Experimental investigation of car cabin environment during real traffic conditions

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Abstract In the paper, the authors refer to measurement of a car cabin heat load and indoor environment during driving in real traffic conditions. The main goal was to obtain data for boundary conditions, model testing and results comparison of the 1D car cabin heat load model. Secondary aim was better understanding of cabin environment inside a car cabin under different operational conditions. As test vehicle Škoda Felicia Combi with dark blue painting was used and GPS data, parameters of ventilation, cabin environment and ambient environment were measured. Measurements were preformed for summer, autumn and winter conditions including parking and driving test circuits around Brno. Driving circuit included driving in the city, out of the city and on the highway D1.

1 Introduction

The 1D model is designed to simulate thermal behaviour of a car cabin during real operational conditions. The model was implemented in Modelica language, which allows using a causal programming and the scheme in the Fig. 1 shows main interfaces, important data parameters and main outputs of the model. Heat loads of the car cabin depend on the weather data, HVAC system setup and on the position and bearing of the car (GPS data). These data are used by the model to calculate heat transfer inside and outside the car cabin, surface temperatures of the cabin exterior and interior, cabin air temperature, cabin air relative humidity and heat loads.

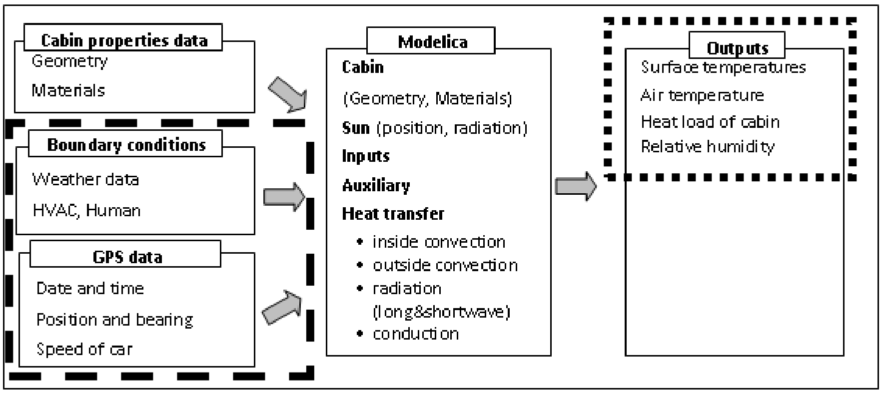

Fig. 1 Flowchart of the car cabin model – input data (dashed box) and data for results comparison (doted box) obtained from real traffic measurements are highlighted.

For testing of model functionality, comparison and validation of model outputs/results the measurements of the real car cabin environment was performed. The main purpose of the measurements was to obtain two groups of the data. The first groups represents all data used as boundary conditions of the model (see Fig. 1 - dashed line box) and the second one represents data which characterized cabin environment and heat transfer in the cabin (see Fig. 1 - dotted line box). After post processing of the data from measurements, the first group of the data was used as boundary conditions for transient simulations. The results of simulations (surface temperatures and cabin environment parameters) were then compared with data from the second group to verify accuracy of the model predictions.

2 Test car and measurement equipment

As test vehicle Škoda Felicia Combi with dark blue painting was used (see to Fig 2.). The car was equipped by sensors (see to Fig. 2 and for detail description see Tab.1) which were divided into groups based on purpose of measured parameters. Main group was focused to obtain boundary conditions for simulation which included measurement of weather conditions (ambient air temperature, air humidity and solar intensity), temperature of air from HVAC system and temperatures of the air in the trunk, in the engine space and ambient air temperature under the cabin floor. Other sensors collected data for comparison and validation of the model results, were split into two groups. The first one included sensors which measured surface temperatures and second one included sensors which measured cabin environment (these sensors were located on co-driver and left rear seat).

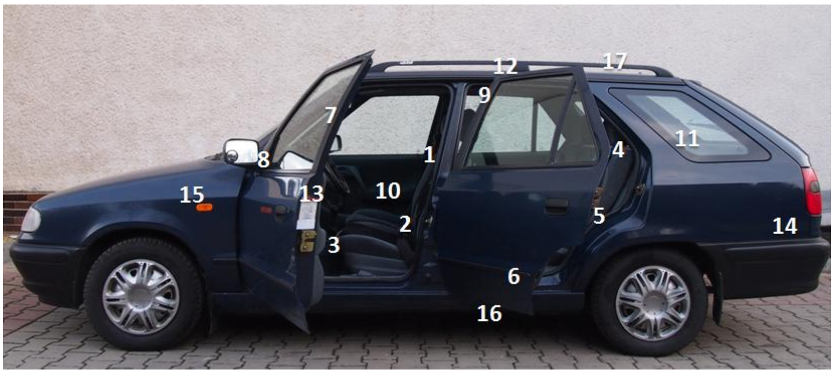

Fig. 2 Test vehicle Škoda Felicia - numbers denotes sensor placements (see Tab. 1.).

The connection of sensors, Testo loggers, Programmable logic controller ELSACO and notebook Acer is shown in figure 3. Most of the sensors were connected with loggers and PLC by wires, but for measurements in inaccessible spaces (the trunk, engine space etc.) and for measurement on the car roof, wireless data transmission equipment was used. The position, bearing, speed and altitude of the car was measured by cell phone Nokia 6220 with internal GPS module and Sport tracker software was used for data logging. All data from measurements were synchronized by time code and post processed in Excel sheet with Visual Basic macros.

	Co-driver front seat			Rear seat on the left			Exterior and interior surfaces						Boundary conditions				
	Head	Torso	Feet	Head	Torso	Feet	Windshield	Dashboard	Roof int.	R. door int.	R. glass int.	Roof ext.	Outlets	Trunk	Engine space	Under car	Weather
Measured location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Air temperature	**C**	**C**	**T**	**P**	**P**	**P**	–	–	–	–	–	–	**T**	**T**	**T**	**T**	**C**
Surface temperature	–	**P**	–	–	–	–	**P**	**P**	**P**	**P**	**P**	**T**	–	–	–	–	**T**
Air velocity	**C**	–	–	–	–	–	–	–	–	–	–	–	**C**	–	–	–	–
Relative humidity	**C**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**C**
Globe temperature	**G**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Solar intensity	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**V**

Tab. 1 Sensor placement and measured quantities: C – Testo with combined probes, G – globe thermometer, P – resistance thermometer PT100, T – thermocouple, V – photovoltaic (PV) panel.

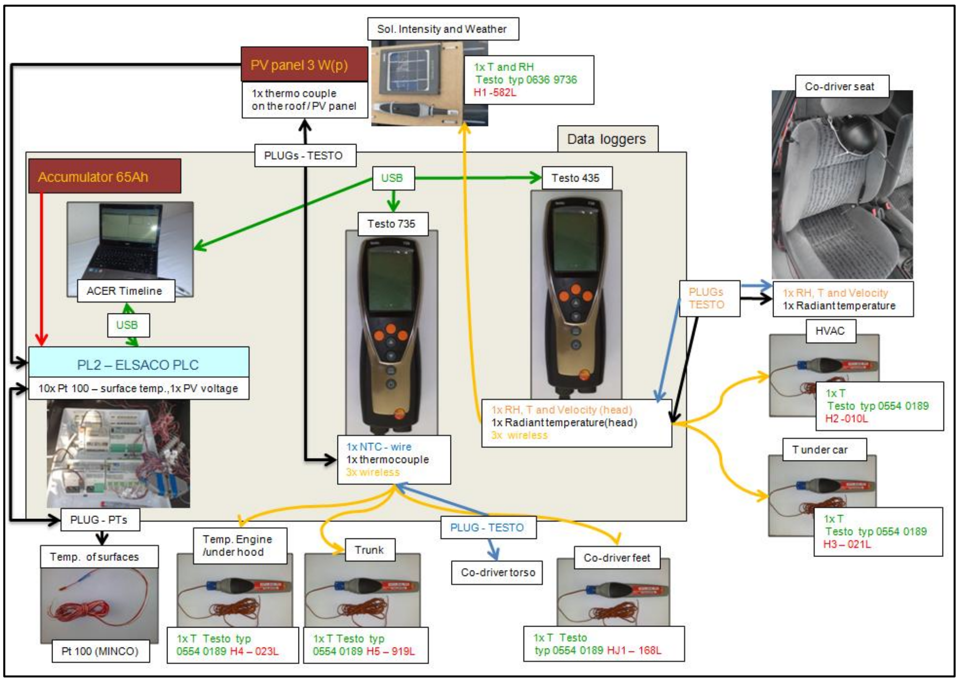

Fig. 3 Schematic connection of measurement equipment.

3 Main results from test circuit measurement

Measurements were performed for summer, autumn and winter conditions including parking and driving test circuits around Brno. Driving test circuit included driving in the city, out of the city and on the highway D1. The main results from parking test cases were presented in the paper [1]. Following paragraphs are focused on the main results of winter driving test and data are presented in form of averaged values to provide an overview about measurement results.

The first group of data describes boundary conditions. The weather conditions during winter driving test (26th January) were cold and dry, the sky was overcast. Solar intensity on the horizontal plane (roof) was 48 W/m^2, ambient air temperature was 0.5 °C and relative humidity 57 %. Maximal speed of the car was 86.8 km/h and average speed was 54.6 km/h, the route led from Brno to Vyškov and back. During driving circuit the car cabin was occupied by two persons, the ventilation was switched on and the fan controller was set up on the 2nd level. The air was distributed to the cabin from middle outlets with the horizontal direction of outlets flaps and from the defrost outlet under windshield. Volumetric flow of ventilation air was 27 l/s and its temperature started on 10 °C and after 10 minutes it value was stabilized on 36 °C. Air velocities at outlets were about 3.3 m/s, however far from the outlets air velocities was much lower, at the head level of co-driver it was 0.13 m/s. Due to the fact that the primary flows were non isothermal and strongly affected by buoyancy the strong vertical air temperature difference was observed at the beginning of the test (see Fig. 4). From the figure can be seen that, the head-feet temperature difference dropped from 11.4 °C (time 14:10) to the 5 °C (time 15:18) as result of air mixing and temperature stratification inside the cabin. There is also seen significant difference between responses to heating at feet level against head and torso level. The response at feet level was very slow and it took more than one hour to reach the stable value close to 16 °C. In contrary at torso and head level the response time was quite short; the air temperatures reached stable values in few minutes after stabilization of ventilation air temperature. Since only central and defrost outlets were opened, the main stream flowed between front seats to the rear seat. From this reason the response time was shorter in case of rear seat against co-driver seat. Other boundary conditions were: air temperature under the car 5.5 °C, in the engine space 11.3 °C and in the trunk 5.6 °C. Floor and firewall are obviously well insulated, thus temperature in engine space and under the car have not great impact to the cabin environment. Air temperature in the trunk was much lower than in the cabin because the space of the trunk was covered by shell thus the cabin-trunk circulation of air was very low.

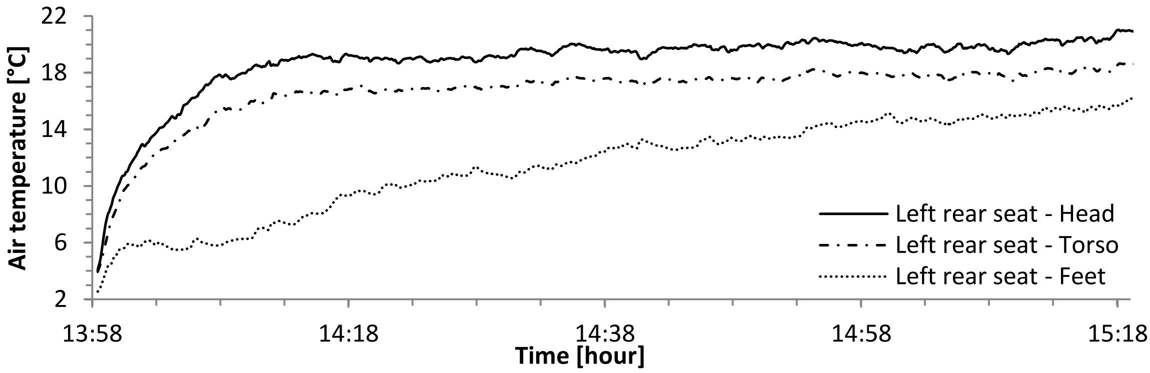

Fig. 4 Air temperatures inside cabin at the rear seat on the left - winter driving test.

The second group of data was used for comparison and validation of the model results:

- Surface temperature of cabin exterior: roof 2.2 °C
- Surface temperatures of cabin interior: roof 18.5 °C, seat 15.8 °C, right side door 11.4 °C, dashboard 14 °C, right side window 7.1 °C and windshield 6.1 °C
- Air temperatures at co-driver's seat: head 18.9 °C, torso 16.8 °C and feet 11.9 °C
- Air temperatures at rear seat on the left: head 17.9 °C, torso 15.9 °C and feet 12.2 °C
- Relative humidity inside cabin 27 % (at co-driver's head)

During winter driving circuit the coldest interior surfaces were windows, due to the low thermal resistance of glass. The temperature of exterior surfaces and interior glassed surfaces was dependent on the car speed. For example, the temperature of roof exterior dropped after start from initial temperature 7 °C to the 1 °C in 30 minutes mainly due to higher outside convection caused by higher car speed.

4 Conclusions

The mobile measurement system was designed for measurements of boundary conditions and car cabin environment during real driving tests. Measurement presented in the paper was performed in the real traffic conditions. Together with results presented in the paper [1] authors collected the set of data for testing, calibration and result comparison of 1D car cabin model.

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Literature

[1] POKORNÝ, Jan., FIŠER, Jan, JÍCHA, Miroslav. Calibration of the Heat Balance Model for Prediction of Car Climate. *In Experimental Fluid Mechanics 2011,* Conference Proceedings Volume 2. 1. Liberec, Technical University of Liberec. 2011. p. 928 - 931. ISBN 978-80-7372-784-0.