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# Determination of clothing heat transfer coefficients for use in the iHVAC system

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Róbert Toma, Kristýna Hrubanová, Jan Fišer, Miroslav Jícha

*Brno University of Technology, Czech Republic*

## Introduction

As standards of comfortable transportation is improving rapidly throughout the last years, automotive companies are more focused on thermal comfort of the passengers to differ themselves from the competition. Another valid reason for improving thermal comfort in car cabins is the large energy consumption of the current HVAC systems, which cause higher fuel consumption for combustion engines and reducing the range of hybrid and electrical vehicles.

The iHVAC (innovative Heating Ventilation and Air-conditioning system) is one of the systems, which evaluates car´s thermal environment and predicts human´s thermal sensation with respect to spatial asymmetry. This system works on the principle of equivalent temperature and comfort zone diagrams[1]. One of the key input data for successful thermal environment prediction by iHVAC system is the information about occupant´s clothing. The aim of this study was to measure the values for typical clothing ensembles for the use in the iHVAC system and to test repeatability of the measurement method. As it is indicated in EN ISO 14505, the heat transfer coefficients are dependent on the ambient temperatures and the last part of the study is to verify whether measurements in multiple ambient temperatures are needed to obtain precise values.

## Methods

The experiments took place at the climate chamber at the Brno University of Technology. The measurement procedure was created as a combination of two standards – EN ISO 15831 [2], which describes the measurement of the clothing thermal resistance, and the appendix C of EN ISO 14505 [3] describing the measurement of the heat transfer coefficients, which are needed for the evaluation of a thermal environment by means of equivalent temperature and comfort zone diagrams[4].

The manikin was suspended in seated position with surface temperature set to 34 ± 0.2°C in a calibration box [5] to ensure air velocity around the 0.05m/s value to provide uniform environment according to EN ISO 14505. Four different cases of pre-set ambient temperature were measured: 16, 20, 24 and 28 °C. Five typical clothing ensembles used for driving were measured to update the heat transfer coefficients values in the iHVAC app and thus enhance its accuracy. The “autumn” ensemble was measured three times to test the repeatability of the procedure and results for this ensemble are presented.

## Results and discussion

Firstly, the effect of changing temperature difference between manikin surface and ambient temperature on heat transfer coefficient values was investigated and example can be seen in Figure 1. It was found that with larger temperature difference (case 16°C) and thus larger heat flux from the manikin, the values of heat transfer coefficients were higher, which is caused by thermal plume around manikin´s body. This applies to all manikin´s segments except feet. Observed abnormality on feet could be caused by the small distance (around 15cm) of the ambient temperature sensor used for feet calculations from the thermal manikin. Thus, the measured ambient temperature was probably affected by the heat from the manikin.

Secondly, it was found that heat flux from thermal manikin was lower than 20 W/m$^2$ for some segments of the ensembles during the case with ambient temperature set to 28°C, which is not allowed by the standard EN ISO 15831. Although the heat flux was too low for some cases, it was found that the precision of the measurement was maintained and thus, this temperature could be still used despite the conflict with the ISO standard.

Thirdly, values of heat transfer coefficient on face are increasing throughout the measurements even though the face is always without any coverage. This is probably caused by differences in boundary layers between the cases, that are affected by ambient temperature and consequent changes in heat fluxes on the face to maintain constant skin temperature.

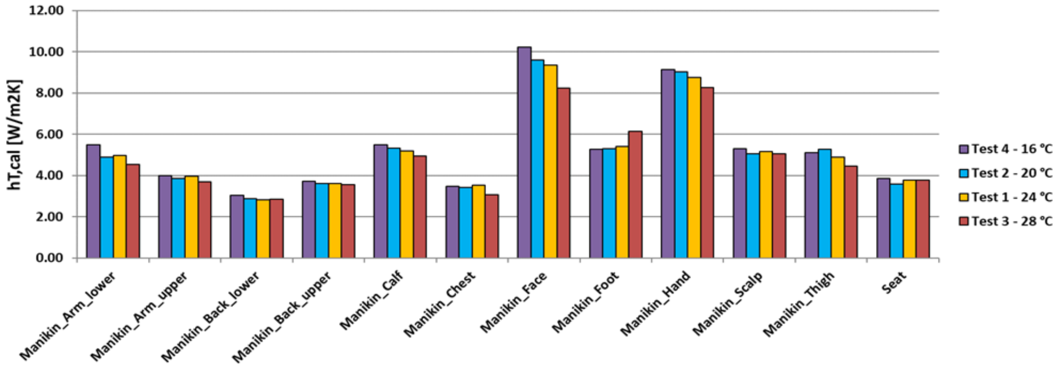


**Figure 1: Example of the results for "autumn" clothing ensemble in 16 to 28°C**

Finally, the repeatability of the procedure was investigated on "autumn" clothing ensemble (Figure 2) and all values lie within the 10% range from the average value for each body segment. The measurement shows high repeatability, even when the whole measuring stand was disassembled and then mounted back between the tests.

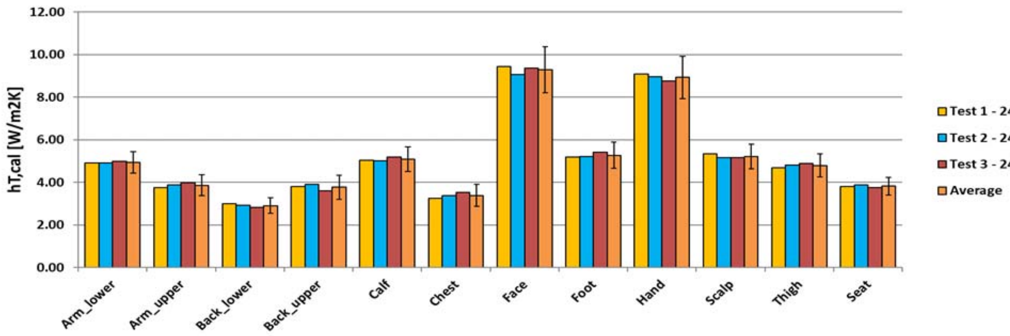


**Figure 2: Analyse of measurement repeatability on "autumn" clothing ensemble in case using 24°C**

## Conclusions

To conclude, it can be deducted from analysed data that the temperature difference has no significant impact on the value of heat transfer coefficient and thus we proved it is acceptable to conduct measurements for only one ambient temperature. EN ISO 14505 standard recommends using the temperature of 24°C. Our investigation agrees with this recommendation as we observed good repeatability while using this temperature, which is also advantageous for climate chamber lower energy consumption.


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