EMBEDED SYSTEM FOR MONITORING
THE TEMPERATURE INSIDE A VEHICLE

Radu MUŞAT*, Ana-Maria PUŞCAŞ*, Elena HELEREA*

*Faculty of Electrical Engineering and Computer Science, "*Transilvania*" University of Brasov, Romania

Abstract: *Nowadays, providing a thermal comfort level is one of the main goals in the vehicle environment and HVAC systems. In this sense, considerable research regarding factors that influence thermal comfort has been accomplished. These factors appear due to the influence of convective, radiative and conductive heat exchange created by the external thermal loads and by the internal heating and ventilation system. The goal of the paper is to investigate the efficiency of the air conditioning system of a vehicle and how quickly the system raises the inside air temperature in a cold environment. The method used for evaluating the thermal comfort was monitoring the air temperature at different body zones by using dedicated digital temperature sensors. The human surface was divided into six segments, each segment being covered with temperature sensors connected in a network. Therefore, an embedded data acquisition and monitoring system was used. The experimental results are emphasized and the differences between the temperature at feet and head level are analyzed.*

Keywords: *thermal comfort, air temperature, monitoring, data acquisition system, control system, air conditioning, thermal manikin, vehicle*

1. INTRODUCTION

Nowadays, people are increasingly dependent on transportation. Therefore, it is important to ensure the optimal thermal comfort in the vehicle, for the passengers and also for the driver [15].

The thermal comfort represents a subjective sensation that occurs in a human body and is the result of the combined effect of six parameters – air temperature, air humidity, mean radiant temperature, air velocity, level activity and clothing type.

The thermal environment inside a vehicle is more complex than inside a building and thus difficult to evaluate. These difficulties appear due to the influence of convective, radiative and conductive heat exchange created by the external thermal loads (solar radiation) and by the internal heating, air conditioning and ventilation system [3].

Achieving a thermally comfortable vehicle environment for passengers has become an issue of primary importance that needs to be assessed. An optimal level of thermal comfort in a vehicle environment can be obtained only by using an automatic air conditioning and climate control system [2].

The goal of the paper is to investigate the efficiency of the air conditioning system and how quickly the system raises the inside air temperature in a cold environment. Also, the

differences between the temperature at feet and head level are analyzed.

The method used for evaluating the thermal comfort inside a vehicle was monitoring the air temperature at different body zones by using a thermal manikin and dedicated digital temperature sensors. The surface of the thermal manikin was divided into six independently monitored segments. Each zone on the surface layer of the manikin was covered with temperature sensors connected in a grid in order to monitor the temperature. Therefore, an embedded control and data acquisition system was used. The experimental results are emphasized in order to analyse the efficiency of the HVAC system.

2. THE THERMAL COMFORT

Over the last years, considerable researches regarding the thermal comfort have been accomplished. The study of thermal comfort in vehicles was developed from basic thermal comfort research and applied works relating to factories and buildings. The first research in vehicles dealt mainly with agricultural vehicles and public transport systems such as subways, trains and buses.

Achieving a thermally comfortable vehicle environment has become an issue of major importance

According to Hensel, the thermal comfort is associated with temperature sensation. The difference between temperature sensation and thermal comfort is that temperature sensation is a rational experience that can be described as being directed towards an objective world in terms of "cold" and "warm". On the other hand, the thermal comfort is an emotional experience which can be characterized in terms of "pleasant" and "unpleasant" [4].

According to ASHARE 55 and ISO 7730, the thermal comfort is defined as "a condition of mind which expresses satisfaction with the thermal environment" [17,18].

Vink described the thermal comfort as "a pleasant state of physiological, psychological, and physical harmony between a human being, and his or her environment" [16].

Parsons considered that "the comfort is a psychological phenomenon not directly related to physiological state or physical environment" [11].

Mansfield defined thermal comfort as a lack of discomfort and Conway states that the thermal comfort depends on the ability of the human body to self adapt to the environment [1,8].

Temming states that, inside vehicles, there are no homogenous temperature areas. The temperature at head level is greater than at feet level. The air temperature inside a vehicle depends on the "class" of the vehicle, its size and quality [15]. Temming observed that, for increasing the thermal comfort, a reduced air flow has to be applied in the passengers' area at reduced external temperatures, and a moderate air flow has to be applied at high external temperatures. The heated air should be directed towards the bottom half of the passenger's body and the cold air should be directed toward the upper half. Because of the reduced volume of the vehicle (as compared to buildings) the air flow can be easily directed to specific zones [15].

Many researchers suggest that factors such as interior upholstery, interior and exterior lights, whole volume of the vehicle and the number of passengers can affect thermal comfort [6,13,14].

The climatic conditions can be changed dramatically because of the dynamic vehicle environment. In the vehicle environment, there are three factors which dramatically affect the vehicle environment: the HVAC system, windows and solar radiation. In such an unpredictable environment, it is more difficult to estimate and control the optimally thermal comfort levels [3,10,15]. Most of the research which tested these influences is focused on air temperature. In this sense, the researchers concluded that air temperature is the most important parameter that influences thermal comfort [3,5,7,9].

The usual method for evaluating the efficiency of the air conditioning system is to apply sensors to measure the air temperature at feet and at head level. The main purpose is to investigate how quickly the system will raise the temperature in a cold environment and to study the difference between the temperature at feet and head level.

“HENRI COANDA”
AIR FORCE ACADEMY
ROMANIA

GERMANY

“GENERAL M.R. STEFANIK”
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

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3. ARCHITECTURE DESCRIPTION AND MEASURING METHOD

The optimal comfort level can be obtained only with automatic air conditioning systems. In the automatic system, the desired temperature is set and the system's role is to maintain it constantly by using inside temperature and humidity sensors placed in key points inside the vehicle. The air flow and the fun speed are automatically controlled using the information received from the inside /outside temperature sensors.

In Fig. 1 there is illustrated a typical HVAC system and the interior air flow repartition through tubes and air vents.
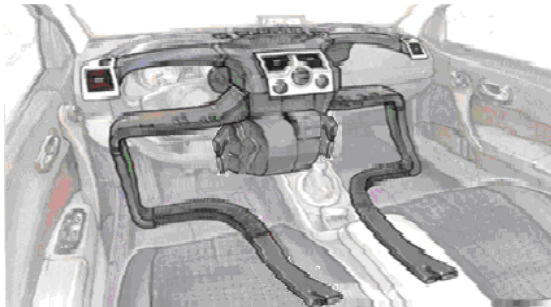

Fig. 1 Air flow distribution inside the vehicle

To monitor the air temperature inside the vehicle, control and data acquisition systems were implemented [12].

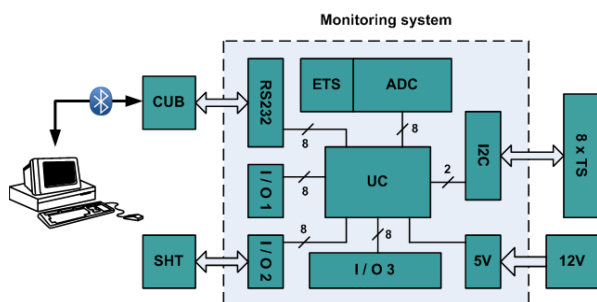The architecture of the control and data acquisition system is illustrated in Fig. 2.

Fig. 2 The architecture of the control and data acquisition system

As is can be seen in Fig.2, the implemented system consists of:
(i)   Microcontroller module;
(ii)   Temperature sensors (TS);
(iii)   Bluetooth module (CUB);
(iv)   Humidity and dew point sensor (SHT);

The microcontroller module consists of: (i) ATMega 128 microcontroller (UC) used to master the control and acquisition processes; (ii) embedded temperature sensor (ETS) used to measure the mean temperature and to control the monitoring process; (iii) analog to digital converter (ADC) used for acquiring information from the ETS; (iv) Inter Integrated Circuit (I2C) protocol used to communicate with the digital temperature sensors (TS); (v) input – output ports (I/O): I/O1 used to enable / disable the monitoring processes, I/O2 used to communicate with SHT, I/O3 used to connect the bar graph; (vi) RS232 port used to interconnect the microcontroller module with CUB.

In the monitoring process of the air temperature at feet, arm and head level, a network of eight LM75 digital temperature sensors were used.

Data from temperature sensors and the control information were transmitted to a local storage and processing unit (Laptop) by using the Bluetooth module (CUB). This module consists of a RS232 to Bluetooth converter, LMX9838 type.

Also a SHT11 humidity and dew point sensor was used to observe the humidity variation while increasing the temperature inside the vehicle's interior.

The monitoring process is enabled when the internal combustion engine (ICE) and the HVAC system of the vehicle are started. The ICE is running at idle speed and the HVAC system is running in automatic mode set at 22 °C.

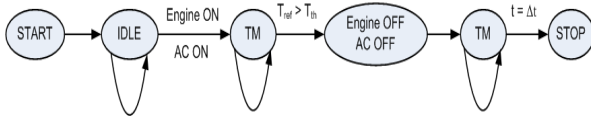In Fig. 3, there is illustrated the control strategy used by the temperature monitoring system.

Fig. 3 Flow diagram for monitoring the air temperature

The ETS permanently communicates with the data acquisition system (DAQ). The control system (CS) interrogates the data acquisition system and processes the information to identify when the mean air temperature reaches the preset threshold temperature value. At this moment, the control system indicates to switch off the HVAC system and the ICE. The monitoring process continues for a predefined time to identify the evolution of the temperature and how quickly the temperature decreases. When the predefined time is reached, the whole system is stopped. The data are transmitted via Bluetooth to the laptop. The stored data are processed in MatLab Software.

4. EXPERIMENTS AND RESULTS

In Fig. 4 there is illustrated the control and data acquisition systems, the Bluetooth module and the digital temperature sensors used in the monitoring process.
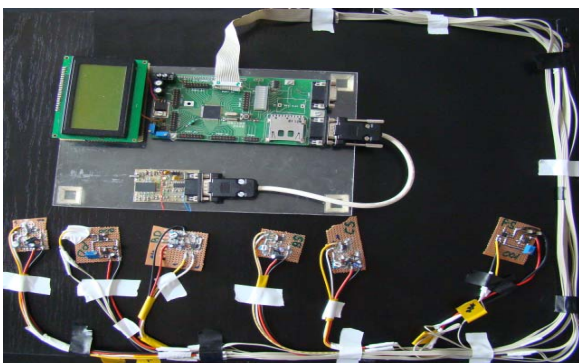

Fig. 4 Monitoring implemented system

For the experiments, a Renault Clio 1.5dci-2005 was used. In order to monitor the temperature evolution inside the vehicle, a thermal manikin was used. The thermal manikin surface was divided into six independently monitored segments: the foot zone, the arm zone and the face zone. Each zone on the surface layer of the manikin was covered with digital temperature sensors connected in a network.

In Fig. 5 and Fig. 6 there are illustrated the position of the temperature sensors and the control and data acquisition systems – top view and side view.
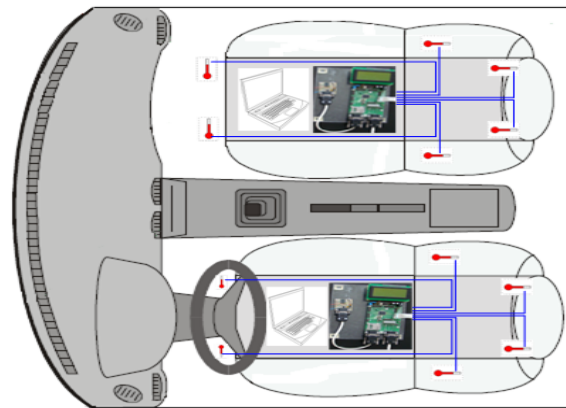

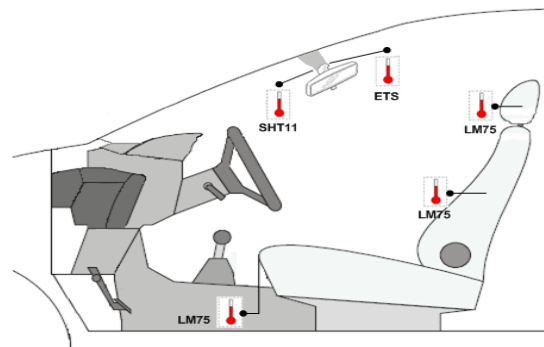Fig. 5 Positioning of the temperature sensors and the CS and DAQ – top view

Fig. 6 Positioning of the temperature sensors and the CS and DAQ– side view

The inside air temperature was monitored both for the driver and the front passenger. The experiments were made in different days at different outside air temperature.

The internal combustion engine of the vehicle was started and running at idle speed, the HVAC system was started in automatic mode, set at a threshold value (T_{th}). At that moment, the monitoring process was enabled. After the monitored temperatures reached the threshold value, the ICE and HVAC system were stopped. The temperature evolution was still monitored until a predefined time (Δt) was reached.

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The experimental results are illustrated in the following figures.

In Fig. 7 there are illustrated the inside air temperature monitoring results for the driver zone when the outside temperature was -11 °C and the interior temperature was -8 °C. The CS and DAQ monitored the temperature evolution for 65 min when the engine and HVAC system are running, and 29 min when the engine and HVAC system are stopped.
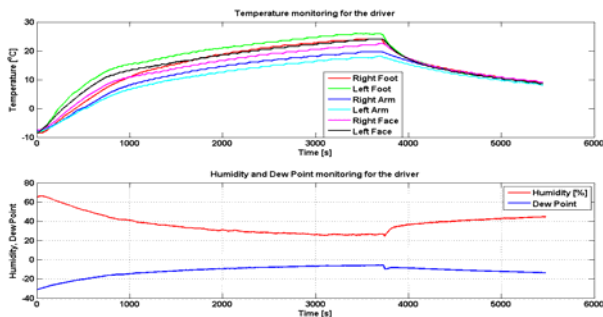

Fig. 7 Temperature monitoring for the driver at outside temperature of -11 °C

In Fig. 8 there are illustrated the inside air temperature monitoring results for the passenger zone when the outside temperature was -9 °C and the interior temperature was -6 °C. The CS and DAQ monitored the temperature evolution for 75 min when the engine and HVAC system are running and 27 min when the engine and HVAC system are stopped.
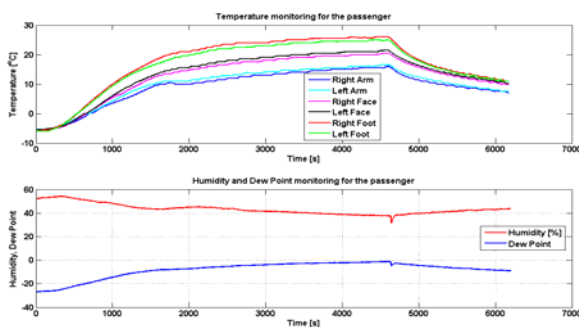

Fig. 8 Temperature monitoring for the passenger at outside temperature of -9 °C

In Fig. 9 there are illustrated the inside air temperature monitoring results for the driver zone when the outside temperature was -19 °C and the interior temperature was -17 °C. The CS and DAQ monitored the temperature evolution for 95 min when the engine and HVAC system are running and 30 min when the engine and HVAC system are stopped.

Fig. 9 Temperature monitoring for the driver at outside temperature of -19 °C

In Fig. 10 there are illustrated the inside air temperature monitoring results for the passenger zone when the outside temperature was -20 °C and the interior temperature was -18 °C. The CS and DAQ monitored the temperature evolution for 90 min when the engine and HVAC system are running and 25 min when the engine and HVAC system are stopped.
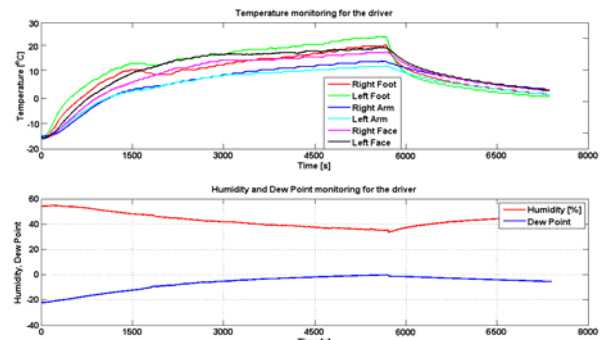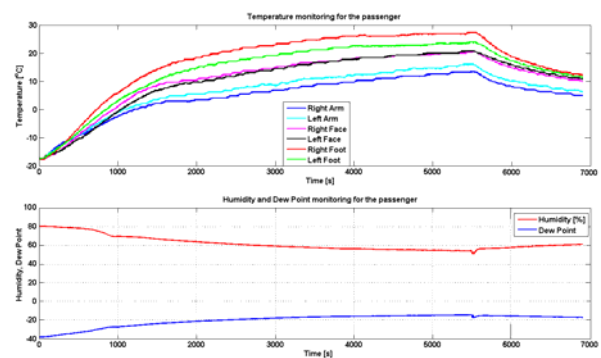

Fig. 10 Temperature monitoring for the passenger at outside temperature of -20 °C

As it can be seen in the experimental results, there is a delay between the moment when the ICE is started and the moment when the inside air temperature starts to increase. This is due to the ICE which cannot cover the necessary heat till it reaches its operating temperature. The delay depends on the outside temperature value and increases at extreme low temperatures.

The experimental results are in accordance with the standards, the temperature at feet level being higher than at head level.

5. CONCLUSIONS

The aim of the HVAC system is to obtain a comfortable temperature as quickly as possible and to eliminate the local thermal comfort.

The performances of the HVAC system were illustrated in the experimental results. Its efficiency increases as the outside temperature increases. In extreme cold weather conditions, experienced across the globe, the efficiency is reduced and it takes a lot of time to heat the vehicle's interior.

The main disadvantage of the HVAC system was identified during the starting regime of the vehicles until the ICE reaches its operating temperature. During this period, the ICE cannot ensure the necessary heat for heating the vehicle interior. In this sense, auxiliary heating devices are required.

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