DETERMINE THE EFFECTIVE THERMAL COMFORT IN A CAR BY USING FUZZY CONTROLLER

NUR MUHD FIRDAUS AMINULLAH B. IBRAHIM

FAKULTI SAINS DAN TEKNOLOGI
UNIVERSITI MALAYSIA TERENGGANU
2009

c/n: 7526

Determine the effective thermal comfort in a car by using fuzzy controller / Nur Muhd Firdaus Aminullah Ibrahim.

DETERMINE THE EFFECTIVE THERMAL COMFORT IN A CAR BY USING FUZZY CONTROLLER

by
Nur Muhd Firdaus Aminullah Bin Ibrahim

This Final Year Project submitted in partial of fulfillment of
the requirements of the award of the degree for
Bachelor of Science (Computational Mathematics)

DEPARTMENT OF MATHEMATICS
FACULTY OF SCIENCE AND TECHNOLOGY
UNIVERSITY MALAYSIA TERENGGANU
2009

UNIVERSITI MALAYSIA TERENGGANU

DEPARTMENT OF MATHEMATIC
FACULTY OF SCIENCE AND TECHNOLOGY
UNIVERSITY MALAYSIA TERENGGANU

VERIFICATION FORM

By this form, avowed and authorized that Final Year Project with title Determine The Effective Thermal Comfort In A Car By Using Fuzzy Controller oleh Nur Muhd Firdaus Aminullah bin Ibrahim, Matrix Number: UK 14041 have been checking and all suggestion correction already done. This Final Year Project submitted in partial of fulfillment of the requirements of the award of the degree for Bachelor of Science (Computational Mathematics), Faculty of Science and Technology, UMT.

?
Satificated by:

....
Supervisor
Name:
Official Stamp:

DR. MOHD LAZIM BIN ABDULLAH
Pensyarah
Jabatan Matematik
Fakulti Sains dan Teknologi
Universiti Malaysia Terengganu
21030 Kuala Terengganu.

Date: 5/5/2009

....
Head of Department
Name:
Official Stamp:

Date: 5/5/2009

DR. HJ. MUSTAFA BIN MAMAT
Ketua
Jabatan Matematik
Fakulti Sains dan Teknologi
Universiti Malaysia Terengganu
21030 Kuala Terengganu

DECLARATION

I hereby declare that this Final Year Project entitled Determine The Effective Thermal Comfort In A Car By Using Fuzzy Controller is the result of my own research except as cited in the references.

Signature :

Name : NUR MUHD FIRDAUS AMINULLAH IBRAHIM

Matrix No. : UK 14041

Date : 5 May 2009

ACKNOWLEDGEMENTS

At the end of my Final Year Project I would like to thank all those people who made this Final Year Project possible and an enjoyable experience for me.

First of all I wish to express my sincere gratitude to Dr. Mohd Lazim Abdullah who's my great Final Year Project's supervisor in order to guided and help me finished this research. Since 5th semester, he guided me from choose the title until proposal been submitted. He is a kind person and tolerant because always deal with me with non-pressure rules.

I am grateful to my friends for their encouragement and help especially to my girlfriends, Nurul Ainn Ismail which give morale supports to me although her also got bigger problems than me in Final Year Project. Others are my housemates, because with them, we finally choose the right supervisor, choose suitable title and collect data's. So, I'm really felt not alone.

Finally, I would like to express my deepest gratitude for a constant support, emotional understanding and love that I received from my family. The data's I only can collect with some help by them. My subject to test also sponsored from my family car, Toyota Vios by my father and Perodua Myvi by my sister.

DETERMINE THE EFFECTIVE THERMAL COMFORT IN A CAR BY USING FUZZY CONTROLLER

ABSTRAK

Providing thermal comfort and saving energy are two main goals of heating, ventilation and air conditioning (HVAC) systems. Thermal comfort influenced by many variables such as; temperature, relative humidity, air velocity, environment radiation, activity level and cloths insulation. Reason of this, a controller with temperature feedback cannot best achieve the thermal comfort. A car compartment thermal comfort model has been developed to aid the automotive engineers in the evaluation and selection of vehicle design parameters to optimize human comfort. This model has as a unique feature the calculation of the thermal comfort of each vehicle occupant as a function of the prevailing local passenger compartment conditions of air temperature, mean radiant temperature, air velocity, air relative humidity, direct solar flux as well as the level of activity and clothing type of each individual.

MENENTUKAN KAEDAH KAWALAN HABA YANG PALING EFFEKTIF DALAM KERETA DENGAN MENGGUNAKAN FUZZY KAWALAN

ABSTRAK

Menyediakan haba persekitaran yang selesa dan penjimatan tenaga adalah merupakan dua sasaran utama Sistem Pemanasan, Peredaran Angin and Penyaman Udara (HVAC). Haba persekitaran yang selesa dipengaruhi oleh banyak faktor antaranya; suhu, kelembapan udara, kelajuan udara, radiasi persekitaran, peringkat aktiviti dan jenis pakaian dan cara berpakaian. Semua ini disebabkan satu kaedah kawalan dengan maklum balas suhu yang menjadi kunci pencapaian bagi persekitaraan yang selesa. Sesebuah kereta dengan kelengkapan model kawalan haba yang telah dibangunkan bersama kejuruteraan automotif dalam menghasilkan parameter untuk mengoptimumkan keselesaan pengguna. Model ini juga mempunyai unsur pengiraan yang unik bagi setiap model kenderaan dalam berfungsi memberi keselesaan kepada pemandu terutamanya. Ini kerana model ini mengambil kira perubahan suhu persekitaran, purata suhu radian, kelajuan udara, kadar kelembapan udara, kadar sinaran terus matahari di samping faktor individu seperti tahap aktiviti yang dilakukan dan jenis serta cara berpakaian.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Nomenclature

bp	blower power (kW)
C	thermal capacity, $\dot{m}Cp$ (kW/°C)
COP	coefficient of performance
Cp	specific heat (kJ/kg °C)
$\dot{E}$	rate of change of energy (kW)
ff	fitness function
$\dot{Q}$	rate of heat transfer (kW)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
NTU	number of transfer units
pf	percent of fresh air
ptd	position of temperature door
T	temperature (°C).
V	velocity (m/s)
$\dot{W}$	power (kW)
ε	heat exchanger effectiveness
M	metabolism (W/m^2).
W	external work (W/m^2).
TI_{cl}	thermal resistance of clothing (Clo).
Fcl	ratio of body's surface area when fully clothed to body's surface area when nude.
T_a	air temperature (°C)
T_{mrt}	mean radiant temperature (°C).
V_{air}	relative air velocity (m/s).
Pa	partial water vapor pressure (kPa).
h_c	convection heat transfer coefficient (W/m^2 k)
T_{clo}	surface temperature of clothing (°C).

Subscripts

a	air
amb	ambient
b	blower
c	cold
cabin	automobile cabin
cooler	cooler compartment
e	evaporator
eR	evaporator refrigerant
fa	fresh air
gen	generation
H	heater core
h	hot
i	in
min	minimum
o	out
R	refrigerant
Ra	re-circulation air
W	water

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Problem statements

Base on research by Daanen et. al (2003) about driving performance in cold, warm, and thermo neutral environments, the temperature in a car cabin is an important factor in the occurrence of traffic accidents. In the books determinants of motor vehicle deaths in the United States: a cross-sectional analysis, special issue: theoretical models for traffic safety, Zlatoper (1991) investigated the influence of 10 factors on traffic accident in Unites States and observed that temperature rated third. A better climate control system in a car improves thermal comfort which results in increased driver caution and thus improves driving performance and safety in different driving conditions. Behr Company's researches, Editorial Team (2001) in Just Auto show air conditioning system is one of the most important comfort equipment in cars which is why most cars today are equipped with it. Performance improvement of an AC system in car requires careful analysis of the air conditioning components. An optimum system should maintain thermal comfort under time varying thermal loads while minimizing energy consumption.

Compressor used in a cooling system is driven by car engine and therefore increases the fuel consumption. Studies by Lambert and Jones (2006) in this area show that the mechanical compressor can increase fuel used in car by about 12–17% for subcompact to mid-size cars.

Control system is a key factor in order to improve the performance of car air conditioning. Manual control requires skill and experience about system. During travel, driver is focused on driving task and in most condition he/she is unaware of complex combination of temperature and climate changes, so he/she may not be able to react to changes. Automatic control frees the driver from this task. Daanen (2003) investigated the influence of driving performance in several climate conditions. They concluded that a thermo neutral temperature in a car enhances driving performance and may thus positively affect safety.

1.2 Objective

The objective of this research are to

1) find the effective feedback controller between temperature feedback and PMV feedback.
2) determine factor make car more comfortable thermal environment
3) compare two thermal controller with minimizing energy consumption.

1.3 Research limitation

This research will use just four car models and this model available in Malaysia. In order to put air temperature as constant value, this research takes place in Gong Badak, K.Terengganu area only.

Got some assumptions were made in Mathematical Model derivation. This assumptions help to simplify the equations while produce negligible error in modeling. Such as;

- Dry air
- Ideal gas behavior
- Perfect air mixing
- Neglect potential energy in all parts.
- Neglect thermal losses between components.
- Negligible infiltration and infiltrations effects.
- Neglect transient effect in components and channels.
- Negligible energy storage in air conditioning components.

- Zero mechanical work in the cabin $W_{cabin} = 0$.
- Air parameters at standard conditions of 20 °C, 50% rh, sea level.
- Air parameters exiting the cabin have the same properties as inside the cabin.

1.4 Planning Steps

For the beginning, tried to derive the mathematical model of thermal environment for a car's cabin. Specific parameters for any model of a car will be used. This model includes blower, evaporator, heater core, important thermal loads such as sun radiation, outside air temperature and passengers on climate control of cabin. A schematic model of system is shown in Fig. 1.1.

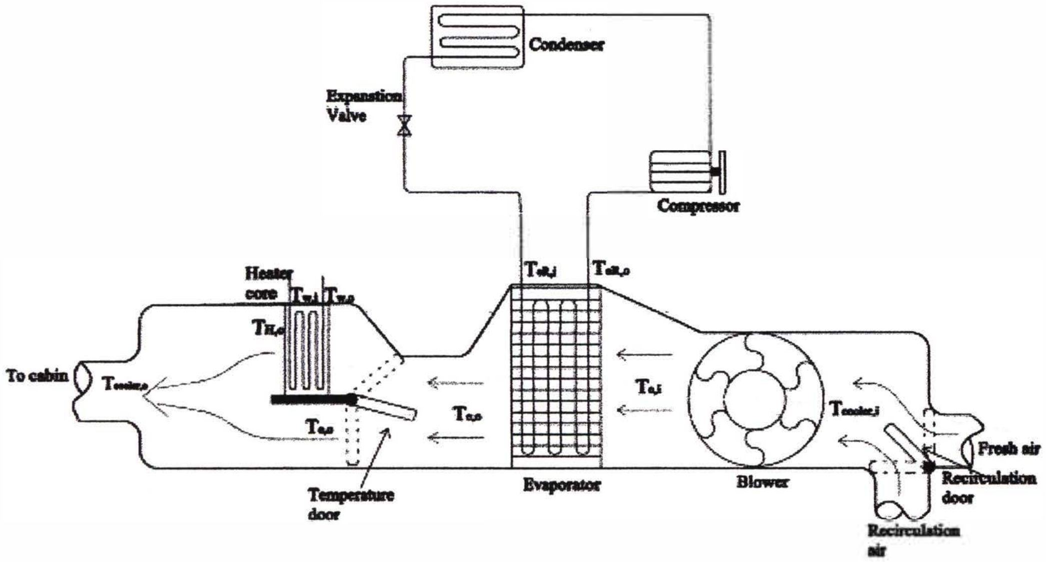


Fig. 1.1: Schematic of a car's cabin and air conditioning systems (Yadollah, 2008).

Mathematical modeling should be performed to clearly show the effect of control parameters on occupant thermal comfort. The main control variables are blower power and the position of temperature door. The first variable regulates the blower speed and the second regulates the necessary blend of hot and cold air.

CHAPTER 2

LITERITURE REVIEW

2.1 Thermal Comfort

Human thermal comfort is defined by Ashrae (2005) in Thermal Comfort as the state of mind that expresses satisfaction with the surrounding environment. Maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC design engineers.

Base on Free Encyclopedia, Wikipedia;

> Thermal comfort is affected by heat conduction, convention, radiation and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.
>
> Factors determining thermal comfort include:
>
> - Air temperature
> - Mean radiant temperature
> - Air movement / velocity
> - Relative humidity
> - Isolative clothing
> - Activity levels.

The concept of thermal comfort is closely related to thermal stress. This attempts to predict the impact of solar radiation, air movement, and humidity for military personnel undergoing training exercises or athletes during competitive events.

Refer to Weiss, Hall (1998):

> The ideal standard for thermal comfort can be defined by the operative temperature. This is the average of the air dry-bulb temperature and of the mean radiant temperature at the given place in a room. In addition, there should be low air velocities and no 'drafts', little variation in the radiant temperatures from different directions in the room, humidity within a comfortable range, and air temperatures in a height of 0.1 m above the floor should not be more than 2 °C lower than the temperature at the place of the occupant's head. The temperatures should also not change too rapidly across neither space nor time.

In addition to environmental conditions, thermal comfort depends on the clothing and activity level of a person. The amount of clothing is measured against a standard amount that is roughly equivalent to a typical business suit, shirt, and undergarments. Activity level is compared to being seated quietly, such as in a classroom.

2.2 Thermal Comfort in Vehicles

The thermal environment in a vehicle cabin is very complex and thus difficult to evaluate. These difficulties are due to the influence of convective, radioactive and conductive heat exchange created by external thermal loads and the internal heating and ventilation system.

Base on article taken from Luma Sense Technology website;

The usual method of evaluating the efficiency of the air conditioning system in vehicles is to apply sensors to measure the air temperature at feet and at head level. The main purpose being to investigate how quickly the system will raise or lower the temperature in a warm or cold vehicle and to study the difference between the temperature at feet and head level. However, using this method only one of the three needed parameters; air temperature, mean radiant temperature and air velocity. The combined effect of: the air temperature, mean radiant temperature and air velocity can be expressed as the Equivalent Temperature that is related to the dry heat loss from the body.

The combined effect of the air velocity, air temperature and mean radiant temperature can be expressed by the equivalent temperature. The difference between the operative temperature and equivalent temperature was carefully studied by Madsen et. Al. and was found to be the preferred parameter for the evaluation of thermal comfort, if high air velocities are present.

2.3 Fuzzy Logic

Fuzzy Logic is a paradigm for an alternative design methodology which can be applied in developing both linear and non-linear systems. By using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance. Furthermore, products can be brought to market faster and more cost-effectively.

In order to appreciate why a fuzzy based design methodology is very attractive in embedded control applications let us examine a typical design flow. Figure 2.0 taken from FIDE website, illustrates a sequence of design steps required to develop a controller using a conventional and a Fuzzy approach.

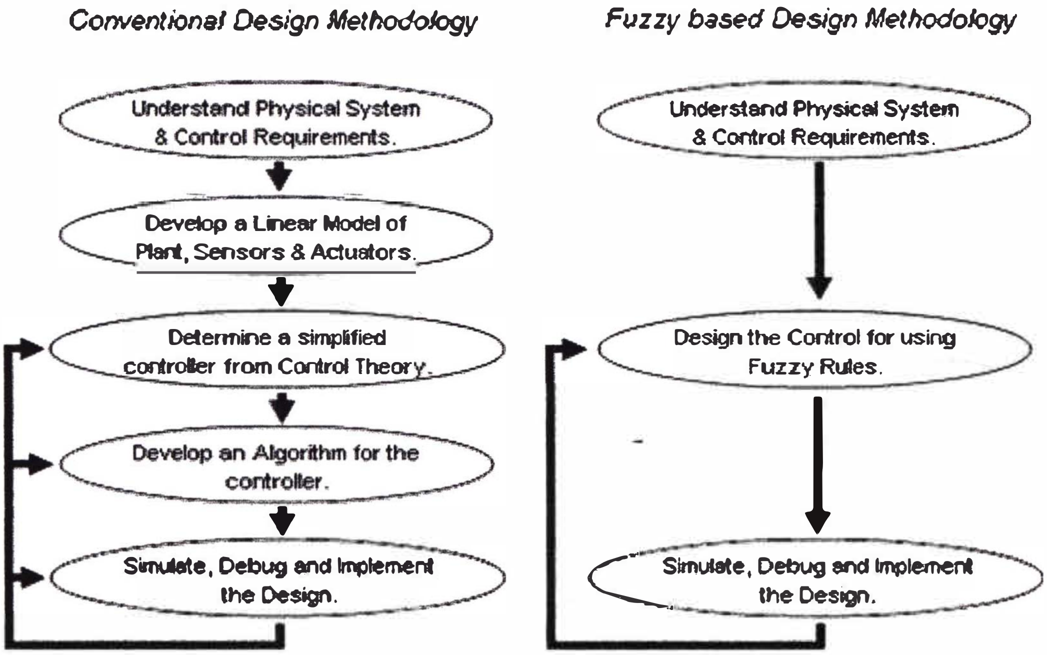


Fig. 2.1: Sequence of design steps required to develop a controller using a conventional and a Fuzzy approach (FIDE, 1996).

Using the conventional approach our first step is to understand the physical system and its control requirements. Based on this understanding, our second step is to develop a model which includes the plant, sensors and actuators. The third step is to use linear control theory in order to determine a simplified version of the controller, such as the parameters of a PID controller. The fourth step is to develop an algorithm for the simplified controller. The last step is to simulate the design including the effects of non-linearity, noise, and parameter variations. If the performance is not satisfactory we need to modify our system modeling, re-design the controller, re-write the algorithm and re-try.

With Fuzzy Logic the first step is to understand and characterize the system behavior by using our knowledge and experience. The second step is to directly design the control algorithm using fuzzy rules, which describe the principles of the controller's regulation in terms of the relationship between its inputs and outputs. The last step is to simulate and debug the design. If the performance is not satisfactory we only need to modify some fuzzy rules and re-try.

2.3.1 Fuzzy Controller

Fuzzy control is the most practical branch of fuzzy logic. Fuzzy control is inherently vague and nonlinear, thus it is suitable for systems with this behavior. Automobile air conditioning system is also nonlinear and complex therefore, it is difficult for conventional methods to control it well. This makes fuzzy control a good choice for controlling this system.

2.3.2 Fuzzy Logic improves control performance

In many applications Fuzzy Logic can result in better control performance than linear, piecewise linear, or lookup table techniques. For instance, a typical problem associated with traditional techniques is trading-off the controller's response time versus overshoot. For the simple one-input temperature controller example this is illustrated in the Figure 2.2:

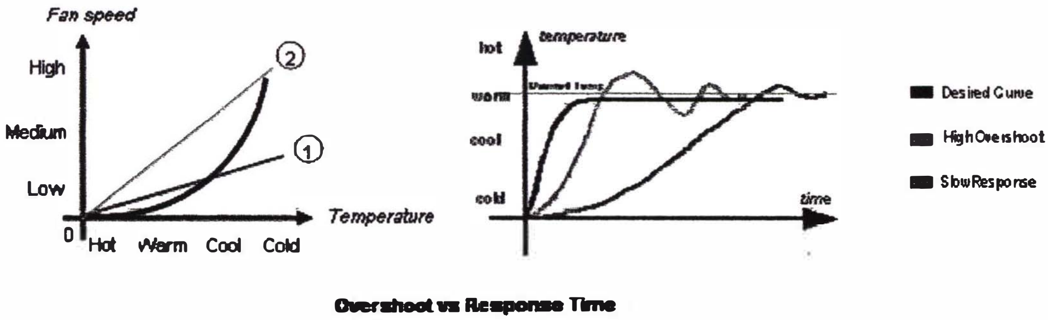


Fig. 2.2: Simple one-input temperature controller

The first linear approximation for the desired curve generates a slow output response with no overshoot, which implies that the room would be too cold for a while. The second linear approximation results in faster response with an overshoot and subsequent fluctuations, which implies that the temperature will be uncomfortable for a period of time.

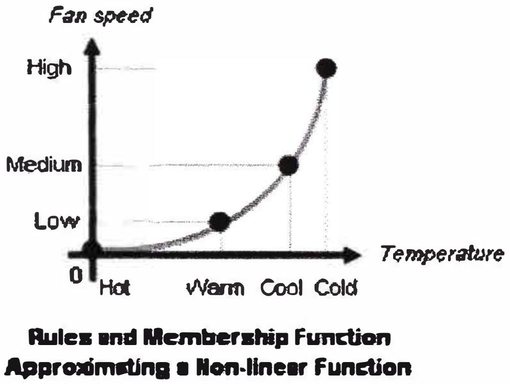


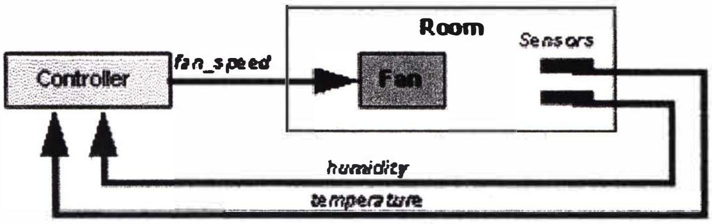
Fig. 2.3: Approximate the desired control for temperature controller using four point

With fuzzy logic we can use rules and membership functions to approximate any continuous function to any degree of precision. Figure 2.3 show how we can approximate the desired control curve for our temperature controller using four points. We can also add more rules to increase the accuracy of the approximation, which yields an improved control performance.

2.3.3 Fuzzy Logic simplifies implementation

The one input temperature controller presented so far has helped us illustrate some fundamental concepts, however real life control is much more complex in nature. Most control applications have multiple inputs and require modeling and tuning of a large number of parameters which makes implementation very tedious and time consuming. Fuzzy rules can help you simplify implementation by combining multiple inputs into single if-then statements while still handling non-linearity.

Consider a modified version of the temperature controller example, with two inputs, temperature and humidity and the same output, fan_speed (Figure 2.4). This example can be described with a small set of rules as follows:



Modified Temperature Controller

Fig. 2.4: Modified version of the temperature controller

CHAPTER 3

METODOLOGY

3.1 Data Collection

In this research, the data about thermal specification of a car will collect from local manufactured model likes Proton, Perodua and Toyota.

3.2 Thermal Loads Model

A car moves in frequently change conditions and its thermal loads depend on many variables, such as sun radiation, interior surface radiation, temperature difference between cabin and ambient, heat from moving parts, combustion heat, human thermal load and fresh air entering the cabin. Shimisou, Hara and Asakawa (1993) and Selow in *SAE Technical Paper 971841* are two works who performed for calculation of thermal loads in automobile. For the control purpose, they said, it is simple to estimate the important loads by either sensors or empirical equations. In this research, the thermal loads generated by solar radiation, outside air and cabin temperature difference as well as assumption of four people in cabin is estimated by an empirical formula for a car suggested by Kalteh, Kakai, Farhani (2004) in 8th Int. and 12th Annual Mechanical Engineering Conference, Persian.

$$E_{gen} = 0.118(T_{amb} - T_{cabin}) + 0.0022(T_{amb} - T_{cabin}) + 0.2618 \qquad (1)$$

3.3 Blower Model

Blower is an important component in achieving comfort. Temperature difference before and after blower and thermal loss are negligible. Relation between blower power, air velocity and air flow rate must be known for the blower. These relations are derived experimentally for Peugeot 206 car's model. Air velocity meter, model DO2003 with probe AP471S from Delta OHM was used. Two experiments were performed.

<u>Experiment 1:</u>

Four front dashboard air inlets were opened while all other air inlets were kept closed. To ensure comfort for the passengers in the back seat the four inlets were pointed directly towards back seats. Air velocity at different power setting was measured near the driver head. This measurement was repeated several times and the average was recorded. Blower power was normalized based on its maximum value. Fig. 3.1 shows the results.

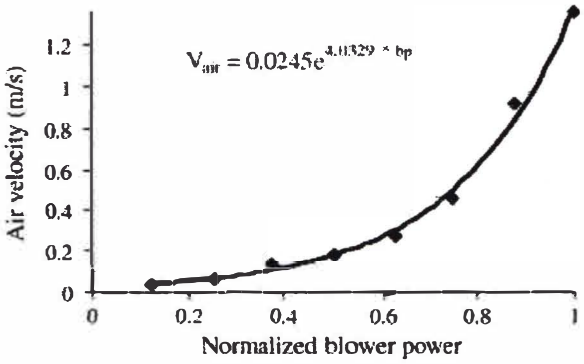


Fig. 3.1: Mean air velocity versus blower speed.

Experiment 2:

To reduce experiment error, a second experiment was performed to obtain air velocity at the dashboard air inlets. Two central dashboard air inlets were opened while all others were kept closed. Air velocity as well as inlet section area were measured. Therefore the relation between air flow rate and blower power can be determined like the result show in Fig. 3.2.

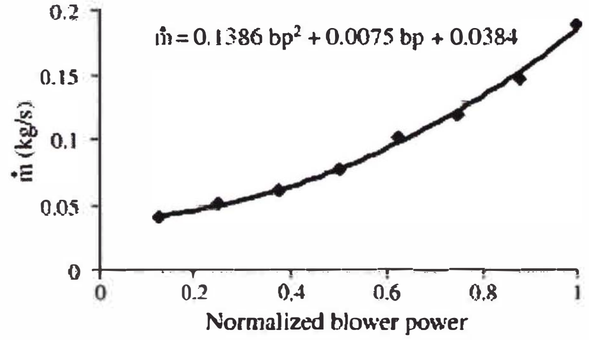


Fig. 3.2: Mass flow rate versus blower speed.

3.4 Heat Exchangers Model

Evaporator is cooled through the flow of refrigerant. Heater core is heated through the flow of hot water from engine. Although these two heat exchangers have different tasks, they are similar from the modeling point of view. Energy equilibrium on air side and working fluid side give the heat transfer equations. Heat transfer coefficients are the most important parameters that should be known for energy equilibrium equations. Based on research by Klimenko (1988) and Kays and London (1984), energy equilibrium equations and ε-NTU procedure are usually used for design and analysis of heat exchangers. E-NTU procedure leads to calculation of heat exchanger effectiveness. However, for simplicity heat exchangers effectiveness value for Peugeot 206 is used. Heat exchanger effectiveness taken from Incropera and De Witt (2002) is defined as

$$\varepsilon = \frac{Q_{actual}}{Q_{\max}} = \frac{Q_{actual}}{C_{\min}\,(T_{hot,i} - T_{cold,i})} \qquad (2)$$

Exhaust air temperature from the heat exchangers is the desired value. It can be found by expanding Eq. (2). For the evaporator and heater core these temperatures are explained by the following equations:

$$T_{e,o} = T_{e,i} - \frac{\varepsilon_e C_{\min,e}}{\dot{m}_{air} Cp_a}(T_{e,i} - T_{eR,i}) \tag{3}$$

$$T_{H,o} = T_{H,i} - \frac{\varepsilon_H C_{\min,H}}{\dot{m}_{air} Cp_a}(T_{w,i} - T_{H,i}) \tag{4}$$

The others controlling parameter is position of temperature door. This position specifies the necessary blend of hot and cold air (Fig. 1.1). It is indicated by ptd (position of temperature door) coefficient and is assume as (0, 1). Applying energy equilibrium after temperature door, the air temperature that enters the cabin is calculated by:

$$\mathrm{T_{cooler,o}} = \mathrm{ptd} \bullet \mathrm{T_{e,o}} + (1 - \mathrm{ptd})\mathrm{T_{H,o}} \tag{5}$$

3.5 Overall model of the system

From thermodynamics concept, energy principle and mass conservation are used to form the system model. To show the air temperature and velocity in the cabin, we derive the overall model of the system. The effect of control parameters is also included in the model

$$\frac{dE_{cabin}}{dt} = \dot{E}_{gen} - \dot{W}_{cabin} + \sum \dot{E}_{cabin,i} - \sum \dot{E}_{cabin,0} \tag{6}$$

$$\frac{dm_{cabin}}{dt} = \sum \dot{m}_{in} - \sum \dot{W}_{out} + \sum \dot{E}_{cabin,i} = 0 \Rightarrow m_{cabin} = const. \tag{7}$$

Variables used in Eq. (6) are simplified as follows:

$$\frac{dE_{cabin}}{dt}=\frac{d(m_{cabin}h_{cabin})}{dt}=\frac{d}{dt}[(\rho_{aim}V_{cabin})(C\rho T_{cabin})] \qquad (8)$$

$$=\rho_{aim}V_{cabin}C\rho\frac{dT_{cabin}}{dt}$$

$$\sum\dot{E}_{cabin,i}=\dot{E}_{cooler,0}=\dot{m}_{air}C\rho T_{cooler,0} \qquad (9)$$

$$\sum\dot{E}_{cabin,0}=\dot{E}_{cooler,i}=\dot{m}_{air}C\rho T_{cabin}$$

(10)

Replace Eq. (1), (8), (9) and (10) are placed into Eq. (6) and we got

$$A\bullet\dot{T}_{cabin}+B\bullet T_{cabin}=C\bullet T_{amb}+D\bullet T_{eR,i}+E\bullet T_{w,j}+F$$

(11)

where

$$A=\rho_{air}V_{cabin}\dot{m}_{air}Cp^{2}{}_{a}$$

$$B=\dot{m}_{air}Cp_{a}\{\dot{m}_{air}Cp_{a}-(1-\mathrm{pf})(1-\varepsilon_{e})\lfloor\dot{m}_{air}Cp_{a}+(1-\mathrm{ptd})\varepsilon_{H}C_{\mathrm{min},H}\rfloor+0.1201\}$$

$$C\equiv pf(1-\varepsilon_{e})\dot{m}_{air}Cp_{a}\lfloor\dot{m}_{air}Cp_{a}+(1-\mathrm{ptd})\varepsilon_{H}C_{\mathrm{min},H}\rfloor+\dot{m}_{air}Cp_{a}0.1201\}$$

$$D=\dot{m}_{air}Cp_{a}\varepsilon_{e}\lfloor\dot{m}_{air}Cp_{a}\mathrm{ptd}+(1-\mathrm{ptd})(\dot{m}_{air}Cp_{a}+\varepsilon_{H}C_{\mathrm{min},H})\rfloor$$

$$E=-\varepsilon_{e}\lfloor\dot{m}_{air}Cp_{a}\mathrm{ptd}+(1-\mathrm{ptd})(\dot{m}_{air}Cp_{a}+\varepsilon_{H}C_{\mathrm{min},H})\rfloor\times(1-\mathrm{ptd})\varepsilon_{H}C_{\mathrm{min},H}$$

$$F=\dot{m}_{air}Cp_{a}0.2618$$

$$V_{air}=0.0245e^{4.0329\times\mathrm{bp}} \qquad (12)$$

3.6 Predicted Mean Value (PMV)

Fanger's PMV refer to environment factors like air temperature, air velocity and humidity and personal factor like activity level and clothing insulation to calculate thermal comfort. From Fanger (1972), PMV equation is given by

$$\begin{aligned} PMV = {} & (0.028+0.3033e^{-0.036M})\bullet\{(M-W)-3.05[5.733-0.000699(M-W) \\ & -PA]-0.42(M-W)-0.0173(5.867-PA)-0.0014M(34-T_a) \\ & -3.96*10^{-8}fcl[(T_{cl}+273)^4-(T_{mrt}+273)^4]-fcl\bullet h_c(T_{cl}-T_a)\} \end{aligned} \tag{13}$$

$$\begin{aligned} T_{cl} = {} & 35.7-0.028(M-W)-0.155I_{cl}\{3.96\times10^{-3}fcl[(\mathrm{T_{cl}}+273)^4-(\mathrm{T_{mrt}}+273)^4] \\ & -fcl\bullet h_c(\mathrm{T_{cl}}-\mathrm{T_a})\} \end{aligned} \tag{14}$$

$$h_c = \begin{cases} 2.38(T_c-T_a)^{0.25} & 2.38(T_c+T_a)^{0.25} \geq 12.1\sqrt{V_{air}} \\ 12.1\sqrt{V_{air}} & 2.38(T_c+T_a)^{0.25} \geq 12.1\sqrt{V_{air}} \end{cases} \tag{15}$$

The parameters are defined as follows:

M: metabolism (W/m^2).

W: external work, equal to zero for most activity (W/m^2).

I_{cl}: thermal resistance of clothing (Clo).

fcl: ratio of body's surface area when fully clothed to body's surface area when nude.

T_{a}: air temperature (°C)

T_{mrt}: mean radiant temperature (°C).

V_{air}: relative air velocity (m/s).

Pa: partial water vapor pressure (kPa).

h_{c}: convection heat transfer coefficient (W/m^2 k)

T_{cl}: surface temperature of clothing (°C).

CHAPTER 4

ANALYSIS & RESULT

4.1 PHASE 1: Thermal Controller (Cooling-system)

Step 1: Averaging cabin temperature

From the data collected, average data's were calculated by still considers the cooling level.

Table 4.1: Average Cabin Temperature

Car's Model	Cooling level	Average Cabin Temperature			
		Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	0	21.53	33.48	31.74	24.98
	1	20.65	29.73	27.01	20.90
Perodua Kancil 850 Exi	0	22.39	32.13	30.60	23.82
	1	19.92	28.40	22.85	19.75
Proton Saga (Baru) 1.3	0	24.18	32.73	34.64	26.52
	1	20.72	26.55	27.70	22.09
Toyota Vios 1.5G	0	19.46	28.10	26.29	21.52
	1	17.51	24.19	21.03	17.92

E.g.:

Car's Model	Cooling level	Afternoon				AV
		1	2	3	4	
Perodua Kancil 850 Exi	0	33.8	32.4	31.6	30.7	32.13
	1	29.8	28.7	28.0	27.1	28.40

Step 2: Calculating Thermal Load

By put cooling level to average level (0), the thermal load for 4 periods time were calculated by using empirical formula.

Thermal loads equation, E_{gen},

$$E_{gen} = 0.118(T_{amb} - T_{cabin}) + 0.0022(T_{amb} - T_{cabin}) + 0.2618 \qquad \text{(Eq. 1)}$$

where

0.118 is a constant for solar radiation

0.0022 is constant for outside air

0.2618 is constant for cabin temperature difference

Table 4.2 showed ambient temperature. The thermometer was set at the constant location and was measure in the same day.

Table 4.2: Ambient Temperature

Time	Temp
Morning	27.8
Afternoon	33.9
Evening	32.4
Night	27.0

Table 4.3: Thermal Load generated

Car Model	E_{gen}			
	Morning $(T_{amb} = 27.8^{o}C)$	Afternoon $(T_{amb} = 33.9^{o}C)$	Evening $(T_{amb} = 32.4^{o}C)$	Night $(T_{amb} = 27.0^{o}C)$
Perodua Myvi 1.3SE	1.121230	0.763635	0.90938	0.99502
Perodua Kancil 850 Exi	1.209204	0.922900	1.40971	1.13371
Proton Saga (New) 1.3	1.112310	1.145270	1.30225	0.85194
Toyota Vios 1.5G	1.498407	1.428599	1.62842	1.35265

E.g.

Refer to the Afternoon's data taken, $T_{amb} = 33.9^oC$, $T_{cabin} = 32.13^oC$, for Perodua Myvi 1.3SE, subs in equation 1.

$$\begin{aligned} E_{gen} &= 0.118(T_{amb} - T_{cabin}) + 0.0022(T_{amb} - T_{cabin}) + 0.2618 \\ &= 0.118(33.9 - 32.13) + 0.0022(33.9 - 32.13) + 0.2618 \\ &= 0.474554 \end{aligned}$$

Step 3: Finding air velocity and air mass

Refer Figure 3.1 and Figure 3.2, Blower Model, already mention 2 experiments to get air velocity, V_{air} and mass flat rate m_{air}.

Result from that figure, air velocity and mass flat rate equations were generated:

- $m_{air} = 0.1386bp^2 + 0.0075bp + 0.0384$ (Eq 2)
- $V_{air} = 0.0245e^{4.0329bp}$

Base on these two equations, air velocity and air mass used in this research showed in the Table 4.4.

Table 4.4: Air velocity and air mass base on blower power

Fan speed	1	2	3	4	Average
Blower power	0.25	0.50	0.75	1.00	-
m_{air} (kg/s)	0.0486375	0.0765000	0.1216875	0.1842000	0.107756
V_{air} (m/s)	0.0671479	0.1840344	0.5043890	1.3823954	0.534492

E.g.

Take 1st level of fan speed with neglected any cooling level, set the blower power to 0.25. Then

$$\begin{aligned} m_{air} &= 0.1386bp^2 + 0.0075bp + 0.0384 \\ &= 0.1386(0.25)^2 + 0.0075(0.25) + 0.0384 \\ &= 0.0486375 \end{aligned}$$

$$\begin{aligned} V_{air} &= 0.0245e^{4.0329bp} \\ &= 0.0245e^{4.0329(0.25)} \\ &= 0.0671479 \end{aligned}$$

Step 4: Finding thermal capacity

Specific heat, Cp is the measure of the heat energy required to increase the temperature of an object by a certain temperature interval. Heat capacity is an *extensive property* because its value is proportional to the amount of material in the object; for example, a bathtub of water has a greater heat capacity than a cup of water. Laider, Keith, J. (1993).. Assuming an altitude of 194 meters above mean sea level (the world–wide median altitude of human habitation), an indoor temperature of 23 °C, a dew point of 9 °C (40.85% relative humidity), and 760 mm–Hg sea level–corrected barometric pressure (molar water vapor content = 1.16%), the specific heat taken is 1.0035 $kJ\ kg^{-1}K^{-1}$.

By the way, thermal capacity, C, defined as heat energy carry on by elements. From Physic knowledge, thermal capacity represent by

$$C = m_{air}Cp \qquad \text{(Eq 2.1)}$$

Table 4.5: Thermal capacity based on fan speed

Fan Speed	1	2	3	4	AV
m_{air} (kg/s)	0.0486375	0.0765000	0.1216875	0.1842000	0.107756
Thermal Capacity, C	0.0488080	0.0767680	0.1221130	0.1848450	0.108133

So, thermal capacity calculated is C = 0.108133 kW^oC.

E.g.

Set fan speed to level 1, we have 0.0486375 kg/s air mass. With specific heat is equal to 1.0035 $kJ\ kg^{-1}K^{-1}$ substitute in Eq 2.1.

$$
\begin{aligned}
C &= m_{air}Cp \\
&= 0.0486375(1.0035) \\
&= 0.048808 kW^{o}C
\end{aligned}
$$

Step 5: Finding heat exchanger effectiveness, ε

Taken from book Introduction to Head Transfer 4th Ed. (2002), the formula is

$$\varepsilon = \frac{Q_{actual}}{Q_{\max}} = \frac{Q_{actual}}{C_{\min}(T_{hot,i} - T_{cold,i})}. \qquad \text{(Eq 3)}$$

where

Q_{actual} is rate of heat transfer.

$C_{\min}$ is minimum thermal capacity with lowest blower power.

Beside is Table 4.6 contain minimum and maximum temperature for 4 times data recorded.

Table 4.6: Min and max temperature

Car's Model	Temperature							
	Morning		Afternoon		Evening		Night	
	T_min	T_max	T_min	T_max	T_min	T_max	T_min	T_max
Perodua Myvi 1.3 Exi	17.30	25.80	30.70	33.80	25.70	35.00	23.00	26.50
Perodua Kancil 850 Exi	19.29	22.14	27.10	29.80	20.70	35.00	21.85	25.35
Proton Saga (Baru) 1.3	21.55	26.46	31.10	34.60	22.00	32.90	24.37	28.18
Toyota Vios 1.5G	15.12	22.16	22.40	29.66	19.49	29.14	16.69	22.86

Heat is associated with the internal potential and kinetic energy of a system. The energy always moves from a warm system to a colder system. The energy that is moving from one system to another is known as heat. The transfer or dispersion of heat can occur by means of three main mechanisms, conduction, convection and radiation. The constant transfer rate in the air is 0.0263 $W / m\ K$.

Since maximum and minimum air were known, min thermal capacity is 0.04880773 kW^oC, heat exchanger effectiveness, ε defined in Table 4.7.

Table 4.7: Heat Exchanger Effectiveness

Car's Model	Heat Exchanger Effectiveness			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	0.063394	0.33680	0.1158815	0.153957
Perodua Kancil 850 Exi	0.189070	0.19960	0.0376818	0.153957
Proton Saga (Baru) 1.3	0.109920	0.15400	0.0494141	0.141640
Toyota Vios 1.5G	0.076574	0.07430	0.0557901	0.087278

E.g.

Take Myvi Model in morning, minimum and maximum temperature are 17.3^oC and 25.8^oC.

$$\varepsilon = \frac{Q_{actual}}{C_{\min}(T_{hot,i} - T_{cold,i})}$$

$$= \frac{0.0263}{0.04880773(25.8 - 17.3)}$$

$$= 0.063394$$

Step 6: Calculating work energy in cabin

Formula taken in journal referred gave

$$W_{cabin} = \rho_{air} V_{cabin} T_{cabin} Cp \qquad \text{(Eq 4)}$$

When the air pressure constant, ρ_{air} is 1, the result of work energy in cabin showed in table below.

Table 4.8: Work Energy

Car's Model	W_{air}			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	11.07588	15.94337	14.4885	11.2100
Perodua Kancil 850 Exi	10.68332	15.20000	12.2559	10.5911
Proton Saga (Baru) 1.3	11.11569	14.24042	12.7354	11.8484
Toyota Vios 1.5G	9.392826	12.97614	11.2799	9.61415

E.g.

Calculate W_{air} for Myvi on Morning, $\rho_{air}=1$, $V_{cabin}=0.534492$, $T_{cabin}=21.53\text{C}$ and $C\rho=1.0035\ kJ\ kg^{-1}K^{-1}$. Substitute in eq 4, we got,

$$\begin{aligned} W_{cabin} &= \rho_{air}V_{cabin}T_{cabin}C\rho \\ &= 1(0.534492)(20.65)(1.0035) \\ &= 11.07588 \end{aligned}$$

Step 7: Finding theoretical temperature

Calculate theoretical temperature of air-conditional or called temperature of output evaporate air using formula

$$T_{e,o}=T_{e,i}-\frac{\varepsilon_e C_{\min}}{\dot{m}_{air}Cp}(T_{e,i}-T_{eR,i}) \qquad \text{(Eq 5)}$$

Earlier, evaporate air temperature, $T_{eR,i}$ entered the cooling system have been recorded. $T_{eR,i}$ is equivalent with air temperature of air-conditioner with automatic current (a/c) was off. The $T_{eR,i}$ recorded at 4 times show in Table 4.9.

Table 4.9: Evaporate air temperature

Time	Temp
Morning	29.0
Afternoon	34.2
Evening	36.7
Night	33.9

By using $C_{\min}=0.04880773\ kW^{o}C$, average mass, $\dot{m}_{air}=0.107756$ kg/s, $T_{e,i}=T_{amb}$, $Cp=1.0035\ kJ\ kg^{-1}K^{-1}$, cabin temperature (actual) calculated and the value were showed in the Table 4.10

Table 4.10: Cabin temperature (theoretical)

Car's Model	$T_{e,o}$			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	27.83	33.95	32.62	27.48
Perodua Kancil 850 Exi	28.35	34.15	32.43	25.12
Proton Saga (Baru) 1.3	28.24	33.90	31.68	25.27
Toyota Vios 1.5G	28.01	32.76	31.58	25.94

E.g.

Calculate $T_{e,o}$ for Myvi on Morning, where $C_{\min}$=0.04880773 kW^oC, average mass, $\dot{m}_{air}$=0.107756 kg/s, Cp=1.0035 $kJ\,kg^{-1}K^{-1}$, $T_{e,i} = T_{amb} = 27.8^oC$, $T_{eR,i} = 29.0^oC$, $E_{gen} = 1.0161$. Substitute in (Eq 5), we got

$$T_{e,o} = T_{e,i} - \frac{\varepsilon_e C_{\min}}{\dot{m}_{air} Cp}(T_{e,i} - T_{eR,i})$$
$$= 27.8 - \frac{0.06339(0.04880773)}{0.107756(1.0035)}(27.8 - 29.0)$$
$$= 27.83^oC$$

Step 8: Finding door temperature parameter

Door temperature is final parameter need to consider. It base on fuzzy criteria whether 0 or 1. Based on Yadollah and Ali (2008), applying energy equilibrium after temperature door, the air temperature that enters the cabin is calculated by:

$$\mathrm{T_{cooler,o} = ptd \bullet T_{e,o} + (1 - ptd)T_{H,o}} \qquad \text{(Eq 6)}$$

Table 4.11, is the table show door temperature or *ptd* assume by user whether the air was hot or cold.

Table 4.11: Door temperature (ptd)

Car's Model	Ptd			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	1	0	0	1
Perodua Kancil 850 Exi	1	0	1	1
Proton Saga (Baru) 1.3	1	0	1	1
Toyota Vios 1.5G	1	1	1	1

Table 4.12 showed temperature in cabin with sealed condition and car's air-conditioner was off.

Table 4.12: Temperature inside cabin

Time	Temp
Morning	27.2
Afternoon	34.0
Evening	34.5
Night	31.5

In order to find the parameter in the approximate temperature, the value of ptd set to 0.5.

Table 4.13: Door temperature (parameter)

Car's Model	$T_{cooler,o}$			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	27.52	33.97	33.56	29.49
Perodua Kancil 850 Exi	27.77	34.08	33.46	28.31
Proton Saga (Baru) 1.3	27.72	33.95	33.09	28.39
Toyota Vios 1.5G	27.61	33.38	33.04	28.72

E.g.

Calculate $T_{cooler,o}$ for Myvi on Morning, where ptd=0.5, $T_{e,o} = 28.35^{o}C$ and $T_{H,o} = 27.2^{o}C$. Substitute in Eq 6, we got

$$
\begin{aligned}
\mathrm{T_{cooler,o}} &= \mathrm{ptd} \bullet \mathrm{T_{e,o}} + (1 - \mathrm{ptd})\mathrm{T_{H,o}} \\
&= 0.5(27.83) + (1 - 0.5)(27.2) \\
&= 27.52^{o}C
\end{aligned}
$$

Step 9: Finding interior and exterior cabin's energy

Based on Yadollah Ali (2008), exterior cabin's energy given by

$$E_{cabin,o} = \dot{m}_{air} C\rho T_{cooler,0} \qquad \text{(Eq 7)}$$

and interior cabin's energy is

$$E_{cabin,i} = \dot{m}_{air} C\rho T_{cabin} \qquad \text{(Eq 8)}$$

Since $C\rho$=1.0035 $kJ\ kg^{-1}K^{-1}$ and $\dot{m}_{air}$=0.107756 kg/s, interior and exterior cabin's energy were showed in the Table 4.14.

Table 4.14: Exterior and Interior cabin's energy (cooling level: 1)

Car's Model	$E_{cabin,o}$			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	2.9755	3.6736	3.6292	3.1888
Perodua Kancil 850 Exi	3.0032	3.6848	3.6184	3.0615
Proton Saga (Baru) 1.3	2.9975	3.6711	3.5780	3.0696
Toyota Vios 1.5G	2.9851	3.6097	3.5729	3.1054

Car's Model	$E_{cabin,i}$			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	2.3276	3.6198	3.4326	2.7006
Perodua Kancil 850 Exi	2.4214	3.4738	3.3089	2.5759
Proton Saga (Baru) 1.3	2.6143	3.5395	3.2102	2.8677
Toyota Vios 1.5G	2.1038	3.0380	2.8433	2.3269

E.g.

Calculate E_{cabin} for Myvi on Morning at cooling level:1, where $C\rho$=1.0035 $kJ\ kg^{-1}K^{-1}$ and $\dot{m}_{air}$=0.107756 kg/s. Substitute in Eq 7 and Eq 8, we got

Exterior cabin's energy:

$$\begin{aligned} E_{cabin,o} &= \dot{m}_{air} C\rho T_{cooler,0} \\ &= 0.107756(1.0035)(27.52) \\ &= 2.9755J \end{aligned}$$

Interior cabin's energy:

$$\begin{aligned} E_{cabin,i} &= \dot{m}_{air} C\rho T_{cabin} \\ &= 0.107756(1.0035)(21.53) \\ &= 2.3276J \end{aligned}$$

Step 10: Finding thermal comfort parameter

Given by Yadollah and Ali (2008)

$$A \bullet \dot{T}_{cabin} + B \bullet T_{cabin} = C \bullet T_{amb} + D \bullet T_{eR,i} + E \bullet T_{w,j} + F$$

where

$$A = \rho_{air} V_{cabin} \dot{m}_{air} Cp^{2}{}_{a}$$

$$B = \dot{m}_{air} Cp_{a} \{\dot{m}_{air} Cp_{a} - (1-\mathrm{pf})(1-\varepsilon_{e}) \lfloor \dot{m}_{air} Cp_{a} + (1-\mathrm{ptd}) \varepsilon_{H} C_{\mathrm{min},H} \rfloor + 0.1201\}$$

$$C \equiv pf(1-\varepsilon_{e}) \dot{m}_{air} Cp_{a} \lfloor \dot{m}_{air} Cp_{a} + (1-\mathrm{ptd}) \varepsilon_{H} C_{\mathrm{min},H} \rfloor + \dot{m}_{air} Cp_{a} 0.1201\}$$

$$D = \dot{m}_{air} Cp_{a} \varepsilon_{e} \lfloor \dot{m}_{air} Cp_{a} \mathrm{ptd} + (1-\mathrm{ptd})(\dot{m}_{air} Cp_{a} + \varepsilon_{H} C_{\mathrm{min},H}) \rfloor$$

$$E = -\varepsilon_{e} \lfloor \dot{m}_{air} Cp_{a} \mathrm{ptd} + (1-\mathrm{ptd})(\dot{m}_{air} Cp_{a} + \varepsilon_{H} C_{\mathrm{min},H}) \rfloor \times (1-\mathrm{ptd}) \varepsilon_{H} C_{\mathrm{min},H}$$

$$F = \dot{m}_{air} Cp_{a} 0.2618$$

$$V_{air} = 0.0245 e^{4.0329 \times \mathrm{bp}}$$

After derived above formula, thermal comfort control parameter can get it by substitute Eq 1, Eq 4, Eq 7 and Eq 8 into

$$\frac{dE_{cabin}}{dt} = \dot{E}_{gen} - \dot{W}_{cabin} + \sum \dot{E}_{cabin,i} - \dot{E}_{cabin,0} \qquad \text{(Eq 9)}$$

Table 4.15 show result or parameter of thermal comfort.

Table 4.15: Thermal comfort parameter

Car's Model	Parameter			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	-8.3697	-12.0193	-10.8548	-8.4432
Perodua Kancil 850 Exi	-7.9021	-11.4498	-8.6849	-7.8078
Proton Saga (Baru) 1.3	-8.1457	-10.3559	-9.2334	-8.8097
Toyota Vios 1.5G	-6.8820	-9.5032	-8.1070	-7.1017

4.2 PHASE 2: FINDING PREDICTED MEAN VALUE (PMV)

<u>Step 1:</u> Defining vapor pressure of water

Garnett, Pat; Anderton, John D; Garnett, Pamela J (1997), partial vapor pressure of water is given by Antoine equation

$$\log_{10} Pa = 7.96681 - \frac{1668.21}{228.0 + T} \qquad \text{(Eq 10)}$$

where $T = T_{H,o}$. Table 4.15 show partial vapor pressure of water at 4 times:

Table 4.16: Vapor pressure of water

Time	Vapor pressure
Morning	26.9
Afternoon	39.8
Evening	40.9
Night	34.5

E.g.

To calculate vapor pressure in the morning with the ambient temperature is 27.2^oC.

$$\log_{10} Pa = 7.96681 - \frac{1668.21}{228.0 + T}$$

$$\log_{10} Pa = 7.96681 - \frac{1668.21}{228.0 + 27.2}$$

$$Pa = 10^{1.43}$$

$$= 26.9kPa$$

<u>Step 2:</u> Defining Mean Radiant Temperature (MRT)

Mean radiant temperature (MRT) is simply the area weighted mean temperature of all the objects surrounding the body. The Mean Radiant Temperature of an environment is defined as that uniform temperature of an imaginary black enclosure which would result in the same heat loss by radiation from the person as the actual enclosure. The equation for the calculation of Mean Radiant Temperature is:

$$T_{mrt} = \sqrt[4]{\sum_n F_{p-i}.(t_i + 273)^4} - 273 \qquad \text{(Eq 11)}$$

where F_{p-i} = angle factor between passenger and source of air, T_i = surface temperature in *Kelvin*. Thus the angle of passenger is straightly with the sources of the blower, 0^o, F_{p-i} is equal to 1. Table 4.16 show Mean Radiant Temperature.

Table 4.17: Mean radiant temperature

Car's Model	MRT			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	29.97	42.14	38.31	29.63
Perodua Kancil 850 Exi	28.51	40.24	32.60	28.01
Proton Saga (Baru) 1.3	29.50	38.76	33.75	31.33
Toyota Vios 1.5G	25.11	34.38	29.90	25.42

E.g.

To calculate vapor pressure for Perodua Myvi in the morning with the ambient temperature is $27.2^o C$.

$$T_{mrt} = \sqrt[4]{\sum_n F_{p-i}.(t_i)^4}$$

$$= \sqrt[4]{24.1^4 + 22.4^4 + 19.2^4 + 16.9^4}$$

$$= \sqrt[4]{806571.88}$$

$$= 29.97^{\circ} C$$

Step 3: Calculating Thermal Insulation

$$T_{cl} = 35.7 - 0.028(M - W) - 0.155 TI_{ct}\{3.96\times10^{-3} fcl[(\mathrm{T_{clo}} + 273)^4 - (\mathrm{T_{mrt}} + 273)^4] \\ - fcl \bullet h_c(\mathrm{T_{clo}} - \mathrm{T_a})\} \qquad \text{(Eq 12)}$$

where $M = 80\ \mathrm{W/m^2}$, $W \approx 1.4\ \mathrm{W/m^2}$, $TI_{cl} = 0.5$, T_{mrt} was referred to Table 18, $T_{clo} = T_{H_2O}$, $T_a = T_{cabin}$, $fcl = 0.7$, $h_c = 10\ \mathrm{W/(m^2K)}$. Table 4.17 show Thermal Insulation.

Table 4.18: Thermal Insulation

Car's Model	Thermal Insulation			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	37.05	35.82	38.14	41.45
Perodua Kancil 850 Exi	38.03	37.12	40.40	40.45
Proton Saga (Baru) 1.3	37.59	38.12	39.91	39.18
Toyota Vios 1.5G	39.33	39.40	41.38	41.44

E.g.

To calculate vapor pressure for Perodua Myvi in the morning with $T_{mrt} = 29.97^\circ C$, $T_{clo} = 27.2^\circ C$ and $T_a = 20.65^\circ C$.

$$\begin{aligned} T_{cl} &= 35.7 - 0.028(M - W) - 0.155 TI_{ct}\{3.96\times10^{-3} fcl[\mathrm{T_{clo}} - \mathrm{T_{mrt}}] - fcl \bullet h_c(\mathrm{T_{clo}} - \mathrm{T_a})\} \\ &= 35.7 - 0.028(58 - 0) - 0.155(0.5)\{3.96\times10^{-3}(0.7)[27.2 - 29.97] - (0.7)\bullet 10(27.2 - 20.65)\} \\ &\approx 37.05 \end{aligned}$$

Step 4: Calculating PMV equation

From Fanger (1972), PMV equation is given by

$$
\begin{aligned}
PMV = {} & (0.028 + 0.3033e^{-0.036M}) \bullet \{(M - W) - 3.05[5.733 - 0.000699(M - W) \\
& - Pa] - 0.42(M - W) - 0.0173(5.867 - Pa) - 0.0014M(34 - T_a) \\
& - 3.96 * 10^{-8} fcl[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] - fcl \bullet h_c(T_{cl} - T_a)\}
\end{aligned}
$$

(Eq 13)

where, Pa were referred to Table 17, $T_a = T_{cabin}$, T_{cl} were referred to Table 4.18, T_{mrt} were referred to Table 4.17. Table 4.19 show PMV values of thermal comfort.

Table 4.19: PMV constant

Car's Model	PMV			
	Morning	Afternoon	Evening	Night
Perodua Myvi 1.3 Exi	-1.2710	3.8605	3.3491	-14.7760
Perodua Kancil 850 Exi	-2.1586	3.5144	0.1766	-2.3625
Proton Saga (Baru) 1.3	-10.2995	2.9804	0.8552	-3.6774
Toyota Vios 1.5G	-26.3554	1.1745	-1.2496	-24.7867

E.g.
To calculate vapor pressure for Perodua Myvi in the morning

$$
\begin{aligned}
PMV = {} & (0.028 + 0.3033e^{-0.036M}) \bullet \{(M - W) - 3.05[5.733 - 0.000699(M - W) \\
& - Pa] - 0.42(M - W) - 0.0173(5.867 - Pa) - 0.0014M(34 - T_a) \\
& - 3.96 * 10^{-8} fcl[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] - fcl \bullet h_c(T_{cl} - T_a)\} \\
= {} & (0.028 + 0.3033e^{-0.036(80)}) \bullet \{(80 - 1.4) - 3.05[5.733 - 0.000699(80 - 1.4) \\
& - 26.9] - 0.42(80 - 1.4) - 0.0173(5.867 - 26.9) - 0.0014(80)(34 - 20.65) \\
& - 3.96 * 10^{-8}(0.7)[(37.05 + 273)^4 - (29.97 + 273)^4] - (0.7) \bullet 10(37.05 - 20.65)\} \\
= {} & 0.045(-28) \\
= {} & -1.271
\end{aligned}
$$

CHAPTER 5

CONCLUSION

5.1 Result discussion

There are two thermal controller had test and the result showed in Table 4.14 and Table 4.18. Both of this result are passenger comfort parameter. One with consider the effectiveness of air-cooling system and another one consider nature factor. Both parameter also still in the right way because show highest air temperature in the Afternoon period. Main different between this two parameter is elements consideration.

The application of Fuzzy Controller taking at two places. 1st it using to create situation of fan-level. Where no exact value to put to replace level of the system. So, fuzzy number between 0 and 1 will used here. Another place, Fuzzy Controller using to replace equipment facilities to measure the different of air temperature. In this research, this scientific equipment are neglected and so, number of fuzzy have been used. It more to comparison of the temperature inside the cabin and outside of cabin with open door. If temperature outside is higher than inside, we assume it as 1. But if vice versa, we assume as 0.

In this research, quite different with previous research done by Yadollah F. and Ali A. T. (2008) because they used Fuzzy Logic with numerical analysis and robustness data converting. Therefore, robustness analysis should be performed after optimization to insure the effectiveness of controller over a wide range of conditions. Robustness is a characteristic of controller which minimizes the effect of uncertainty or variation in system parameters without eliminating the source of the uncertainty or variation.

5.1.1 Parameter Analysis

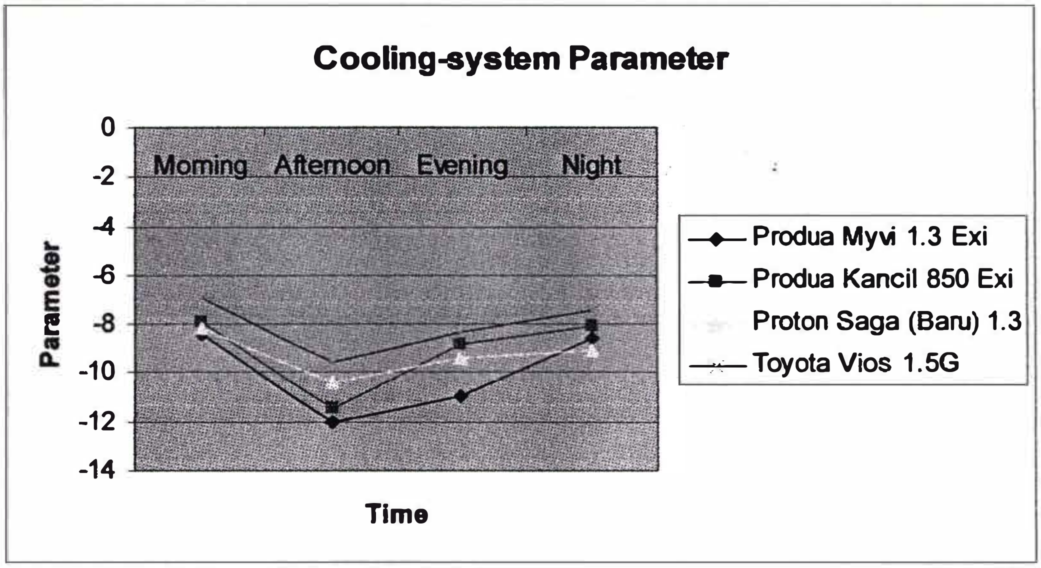


Fig. 5.1: Graph: Cooling=system Parameter

Car cooling-system is factory standard setting. So it just perform by the user setting without consider weather effect and passenger condition. That why its parameters not so much different.

Figure 5.1 show graph of cooling-system parameter for 4 car's model. There are not so much difference between this models. All models show thermal parameter at Afternoon highest and lowest at Morning (overall). It satisfy passenger comfortable level where passenger felt not so comfort in hot condition. During Evening until night, thermal comfort became more comfortable for passenger in slow motion. It because sometimes, ambient temperature not much differences. Beach location be the major factor that effect this condition.

PMV Parameter is passenger thermal controller. It more to natural or common factors that effect passenger satisfaction like clothing style, type of cloth and activities. For example, activities doing by passenger affect thermal produced by their body. So it also give major effect for thermal comfort.

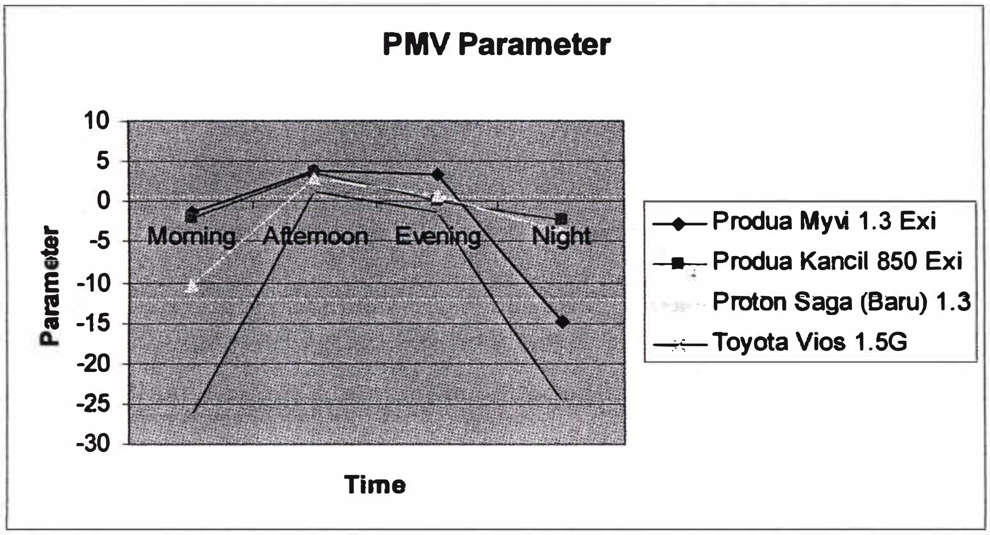


Fig. 5.2: Graph: PMV Parameter

Figure 5.2 show graph of PMV parameter for 4 car's model. Parameter's elements consideration be main factor that influence parameter for every cars. That's why we can see largest differences at 4 times. Passenger satisfaction overall still parallel with PMV parameter. PMV parameter quite difference with cooling-system parameter at night. Clothing style and screen-filter always keep passenger comfort especially in cool temperature. Proton Saga (New) and Perodua Myvi already provide with screen-tinted. Types of tinted using make this two model give difference thermal parameter. In Perodua Myvi, 75% transparency level with gold layer can trapped more thermal and give passenger more comfort but without dazzling layer, it not comfort in Afternoon.

5.1.2 Remain constants

There are remains 4 variables should assumed constant. This will simplify the equation problems without consider any significant error.

By refer to Ashraf (2001), mean value used in PMV calculation are:

i) Metabolic activity assumed 1 mat and 1.5 mats for the passenger and the driver. Passengers in the cabin are usually just sits without doing anything.

ii) Thermal insulation of 0.7 is an average in clothing insulation and it assumed as I_{cl} (clo). Clothing insulation 1.0 clo is equivalent to 0.155 m^2 K/W.

iii) Constant humidity level assumes 50%. In fact, people can feel comfortable in a wide range of relative humidity (20–70%) as long as the operative temperature is within comfort zone.

iv) Mean Radiant Temperature (MRT) is assume equals to inside air temperature. It refers from books written by Fanger, Jorgensen and Toftum (1998). Upper limits for indoor air humidity to avoid uncomfortably humid skin, *Energy Building*

5.2 Objective achievement

There are 3 objectives completed by the end of this thesis.

1. The effective feedback controller between Temperature feedback and PMV feedback is Temperature feedback. Represented by Cooling-system parameter, Temperature feedback neglect nature elements that became thermal comfort. It because passenger still have a choice to control level of their comfort with cooling level and fan speed.

2. Several factors make cars having more comfort thermal environment. In Temperature Feedback, speed of fan became major factor if compare with cooling level. Without lowest temperature level, thermal comfort achieve effectively by increase fan speed. In PMV Feedback, screen-tinted became major factor. If compare to clothing insulation, metabolisme rate and humidity, its all depend on passenger and can controlled by own. Screen-tinted effective because filtering ambient thermal and sun exposure.

3. If compare this two thermal controllers with minimizing energy consumption, PMV Feedback became more suitable. It because PMV depend on nature and cooling-system is base on engine. So if we increase car temperature more energy combustion required. That why by reduce cooling level, we can save petrol combustion.

5.3 Conclusion

There are several controller or element involve in determine thermal comfort for car's passenger like nature, weather, sun exposure and pollution index. Main element consider by car and air-conditional provider is air-cooling system. Using specific criteria to develop thermal controller for car, thermal comfort not simplify provide suitable temperature for passengers. So experts recommend Predicted Mean Value (PMV) that outside elements influence passengers satisfaction. This elements are like tinted, types and clothing styles, metabolisme rate and body posture. For more passenger's satisfaction both of this thermal controller should be consider.

5.4 Suggestion

In order to minimize the data reading error, the data taken for every cars must at the same time. It because ambient temperature and also sun exposure are always changes. It give a little bit effect to ambient temperature, engine cooling system, body metabolisme, trapped air temperature and so on. Unpredicted weather in Gong Badak along December until February be major constraint to collect exact data. Weather beside the beach also exactly difference with another place, so for more accurate temperature feedback controller, difference location data taken can be various.

REFERENCES

Ashrae. 2005. Thermal Comfort chapter, Fundamentals volume of the *ASHRAE Handbook*, Inc., Atlanta, GA.

Daanen, H.A.M., E. Vliert and X. Huang. 2003. Driving performance in cold, warm, and thermoneutral environments. *Appl. Ergon:* 597–602.

Durovic, H.M., Kovazevic, B.D.. 2004. Control of heating, ventilation and air conditioning system based on neural network, in: 7th IEEE Seminar on Neural Network Application in Electrical Engineering.

Editorial Team. 2001 The Global Market for Automotive Heating, Ventilation, Refrigeration and Air Conditioning. *Just Auto.*

Fanger, P.O. 1972. *Thermal Comfort, Analysis and Applications in Environmental Engineering*, McGraw Hill.

Fide. 1996. Why use fuzzy logic?
http://www.aptronix.com/fide/whatfuzzy.htm

Incropera, F.P. and De Witt, D.P. 2002. Introduction to heat transfer (fourth ed.), McGraw Hill.

Lambert, M.A. and Jones, B.J.. 2006. Automotive adsorption air conditioner powered by exhaust heat. Part 1: conceptual and embodiment design, *Proc. IMechE Part D: J. Automobile Eng.*: 959–972.

Kalteh, A.M., Kakai, A.H., Farhani, B. 2004. Investigate the performance of Peugeot 206 cooler in different climate condition, in: 8th Int. and 12th Annual Mechanical Engineering Conference.

Kays W. M. and A.L. London. 1984. Compact Heat Exchangers (third ed.), McGraw Hill, New York.

Klimenko, V. 1988. A generalized correlation for two-phase forced flow heat transfer, *Int. J. Heat Mass Transfer:* 541–552.

Shimisou, S, Hara, H. and Asakawa, F. 1993. Analyzing on air conditioning of a passenger vehicle, *Int. J. Vehicle Des.*

Thermal Comfort in Automobiles
http://www.lumasenseinc.com/Applications/Automotive/thermal_comfort_in_automobiles.html

Toftum, J, Jorgensen, A.S. and Fanger, P.O. 1998. Upper limits for indoor air humidity to avoid uncomfortably humid skin, *Energy Buildings* **28**. pp. 1–13.

Weiss, H. 1998. *Secrets of Warmth: For Comfort or Survival.* Seattle, WA: Mountaineers Books.

Wikipedia, the free encyclopedia. 2008. Thermal comfort.
http://en.wikipedia.org/wiki/Thermal_comfort [4 JUN 2008]

Yadollah F. and Ali A. T. (2008). Controlling automobile thermal comfort using optimized fuzzy controller, Applied Thermal Engineering **28**. pp 1906-1917

Zlatoper, T. 1991. Determinants of motor vehicle deaths in the United States: a cross-sectional analysis, special issue: theoretical models for traffic safety. *Accid. Ana:* 431–436.

ATTACHMENTS

Appendix A: Formula calculation using to calculate parameters

Control Parameter

> *restart*;

> $T_{amb} := c;\ T_{cabin} := d;$
> $E_{gen} := 0.118 \cdot \left(T_{amb} - T_{cabin}\right) + 0.0022 \cdot \left(T_{amb} - T_{cabin}\right) + 0.2618;$

$$T_{amb} := c$$

$$T_{cabin} := d$$

$$E_{gen} := 0.1202\,c - 0.1202\,d + 0.2618$$

> $bp := k;$
> $m_{air} := 0.1386\,bp^2 + 0.0075\,bp + 0.0381;$
> $V_{air} := 0.0245 \cdot \exp(4.0329 \cdot bp);$
> $Cp := 1.0035;$

$$bp := k$$

$$m_{air} := 0.1386\,k^2 + 0.0075\,k + 0.0381$$

$$V_{air} := 0.0245\,e^{4.0329\,k}$$

$$Cp := 1.0035$$

>
> $C := 0.1842 \cdot Cp;$
> $C_{\min} := m_{air} \cdot Cp;$
> $Q_{actual} := 0.0263;$
> $T_{hot,\,i} := a;$
> $T_{cold,\,i} := b;$
> $\varepsilon := \dfrac{Q_{actual}}{C_{\min} \cdot \left(T_{hot,\,i} - T_{cold,\,i}\right)};$

$$C := 0.18484470$$

$$C_{\min} := 0.13908510\,k^2 + 0.00752625\,k + 0.03823335$$

$$Q_{actual} := 0.0263$$

$$T_{hot,\,i} := a$$

$$T_{cold,\,i} := b$$

$$\varepsilon := \frac{0.0263}{\left(0.13908510\,k^2 + 0.00752625\,k + 0.03823335\right)\,(a - b)}$$

> $p_{air} := 1;\ W_{cabin} := p_{air} \cdot V_{air} \cdot Cp \cdot T_{cabin};$

$$p_{air} := 1$$

$$W_{cabin} := 0.02458575\,e^{4.0329\,k}\,d$$

> $T_{e,i} := T_{amb};\ T_{eR,i} := P;\ T_{e,o} := T_{e,i} - \frac{\varepsilon \cdot C}{m_{air} \cdot Cp} \cdot \left(T_{e,i} - T_{eR,i}\right);$

$$T_{e,i} := c$$

$$T_{eR,i} := P$$

$$T_{e,o} := c - (0.02620827105C\,(c-P)) / \big((0.13908510k^2 + 0.00752625k + 0.03823335)\,(a-b)\,(0.1386k^2 + 0.0075k + 0.0381)\big)$$

> $T_{H,o} := Q;\quad ptd := 0.5;\ T_{cooler,o} := ptd \cdot T_{e,o} + (1 - ptd) \cdot T_{H,o};$

$$T_{H,o} := Q$$

$$ptd := 0.5$$

$$T_{cooler,o} := 0.5\,c - (0.01310413552C\,(c-P)) / \big((0.13908510k^2 + 0.00752625k + 0.03823335)\,(a-b)\,(0.1386k^2 + 0.0075k + 0.0381)\big) + 0.5\,Q$$

> $E_{cabin,o} := m_{air} \cdot Cp \cdot T_{cooler,o};$

$$E_{cabin,o} := 1.0035\,(0.1386k^2 + 0.0075k + 0.0381)\Big(0.5\,c - (0.01310413552C\,(c-P)) / \big((0.13908510k^2 + 0.00752625k + 0.03823335)\,(a-b)\,(0.1386k^2 + 0.0075k + 0.0381)\big) + 0.5\,Q\Big)$$

> $E_{cabin,i} := m_{air} \cdot Cp \cdot T_{cabin};$

$$E_{cabin,i} := 1.0035\,(0.1386k^2 + 0.0075k + 0.0381)\,d$$

> $Controlparameter := \left(E_{gen} - W_{cabin} + E_{cabin,i} - E_{cabin,o}\right);$

$$Controlparameter := 0.1202c - 0.1202d + 0.2618 - 0.02458575\mathrm{e}^{4.0329\,k}\,d + 1.0035\,(0.1386k^2 + 0.0075k + 0.0381)\,d - 1.0035\,(0.1386k^2 + 0.0075k + 0.0381)\Big(0.5\,c - (0.01310413552C\,(c-P)) / \big((0.13908510k^2 + 0.00752625k + 0.03823335)\,(a-b)\,(0.1386k^2 + 0.0075k + 0.0381)\big) + 0.5\,Q\Big)$$

PMV Parameter

> $T_{H,o} := T_{amb};\ Pa_{water} := 10^{7.96681 - \left(\frac{1668.21}{228 + T_{H,o}}\right)};$

$$T_{H,o} := c$$

$$Pa_{water} := 10^{7.96681 - \frac{1668.21}{228 + c}}$$

> $T_{mrt} := \sqrt[4]{\sum_{n=4} F_{p-i} \cdot t_i^4};$

$$T_{mrt} := \left(F_{p-i}\, t_i^4\right)^{1/4}$$

>

$M := 80;$

$W := 1.4;$

$h_c := 10;$

$fcl := 0.7;$

$T_a := T_{cabin};$

$T_{clo} := T_{amb};$

$T_{cl} := 35.7 - 0.028(M - W) - 0.155\, TI_{ct}\left(3.96 \cdot 10^{-3} \cdot fcl \cdot \left(T_{clo} - T_{mrt}\right) - fcl \cdot h_c \cdot \left(T_{clo} - T_a\right)\right);$

$$M := 80$$

$$W := 1.4$$

$$h_c := 10$$

$$fcl := 0.7$$

$$T_a := d$$

$$T_{clo} := c$$

$$T_{cl} := 33.4992 - 0.155\, TI_{ct}\left(-6.997228000 c - 0.002772000000 \left(F_{p-i}\, t_i^4\right)^{1/4} + 7.0\, d\right)$$

> $PMVparameter := (0.028 + 0.3033 \cdot \exp(-0.036 \cdot M)) \cdot \left((M - W) - 3.05 \cdot \left(5.733 - 0.000699 \cdot (M - W) - Pa_{water}\right) - 0.42 \cdot (M - W) - 0.0173 \cdot \left(5.867 - Pa_{water}\right) - 0.0014 \cdot M \cdot \left(34 - T_a\right) - 3.96 \cdot 10^{-8} \cdot fcl \cdot \mathrm{abs}\left(\left(T_{clo} + 273\right)^4 - \left(T_{mrt} + 273\right)^4\right) - fcl \cdot h_c \cdot \left(T_{clo} - T_a\right)\right);$

$$PMVparameter := 1.096844417 + 0.138107248510^{7.96681 - \frac{1668.21}{228 + c}} + 0.3202225904 d - 1.24811167110^{-9} \left|(c + 273)^4 - \left(\left(F_{p-i}\, t_i^4\right)^{1/4} + 273\right)^4\right| - 0.3151797150 c$$

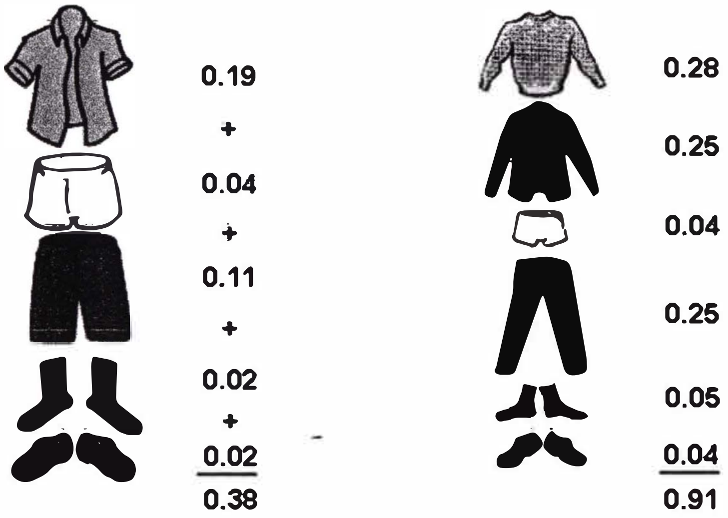
Appendix B: Clo values table

Garment description		Iclu Clo	m2°C/W
Underwear, pants	Pantyhose	0.02	0.003
	Panties	0.03	0.005
	Briefs	0.04	0.006
	Pants 1/2 long legs, wool	0.06	0.009
	Pants long legs	0.1	0.016
Underwear, shirts	Bra	0.01	0.002
	Shirt sleeveless	0.06	0.009
	T-shirt	0.09	0.014
	Shirt with long sleeves	0.12	0.019
	Half-slip, nylon	0.14	0.022
Shirts	Tube top	0.06	0.009
	Short sleeve	0.09	0.029
	Light weight blouse, long sleeves	0.15	0.023
	Light weight, long sleeves	0.20	0.031
	Normal, long sleeves	0.25	0.039
	Flannel shirt, long sleeves	0.3	0.047
	Long sleeves, turtleneck blouse	0.34	0.053
Trousers	Shorts	0.06	0.009
	Walking shorts	0.11	0.017
	Light-weight trousers	0.20	0.031
	Normal trousers	0.25	0.039
	Flannel trousers	0.28	0.043
	Overalls	0.28	0.043
Coveralls	Daily wear, belted	0.49	0.076

	Work	0.50
0.078		
Highly-insulating	Multi-component, filling	1.03
0.160		
coveralls	Fiber-pelt	1.13
0.175		
Sweaters	Sleeveless vest	0.12
0.019		
	Thin sweater	0.2
0.031		
	Long sleeves, turtleneck (thin)	0.26
0.040		
	Sweater 0.28 0.043 Thick sweater	0.35
0.054		
	Long sleeves, turtleneck (thick)	0.37
0.057		
Jacket	Vest	0.13
0.020		
	Light summer jacket	0.25
0.039		
	Jacket	0.35
0.054		
	Smock	0.3
0.047		
Coats and	Coat	0.6
0.093		
Over-jackets	Down jacket	0.55
0.085		
and over-trousers	Parka	0.7
0.109		
	Overalls multi-component	0.52
0.081		
Sundries	Socks	0.02
0.003		
	Thick, ankle socks	0.05
0.008		
	Thick, long socks	0.1
0.016		
	Slippers, quilted fleece	0.03
0.005		
	Shoes (thin soled)	0.02
0.003		
	Shoes (thick soled)	0.04
0.006		
	Boots 0.1 0.016 Gloves	0.05
0.008		
Skirts, dresses	Light skirt, 15 cm. above knee	0.10
0.016		
	Light skirt, 15 cm. below knee	0.18
0.028		
	Heavy skirt, knee-length	0.25
0.039		
	Light dress, sleeveless	0.25
0.039		

	Winter dress, long sleeves	0.4	0.062
Sleepwear	Long sleeve, long gown	0.3	0.047
	Thin strap, short gown	0.15	0.023
	Hospital gown	0.31	0.048
	Long sleeve, long pajamas	0.50	0.078
	Body sleep with feet	0.72	0.112
	Under-shorts	0.1	0.016
Robes	Long sleeve, wrap, long	0.53	0.082
	Long sleeve, wrap, short	0.41	0.064
Chairs	Wooden or metal	0.00	0.000
	Fabric-covered, cushioned, swivel	0.10	0.016
	Armchair	0.20	0.032

Insulation for the entire clothing: $I_{cl} = \sum I_{clu}$



Appendix C: Met value table

Activity	Metabolic rates [M] W/m2	Met
Reclining	46	0.8
Seated relaxed	58	1.0
Clock and watch repairer	65	1.1
Standing relaxed	70	1.2
Sedentary activity (office, dwelling, school, laboratory)	70	1.2
Car driving	80	1.4
Graphic profession - Book Binder	85	1.5
Standing, light activity (shopping, laboratory, light industry)	93	1.6
Teacher	95	1.6
Domestic work -shaving, washing and dressing	100	1.7
Walking on the level, 2 km/h	110	1.9
Standing, medium activity (shop assistant, domestic work)	116	2.0
Building industry -Brick laying (Block of 15.3 kg)	125	2.2
Washing dishes standing	145	2,5
Domestic work -raking leaves on the lawn	170	2.9
Domestic work -washing by hand and ironing (120-220 W/m2)	170	2.9
Iron and steel -ramming the mould with a pneumatic hammer	175	3.0
Building industry -forming the mould	180	3.1
Walking on the level, 5 km/h	200	3.4
Forestry -cutting across the grain with a one-man power saw	205	3.5
Agriculture -Ploughing with a team of horses	235	4.0
Building industry -loading a wheelbarrow with stones and mortar	275	4.7
Sports -Ice skating, 18 km/h	360	6.2
Agriculture -digging with a spade (24 lifts/min.)	380	6.5
Sports -Skiing on level, good snow, 9 km/h	405	7.0
Forestry -working with an axe (weight 2 kg. 33 blows/min.)	500	8.6
Sports -Running, 15 km/h	550	9.5

Appendix D: Calculation of Plane Radiant and Operative Temperature

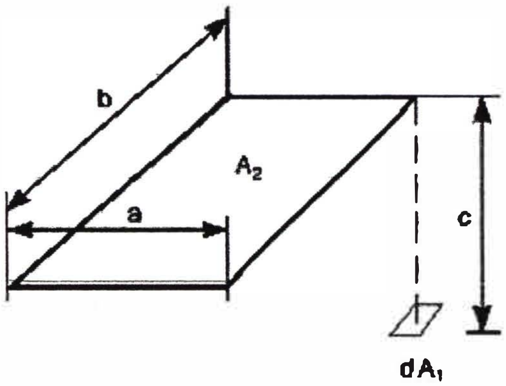
The following equation may be used to calculate the Plane Radiant Temperature:

$$t_{pr} = \sqrt[4]{\sum_{n} F_{pl-i}\cdot\left(t_i + 273\right)^4} - 273$$

t_i is surface temperature of surface no. i [°C]
F_{pl-i} is angle factor between a small plane and surface i.

$$\sum F_{pl-i} = 1$$

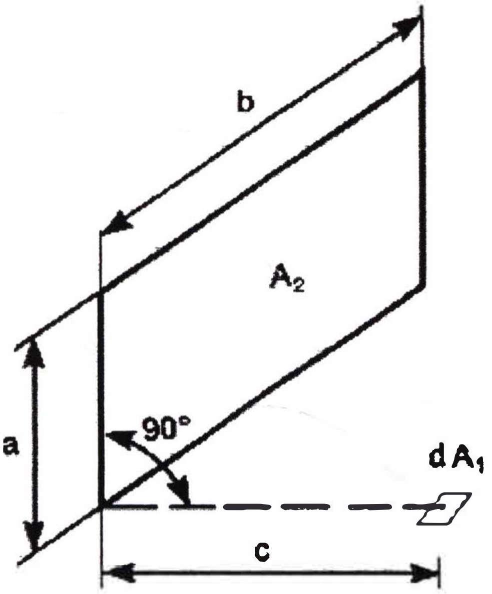
$$x := \frac{a}{c} \qquad y := \frac{b}{c}$$



$$F_{pl-2} = \frac{1}{2\cdot\pi}\cdot\left(\frac{x}{\sqrt{1+x^2}}\cdot\tan^{-1}\left(\frac{y}{\sqrt{1+x^2}}\right) + \frac{y}{\sqrt{1+y^2}}\cdot\tan^{-1}\left(\frac{x}{\sqrt{1+y^2}}\right)\right)$$

$$x := \frac{a}{b} \qquad y := \frac{c}{b}$$

$$F_{pl-3} = \frac{1}{2\cdot\pi}\cdot\left(\tan^{-1}\left(\frac{1}{y}\right) - \frac{y}{\sqrt{x^2+y^2}}\cdot\tan^{-1}\left(\frac{1}{\sqrt{x^2+y^2}}\right)\right)$$



Calculation of Operative Temperature

The following simplified equation gives reasonable accuracy:

$$t_o = A\cdot t_a + (1 - A)\cdot\bar{t}_r$$

v_{ar}	< 0.2	0.2 - 0.6	0.6 - 1.0
A	0.5	0.6	0.7

Appendix E: Table of specific heat capacities

Note that especially high values, as for paraffin, water and ammonia, result from calculating specific heats in terms of moles of molecules. If specific heat is expressed per mole of atoms for these substances, few values exceed the theoretical Dulong-Petit limit of 25 J/K/mole = 3 R per mole.

Substance	**Phase**	C_p kJ kg^{-1} K^{-1}	$C_{p,m}$ J mol^{-1} K^{-1}	$C_{v,m}$ J mol^{-1} K^{-1}	**Volumetric heat capacity J cm^{-3} K^{-1}**
Air (Sea level, dry, 0 °C)	Gas	1.0035	29.07	20.7643	0.001297
Air (typical room conditions)	Gas	1.012	29.19	20.85	
Aluminium	Solid	0.897	24.2		2.422
Ammonia	Liquid	4.700	**80.08**		3.263
Animal (and human) tissue	Mixed	3.5	-		3.7*
Antimony	Solid	0.207	25.2		1.386
Argon	gas	0.5203	20.7862	12.4717	
Arsenic	solid	0.328	24.6		1.878
Beryllium	solid	1.82	16.4		3.367
Bismuth	solid	0.123	25.7		1.20
Copper	solid	0.385	24.47		3.45
Carbon dioxide CO_2	gas	0.839*	36.94	28.46	
Diamond	solid	0.5091	**6.115**		1.782
Ethanol	liquid	2.44	112		1.925
Gasoline	liquid	2.22	228		1.64
Glass	solid	0.84			
Gold	solid	0.2291	25.42		2.492
Granite	solid	0.790			2.17
Graphite	solid	0.710	8.53		1.534
Helium	gas	5.1932	20.7862	12.4717	
Hydrogen	gas	**14.30**	28.82		
Hydrogen sulfide H_2S	gas	1.015*	34.60		
Iron	solid	0.450	25.1		3.537

Lead	solid	0.127	26.4		1.44
Lithium	solid	3.58	24.8		1.912
Magnesium	solid	1.02	24.9		1.773
Mercury	liquid	0.1395	27.98		1.888
Methane 275K	gas	2.191			
Nitrogen	gas	1.040	29.12	20.8	
Neon	gas	1.0301	20.7862	12.4717	
Oxygen	gas	0.918	29.38		
Paraffin wax	solid	2.5	**900**		2.325
Polyethylene (rot-molding grade)	solid	2.3027			
Polyethylene (rot-molding grade)	liquid	2.9308			
Silica (fused)	solid	0.703	42.2		1.547
Silver	solid	0.233	24.9		2.44
Tungsten	solid	0.134	24.8		2.58
Uranium	solid	**0.116**	27.7		2.216
Water	gas (100 °C)	**2.080**	**37.47**	**28.03**	
Water	liquid (25 °C)	**4.1813**	**75.327**	**74.53**	**4.186**
Water (ice)	solid (-10 °C)	**2.050**	**38.09**		**1.938**
Zinc	Solid	0.387	25.2		2.76
All measurements are at 25 °C unless otherwise noted. **Notable minima and maxima are shown in maroon.**					

[A] Assuming an altitude of 194 meters above mean sea level (the world–wide median altitude of human habitation), an indoor temperature of 23 °C, a dew-point of 9 °C (40.85% relative humidity), and 760 mm–Hg sea level–corrected barometric pressure (molar water vapor content = 1.16%).

*Derived data by calculation

Appendix F: Data collected

Car's Model	Cooling level	Morning					Afternoon					Evening					Night				
		1	2	1	2	3	4	AV	3	4	AV	1	2	3	4	AV	1	2	3	4	AV
Perodua Myvi 1.3 Exi	0	25.80	23.30	19.70	17.30	21.53	35.40	34.80	32.10	31.60	33.48	34.10	32.45	30.98	29.45	31.74	26.50	26.00	24.40	23.00	24.98
	1	24.10	22.40	19.20	16.90	20.65	31.40	30.20	29.10	28.20	29.73	28.65	27.48	26.43	25.50	27.01	21.90	21.30	20.90	19.50	20.90
Perodua Kancil 850 Exi	0	25.29	23.79	21.19	19.29	22.39	33.80	32.40	31.60	30.70	32.13	35.00	32.60	29.10	25.70	30.60	25.35	24.85	23.25	21.85	23.82
	1	22.14	20.99	19.19	17.34	19.92	29.80	28.70	28.00	27.10	28.40	25.20	23.80	21.70	20.70	22.85	20.75	20.15	19.75	18.35	19.75
Proton Saga (Baru) 1.3	0	26.46	25.43	23.26	21.55	24.18	34.60	33.33	31.90	31.10	32.73	32.90	30.98	28.61	26.26	29.69	28.18	27.63	25.89	24.37	26.52
	1	22.38	21.48	20.36	18.68	20.72	30.50	19.50	28.40	27.80	26.55	25.64	24.42	22.92	22.00	23.74	23.18	22.53	22.09	20.57	22.09
Toyota Vios 1.5G	0	22.16	20.72	18.33	16.61	19.46	29.66	28.72	27.31	26.69	28.10	29.14	27.44	25.34	23.26	26.29	22.86	22.42	21.01	19.78	21.52
	1	19.61	18.53	16.79	15.12	17.51	26.20	22.40	24.43	23.74	24.19	22.71	21.63	20.30	19.49	21.03	18.81	18.28	17.92	16.69	17.92

BIBLIOGRAFY

NAME : Nur Muhd Firdaus Aminullah bin Ibrahim
ADDRESS : A-1-4, Quarters Institusi Pendidikan,
Jalan Air Madu off Jalan Air Panas,
Setapak, 53200 K. Lumpur.
TEL. NO. : 013-9112424 / 017-4504342
E-MAIL : lirva_iera@yahoo.com

D.O.B : 4 April 1987
BIRTH PLACE : K. Lumpur
NATIONALITY : Malaysian
RACE : Malay
SEX : Male
RELIGION : Islam

EDUCATION : Sek. Keb. Batu Gajah, Tanah Merah, Kelantan
: Sek. Keb. Ayer Lanas, Jeli, Kelantan
: Sek. Men. Ayer Lanas, Jeli, Kelantan
: MJSC Kuantan, Pahang
: Pulau Pinang Matriculation College
: University Malaysia Terengganu

DETERMINE THE EFFECTIVE THERMAL COMFORT IN A CAR BY USING FUZZY CONTROLLER - NUR MUHD FIRDAUS AMINULLAH B. IBRAHIM