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VEHICLE AIR CONDITIONER (VAC) CONTROL SYSTEM BASED ON PASSENGER COMFORT: A PROOF OF CONCEPT

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ABSTRACT: The air conditioning system (AC) in passenger cars requires precise control to provide a comfortable and healthy driving. In an AC system with limited manual control, the driver has to repeatedly change the setting to improve comfort. This problem may be overcome by implementing an automatic control system to maintain cabin temperature and humidity to meet passenger's thermal comfort. Therefore, this paper presents the development of a laboratory-scale prototype air conditioning control system to regulate temperature, humidity and air circulation in the cabin. The experimental results show that the control system is able to control air temperature in the range of 21 °C to 23 °C and cabin air humidity between 40% to 60% in various simulated environmental conditions which indicate acceptance for comfort and health standards in the vehicle. In conclusion, this method can be applied to older vehicles with reasonable modifications.

ABSTRAK: Sistem penyejuk udara (AC) pada kenderaan penumpang memerlukan ketepatan kawalan bagi menyediakan keselesaan dan kesejahteraan pemanduan. Melalui sistem AC dengan kawalan manual terhad, pemandu perlu berulang kali mengubah penyesuaian latar bagi meningkatkan keselesaan. Masalah ini dapat diatasi dengan menerapkan sistem kawalan automatik bagi menjaga suhu dan kelembapan kabin agar memenuhi keselesaan suhu penumpang. Oleh itu, kajian ini merupakan pembangunan prototaip sistem kawalan AC skala laboratari bagi mengawal suhu, kelembapan dan peredaran udara dalam kabin. Hasil eksperimen menunjukkan sistem kawalan ini mampu mengendali suhu udara pada kitaran 21 °C hingga 23 °C dan kelembaban udara kabin antara 40% hingga 60% pada pelbagai keadaan persekitaran simulasi yang menunjukkan penerimaan standard keselesaan dan kesejahteraan kenderaan. Sebagai kesimpulan, cara ini dapat diaplikasi pada kenderaan lama dengan modifikasi bersesuaian.

KEYWORDS: *air conditioner; control system; humidity; temperature*

1. INTRODUCTION

The vehicle air conditioner (AC) system was developed to provide passenger comfort. Initially, the AC system was only used to regulate temperature but that is not enough anymore. Although the thermal comfort of building occupants has been studied extensively, in-vehicle thermal comfort is continuously being developed due to its dynamics. Since vehicles operate in a dynamic environment, therefore passenger comfort in the vehicle is very important to ensure people travel safely [1–3]. Moreover, as climate change causes

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temperature extremes, a study proposes to formulate new guidelines for car design based on passengers' thermal comfort to avoid health impacts [4].

Apart from temperature, to provide passenger comfort in the targeted cabin, humidity and air circulation speed are also important parts that must be considered [5,6]. Humidity greatly affects health [7,8] and changes in extreme humidity lead to new disease symptoms [9]. Maintaining humidity in the cabin can be done by opening the windows while driving [10]. However, in extreme weather such as summer, connecting cabin space with environment will add excessive load to air conditioning system. On the other hand, if the humidity is too low it can cause dehydration and endanger driving safety due to driving errors [11]. Another method is to put phase change material (PCM) to control humidity and temperature in the car, but it works passively [12]. Temperature-humidity- air circulation speed is interrelated air property [13,14]. The speed of air circulation in vehicle air conditioners is generally controlled manually via a knob on the dashboard, except in modern cars equipped with sophisticated sensors. Manual controls cannot provide good thermal comfort, as airspeed reset is based solely on feedback from the passenger or driver. Therefore, air speed control in an AC system also needs to be developed.

Increasing passenger comfort in the cabin by maintaining temperature has been discussed extensively, both while the vehicle is running and when the vehicle is from a parking location [2,4,12,13,15]. However, the discussion on the integration of temperature-humidity-air speed control systems based on effective human comfort is still very limited, except at the simulation stage [16-18]. Therefore, this study aims to develop a specific air conditioning control system used in vehicles to adjust temperature-humidity-air speed based on effective human comfort (22 °C; 40% to 60% of relative humidity, RH). The lab-scale prototype is tested in a simulation room, conditioned to resemble real environmental conditions. Furthermore, the room temperature was measured using a thermometer, humidity was evaluated by humidity meter, and the airflow meter was applied to estimate airflow.

2. METHOD

2.1 System Description

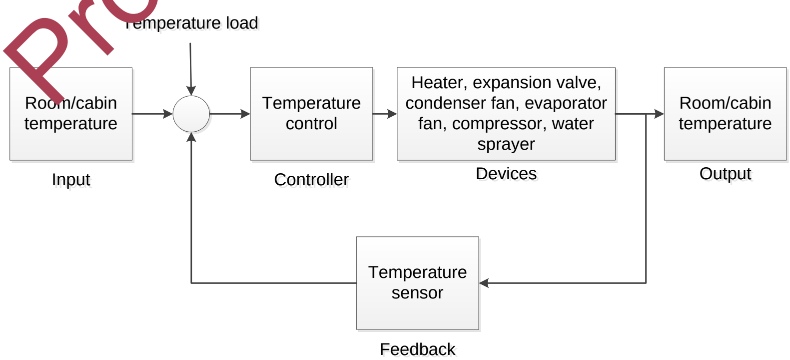

Fig. 1: The block diagram of temperature control.

The system developed is presented in Fig. 1 and Fig. 2. This system has five main blocks including the input, controller, devices, feedback, and output. Temperature control uses a closed loops system, and the feedback mechanism uses a sensor. The prototype has five components, encompassing the heater, condenser fan, evaporator fan, expansion valve, and compressor. The confounding factor of temperature control is the heat load from the

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outside. The humidity control system consists of a heater, water sprayer and humidity sensor to provide feedback.

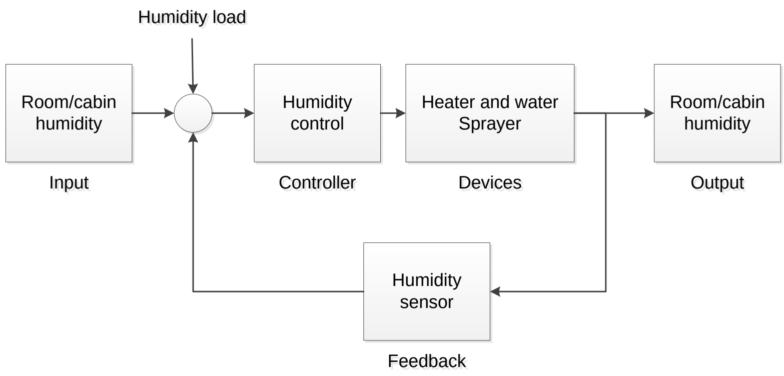

Fig. 2: The block diagram of humidity control.

2.2 Experiment Set-up

Figure 3 shows the experimental set-up which includes the electronic control module (1), evaporator (2), compressor (3), condenser (4), and expansion valve (5). The specifications of each equipment are shown in Table 1. The electronic control module (ECM) consists of a microcontroller, relay, and electronic circuits that are programmed based on the desired needs. The ECM works based on input from temperature and humidity sensors, and produces output to the water sprayer, condenser fan, evaporator fan, heater, and compressor. The performance mechanism of this air conditioning system follows the process shown in Fig. 4. This figure shows a psychometric diagram used to explain the conditions of the cabin space. When the cabin room has a high temperature and humidity (at point 1), the AC system will regulate temperature and humidity in a condition of thermal comfort (point 3). Process from point 1 to point 3 is a process of dehumidifying (1 to 2) and cooling (2 to 3). When a vehicle suddenly passes a highly cold temperatures area, the AC system will turn on the heater (R) to increase the temperature. Likewise, when a vehicle suddenly passes through an immensely low humidity area, the AC system turns on the water sprayer which will spray water (in the form of fog) to increase the humidity in order to achieve thermal comfort conditions.

Table 1: Specifications of the tools used in the study

No	Parts	Specification
1.	Evaporator	Evaporator Unit A3 Toyota; DENSO
2.	Compressor	Type SD505 - SD 505 - Universal Model Sanden, piston type, driven by a 220-volt AC motor with a power of 2 HP.
3.	Expansion valve	TEV type (thermo expansion valve)
4.	Temperature sensor	Sensor type DS18B20; Wrapped in stainless steel pipe; Dimensions 6 x 50 mm; Cable length 100 cm; Power supply 3-5.5V; Temperature range -55 to + 125C; Analog type
5.	Humidity sensor	Dimension: 28.2 x 13.1 x 10 mm; Weight: 6 g; Working voltage: 3V ~ 5.5V; Output signal: digital signal; Temperature measurement range: -40°C to 80 C; Accuracy: 0.5 °C; Humidity range: 0 ~ 100%; RH Accuracy: 2%
6.	Heater	12 volts 300 W with coil type heating element
7.	Simulation environment	Dimension: 1.5 x 1.5 x 3 m

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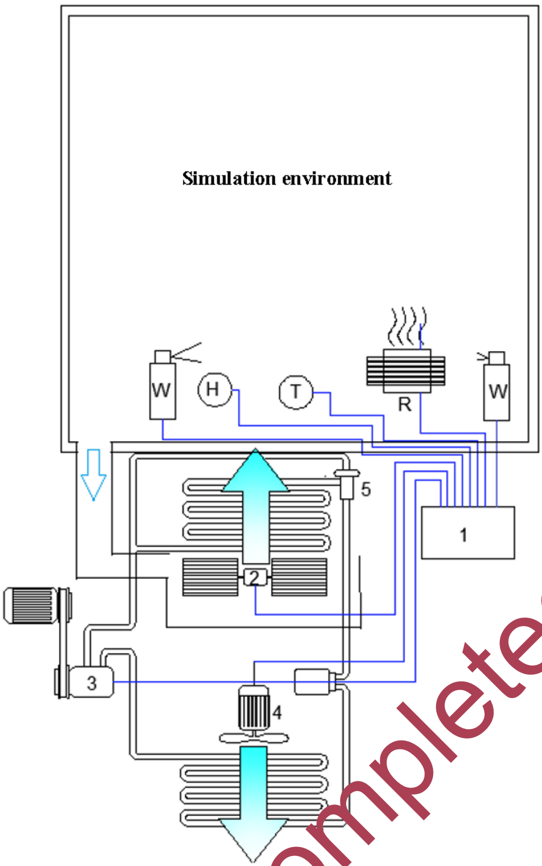

Fig. 3: Set up experiment: 1-electronic control module (ECM); 2-evaporator; 3-compressor; 4-condenser; 5-expansion valve; T-temperature sensor; H-humidity sensor; W-water sprayer; and R-heater.

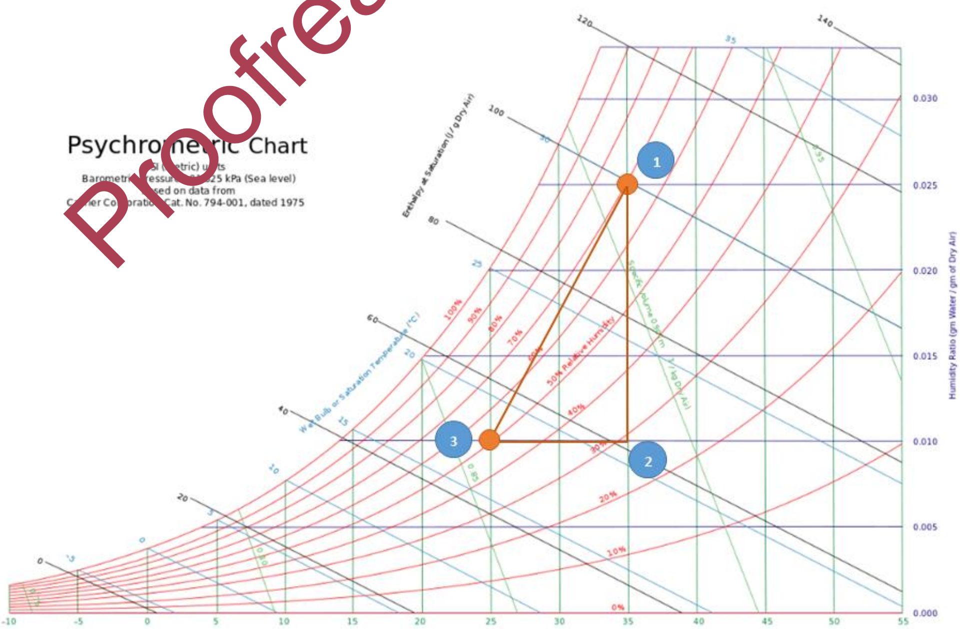

Fig. 4: Psychometric chart of AC system.

Installation of heating sensors, water spray, temperature and humidity sensors are paired adjacent to the evaporator. The ECM input includes temperature and humidity

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sensors, while the evaporator is mounted in series against the condenser and compressor. This prototype was tested during hot climates with a location in Indonesia which has a longitude position of -7.520639969601074 and latitude 110.22739445901612.

2.3 Logic Rule of Control System

The control system has two subsystems to control temperature and humidity of cabin air as shown in Fig. 5 and Fig. 6. The logic rule of temperature control has a working structure as follows. If the temperature is below 16 °C, the programming statement is set to turn on the heater (R) and turn off the air conditioner but the evaporator fan is on (P1). The length of time the heater runs depends on the high and low temperature of the cabin space, so if the temperature of the cabin space is very low, it takes a longer heater lifetime to achieve thermal comfort. If the temperature of the cabin space is in the range of 17 to 20 °C, then the statement program is set to activate the AC compressor and heater with the evaporator fan at very low speed (P2). The statement program is set to turn on the evaporator fan in a very low position speed to reach a range of 21 to 24 °C (P3) and so on according to Fig. 5.

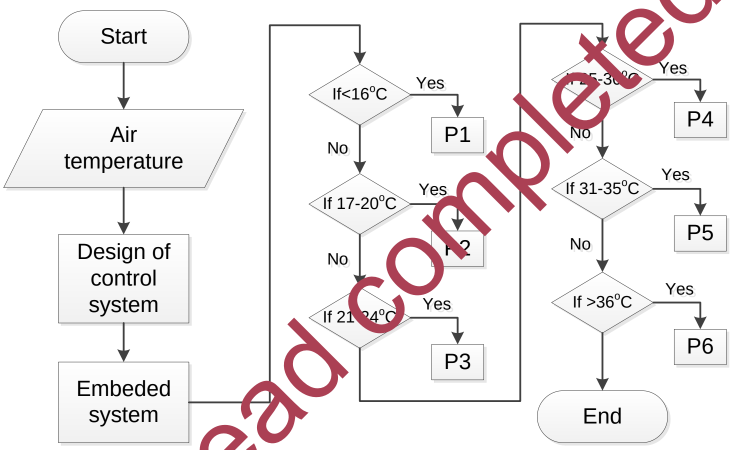

Fig. 5: Logic rule of temperature control system.

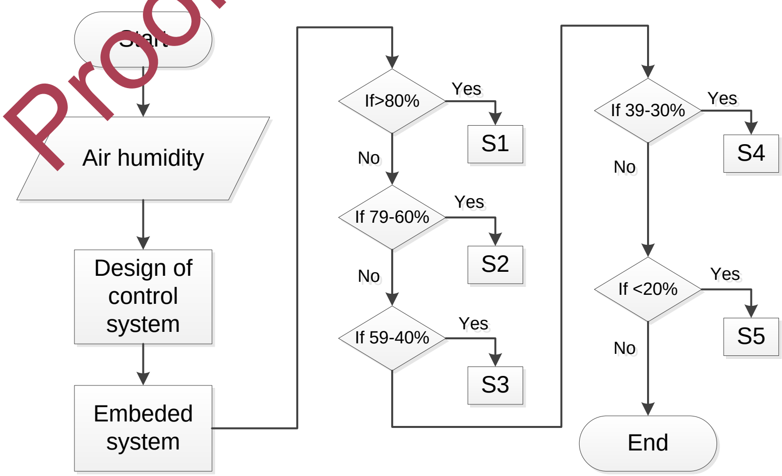

Fig. 6: Logic rule of humidity control system.

The cabin temperature is set at 25 to 30 °C, where the programming statement turns on evaporator fan to medium speed position, condenser, and expansion valve are in position 2 (P2). Furthermore, a cabin temperature of 31 to 35 °C requires the statement program to turn on the evaporator fan to high speed, while the condenser fan and expansion valve are

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in position 3 (P3). In addition, cabin temperatures above 36 °C require the statement program to turn on a maximum high evaporator fan, while the condenser and expansion valve are in position 4 (P4). Table 2 shows the various temperature control system statements. The condenser fan, compressor and magnetic coupling are connected in one line, so that if the magnetic coupling is on, condenser fan, the compressor will start. Likewise, if the magnetic coupling turns off, the condenser fan, the compressor will shut off.

Table 2: Statement of the air temperature control system

No	Position	Functioning system
1.	P1	• Heater on • Evaporator fan off • Compressor off
2.	P2	• Heater on • Evaporator fan on (min. low speed) • Compressor on
3.	P3	• Heater off • Evaporator fan on (low speed) • Compressor on
4.	P4	• Heater off • Evaporator fan on (medium speed) • Compressor on
5.	P5	• Heater off • Evaporator fan on (hight speed) • Compressor on
6.	P6	• Heater off • Evaporator fan on (max. high speed) • Compressor on

The humidity control system algorithm works with the following conditions. If the humidity in cabin space is more than 80%, the statement program is set to turn on the air conditioning system which aims to remove moisture in cabin space. If the air reads very dry (below 39%), water spray is activated to increase humidity. Meanwhile, if the humidity reads at 40 to 60%, the sprinkler and heater are turned off. Table 3 shows the humidity control system statements and algorithms.

Table 3: Statement of the air humidity control system

No	Position	Functioning system
1.	S1	Heater on
2.	S2	Heater on
3.	S3	-
4.	S4	Sprayer in position 1
5.	S5	Sprayer in position 2

Air temperature and humidity were measured in the cabin space, the lowest and highest values observed were 17 °C and 31 °C, respectively. Meanwhile, the lowest and highest humidity data were obtained in the range of 20% and 84%. Data is collected at 380 meters above sea level. Temperature, air velocity, and humidity data were collected using a digital thermometer, airflow meter and humidity meter, respectively.

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3. RESULTS AND DISCUSSION

3.1 Wiring Diagram of Developed Prototype

Integrated control system for cabin room comfort has interconnected parts. The circuit which includes input, controller, actuator, output and feedback is characterized by a sequential working system. The LM 35 sensor is a temperature sensitive device that is known to produce analog signals. Therefore, changes in temperature of simulation room can be detected based on modification of the resistance. The DHT11 sensor is able to detect ambient air humidity by measuring amount of water vapor in simulation room. Figure 7 shows the wiring diagram made.

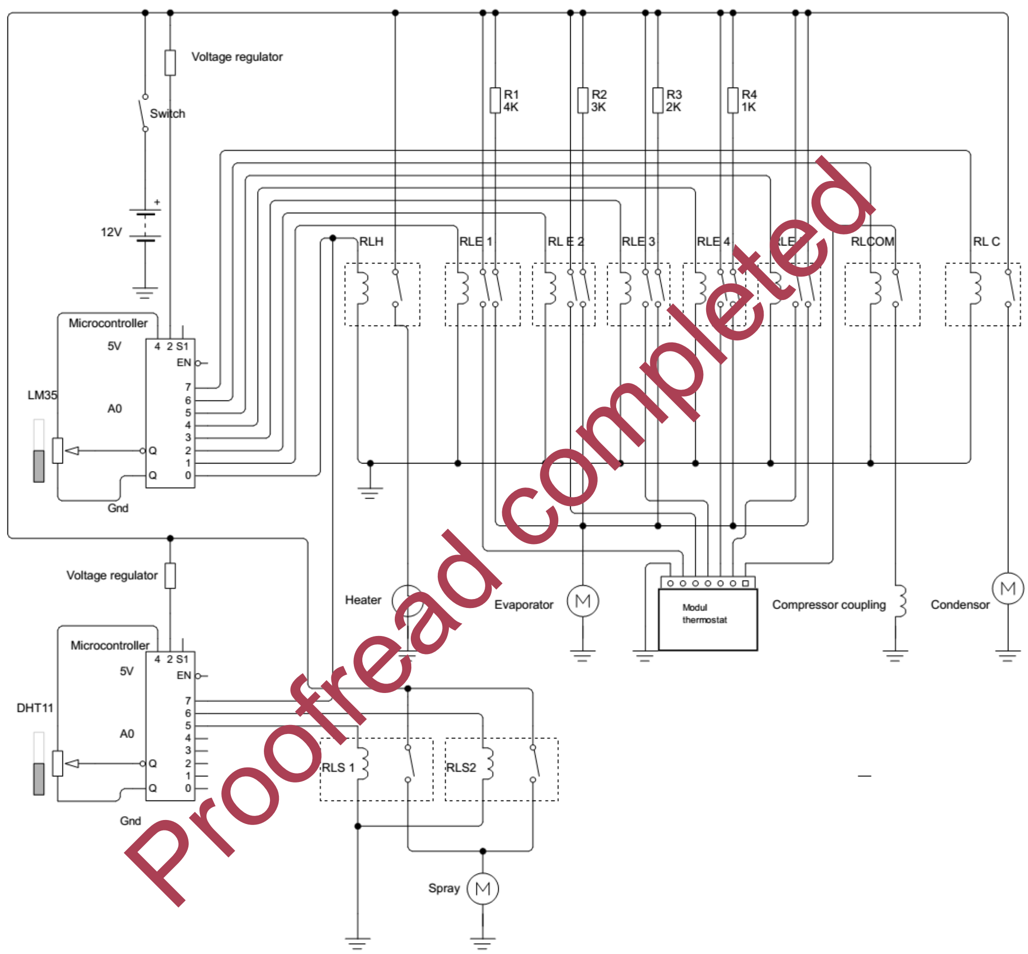

Fig. 7: Wiring diagram of the controller system.

3.2 Air Speed, Temperature, and Humidity Measurement

The automatic integration control system for room comfort was set at 22 °C, based on the effective comfort for humans [19], while the simulation room temperature was obtained from 31 °C. The temperature at the 21st minute has reached a precise setting, and period of decline is affected by thermal load. Furthermore, airspeed is modified based on temperature previously achieved, as 7.8 m/s produced by evaporator fan is generated at 31°C. Based on the evaluation, an automatic decline to 7 m/s was reported at 30°C, and 6.5 m/s was achieved after reaching 22 °C. The controller system subsequently maintains temperature in the range of 21 to 23 °C, and the results in Fig. 8 show comparison between automatic and manual techniques.

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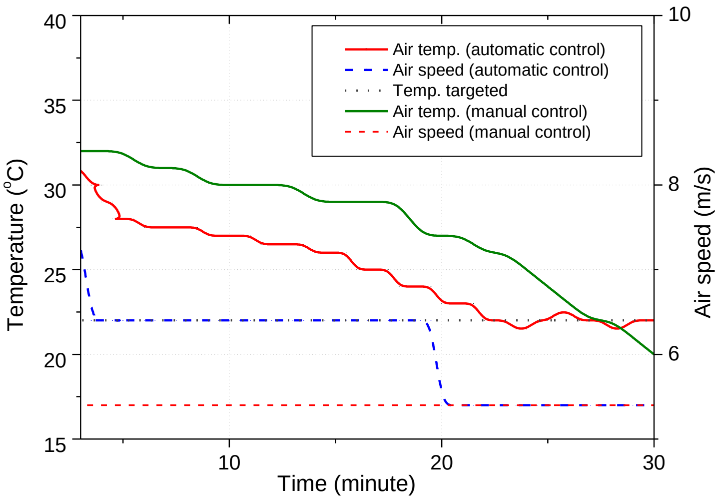

Fig. 8: Temperature and airspeed at the highest temperature position.

Manually controlled air temperatures have several conditions, and 5.5 m/s is used as speed position of evaporator fan. Furthermore, a decline in temperature requires a longer time compared to an automatic control system, as only 18 °C, is reached within 30 minutes. This condition possibly occurs due to the presence of constant evaporator fan speed, which does not increase automatically, hence the need to achieve the addition of automatic comfort temperature. In addition, it was not possible for the manual control system to reach an effective position for humans (22 °C) in the 30th minute.

Data were collected at 17 °C, and under this condition, the controller turns on the heater. This subsequently generates heat in the simulation enviroment, while the airspeed assists in spreading the warm air emitted. Furthermore, 20 °C was reached on the 20th minute, and then the control system turns off the heater, subsequently circulating the heat in order to maintain 22 °C. Also, the system works to achieve an effective temperature for humans, and Fig. 9 shows the simulation environment characteristics with the heater. The manually controlled systems require a speed of 5.5 m/s and only 18 °C is reached at the 30th minute. The temperature increase process tends to be slower because the manual controls are not integrated with the heater system. The performance characteristics of the temperature control system are successful in working in the range of 21 °C to 23 °C which is closer to human thermal comfort (effective temperature setting).

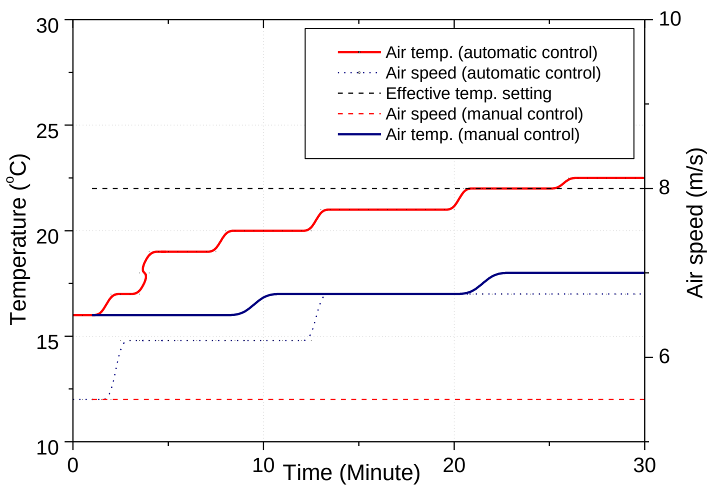

Fig. 9: Temperature and airspeed at the lowest temperature position.

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Air humidity data is obtained from simulation chamber at the highest condition of 90%, characterized by relatively large (wet) water vapor content. Furthermore, the automatic control system turns on the heater to 60% position and aimed at achieving the simulation room dry out. The heated air with water vapor content is further removed from the room with a removal system, while the humidity decreases. Meanwhile, the automatic system has the ability to maintain the humidity conditions at 40% to 60%. Figure 10 shows the control system characteristics. The regulation data for air humidity in a manual system is obtained at around 90%, in order to turn on the heater. However, a slight decline was observed at 89% on the 30th minute, resulting from the opened ventilation.

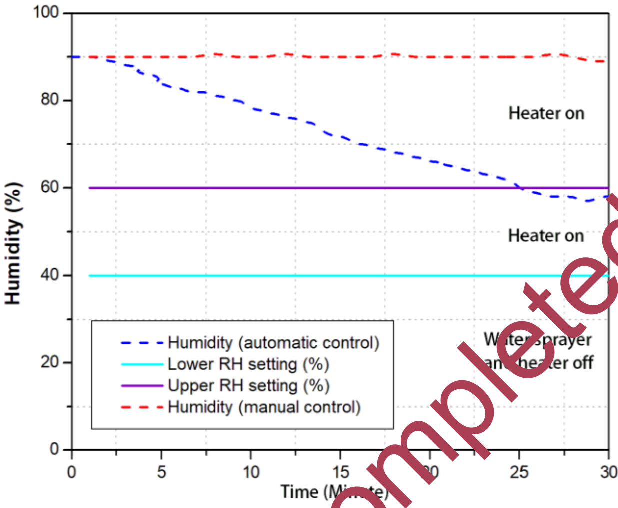

Fig. 10: Air humidity at the highest position.

The air humidity is obtained at the lowest position (dry) in simulation room, using a humidity tester. Therefore, the speed of achieving this condition is increased by exposing the environment to an initial draining process. This involves the removal of hot air, and new data is collected after reaching the least position (dry). The automatic control systems operated is then commenced at the initial lowest humidity level of 20%, where the water sprayer is turned on, and consequently emitting moist mist. Therefore, the humidity slowly increases to 40%, where the sprayer is turned off. This controller system maintains ideal humidity conditions between 40% to 60%, and Fig. 11 shows test results from the lowest humidity position.

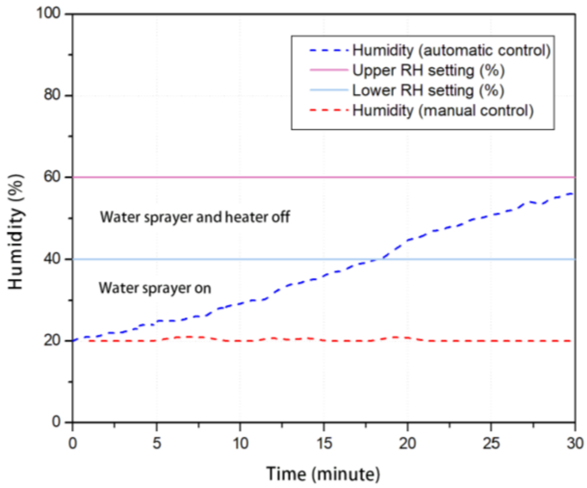

Fig. 11: Air humidity at the lowest position.

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Furthermore, the air humidity in a manual system is obtained data at 20% because of the inability to turn on the water sprayer. Hence, there is a high difference between this application and an automatic system with the capacity to reduce and maintain effective humidity for humans. The script programming of the temperature control system is shown in **Appendix 1**.

4. CONCLUSION

Comprehensive conclusion was made based on the test results, which include:

- In the aspect of room temperature, the control system data retrieved was in the highest position (hot), and the automatic control system was able to reduce the room temperature from 31 ºC to range from 21 °C to 23 °C in 21 minutes. This prototype works according to settings in effective temperature area to attain human comfort. However, the manual controllers only reach 27 °C in 21 minute, hence longer time is required to cool the room, and it is also difficult to achieve optimal temperatures for passengers. Room control systems are tested from the lowest temperature position (cold), where automatic unit turns on heater in the simulation room. Therefore, 17 °C is raised to the settings in range of 21 °C to 23 °C, and the speed temperature fluctuation is influenced by room volume and heater/AC control capacity. Furthermore, effective temperatures are not reached in manual control systems because of the inability to warm up the room.
- Based on the data retrieved, the humidity control system was at the highest position (wet) at 90%. Therefore, the automatic unit turns on the heater system to promote air vapor dryness and subsequent removal from the simulation room. This unit reduces humidity to a range of 40% to 60% (effective humidity for human comfort). Meanwhile, the manual system is unable to cause a decline to the effective value for passengers due to the non-integration with the heater and sprayer.
- Based on the data retrieved, humidity control system was in the least position (dry), working at 20%. Furthermore, automatic unit turns on water sprayer, subsequently leading to higher humidity up to the range of 40% to 60%. Also, it is able to work according to the setting of humans effective comfort, both in terms of temperature and humidity regulation. However, this condition is not attainable by the manual controllers. This is a model study, and the automatic system created shows better work capacity than the manual, hence greater potential for application in the cabin rooms of real vehicles. The fluctuation rate of temperature and humidity is set based on the regulation capacity of the heater, air conditioner, and room volume.

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Appendix 1: Script Programming

```
const int TemperatureLM35 = A0;
float temperature, data;
const int relay1 = 2 ;
const int relay2 = 3 ;
const int relay3 = 4 ;
const int relay4 = 5 ;
const int relay5 = 6 ;
const int relay6 = 7 ;

void setup() {
 Serial.begin(9600);
pinMode(TemperatureLM35, INPUT);
pinMode(relay1, OUTPUT);
pinMode(relay2, OUTPUT);
pinMode(relay3, OUTPUT);
pinMode(relay4, OUTPUT);
pinMode(relay5, OUTPUT);
pinMode(relay6, OUTPUT);
}
void loop() {
 data = analogRead (TemperatureLM35);
  temperature = data / 2.0408;
  Serial.print("temperature: ");
  Serial.print(temperature);
  Serial.println();
  delay(1000);
   if (temperature <= 16 ) //heater on
 {
  digitalWrite(relay1, HIGH);
  digitalWrite(relay2, LOW);
  digitalWrite(relay3, LOW);
  digitalWrite(relay4, LOW);
  digitalWrite(relay5, LOW);
  digitalWrite(relay6, LOW);
 }
 else if (  temperature <= 20 )// very low speed
 {
  digitalWrite(relay1, HIGH);
  digitalWrite(relay2, HIGH);
  digitalWrite(relay3, LOW);
  digitalWrite(relay4, LOW);
  digitalWrite(relay5, LOW);
  digitalWrite(relay6, LOW);
 }
  else if(  temperature <= 24)// low speed
 {
  digitalWrite(relay1, LOW);
  digitalWrite(relay2, LOW);
  digitalWrite(relay3, HIGH);
  digitalWrite(relay4, LOW);
  digitalWrite(relay5, LOW);
  digitalWrite(relay6, LOW);
 }
  else if(  temperature <= 30)// medium speed
 {
  digitalWrite(relay1, LOW);
  digitalWrite(relay2, LOW);
  digitalWrite(relay3, LOW);
```

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```
  digitalWrite(relay4, HIGH);
  digitalWrite(relay5, LOW);
  digitalWrite(relay6, LOW);
 }
 else if (  temperature <= 35)// high speed
 {
  digitalWrite(relay1, LOW);
  digitalWrite(relay2, LOW);
  digitalWrite(relay3, LOW);
  digitalWrite(relay4, LOW);
  digitalWrite(relay5, HIGH);
  digitalWrite(relay6, LOW);
 }
 else if (  temperature >= 36)// very high speed
 {
  digitalWrite(relay1, LOW);
  digitalWrite(relay2, LOW);
  digitalWrite(relay3, LOW);
  digitalWrite(relay4, LOW);
  digitalWrite(relay5, LOW);
  digitalWrite(relay6, HIGH);
}
}
```

Meanwhile, the script embedded in the humidity control system is shown as follows =

```
#include <dht.h>
#define sensor A0
dht DHT;
int relay1= 2;
int relay2= 3;
int relay3= 4;
void setup(){
Serial.begin(9600);
delay(500);
pinMode(sensor, INPUT);
pinMode(relay1, OUTPUT);
pinMode(relay2, OUTPUT);
pinMode(relay3, OUTPUT);
}
void loop(){
DHT.read11(sensor);
Serial.print("air humidity = ");
Serial.print(DHT.humidity);
Serial.println("% ");
delay (1000);
int sen = DHT.humidity;
if ( sen <= 20.00){
        digitalWrite(relay1, HIGH);
        digitalWrite(relay2, LOW);
        digitalWrite(relay3, LOW);
}
if ( sen <= 40.00){
        digitalWrite(relay1, HIGH);
        delay(500);
        digitalWrite(relay2, LOW);
        digitalWrite(relay3, LOW);
else if ( sen <= 60.00){
        digitalWrite(relay1, LOW);
        digitalWrite(relay2, LOW);
        digitalWrite(relay3, LOW);
```

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```
}
else if ( sen <= 80.00){
      digitalWrite(relay1, LOW);
      digitalWrite(relay2, LOW);
      digitalWrite(relay3, HIGH);
      delay(500);
  }
else if ( sen <= 100.00){
      digitalWrite(relay1, LOW);
      digitalWrite(relay2, LOW);
      digitalWrite(relay3, HIGH);
}
}
```