed of exhaust fan to control the flow rate which pumps the hot air inside the cabin to outside. In this paper, the importance and effectivity of using ventilation system will be discussed with the experimental and simulation results.

Keywords: Solar Powered Vehicle Ventilation Device: Solar Energy: Thermal Accumulation in a parked vehicle: Greenhouse effect

Background and Introduction

Parking a vehicle in an open area can lead to accumulating the heat inside the vehicle which can cause due to the greenhouse effect. This scenario can make the passengers discomfort when they came back to the vehicle and damage heat sensitive materials and components inside the

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