Influence of Passenger Car Air Conditioner System Thermostat Level Setting to Fuel Consumption and Thermal Comfort

Rawaida Muhammad, Muhammad Khiril Kamaruddin and Yeoh Poh See

Abstract Users would adjust air conditioner knob position to regulate the cool air supply to the cabin. Essentially, adjusting the knob position would affect fuel consumption of the vehicle. Thus, this study is done to measure the fuel consumption of different thermostat level settings of an air conditioning system, in the case of stationary car, without passengers and driver in it. The data in this study were taken in four different modes and two levels of selected fan speed. At the same time, the cabin temperature was monitored by a specific device to record the temperature, relative humidity, and CO_2 emission. Fuel consumption is monitored by filling 5 L of petrol into an external tank. After running for one hour, the total fuel consumption is calculated by measuring the remaining of the fuel amount. At the end of the experiment, the most practical and suitable thermostat level setting is proposed. Besides saving fuel, the outcome of this study showed that the most comfortable condition in the cabin is 25.83 °C, 51.72% relative humidity and CO_2 is 553 ppm. The selected mode is actually at mode 4, low blower fan speed with the fuel consumption is amounted at 1220 mL.

Keywords Air conditioner · Thermostat · Fuel consumption · Thermal

R. Muhammad (✉) · M. K. Kamaruddin · Y. P. See
Department of Mechanical Engineering, Politeknik Ungku Omar,
Jalan Raja Musa Mahadi, 31400 Ipoh, Perak, Malaysia
e-mail: rawaida_muhammad@yahoo.com

M. K. Kamaruddin
e-mail: mkhirilk@gmail.com

Y. P. See
e-mail: yeohpohsee@gmail.com

1 Introduction

Malaysian car users desperately need comfort while driving because of the hot and humid weather throughout the year. It is most important during driving in long journeys. The human thermal comfort is defined by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), as the state of mind that expresses satisfaction with the surrounding environment [1].

Thermal comfort of humans corresponds to a simple but permanent motivation that compels them to seek certain climatic situations, to maintain some of them, and to judge them in terms of pleasure or inconvenience. It becomes one of the significant criteria of selection during the acquisition of a car [2].

When the car users need comfort, the thermostat adjuster is set to a low temperature level. This will force the air condition system to use more power and increase the fuel consumption. In the automotive industry, fuel reduction can be done by controlling the use of air conditioning systems, mainly the compressor. Automotive industry today has applied a few modifications to control air conditioning compressors [3]. This system can affect the fuel consumption because the compressor engages with the engine. This will result in an increased load on the engine and fuel consumption also increases. The effect is larger with higher fuel economy vehicles [4]. As the fuel price can get very high depending on demand, the need to minimize fuel usage is a must and at the same time, comfort in the vehicle cannot be ignored.

Normally car users adjust the thermostat without taking into consideration of the fuel consumption. When the thermostat level is at a lower temperature set point, it can cause the compressor to continue to operate and it leads to an increase in the energy consumption. At the same time the temperature in the car becomes too cold that can cause discomfort. The results from this study will provide a temperature adjustment that can reduce fuel consumption and at the same time maintain the car cabin thermal comfort at an acceptable level.

Prediction the thermal comfort in a vehicle is very complex. It is because of the behaviour during a fast cool-down after a hot soak, a non-uniform thermal environment related with a very limited to a small area air velocity and temperature distribution, and solar flux and heat flux of radiation around the inner surface. Analyzing the temperature and velocity distribution in the passenger compartment, coupled with the forecast of the thermal comfort can guide the direction of the design in the early stages of the vehicle development process [5].

Thus, this study is done to measure the fuel consumption regarding to the thermostat level in a car air-conditioning system and also to suggest the most reasonable set point that achieves a good balance between thermal comfort and fuel consumption. It focuses on a Sedan car with approximately 3 m^3 volume of size as a model. Experiments are conducted in the morning around 9.00 a.m to 11.00 a.m. The tested vehicle is static in parking mode and uses 5 L of fuel, supplied to an external tank. The fuel consumption is practically measured after 1 h of experiment together with the temperature and humidity reading.

2 Experimental Setup

2.1 Experimental Parameter

The car cabin temperature environment is complex as it cannot be assessed with temperatures only because it will change from time to time. Air temperature, relative humidity, air velocity, environment radiation are important parameters that affect the thermal comfort [6]. In order to get the appropriate comfort, the temperature and humidity should be at about 72 F (22 °C) to 80 F (26.67 °C) and 30–60% in the summer according to the *ANSI/ASHRAE Standard 55*. Whereas for the CO_2 reading, 1000 ppm would be regarded as the upper limit of healthy condition, and the equipment limitation should be acceptable in the determining of the quality of air in the compartment [7]. Those parameters are actually controlled by using a thermostat.

Thus, this experiment is intended to study the thermostat level setting and also the blower fan speed that affect fuel consumption. Besides, additional parameters that influence the transient thermal comfort during the experiment period are also recorded. The experiments included conditions of 2 blower fan speeds, and 4 thermostat level settings. Each test is repeated in the same manner with different settings.

The procedure to study the temperature-time dependence is done by transferring data from the acquisition to the computer system for every 60 s. The air conditioning system has been used in both situations and the parameters were the same (temperature, flow, type). Values for four cases in the experiment are presented in tables considering between the hours 9:00–10:00 for Case 1 and between 12:00–13:00 for Case 2 [8].

2.2 Experimental Procedures

This research started with the fabrication of the external fuel tank, see Fig. 1. It is made of iron plates and upon completion it has the capacity to store up to 10 L of fuel. The need for an external tank is to enable a more accurate observation and measure of the consumed rate of fuel.

A Proton Persona car as in Fig. 2 is used to collect all the data needed for this study. The Proton Persona is a 2009 model with 1.6 L high line, as shown in Fig. 3. For the purpose of this study, the car's usage is assumed at good conditions and using tinted film on the front side windows at 70% of light transparency, side windows and rear windows at 50% light transparency.

A measuring instrument is used to measure and record the data of temperature and CO_2 emission inside the car. Then, it is installed with a data logger that is capable of logging data every hour, or by minutes or seconds. Other than that, in order to measure the air velocity and volume flow, an anemometer is used.
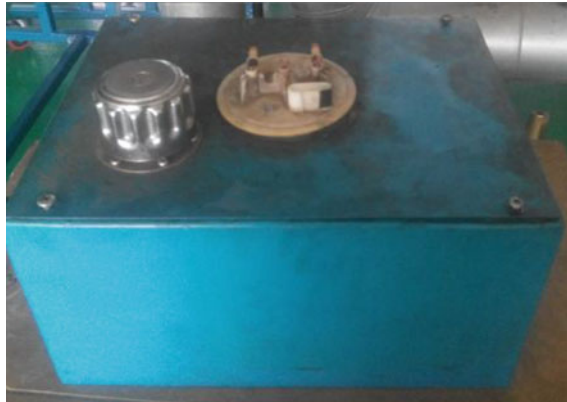
Fig. 1 External fuel tank

Fig. 2 Experiment car, proton persona, model 2009
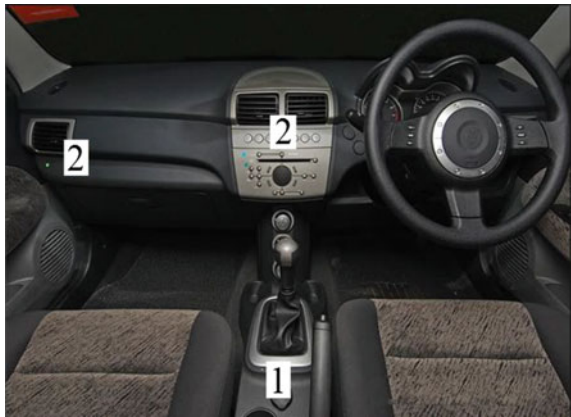

Fig. 3 Proton persona specification

Fig. 4 External fuel tank in front of the car

Fig. 5 Instrument positioning; **1**-temperature and CO_2 measuring instrument and RH/temperature data logging kit 2077 7001 and **2**-anemometer


Once the external fuel tank is ready, a new fuel hose is used to supply fuel from the external tank to the engine. By using the new hose, it minimizes the possible contamination of other materials to the system. This ensemble of fuel tank is placed at the exterior front end of the car as shown in Fig. 4. The measuring instrument is placed in the car between the driver and passenger seat; at the left side of the driver; kindly refer to Fig. 5. By using the anemometer to measure the air velocity and volume flow, the rate of air speed at each phase of the speed blower fan is determined.

Once the setup is ready, the car is placed at a suitable area in the workshop where the temperature is at 28 °C ± 1. The experiment is run between 9.00 am and 10.00 am in the workshop. The temperature measured at that particular workshop area around this time ranged between 27 and 29 °C.

Data for this experiment is recorded once the temperature is measured at 28 °C and this is to ensure stable environment temperature readings as referred to ASHRAE readings. Therefore, the initial temperature inside the car's cabin is the same for each phase of experiment. Data collection carried out for after 1 h engine run and ended as soon as it reached 1 h.

Fig. 6 Comfort zones for
summer and winter
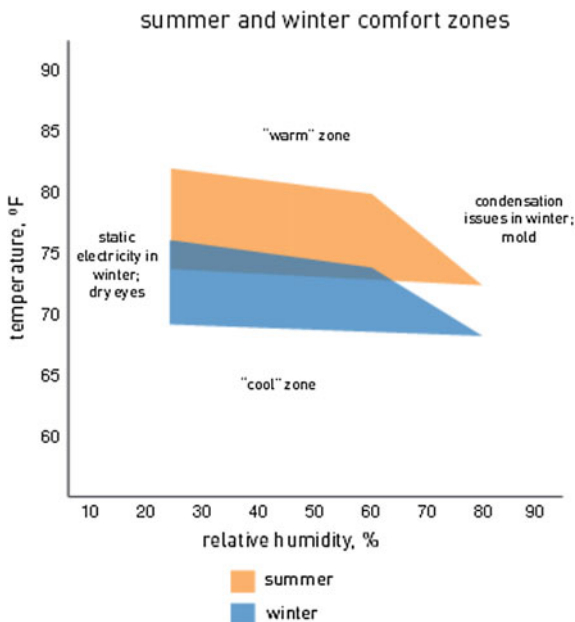
All collected and recorded data are presented in the data collection form. Every speed run is recorded in a single form. The data logger also recorded the temperature, humidity and CO_2. Simultaneously, the fuel consumption is obtained using a measuring cylinder. After the experiment ended, the measuring cylinder is used to measure the remaining fuel. This amount is deducted from the initial 5 L in order to obtain the consumed fuel.

Results are then plotted in a graph. From the plotted graph, select the mode, which is most fuel-efficient, and at the same time car's cabin reading as most comfortable. Refer to Fig. 6 for the determination criteria that this research referred to.

3   Results and Discussion

In regards to the results and discussions of the experiment, it is mainly about the effect of the thermostat level setting on the fuel consumption. As the thermostat level knob in this vehicle is not marked with the temperatures, it is assumed that this vehicle is not equipped with an automatic climate control system.

Thus, the thermostat level is believed to indicate the temperature of air supplied to the cabin from the air-conditioning system (which remains fixed without taking the cabin temperature into consideration), and not the temperature of the cabin itself. Such, the decision of the vehicle maker to omit the temperature marking is

understandable as any marking will make the passenger think that the air-conditioning system is trying to regulate the cabin temperature as per the displayed temperature marking, which is not true.

## 3.1 Experiment of Low Fan Speed Performance

The highest temperature as shown in Fig. 7 is 26.16 °C whereas the lowest temperature is at 23.88 °C when the experiment is running at Mode 4. This experiment runs for a span of 5 min or 300 s. The data was not stable in Mode 3 and Mode 4. To overcome this problem, assumptions were made to set these two modes higher than Mode 1 and Mode 2. However, after running the experiment for 1 h, these two modes were still not stable.

To discuss the instability at Mode 3 and Mode 4, it is concluded that a higher heat transfer was needed to decrease the cabin's temperature, thus, longer time recorded. This has resulted in the need that the compressor continuously compresses within the period of experiment. When this happens, extra load is applied on the engine by the compressor and as a result of this, more fuel is consumed.

The graph in Fig. 8 shows how the relative humidity is plotted against time. The highest humidity indicated in this graph is 52.875% at Mode 4 and the lowest temperature is 38.784% at Mode 2. The thermal comfort sensation is optimal when the relative humidity value is about 50% [9]. The ASHRAE guidelines recommend a relative humidity (RH) of 30–60% from *ANSI/ASHRAE Standard 55*, 2010. Through the experiment, data has shown that Mode 1 is the most comfortable because the value of the relative humidity falls in the range of 50–55%. Figure 9 shows that the total CO_2 at Mode 1 and Mode 2 is higher than at Mode 3 and Mode 4.

However, the CO_2 amount is still considered in stable condition. The best starting condition of CO_2 is at Mode 3 because it recorded the lowest reading for the fan speed level. But then again, it is also important to bear in mind, that this data was recorded in a situation whereby there is not a driver or passengers in the car's cabin. It is definitely needed to acknowledge that the effect of CO_2 at this very low
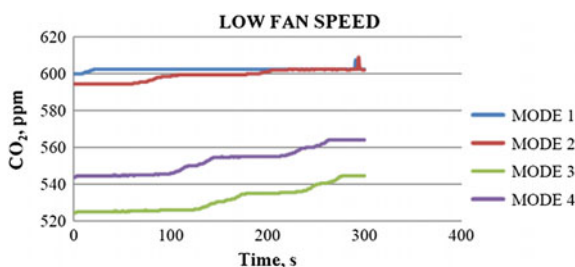

Fig. 7 Graph showing temperature versus time at low fan speed condition
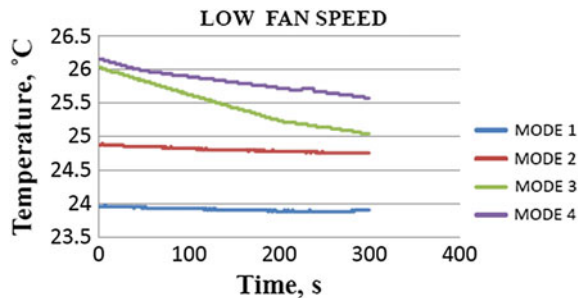
Fig. 8 Graph relative
humidity versus time at low
fan speed condition
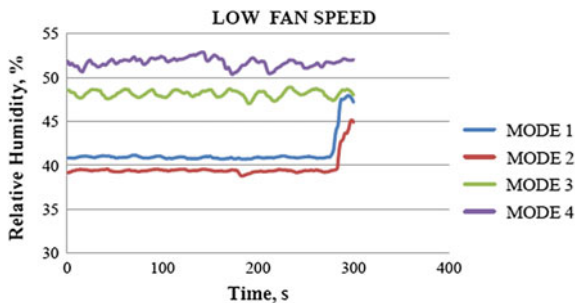
Fig. 9 Graph CO_2 versus
time at low fan speed
condition

Table 1 The average result for low blower fan in last 5 min data

	Temperature (°C)	Relative humidity (%)	CO_2 (ppm)	Fuel consumption (mL)
Mode 1	23.91	41.30	602	1825
Mode 2	24.75	39.61	599	1770
Mode 3	25.43	48.16	532	1655
Mode 4	25.67	51.72	553	1220

level is also due to non-contributing human factor. The CO_2 is influenced by the air
recirculation. The air re-circulation must contain fresh air to reduce the CO_2.

Table 1 presents the average data result collected and recorded for 5 min for low
blower fan speed. The parameters shown recorded are temperature, relative
humidity, CO_2 emission and fuel consumption. Filling the external tank with 5 L of
fuel is used to test the fuel consumption. After running the experiment for 1 h, the
amount of remaining fuel is measured. The total of fuel consumption is calculated
by deducting the amount of fuel left to the initial 5 L of fuel.

Table 2 The average result for medium blower fan in last 5 min data

	Temperature (°C)	Relative humidity (%)	CO_2 (ppm)	Fuel consumption (mL)
Mode 1	18.5	47.31	650	1660
Mode 2	20.53	50.19	637	1605
Mode 3	22.67	50.14	600	1550
Mode 4	23.4	51.16	602	1440

3.2 The Experiment of Medium Fan Speed Performance

Table 2 presents the average result data in the last 5 min for medium blower fan speed. The parameter shown here are the temperature, relative humidity, CO_2 and fuel consumption.

3.3 Fuel Consumption for Two Different Types of Blower Fan Speed

Figure 10 shows the fuel consumption when two different blower fan speeds are implemented. At Mode 4 for the low blower fan speed, it recorded the lowest fuel consumption at 1220 L. The highest fuel consumption is at Mode 1, for the low blower fan speed with a total of 1825 mL of fuel.

3.4 Temperature History and Fuel Usage During Total Experiment Time (1 h) of Low Blower Fan Speed

At the beginning of the graph in Fig. 11, all modes started at the initial temperature of 28 °C. For this research, the temperature reached the comfort zone at 26 °C when applying Mode 1 in the shortest time i.e. at 1000 s. At that time, the recorded fuel consumption was 550 mL. While Mode 2 was only able to reach the same temperature after 2000 s the air-conditioning turned on. The fuel used was 1000 mL. Mode 3 and Mode 4 were able to reach the comfort zone at 26 °C over 3500 s after the air conditioning was turned on.

However, the lowest fuel consumption is at Mode 4. The temperature at the time was 25.186 °C. This situation is still within the comfort zone. Although the fuel consumption was at its lowest but to reach the comfort zone system, it has actually taken a longer time compared to other modes.

The fastest mode to achieve a comfort level was when applying Mode 1; at 1000 s. Therefore, it is suggested that, this mode is used as an option for the user to achieve faster comfort in a car. But then again, the fuel consumption is still high at this stage recording at 1825 mL of fuel consumed.

Fig. 10 Graph fuel versus mode for two different type of blower fan speed
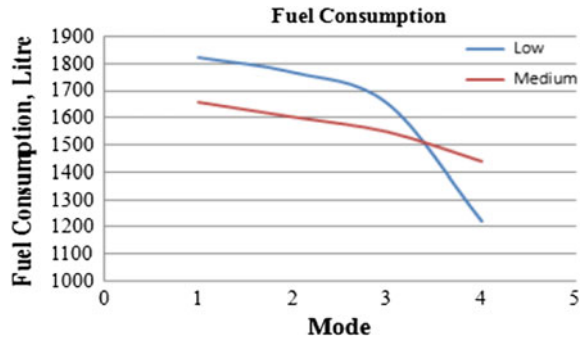
Fig. 11 Temperature and fuel total versus time for low blower fan speed
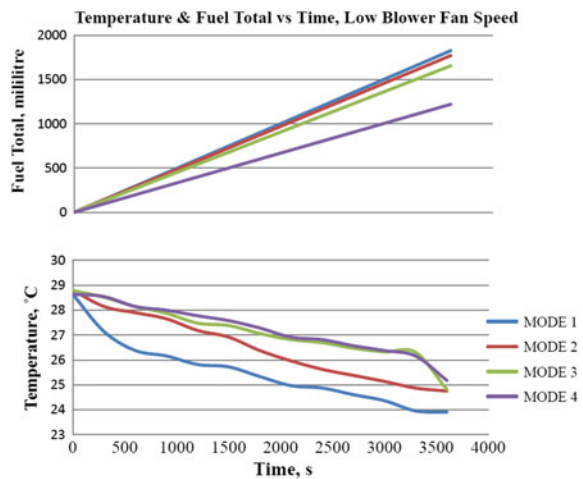
Through the analysis, the user can also reduce the fuel consumption with multiple choice modes. The first option is applying Mode 1. This is because the Mode 1 is able to achieve the level of comfort the fastest. The next selection mode is Mode 2; when the temperature reaches 25 °C at 2000 s. At this point, the fuel consumption was amounted to 1000 mL.

When combined, these modes gave a more efficient result. It is suggested that, first starts the thermostat at Mode 2 for the first 2000 s until 3300 s and then change to mode 4. Total fuel consumption while in Mode 2 amounted to 600 mL at the changed situation, the temperature at Mode 2 recorded at 24.7 °C. At the same time the temperature at the start of Mode 4 was 26 °C, it remained until 3600 s, and the total fuel consumption at Mode 4 amounted to 120 mL. So, the total amount of fuel with diversifies selection mode was recorded and calculated at 1720 mL.

It is more economical for fuel consumption for Mode 1 and Mode 2 but higher for Mode 3 and Mode 4. Therefore, the choice in this range can accelerate the level of comfort achieved and at the same time reduce the fuel consumption.

3.5 Temperature History and Fuel Usage During Total Experiment Time (1 h) of Low Blower Fan Speed

In Fig. 12, the lowest fuel consumption is at Mode 4 with an amount of 1440 mL and a temperature at 23 °C. But at this point the comfort temperature is within the range of 22–26 °C and it is achieved in 1250 s. The fastest mode to reach the comfort temperature of 26 °C is Mode 1. In this mode the fuel consumption is 100 mL. Mode 4 at medium blower fan speed achieved the level of comfort at a faster rate compared to Mode 1 at low blower fan speed.

However, the temperature at Mode 1 as in Fig. 12 shows that it is not within the comfort zone. The temperature ranged from 21 to 18.438 °C at Mode 1 started from 1200 to 3600 s. The temperature in this range is considered to be too cold. Figure 12 shows that Mode 3 achieved the comfort zone because the temperature recorded at that point read 22.011 °C.

From the graph itself, Mode 3 and Mode 4 are selected because they are in the comfort zone. If selections are made with diversify selection modes, then Mode 1 is selected first. Mode 1 reached the level of comfort at 26 °C with a fuel consumption at 100 mL running for 700 s. When Mode 2 reached 26 °C, the thermostat is changed from Mode 1 to Mode 2. The fuel consumption at Mode 2 is 100 mL. Change the thermostat to Mode 3 when it reached a temperature reading of 26 °C. Use Mode 3 for 300 s then switch to Mode 4. For 300 s in Mode 3 only 200 mL fuel was consume. The use of Mode 4 is the longest set point caused of fuel savings going on here. Mode 4 begins at 1300 s and ended at 3600 s, calculated 2300 s used in this mode. Temperature for Mode 4 at 3600 s is 23.016 °C. The fuel that has been used at this mode is 940 mL.

Fig. 12 Temperature and fuel total versus time for low blower fan speed
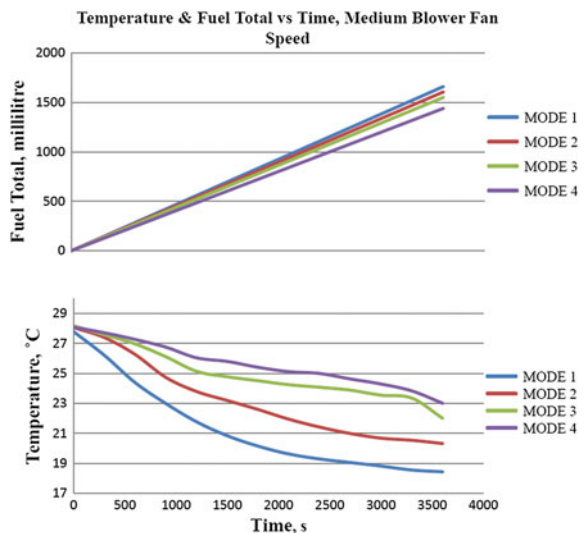
So, the total amount of fuel with diversifies selection modes was 1540 mL. Definitely the fuel consumption is more economical for Mode 1, Mode 2 and Mode 3 but higher than Mode 4. Therefore the choice in this range can accelerate the level of comfort achieved and at the same time reduce the fuel consumption.

4 Conclusion

This study shows that changing the thermostat level can reduce the fuel consumption. Through data collection and recording, it has been analyzed and discussed that for reducing the fuel consumption, Mode 4 working on the low blower fan speed proved to be the most fuel saving run. The fuel consumed amounted to a mere 1220 mL. The savings earned compared to the highest oil consumption stood at 605 mL. Besides saving fuel, it is also in this mode that the condition of temperature and humidity in the car's cabin were found to be most comfortable. Recorded temperature was 25.83 °C, relative humidity 51.72% and CO_2 is 553 ppm. The selected mode is at mode 4 with low blower fan speed.

In addition to the objective achieved, a choice can also be made to diversify the selection mode. Selection of this mode is to speed up the comfort ability achieved. This situation has been selected by not taking into account the minimum fuel consumption. From experiments made as analyzed and discussed before, at the early stages of Mode 1 on moderate selected fan speed blower until 1200 s; temperature recorded was 22 °C. Right after this, select Mode 2 at medium fan speed blower until 2000 s. At this point the temperature was between 24 °C down to 22 °C. Then, the next selected mode is Mode 3 and Mode 4 at medium blower fan speed or Mode 1 and Mode 2 at low blower fan speed.

It is suggested that this selection/option be used as a last resort; because until 3600 s the situation of temperature is still within the comfortable circumstances. In addition to this, the user can also decide to select Mode 4 at low blower fan speed starting from 3000 s because the use of this mode proved to save fuel but remain and maintain the comfort level.

References

1. Oleesen, B., Brager, G.: A better way to predict comfort: the new ASHRAE standard 55-2004. ASHRAE J. **46**, 20–26 (2004)
2. Mezrhab, A., Bouzidi, M.: Computation of thermal comfort inside a passenger car compartment. Appl. Therm. Eng. **26**(14–15), 1697–1704 (2006)

3. Tenberge, P., Baumgart, R.: Reducing the fuel consumption by optimizing the air conditioning system. In: International Refrigeration and Air Conditioning Conference, vol. 1058. Retrieved from http://docs.lib.purdue.edu/iracc (2010)
4. Johnson, V.H.: Fuel used for vehicle air conditioning: a state-by-state thermal comfort-based approach. SAE Technical Paper (2002)
5. Han, T., Huang, L.: A sensitivity study of occupant thermal comfort in a cabin using virtual thermal comfort engineering. SAE Technical Paper. Reprinted from Climate Control, 724, 2005. (Paper Series)
6. Farzaneh, Y., Tootoonchi, A.A.: Controlling automobile thermal comfort using optimized fuzzy controller. Appl. Therm. Eng. **28**(14–15), 1906–1917 (2008)
7. Sahril, M., Fouzi, M., Othoman, A.M., Sulaiman, S.A.: Effect of recirculation on air quality in a car compartment. Aust. J. Basic Appl. Sci. **8**(4), 466–470 (2014) (Special 2014)
8. Neacsu, C., Ivanescu, M., Tabacu, I.: The influence of the solar radiation on the interior temperature of the car. ESFA 2009, Bucuresti **1**, 173–182 (2009)
9. Musat, R., Helerea, E.: Parameters and models of the vehicle thermal comfort. Acta Univ. Sapientiae, Electr. Mech. Eng. **1**, 215–226 (2009)
10. Boduch, M., Fincher, W.: Standards of Human Comfort. The University of Texas at Austin, School of Architecture, Texas (2009)