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EXPERIMENTAL TESTING OF THE VEHICLE HEATING SYSTEM

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Abstract

An important problem in the design of machinery and equipment at the stage of determining their structure is the issue of providing adequate thermal comfort to users while operating in variable climatic and environmental conditions. This issue is of particular importance because all types of machinery and devices are equipped with very expensive and automated control and monitoring system, which should guarantee adequate warming conditions and should work under different climatic conditions. Examples of these tendencies are special solutions for vibroacoustic insulation of the inside of the devices, special air conditioning equipment, special constructions, ergonomic inside solutions. The process of shaping the discussed structural design of vehicles in terms of meeting the relevant technical and operational criteria is currently being increasingly realized through experimental tests of prototypes supported by numerical calculations. The purpose of this paper is to present the methodology of conducting test stand as a stage for the experimental determination and verification of temperature distribution, the location of heating and air conditioning devices in a prototype vehicle in variable climatic conditions (minus 15°C). The research was carried out in a large-scale climate chamber. It covered the process of heating up the passenger area of the bus and the time of temperature stabilization on the inside of the vehicle while operating the heating systems. An additional attempt was made to test the heating system while the vehicle was in motion and to open the vehicle door to simulate the stopping of the vehicle at the bus stop. Another aspect that was analysed was the impact of the installed convector on the vehicle when the liquid heater was off.

***Keywords**: heating system, temperature distribution, temperature tests, thermal chamber*

1. Introduction

At present, the design of all types of machines and devices introduced into the market comes down to the performance of functional requirements, durability and reliability requirements. It is used to define these requirements a wide range of specialist software supporting the work of designers [1, 7]. Most of the time, the designers work ends in the computer simulation phase [3, 4, 6], which responds to the requirements and start the production phase of the product. Often without the prototype being tested and checked for correctness of design and performance of the requirements, which is manifested by the appearance of constructional or design defects, resulting in accelerated wear or malfunction in certain specific situations. In order to avoid this type of phenomena prototype research should be doing test stand, which will show weaknesses of the facility and at the stage of project modernization will eliminate design or construction errors. While designing objects that work in a typical temperature exposure environment, we can design machines and devices in a way that is based on the programs and experience of designers, especially their expert knowledge. Objects working in extreme environmental exposures require a special approach as well as special materials and elements that will guarantee proper work. Production of objects designed to operate under extreme temperature conditions minus 40°C and even minus 50°C or temperatures plus 60°C or 70°C require designers to know about the working conditions of individual components at such temperatures [11]. This knowledge is most often taken from the information in the catalogues of the manufacturers, which are often given up and cause the complex object to use these components does not meet the requirements. It is therefore very important that objects operating under different climatic conditions as prototypes undergo tests in which they will actually be operated [9]. Based on comprehensive information obtained from experimental research with the design process, machines and devices can be adapted to the changing environmental conditions in which they operate [8]. A very important concept in the correct functioning of heating and air conditioning systems is the definition of operator/user thermal comfort. The development of the construction of vehicles, machinery, and devices, in the direction of providing the operator and user with thermal comfort, requires research and design work to take into account the conditions set out, inter alia, in the series standards: PN-EN 60068, PN-ISO 10263 [2]. On the thermal comfort, inter alia, factors such as temperature difference between indoor and outdoor air, indoor air fluctuations, air humidity, solar radiation, air velocity of the surrounding air are also significantly influenced. In view of the above, providing conditions for the user to feel comfortable with heat is the main goal of installing heating and air-conditioning equipment and projects in the construction of various types of enclosed spaces and the selection of materials for their construction. Based on the operator/user thermal equilibrium, the general equation for the comfort state is the function of:

$$\begin{bmatrix} thermal \\ comfort \end{bmatrix} = \begin{bmatrix} temperature, \\ humidity, \\ air\ velocity, \\ fluctuation \end{bmatrix}.$$

An example of research in which the main task was to determine the user's comfort was the study conducted at low-temperature city buses, which was supposed to answer the question of determining the efficiency of the heating system used in this vehicle.

2. Research object

Achieving adequate thermal comfort for people moving a vehicle is one of the important aspects of the design of the heating and air conditioning system in the city bus. This is realized using passive and active elements of the heating or air conditioning system. Passive elements are understood to mean the use of all kinds of insulating materials or coatings, the elimination of all kinds of thermal bridges and the escape of heat through leaks. The active elements are heating-ventilation-air-conditioning.

The object of the test was a 12 m long city bus designed to carry 31 people in a sitting position and 59 people in a standing position. The vehicle is equipped with a heating system consisting of three liquid heaters located in the front centre and rear of the passenger area (Q_{c1}, Q_{c2}, Q_{c3}), one heater located in the driver space (Q_{c4}) and liquid convector (Q_{k1}) located in the middle of the passenger vehicle space (Fig. 1).

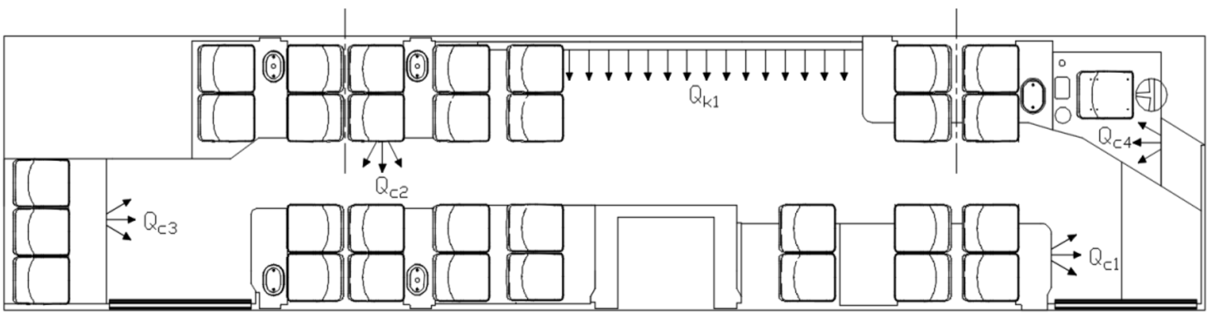

Fig. 1. Scheme of the research object with the location of the heating system

3. Experimental research

An experimental test was carried out under reduced temperature minus 15ºC using a large-scale thermoclimatic chamber of the Laboratory of Techno-Climatic Research and Heavy Machines of the Faculty of Mechanical Engineering, Cracow University of Technology, characterized by the following parameters:

- the range of stabilized temperature limits –50°C-+70°C,
- the accuracy of temperature stabilization at selected level: ± 2 °C,
- internal dimensions: 19.4 [m] x 7.8 [m] x 8 [m],
- range of air velocity in the chamber: 0-3 [m/s].

Temperature measurement was done using resistive sensors Pt-100/3 and three-wire compensating measuring lines. For registration, dedicated temperature modules were used to cooperate with the diagnostic system to monitor and record the measured air temperature values. The measurement and diagnostic resolution of the temperature measurement system used were 0.1°C. The system automatically calibrates itself and allows the measurement at 1 Hz, due to the slow change values being sufficient.

The purpose of the test was to perform tests in a thermoclimatic chamber designed to determine the proper design, proper distribution and to determine the efficiency of heating a 12-meter city bus under lowered temperature conditions to minus 15°C. The test included determining the course of the passenger bus heating process and the time of temperature stabilization in the vehicle inside when operating heating systems. An additional attempt was made to test the heating system while the vehicle stopped and opened the vehicle door to simulate stopping the vehicle at the bus stop. Another aspect that was analysed was the impact of the installed convector on the vehicle when the liquid heater was off. Temperature sensors were installed outside the object in the chamber space, and inside the object being tested. Inside the vehicle, a grid of thirty-one temperature sensors was installed, allowing a temperature map of the vehicle space to be prepared (Fig. 3). Twelve transducers were installed at three heights: 300, 1200 and 1800 mm from the vehicle floor in the driver's compartment area and in the front, middle and rear door areas. Twelve sensors were installed in various vehicle areas at 300 and 1800 mm, five sensors installed at 1200 mm between the seats and 2 sensors have been installed on the additional heat exchanger and the convection blower. The distribution of installed sensors together with the location of the test vehicle in the space of the thermoclimatic chamber shows Fig. 2.

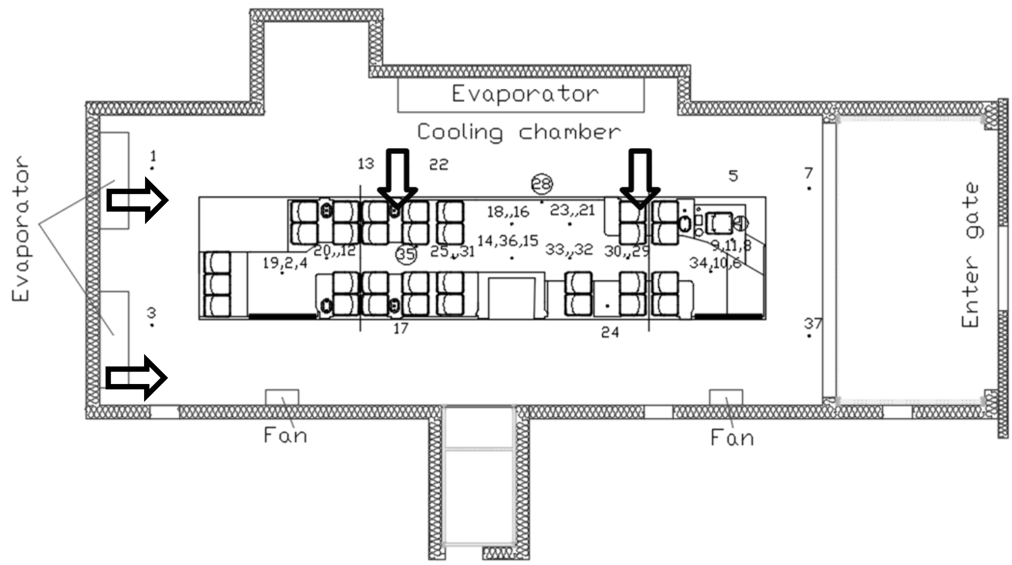

Fig. 2. Location of the temperature transducers in the tested vehicle

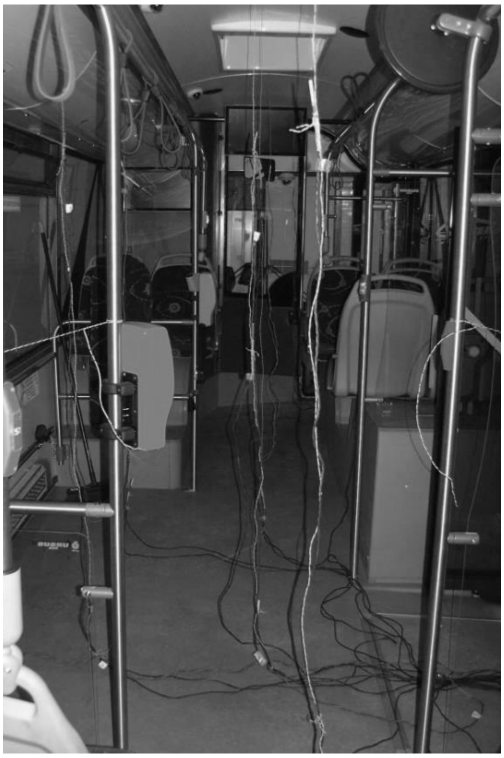

Fig. 3. Sensor grid of installed transducers inside the vehicle

The verification process of the heating system began with the vehicle entering the thermoclimatic chamber, lowering the temperature to minus 15°C and then holding the object at reduced temperature until it was fully cooled. The next stage, after stabilizing the temperature of the entire test object, was to start a proper test, starting the engine of the vehicle and switching on the heating system to the vehicle. This is illustrated in Fig. 3, which shows the temperature distribution of the sensors located on the liquid heater outlet (T35) and the liquid convector outlet (T28). Additionally, the average outdoor temperature distribution (TOT) is also shown.

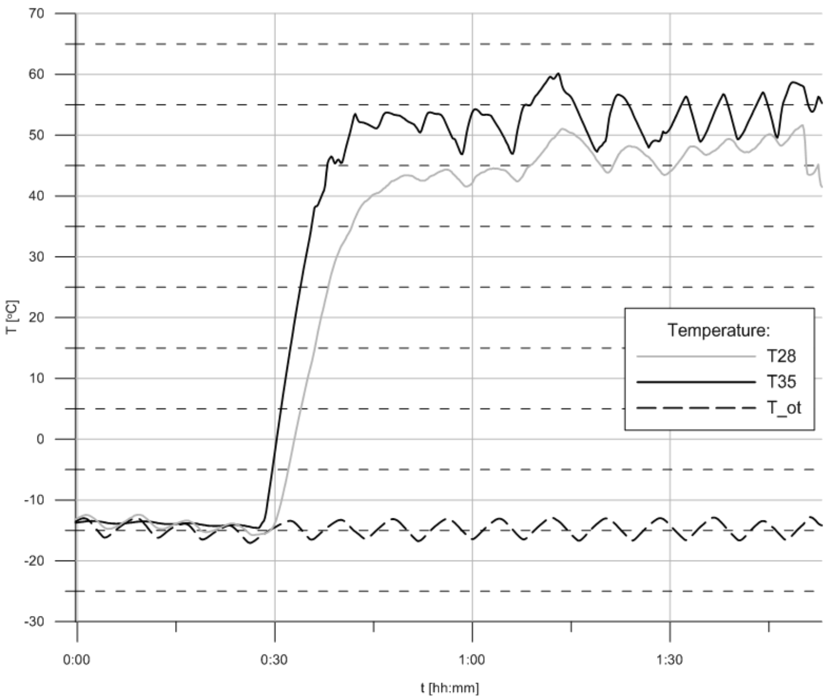

Fig. 4. Plots of system parameters for the heater (T35) and the convector during the test stand (T28)

The temperature at the liquid heater outlet after about 15 minutes reaches the oscillating temperature around plus 50°C, while the temperature at the liquid convector after about 20 minutes reaches a temperature of over 40°C. The work of heating systems looks correct throughout the test period; the observed fluctuations in temperature are typical for such devices and result from the operation of the regulation system. The Fig. 5 and 6 show the temperature distribution in the interior of the vehicle, recorded during the test for sensors located at three heights of 300, 1200 and 1800 mm from floor level and located in different areas: rear door, central door zone, front door zone.

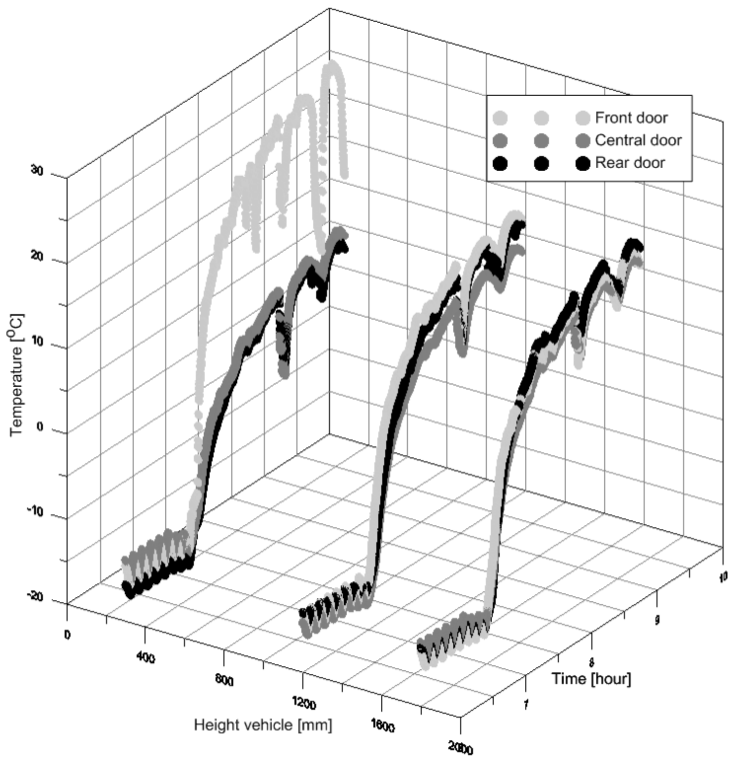

Fig. 5. Temperature changing in the inside of the vehicle, located at three heights (300, 1200, 1800) and in three door location areas (front, central, rear)

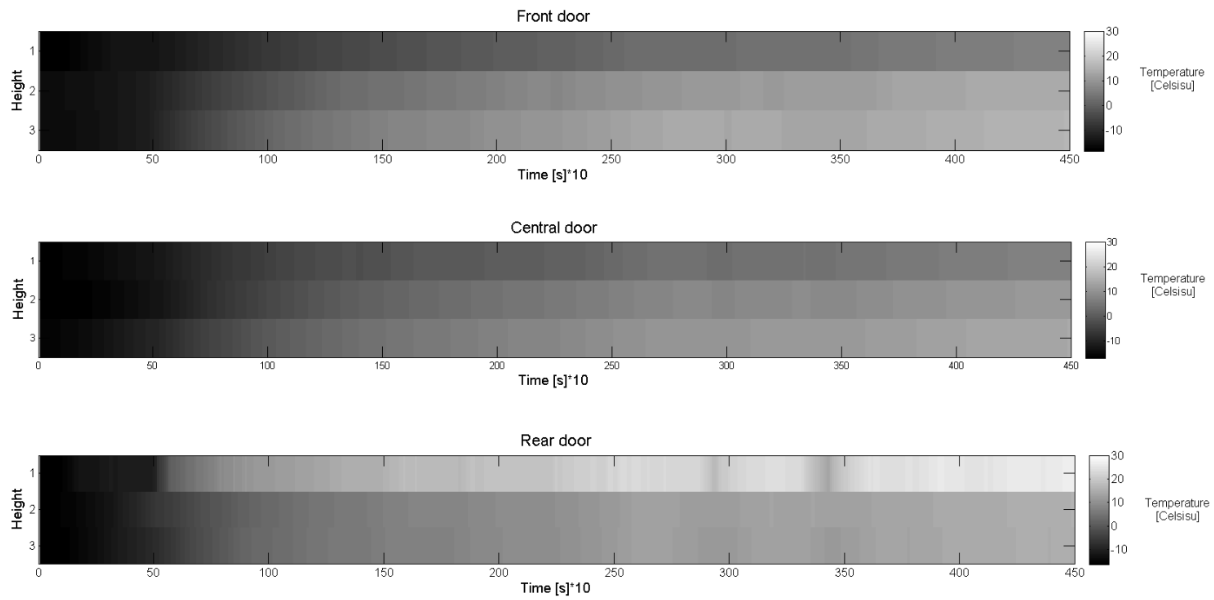

Fig. 6. Temperature changing in the inside of the vehicle, located at three heights (1-300 mm, 2-1200 mm, 3-1800 mm) and in three door location areas (front, central, rear) in the colour chart

This plot very well illustrates the temperature distribution of the tested object in the form of temperature-domain planes, which are formed from the lowest point on the floor of the vehicle to the highest one under the roof. The distribution of these temperatures is correct as evidenced by the correct selection of the heating system and the proper location of the airflow of heaters. Significant differences can be observed in the rear door area where the highest temperature is at the lowest level (300 mm distance from the floor). This is conditioned by the location of the airflow of the heater in the rear, which directly affects the distribution in that part of the vehicle.

Figure 7 shows the distribution of temperatures in three surface (300, 1200 and 1800 mm) and distribution along the length of the vehicle.

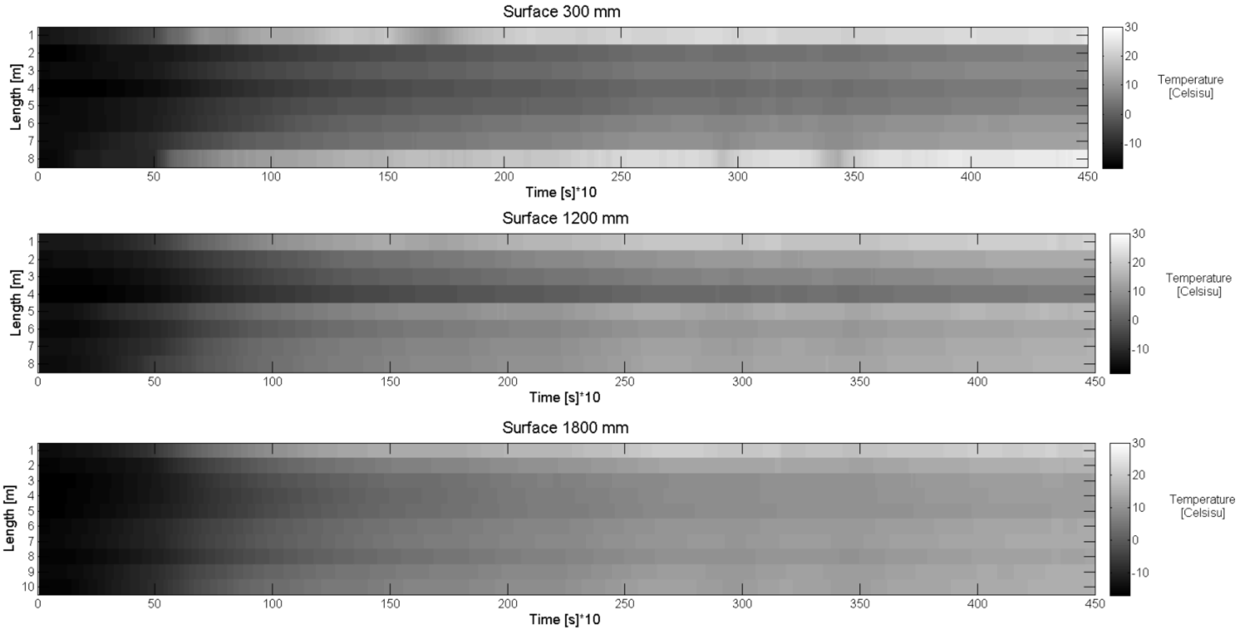

Fig. 7. Plots of temperature distribution in three surface and along the vehicle

The presented Fig. 7 highlights the effects on the heater's temperature field causing increased surface temperatures of 300, 1200 and 1800 mm from the floor of the rear door as well as around the front door. It is possible to observe areas of temperature differentiation; however, these differences are acceptable and are related to air movement. After analysis, it was determined that the temperature in the rear, centre and front door areas after about 1.5 hours after the start of the heating system reached the temperature range of plus 11°C to plus 16°C.

A test simulating the stopping of the vehicle and the opening of the door at the bus stop caused a drop in temperature in the door opening coin and the temperature stabilized at plus 6°C.

Turning off the heater and running, only the heating system with the engine coolant resulted in a lowering of the temperature of the test object; however, this system allows the user stabilizing the temperature. It can be used as an auxiliary heat source.

4. Summary

The test to determine the efficiency of the vehicle’s heating was carried out in three phases: the first phase consisted of starting the heating system until the temperature stabilized, the second phase consisted in the simulation of stopping the bus at the bus stop by opening the door; the third phase consisted of checking the efficiency of the heating only by heating from the running engine.

The proposed test procedure enabled the determination of the characteristics of the minimum warm-up time of the inside of the vehicle to meet the comfort conditions as a function of the ambient temperature. The analyses presented in the paper show that it is possible to extend the design of the vehicle designer, earthmoving and construction machines, and other devices for thermal comfort through experiments conducted on the prototype. The developed methodology of conducting tests allows determining the temperature fields, the proper positioning of elements of the heating and air conditioning system, and the appropriate choice of heat system power. Verification of the appearance of thermal bridges, determination of the heat transfer coefficient for individual representative structural elements of the examined object, with the possibility of taking into account the general coefficient of heat loss.

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