Performance of SIMC Based PID Controller for Automobile Vehicle Temperature

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Abstract— Thermal comfort in vehicles was highly regarded as one of the most important factors when vehicular thermal environments were designed. These gives a subjective sensation of heat balance that occurs in the human body when environmental parameters such as air temperature, air humidity, radiant temperature, air velocity, human level activity, and clothing insulation are in a range of well-defined values However, the temperature rise in the automobiles during the parking on sunny days creates uncomfortable feelings for the passengers. The use of conventional techniques suffered inefficient and non-lasting solution to the heat generated within the cabin walls. Hence, a Simple Internal Model Control based Proportional Integral Derivative (SIMC-PID) controller for automobile vehicle temperature and the mathematical model of automobile cabin temperature was adopted based on energy conservation and mass balance principles. The SIMC-PID controller was employed in controlling the cabin temperature model and the conventional tuning methods such as Zeigler-Nichols, Cohen-Coon and Chien-Hrones-Reswick was compared. Results of the proposed model perform better when compared with existing models.

Index Terms— Auto-tuned PID Controller, Automobile Vehicle, MATLAB-Simulink, Temperature control performance, Temperature, Automobile, Heat

1 Introduction

THE thermal comfort of occupants in vehicles has become more important due to their increased mobility, leading to more time spent by people inside the vehicles [1][2]. Vehicles parked under the daylight experience sharp rise in the cabin temperature due to the trapped solar radiation [3]. It's often seen that, vehicles which are parked in the sun especially during hot summer day, experience drastic rise in the cabin temperature especially, the steering wheel, seats, dashboards record temperature. Vehicle Heating Ventilation and Air Conditioning system as known to be a technology for indoor and automotive ambient comfort, obtains the desired interior environment by introducing the cooled/heated/dried air into the cab air through the system's outlets [4]. Passengers are also being affected with the thermal condition inside the vehicle itself. More often it is observed, that the passengers and drivers are forced to wait for a period of time around 2-5 minutes before getting into the car to cool down the interior condition either by rolling down the windows or running the air conditioner at high speed that which will results in higher fuel consumption. Therefore, this paper brings the possibility of adaptive an accurate mathematical Heating Ventilation Air Condition (HVAC) model for the necessity, subjectivity of thermal comfort and intelligent control systems are proposed for the strategies for achieving superior results in HVAC applications. With the rate of energy use in thermal comfort, the air conditioning system needs to be controlled in order to save energy use and fuel consumption in driving which would create a better performance. In this paper, a method combining the simplicity, adaptability, and flexibility of Simple Internal Model Control with the mathematical precision of the Proportional Integral Derivative controller (SIMC-PID) for the automotive vehicle air conditioning system was adopted. The significant factor of applying the SIMC-PID controller for an automotive vehicle air conditioning system is to give a satisfactory control performance under different operating conditions.
The remainder of this paper is organized as follows: Section 2 presents the system description. Section 3, presents the mathematical modeling equations, Section 4, presents simulation results and discussion, Section 5 presents the conclusion and future recommendation.2 Procedure for Paper Submission

2 System Description

Heating Ventilation Air Conditioning system is a complex, nonlinear, multi-input multi-output (MIMO) system with interrelated variables of air temperature, relative humidity and air velocity that exposed to various and uncertainties disturbances such as external air temperature and occupant's activities. Air conditioning system has many dynamical variables and a typical nonlinear time variable with disturbances and uncertainties that comprises of humidification, ventilation and heating process [5]. Ventilation is the process where clean air normally outdoor air is intentionally provided to space and stale air is removed; it can be accomplished by either natural or mechanical means. The automobile ventilation system is used to keep the passenger compartment at a comfortable temperature [6].
The comfort control can be achieved by the desired air temperature in an automobile, also maintaining the desired level of absolute humidity, air pressure, radiant energy, carbon dioxide concentration as well as windscreen surface temperature for the fog detection [7]. HVAC application is designed to deliver low energy cost, low maintenance, high efficiency opera-

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tion and good comfort performance. Based on the survey, the consumption of energy in the automobile HVAC system is very high and thus needs to be minimized as a major parameter in all automobiles in order to gives a satisfactory control performance. The present aims is to optimize the HVAC in achieving the desired temperature in a building via maintaining the desired level of humidity, pressure, radiant energy, air motion, and air quality using Internal Model Control Proportional Integral Derivative controller. PID controller has optimum dynamics control as well as impressive properties due to its simplicity, clear functionality, reliability and applicability to linear system, reduce steady state error, fast response, easy to implement, no oscillations, higher stability and robust performance [8][9].

2.1 System Modeling

The purpose of air condition is to alter the properties of air such as primarily temperature and humidity to more comfortable conditions via distributes the conditioned air to an occupied space to improve thermal comfort and indoor air quality. The cooling is typically achieved through a refrigeration cycle [9]. The two major types of A/C mostly used in automobile vehicles are Receiver Drier Thermostatic valve (RD-TXV) and Accumulator drier – Orifice Tube (AD-OT) which are the components and system of a typical modern air conditioning system. The full compartment of the air conditioning system is shown in Figure 1 which comprises of four major component; compressor, condenser, evaporator, pressure-regulating devices, and thermal expansion valve [10].

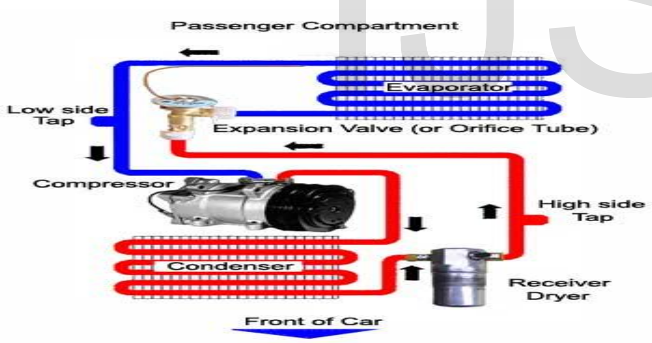

Fig. 1: Full compartment of an Air Condition

Compressor: This is the heart of the system. It is responsible for compressing and transferring refrigerant gas, also it is a belt-driven pump that is fastened to the engine.
Condenser: This is the area in which heat dissipation occurs. The condenser is designed to radiate heat and mostly located in front of the radiator to deliver good airflow anytime the system is in operation.
Evaporator: Evaporator serves as the heat absorption component located inside the vehicles. Its primary duty is to remove heat inside the vehicle and its secondary benefit is to dehumidify.
Pressure-regulating devices: Controlling the evaporator temperature can be accomplished by controlling the refrigerant pressure that flows during the evaporator. A pressure regulator is a valve that controls the pressure of a fluid or gas to a desired value.
Thermal expansion valve: Thermal expansion valve senses both temperature and pressure and is very efficient at regulating refrigerant flow to the evaporator [11].

3 THE SUGGESTED MATHEMATICAL MODEL OF HVAC

According to the first law of thermodynamics, the cooling capacity of the experimental vehicle air conditioning system can be related to the heat taken from the air stream passing through the evaporator as given in equation 1:

$$Q_{evap} = m_a\left[\left(h_a + \omega h_g\right)B - \left(h_a + \omega h_g\right)C\right] - m_a\left[\left(w_B - w_C\right)h_f\right] \quad (1)$$

The cooling capacity is a function of the air mass flow rate, specific enthalpies of the moisture at the inlet and outlet of the evaporator, and enthalpy of the condensate leaving the evaporator.
The modeling of the cabin temperature was considered to involve three heat transfer methods namely; Conduction, Convection and Radiation of heat around the system. The cabin temperature is determined by the total amount of heat stored in the cabin air at time *t* and is given as:

$$Q_{cab} = \int \left(\dot{Q}_{HVAC}(\tau) + \dot{Q}_{ATA}(\tau) + \dot{Q}_{loss}(\tau) + \dot{Q}_{walls}(\tau) + \dot{Q}_{eng}(\tau)\, d\tau\right) \quad (2)$$

Where $\dot{Q}_{eng}$ is the heat transfer coefficient between the engine compartment, $\dot{Q}_{walls}$Is the heat coefficient of the cabin walls, $\dot{Q}_{loss}$ is the heat flow through the cabin wall, $\dot{Q}_{HVAC}$ is the total heat stored in the cabin wall, $\dot{Q}_{ATA}$ is the quantity of the heating power generated.
It should be noted that the cabin temperature is determined by the heat stored in the cabin walls and is considered as a contributor to the cabin air temperature dynamics. The heat stored in the cabin is made up of five constituent heats as presented in equation (2) and each of the constituent heat is modeled in equations (3) to (6)

$$\dot{Q}_{HVAC} = \dot{m}_{HVAC}(T_{HVAC} - T_{cab}) \quad (3)$$

$$\dot{Q}_{ATA} = \dot{m}_{ATA}(T_{ATA} - T_{cab}) \quad (4)$$

$$\dot{Q}_{loss} = (\alpha + \beta \upsilon)\sigma_{cab} C_{p,air}(T_{out} - T_{cab}) \quad (5)$$

$$\dot{Q}_{eng} = C_{p,air}\sigma_{eng}(T_{eng} - T_{cab}) \quad (6)$$

T_{eng} is the temperature in the engine compartment.

$$Q_{wall} = C_{p,air}\left(\sigma_{in} T_{cab} + \sigma_{out} T_{out} + T_{wall}(-\sigma_{in} - \sigma_{out})\right) \quad (7)$$

Differentiating equation 4 and substituting for equations 3 to 7 yields 8

$$m_{cab}\dot{T}_{cab} = \dot{m}_{HVAC}(T_{HVAC} - T_{cab}) + \dot{m}_{ATA}(T_{ATA} - T_{cab}) + f(v)\sigma_{cab}(T_{out} - T_{cab}) + (\sigma_{in} + \sigma_{out})T_{walls} - \sigma_{in} T_{cab} - \sigma_{out} T_{out} + \sigma_{eng}(T_{eng} - T_{cab}) \quad (8)$$

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Re arranging equations (8), we have

$$\dot{T}_{cab} = -\frac{\dot{m}_{HVAC} + \dot{m}_{ATA} + f(v)\sigma_{cab} + \sigma_{in} + \sigma_{eng}}{m_{cab}} + T_{cab}\frac{\sigma_{in} + \sigma_{out}}{m_{cab}} + T_{walls} + \frac{\dot{m}_{HVAC}T_{HVAC} + \dot{m}_{ATA}T_{ATA} + f(v)\sigma_{cab}T_{out} - \sigma_{out}T_{out} + \sigma_{eng}T_{eng}}{m_{cab}} \quad (9)$$

The equations 8 and 9 can be combined to form a system of matrix as shown, in 10

$$\begin{pmatrix} \dot{T}_{cab} \\ \dot{T}_{walls} \end{pmatrix} = -\frac{1}{m_{cab}}\begin{bmatrix} \dot{m}_{HVAC} + \dot{m}_{ATA} + f(v)\sigma_{cab} + \sigma_{in} + \sigma_{eng} & -(\sigma_{in} + \sigma_{out}) \\ -\sigma_{in}m_{cab} & (\sigma_{in} + \sigma_{out})m_{cab} \end{bmatrix}\begin{pmatrix} T_{cab} \\ T_{walls} \end{pmatrix} + \frac{1}{m_{cab}}\begin{bmatrix} \dot{m}_{HVAC}T_{HVAC} + \dot{m}_{ATA}T_{ATA} + f(v)\sigma_{cab}T_{out} - \sigma_{out}T_{out} + \sigma_{eng}T_{eng} \\ \sigma_{out}T_{out}m_{cab} \end{bmatrix} \quad (10)$$

From equation (9)

Let $$Y = \begin{pmatrix} \dot{T}_{cab} \\ \dot{T}_{walls} \end{pmatrix}, X = m_{cab}, \quad (11)$$

$$A = \begin{bmatrix} \dot{m}_{HVAC} + \dot{m}_{ATA} + f(v)\sigma_{cab} + \sigma_{in} + \sigma_{eng} & -(\sigma_{in} + \sigma_{out}) \\ -\sigma_{in}m_{cab} & (\sigma_{in} + \sigma_{out})m_{cab} \end{bmatrix} \quad (12)$$

$$B = \begin{bmatrix} \dot{m}_{HVAC}T_{HVAC} + \dot{m}_{ATA}T_{ATA} + f(v)\sigma_{cab}T_{out} - \sigma_{out}T_{out} + \sigma_{eng}T_{eng} \\ \sigma_{out}T_{out}m_{cab} \end{bmatrix} \quad \mathbf{(13)}$$

Therefore, equations (9) and (10) can be written in a matrix form to give equation (14).

$$Y = \frac{1}{X}[A]Y + \frac{1}{X}[B] \quad (14)$$

By factorizing Y in equation (10), equation (14) which represents the transfer function of the cabin and the cabin wall temperature is derived

$$\mathbf{Y} = \frac{\mathbf{[B]}}{\mathbf{[A]-X}} \quad (15)$$

3.1 Proposed System Vehicle Temperature Model

The system model of Vehicle Temperature Control Using SIMC-PID Controller is presented in Figure 2. The Internal model control based proportional integral derivative was adopted to achieve the desired temperature for a better cabin temperature control system that enhances driving performance. The desired temperature was set at 30ºC and 40ºC sense with the temperature sensor, the comparator compares the atmospheric temperature with the vehicle temperature. The data signals from the sensors were sent into the SIMC-PID controller for regulation, simulation, and interpretation. The controlled signal regulates the temperature with respect to atmospheric conditions. The combination of the SIMC-PID controller enabled the vehicle temperature to reach a predetermined set point in the shortest time.

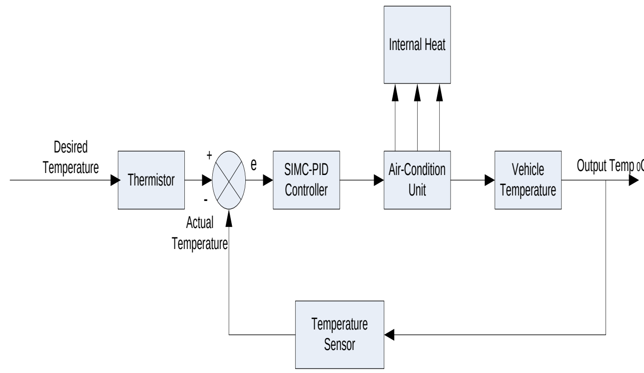

Fig. 2: Model for Vehicle Temperature Control Using SIMC-PID Controller

4. SIMULATION RESULTS AND DISCUSSION

The MATLAB/Simulink package model that shows the essential steps taken in this research of Vehicle Temperature Control Using SIMC-PID Controller is as shown in Figure 3 respectively.

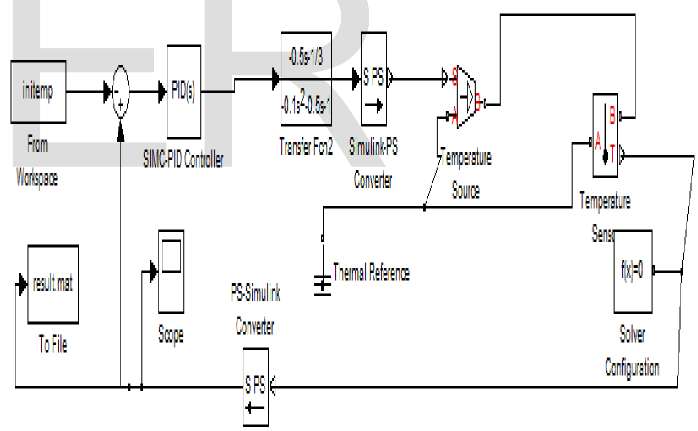

Fig. 3: The Simulink Model of Vehicle Temperature Control Using SIMC-PID

The results obtained showed the effectiveness and better performance of automotive vehicle temperature 40ºC in terms of rise time, settling time and percentage overshoot using SIMC-PID controller and with other tuning controllers Cohen-Coon-PID, Chien-Hrones-Reswick-PID and Ziegler-Nichols-PID. The Figure 4 shows the performance of the temperature control of the automobile vehicle using Cohen-Coon. The rise time is 0.90sec and the time required for the steady-state responses to settle within the certain overshoot percentage of 33.3% to its final value was 30sec at a temperature of 40ºC. Figure 5 shows the performance of the temperature control of the automobile vehicle using Chien-reswick. The rise time was 0.60sec via the time taken for the system responses to reach the steady-state val-

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ue was 28sec within a certain percentage overshoot of 20.5% at a temperature of 40ºC. Figure 6 indicates the performance of the temperature control of the automobile vehicle using Ziegler Nichols. The rise time was 0.30sec and at a temperature of 40ºC, the time required for the steady-state responses to settle within the certain overshoot percentage of 13.3% to its final value was 25sec. Figure 7 indicates the performance of the temperature control of the automobile vehicle using SIMC-PID. The rise time was 0.10sec and at a temperature of 40ºC, the time required for the steady-state responses to settle within the certain overshoot percentage of 10.2% to its final value was 21sec.

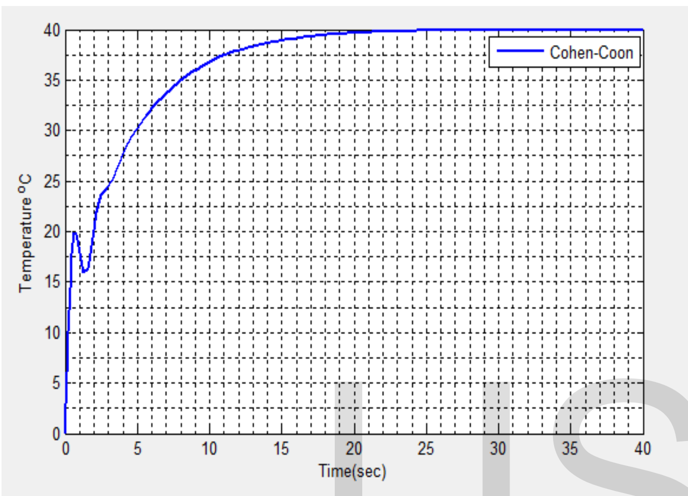

Fig. 4: Automobile Vehicle Temperature Control using Cohen-Coon of 40ºC

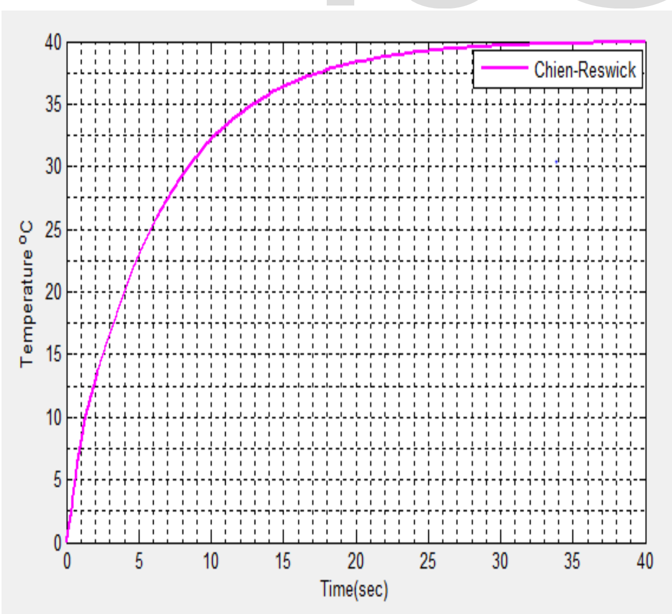

Fig. 5: Automobile Vehicle Temperature Control using Chien-Reswick of 40ºC

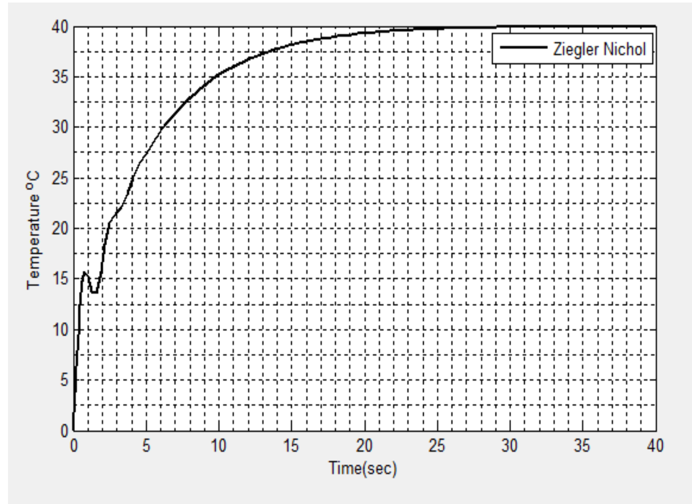

Figure 6: Automobile Vehicle Temperature Control using Ziegler-Nichols of 40ºC

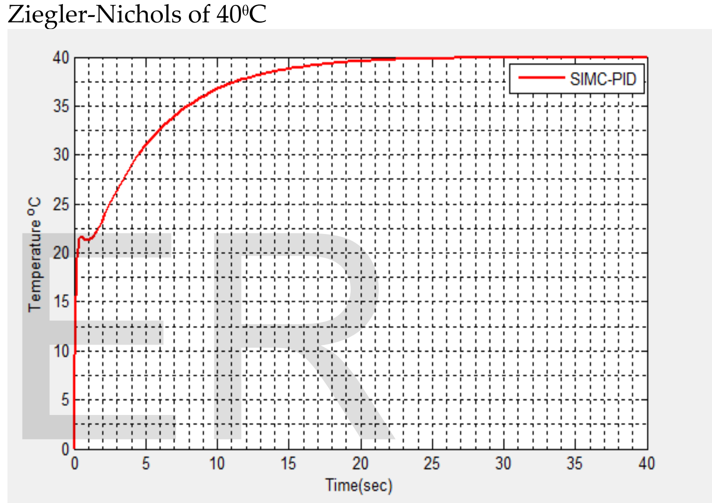

Fig. 6: Automobile Vehicle Temperature Control using Ziegler-Nichols of 40ºC

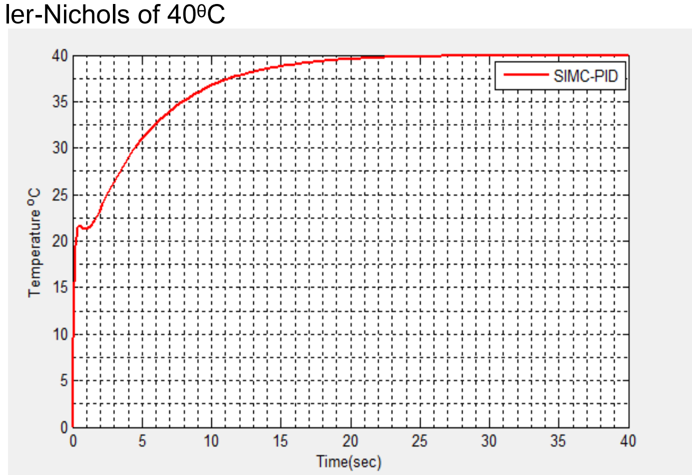

Fig. 7: Automobile Vehicle Temperature Control using SIMC-PID of 40ºC

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Figure 8 showed the comparison performances of Cohen-Coon-PID, Chien-Hrones-Reswick-PID, Ziegler-Nichols-PID and SIMC-PID controller for automobile vehicle temperature control. The desired temperature was set to 40⁰C which falls within the thermal zone respect with the vehicle humidity in terms of rise time, settling time and overshoot percentage as shown in Table 1. This reflects the superior performance of the SIMC PID over other investigated controllers.

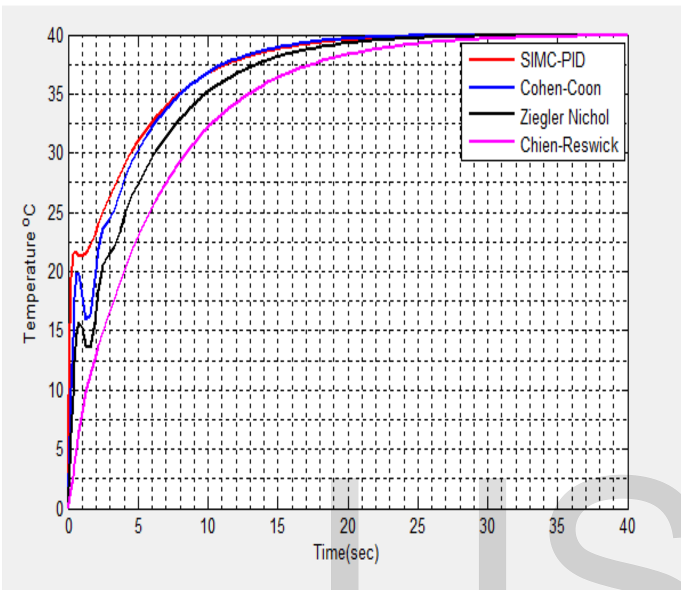

Figure 8: The Comparison of Cohen-Coon, Chien-Reswick, Ziegler Nichols and SIMC-PID for Automobile Vehicle Temperature Control of 0⁰C to 40⁰C

Table 1: Cohen-Coon, Chien-Reswick, Ziegler Nichols and SIMC-PID for Automobile Vehicle Temperature Control of 0⁰C to 40⁰C

Controllers	Rise Time (sec)	Settling Time (sec)	Overshoot (%)
Cohen-Coon-PID	0.90	30.0	33.3
Chien-Hrones-Reswick-PID	0.60	28.0	20.5
Ziegler-Nichols-PID	0.30	25.0	13.3
SIMC-PID	0.10	21.0	10.2

Figure 9 showed the comparison performances of Cohen-Coon-PID, Chien-Hrones-Reswick-PID, Ziegler-Nichols-PID and SIMC-PID controller for automobile vehicle temperature control. The desired temperature was set to 30⁰C which falls within the thermal zone respect with the vehicle humidity in terms of rise time, settling time and overshoot percentage as shown in Table 2. This reflects the superior performance of the SIMC PID over other investigated controllers.

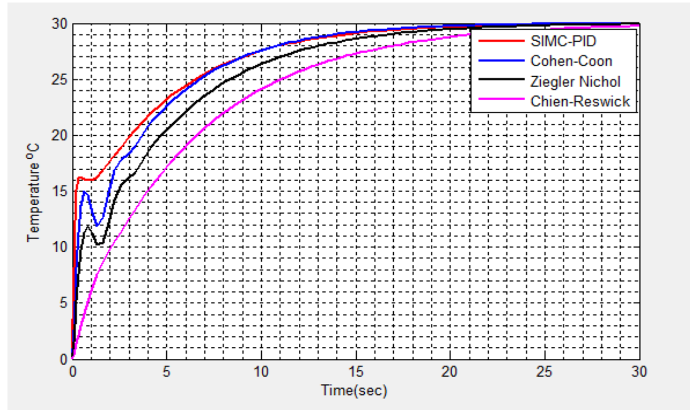

Figure 9: The Comparison of Cohen-Coon, Chien-Reswick, Ziegler Nichols and SIMC-PID for Automobile Vehicle Temperature Control of 0⁰C to 30⁰C

Table 2: Cohen-Coon, Chien-Reswick, Ziegler Nichols and SIMC-PID for Automobile Vehicle Temperature Control of 0⁰C to 30⁰C

Controllers	Rise Time (sec)	Settling Time (Sec)	Overshoot (%)
Cohen-Coon-PID	0.60	28.0	24.5
Chien-Hrones-Reswick-PID	0.40	27.0	19.5
Ziegler-Nichols-PID	0.20	24.0	13.1
SIMC-PID	0.10	19.0	10.1

5 Conclusion

The performance of Cohen-Coon-PID, Chien-Hrones-Reswick-PID, Ziegler-Nichols-PID and SIMC-PID for temperature control of automobile vehicle used by heating ventilation and air conditioning engineers to design more efficient air conditioning systems for different applications such as the cabin temperature control technique that aids better driving performance based on a good rise time, percentages overshoot and settling time on the cabin temperature so as to reduce the heating loss of energy and fuel consumption were investigated in this paper. The results of the simulation showed that SIMC-PID controller demonstrated a superior performance over other controllers investigated based on the performance metrics used.

References

[1] Paul D, Andreea V, Angel D, An overview of current methods for thermal comfort assessment in vehicle cabin; Sustainable Solutions for Energy and Environment, EENVIRO - YRC 2015, 18-20 November 2015, Bucharest, Romania, https://doi.org/10.1016/j.egypro.2015.12.322.

[2] Clements-Croome, D. J. Environmental quality and the productive workplace. In: Anumba, C. J. (ed.) Innovative Developments in Architecture, Engineering and Contruc-

tion. Millpress Science Publishers, Rotterdam, pp. 335-341. Edinburgh, Scotland, 24-26 September 2003.

[3] Garrett J. Marshalla, Colin P. Mahonya, Matthew J. Rhodesa, Steve R. Daniewiczb, Nicholas Tsolasc, Scott M. Thompsonc (2019) "Thermal Management of Vehicle Cabins, External Surfaces, and OnboardElectronics: An Overview".

[4] Arens E, Zhang H, Huizenga C., Partial- and whole-body thermal sensation and comfort. Part I and II, Journal of Thermal Biology 31, 2006, pp. 53 – 66. DOI: 10.1016/j.jtherbio.2005.11.028

[5] Dounis, A.I. and C. Caraiscos (2009), Advanced control systems engineering for energy and comfort management in a building environment-A review. Renewable and Sustainable Energy Reviews,13(6-7): p. 1246-1261.

[6] Mir Munawar Ali et al., (2014), "International Journal of Modern Engineering Research (IJMER) | IJMER | ISSN: 2249–6645 | www.ijmer.com| Vol. 4 | Iss.9| Sept. 2014 | 24

[7] Swenson, S. D. (1995), "HVAC: Heating, Ventilating, and Air Conditioning". Homewood, Illinois: American Technical Publishers.

[8] Sangram K. and Mehetab A. (2011), "Design and Tuning Method of PID Controller Based on Fuzzy Logic and Genetic Algorithm" vol.3, no.5, pp.65.

[9] Anderson, M., Young P., Hittle D., Anderson C. and Hodgson D. (2002), MIMO robust control for Heating, Ventilating and Air Conditioning (HVAC) systems. Proceeding of the 41st IEEE Conference on Decision and Control, Las Vegas, Nevada, USA, pp: 167-172.

[10] Farrington R, Rugh J. "Impact of vehicle air-conditioning on fuel economy, tailpipe emissions, and electric vehicle range". In: Proceedings of the Earth Technologies Forum; 2000 Oct 31; Washington, DC, USA.

[11] Reddy, V.R., Ravikumar A.S. and Shah R.K.(2006), Recent Technology Developments in Automotive Air- Conditioning Evaporators, Proceedings of 7th ISHMT-ASME Heat and Mass Transfer Conference, pp.1088-1095.