Practical studies on car air conditioning systems

S Rațiu¹, I Laza², V Alexa¹ and V G Cioată¹

¹University Politehnica Timișoara, Faculty of Engineering Hunedoara, Department of Engineering and Management, 5 Revoluției Street, 331128 Hunedoara, Romania
²University Politehnica Timișoara, Mechanical Faculty, Department of Mechanical Machines, Equipment and Transportation, 1 Mihai Viteazu Street, 300222, Timișoara, Romania

E-mail: sorin.ratiu@fih.upt.ro

Abstract. The article presents an experimental demonstration stand that allows the study of phenomena that occur in a car air-conditioned installation. The stand is specifically designed to highlight the processes that take place in each component of the installation and how to vary the functional parameters of the plant, according to the user's requirements. There are presented 3D graphs of variation for the studied parameters.

1. Introduction

The major car manufacturers have early understood the key role played by the comfort, along with the price, in choosing a particular car model. Thus, with the emergence of the first car models, manufacturers have identified passenger thermal comfort as a major comfort and safety factor.

Car manufacturers have attempted to introduce a number of additional auxiliary equipment to provide substantial improvements to passenger comfort in the interior of the passenger compartment while increasing vehicle performance, thereby achieving reliability and quality/price ratio.

The development of air conditioning systems over time and the reduction of production costs have led to an increasing demand from customers. Thus, in the 1960s, about 20% of the cars produced in the United States were air-conditioned, and the proportion in southern warm areas was 80%.

The car's air conditioning revolution occurs in 1999, when more than half of the new cars are sold with a standard air conditioning system, as in 2007 the percentage is almost 90%.

2. Thermal comfort

By the term "thermal comfort", according to ISO 7730, "the condition of the mind expressing the degree of general satisfaction with the surrounding environment" is understood.

Thermal comfort sensation, i.e. neutral temperature sensation, is defined by the human body's thermal balance equation described by Flanger in 1970 through a simple one-dimensional model, equation also included in ISO standard 7730 [1]:

\[ Q_H - Q_D - Q_F - Q_R - Q_L = Q_{RA} + Q_C \]  

where:

- \( Q_H \) – internal heat due to metabolism;
- \( Q_D \) – heat lost due to vapor diffusion through the skin;
- \( Q_F \) – heat lost due to perspiration;
Q_R – latent heat lost due to breathing;  
Q_L – heat lost due to dry breath;  
Q_RA – heat lost through radiation to the surface of the dressed up human body;  
Q_C – heat lost through convection to the surface of the dressed up human body.

As a result of the experimental data correlated with equation (1), a thermal comfort coefficient was set on a scale in the range of – 3 (feeling too cold) to + 3 (feeling too hot), called PMV (Predicted Mean Vote), which expresses the predictable average opinion of a group of people about the thermal comfort sensation, generated by a given environment and is calculated from the thermal balance of the human body (according to ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers).

\[
PMV = (0.33 \cdot e^{-0.036M} + 0.028)(Q_{sl} - Q_{d} - Q_{x} - Q_{k} - Q_{L} - Q_{RA} - Q_{C})
\]

Where M – is the metabolism of the human body [met] (1met = 58.15 W/m^2, without physical activity).

The following situations occur:

- PMV=0 - total thermal comfort. There is, however, a percentage of 5% of people not satisfied with thermal comfort;
- 0.85 < PMV < + 0.85 - the maximum percentage of 20% of people not satisfied with thermal comfort.

Humans control their body temperature by sweating and shivering. The United States Environmental Protection Agency cites the ASHRAE Standard 55-1992 Thermal Environmental Conditions for Human Occupancy, which recommends keeping relative humidity between 30% and 60%, with below 50% preferred to control dust mites. At high humidity sweating is less effective so we feel hotter; thus the desire to remove humidity from air with air conditioning in the summer. In the winter, heating cold outdoor air can decrease indoor relative humidity levels to below 30%, leading to discomfort such as dry skin and excessive thirst [2].

3. Theoretical considerations

From a theoretical point of view, the operating principle of air conditioning systems and, in general, refrigeration systems, are based on the reversed Carnot cycle - heat transfer from the cold source to the hot source - with energy input. Next, we present a real cycle of operation (Figure 1) of a mechanical compression refrigeration plant, which differs from the inverse reversible Carnot cycle, following the thermodynamic transformations that compose it in the T - s diagram (temperature - entropy) [3].

This type of installation is built in two classic variants:

- with expansion valve;
- with orifice tube.

The air conditioning system studied in this article is one with expansion valve (Figure 2). It transfers heat (Q_0) from low temperatures to high temperatures, consuming mechanical work. The refrigerant vaporizes in the evaporator, taking heat from the external environment to be cooled, according to the isobar-isothermal process 4-1, to the state of dry saturated vapour (Figure 1). It is then compressed adiabatically into the compressor (process 1 - 2), in the form of superheated vapors at temperature T_2, higher than the condensing temperature T_3. In the condenser, these superheated vapours cools down at p_2 = constant until the saturation temperature will be reached, in the 2 - 2' process, then condense in the isobar – isothermal process, according to the 2' - 3 curve. The cooling down process (2 - 2') and the condensation process (2' - 3) take place with refrigerant heat release (Q_k) to the cooling water (or air if the condenser is cool down by the air). Next step is the adiabatic expansion process of saturated liquid from state 3, in the expansion valve (process 3 - 4). The expansion process is accompanied by temperature drop of the refrigerant and partial evaporation of the liquid [4].
4. Experimental research. Equipment and procedures

The experimental equipment is designed as a demonstration stand that allows visualization of the components of an air conditioning system and the measurement of the main functional parameters.

4.1. Presentation of the experimental stand

In order to better study the processes that take place in each component of the plant, the manual control of the operating modes was used (figure 3).

Thus, the stand is equipped with snap switches, through which it can be coupled: the electric drive motor (simulating the torque supplied by the thermal engine under real conditions), the electromagnetic clutch of the compressor and the electric fan.

The temperature values of the inside condenser and evaporator and the pressure values on the low and high pressure circuits can be measured. A voltmeter always indicates the charge voltage of the battery. In addition, air temperature and relative humidity will be measured near the passenger compartment ventilation grilles, as well as the air velocity near them. For these measurements, it was used the Testo Smart Probes - VAC SET (Figure 4).

The measuring instruments in the Testo Smart Probes Ventilation & Air Conditioning set can be connected quickly and easily to a smartphone or tablet via Bluetooth. It is possible therefore to measure air velocities, humidity, volume flows and temperatures with intuitive ease using the Testo Smart Probes App. Measurement data is transmitted wirelessly from the relevant measuring instrument to the Testo Smart Probes App and can be viewed conveniently on mobile terminal devices [5].

Figure 1. Thermodynamic cycle in the T - s diagram.

Figure 2. Air conditioning system with mechanical compression.

Figure 3. Overall view of the experimental stand.

Figure 4. Testo Smart Probes – VAC SET.
4.2. Research methodology

As we have already said, a car air conditioning system must ensure, in addition to the passenger's thermal comfort, also the air quality inside the passenger compartment.

Experimental research in this article focuses on determining how functional parameters of the air conditioning installation affect air quality by modifying its relative humidity. It is also intended to establish a correlation between these parameters.

In order to study the variation of functional parameters, it is necessary to create conditions in the laboratory similar to those of an air-conditioning system, fitted to the vehicle. Thus, an air conditioning system identical to that fitted to the Dacia Logan 1.4 MPI car is used.

The variation of average values of the temperatures inside the condenser and evaporator is monitored by means of thermometer mounted on the stand. Also, the pressures in the low and high pressure circuits are determined by the stand's own instruments.

Additionally, air relative humidity, air temperature and air velocity in front of the ventilation grilles are measured with the Testo Smart Probes - VAC SET measuring equipment.

5. Results and conclusions

The measurements were made from the moment when the compressor was manually coupled over a period of 2 minutes, without reaching the dew point.
The evaporator pressure (on the low pressure side) decreases and stabilizes to a constant value of 2.2 bar. When the electric fan is coupled, the condenser pressure drops, while the evaporator pressure continues to remain constant.

Following the temperature variation, Figure 6 also shows a rapid increase in the condenser temperature until the start of the electric fan. In the beginning, after the compressor is started, the evaporator temperature drops sharply, then decreases continuously slowly until the end of the period considered. The air temperature delivered in the passenger compartment has a steady decreasing trend.

In Figures 7 and 8 it is observed that the relative humidity of the air increases with time as the temperature decreases. This phenomenon occurs until the dew point reaches, and the air is saturated with water vapor. From that moment on, the relative humidity will drop and the air in the passenger compartment will become drier.

In conclusion, can be said that the presented stand allows studying the phenomena that take place inside a car air conditioning facility in an easy and intuitive way, and it can also serve as a teaching stand for students.

On the other hand, the possibility of manually modifying some functional parameters allows for correlations between them and their variation to extreme values. Thus, phenomena that occur in special conditions and which can adversely affect the air quality in the passenger compartment of the car can be studied.
References
[1] ISO 7730, *Ergonomics of the Thermal Environment – Analytical Determination 2005*
[2] Daly S 2006 *Automotive Air Conditioning and Climate Control Systems*, Butterworth-Heinemann
[3] Leonăchescu N 1974 *Thermotechnics*, Didactic and Pedagogical Publishing House Bucharest
[4] Petrescu S 1978 *Thermotechnics and Thermal Machines*, Didactic and Pedagogical Publishing House Bucharest
[5] Testo Smart Probes – VAC SET, https://www.testo.com/ro-RO/sonde-inteligene/p/0563-0003 (accessed on December 2017)