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Equivalent temperature calculation: The issue of total thermal resistance for Face and Scalp parts measured by thermal manikin

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Jan Fišer, Jan Pokorný, Miloš Fojtlín, Róbert Toma and Miroslav Jícha

Brno University of Technology, Czech Republic

Introduction

A thermal comfort evaluation based on the Equivalent (homogenous) temperature and Comfort zone diagram method was found as a progressive, promising and widely used routine [1]. The main idea of the method was published already in 80's by Madsen and Wyon, in 90's it was extended by Holmér, and the method was finalised by Håkan O. Nilsson in his PhD thesis [2] and in the paper [3] published in 2007. In 2002, Gameiro da Silva reported that "the concept of equivalent temperature is nowadays widely used to evaluate the thermal environment in cars" and "ISO Standard is currently in preparation, including some of the major findings of the European Project EQUIV" [4]. A standardization process was successful and the method is established in the standard ISO 14505, where principles, measurement procedure, measurement equipment, and evaluation of thermal comfort are described.

The method published by Håkan O. Nilsson in thesis [2] and paper [3] was adopted and interpreted by the team of Thermal comfort laboratory at Brno University of Technology in 2009. The main application areas were CFD simulations of cabin environments connected with a thermal comfort prediction [5]. In 2011 the Newton type manikin was purchased, and the laboratory was able to start experiments with measurements of equivalent temperature. This procedure consist of calibration of total thermal resistance RT_{cal} of clothing and calculation of comfort zone diagram base on procedure from [3]. The measured values of RT_{cal} were identical with reported ones from [3] for the most parts, however, unexpected results were obtained for part Face. This issue was directly discussed with H. O. Nilsson and K. Kuklane and first evidence was published in [6].

Base on this fact, the team of Thermal comfort laboratory designed an experiment to verify the values of total thermal resistances and calculations of equivalent temperatures for body parts Face and Scalp.

Methods

Based on [2, 3], the equivalent temperature for each body part of the manikin is defined as follows:

$$t_{eq} = t_s - RT_{cal} \times q \tag{1}$$

where t_s is the skin/surface temperature of the manikin, RT_{cal} is the total thermal resistance of the clothing and/or the air boundary layer obtained from the calibration, and q is the dry heat lost from the given body part. RT_{cal} values are also used in Eq. (2) to calculate the comfort zone diagram

$$t_{eq,zone} = t_s - RT_{cal}(a + b \times MTV_{zone}) \tag{2}$$

where a and b are the linear regression constants and *MTVzone* is the value of the mean thermal vote to set boarders among the comfort diagram zones. The total thermal resistance on the given body part of the manikin is calculated as follows:

$$RT_{cal} = \frac{t_s - t_{amb}}{q_{part}} \tag{3}$$

where q_{part} is the heat flux necessary to maintain the prescribed surface temperature t_s of the manikin's body part (typically 34 °C), and t_{amb} is the temperature of the ambient calibration environment (typically 24 °C). Two types of clothing were measured in the presented work: LS clothing with RT_{cal} of 1.0 clo and EW clothing with RT_{cal} of 1.7 clo. Next, the RT_{cal} for parts Face and Scalp were calculated by Eq. 3 and then used in Eq. 2 to calculated t_{eq} for *MTV = 0* (constants a and b same as in the paper [3], Table 1.)

Results and discussion

The RT_{cal} and t_{eq} for the part Scalp are within the typical error of measurement (Figure 1, Table 1), and the present study confirms the results from paper [3] for this part. The RT_{cal} values for Face, presented in [3], are two times higher compared to our findings. This is also reflected in the resulting t_{eq} (Figure 1 - on the right). These results are completely inconsistent, because if the RT_{cal} values tabulated in [3] are the same for the Face and the Scalp then (based on Eq. 2) T_{eq} for both have to be the same as well.

Table 1. Comparison of RT_{cal} and $t_{eq}(0)$ for MTV = 0

	Present study				Nilsson 2007 [3]			
	LS		EW		LS		EW	
Part	RTcal	Teq(0)	RTcal	Teq(0)	RTcal	Teq(0)	RTcal	Teq(0)
Face	0.107	27.0	0.104	27.2	0.199	25.7	0.193	17.2
Scalp with hair	0.194	21.3	0.188	21.7	0.199	21.0	0.193	21.4

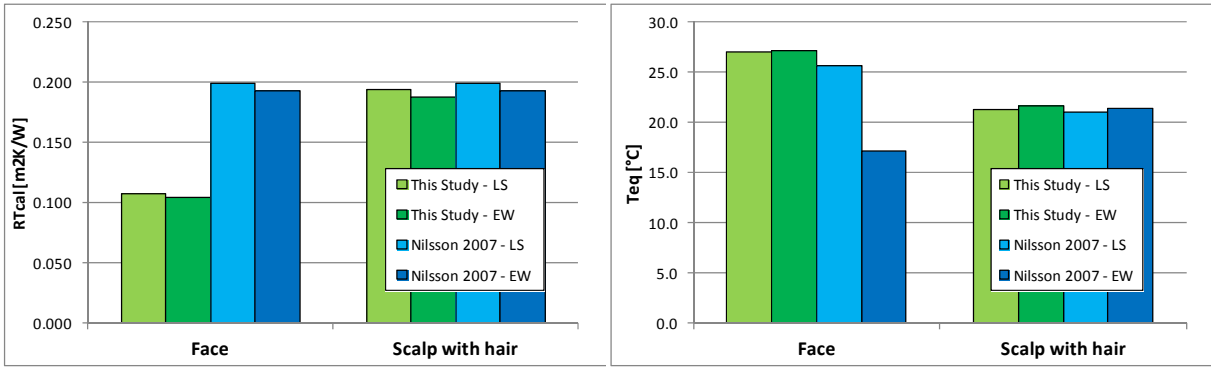

Figure 1.Data for RT_{cal} (left hand side) and T_{eq} (right hand side) in graphical form

Conclusions

Based on our results, we conclude that the originally presented values of RT_{cal} for the Face are incorrect and their use in Eq. 2 leads to incorrect equivalent temperature for Face part. The authors of the study made further tests to verify the relationship between t_{eq} vs. MTV for Face and Scalp and to obtain new data to correct regression constants *a* and *b* for Eq. 2.

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References

[1] Liu, W. Mazumdar S., Zhang, Z., Poussou ,S.B., Liu, J., Lin, CH., Chen, Q. State-of-the-art methods for studying air distributions in commercial airliner cabins. Building and Environment 2012;47:5–12.

[2] Nilsson, H.O. Comfort climate evaluation with thermal manikin methods and computer simulation models. Stockholm: National Institute for Working Life; 2004.

[3] Nilsson, H.O. Thermal comfort evaluation with virtual manikin methods. Building and Environment 2007;42:4000–4005.

[4] da Silva MCG. Measurements of comfort in vehicles, Measurement science and technology 2002;13:41–60.

[5] Volavý, F., Fišer, J., Nöske, I. Prediction of air temperature in the aircraft cabin under different operational conditions (2013) EPJ Web of Conferences, 45, art. no. 01096, .

[6] Fišer, J. Impact of variance of clothing thermal resistance on comfort zone diagram modification (2014) Indoor Air 2014 - 13th International Conference on Indoor Air Quality and Climate, pp. 95-99.