The effects of air channel construction and design elements on heat transfer characteristics of bicycle helmets for commuters

Aljaste, Helena; Kuklane, Kalev; Heidmets, Sixten Sebastian

Published in:
International Cycling Safety Conference 2015

2015

The effects of air channel construction and design elements on heat transfer characteristics of bicycle helmets for commuters

H. Aljaste[*,†], K. Kuklane[#,†], S.S. Heidmets[*,†], COST Action TU1101 WG4[†]

[*] Department of Product Design
Estonian Academy of Arts
Estonia pst. 7, EE-10143 Tallinn, Estonia
e-mail: helena.aljaste@artun.ee

[#] Department of Design Sciences
Lund University
Sölvegatan 26, Box 118, SE-22100 Lund, Sweden
e-mail: kalev.kuklane@design.lth.se

[†] HOPE–Helmet OPtimization in Europe, COST Action TU1101 Working Group 4 with the participation of Jean-Marie Aerts, Simon Annaheim, Cornelis P. Bogerd, Peter Bröde, Guido De Bruyne, Andreas D. Flouris, Anica Hursa, Tiago S. Mayor, René M. Rossi
http://www.bicycle-helmets.eu/

ABSTRACT

The earlier studies in this measurement series defined the limits and aims for design process to create better ventilating helmets [1], and tested the insulation [2] and evaporative characteristics [3] of the designed mock-ups. In addition some of the tested mock-ups were modified to study more closely the factors that were expected to improve heat transfer from the bicycle helmets. The present paper covers making a new prototype that allowed modifications of the air channels and in- and outlet openings. In total 2 new helmet design concept mock-ups were created and tested with 13 modifications in comparison with 6 selected helmets from the previous studies including the modified versions. The mock-ups were tested at the Thermal Environment Laboratory, Lund University for insulation and evaporative resistance. Dry tests for insulation were carried on at 20 °C temperature in a wind tunnel on a thermal head manikin at the chosen air velocities of 1.6 m/s on a bald head and 1.6 m/s and 6 m/s with the wig in order to simulate the effect of hair. Wet tests were carried out with textile skin on the head manikin, using the air velocity 1.6 m/s with and without the wig. As the main result it was concluded that a well ventilating helmet is characterized by less contact with the head, and proper air channels with strategically placed air inlets and outlets. Large openings worked much better than a several small ones, yet, the care has to be taken as too large openings reduce the helmet protective capabilities. The shape and other design related modifications of the air inlets and outlets had minimal effect on ventilation.

Keywords: bicycle helmets, insulation, ventilation, evaporative resistance, design.

1 INTRODUCTION

The number of adult bicycle helmet users in Sweden has stayed over the years relatively stable around 20 % [4] In Europe the number of helmet users varies between 1 and 40 % depending on country. Research has shown that the use of helmet considerably diminishes head injuries in the case of traffic accidents [5]. In spite of that it is not fully clear what are the main factors why only a small number of bicyclists use a helmet.

Why helmet use is not popular? Several reasons could be pointed out: design, destroys the hair style, attitudes against helmet use, nowhere to put, too warm etc. Often the initial complaints are related to heat [6]. In cold additional insulation from the helmet may be a positive factor while compatibility issues with other clothing or items may rise.

As the professional bicyclists and most training/competing amateurs do wear the helmets then the aim for traffic safety should be increasing helmet use among commuters, and bicyclists who go cycling just for fun. Therefore, a project was initiated where the main aim was to reduce thermal disturbance from a bicycle helmet while keeping in mind visibility, protection aspects, look, and issues related to wearing comfort etc. The work aimed for testing and comparing various design solutions that may lead to good helmet ventilation for commuters [1,2,3]. Therefore, in order to promote creativity and avoid the helmets look like the one in supervisors mind, then the participating students were encouraged for wide freedom of action. After testing the solutions [2,3] a new helmet was created to allow modifications, and these were tested for insulation and evaporative resistance in order to find specific positive design elements for increasing ventilation and eliminate these that did not allow improvements. The modifications were compared to earlier solutions and helmets available on the market.

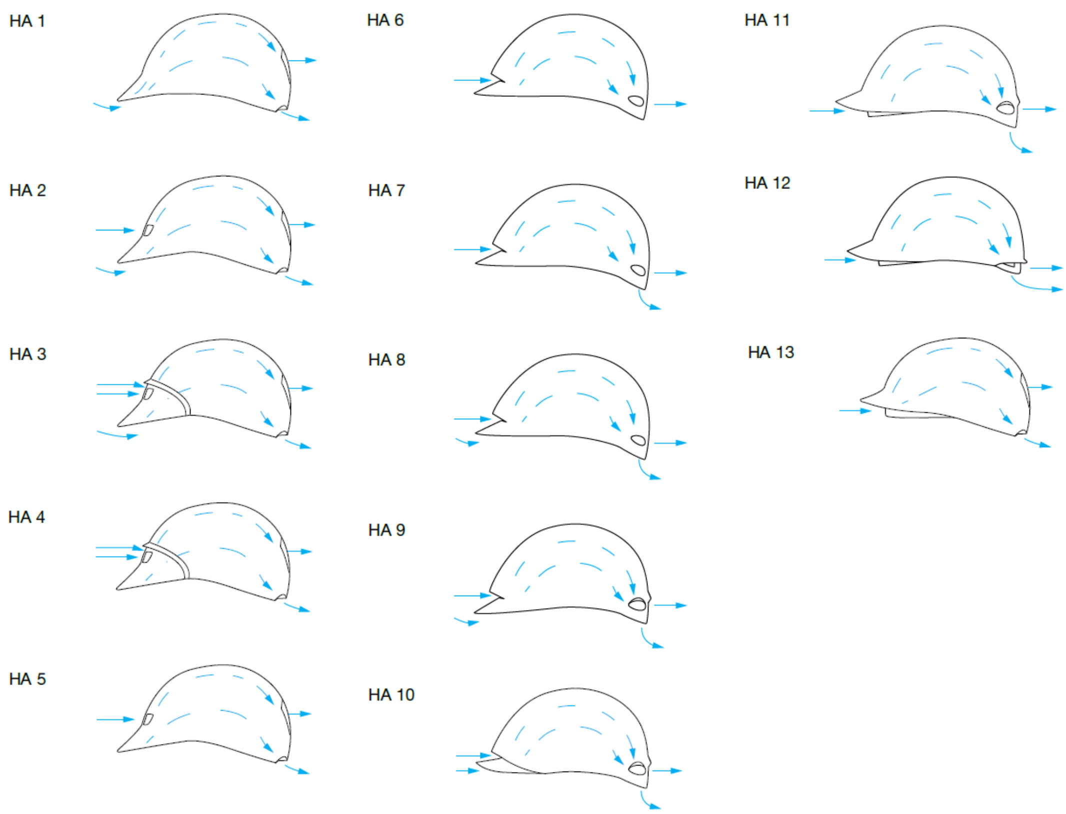

Figure 1. The alternative modifications of the design helmets with arrows showing the inlet and outlet locations and the expected flow paths.

2 METHODS

The 1:1 scaled bicycle helmet mock-ups (Figure 1) were tested at the Thermal Environment Laboratory, Lund University for their dry (insulation) and wet (evaporative resistance) heat transfer characteristics in a wind tunnel (Figure 2) on a thermal head manikin (Figure 3a, [7]). Due to the time limit all helmet modifications and reference helmets were not tested in all conditions.

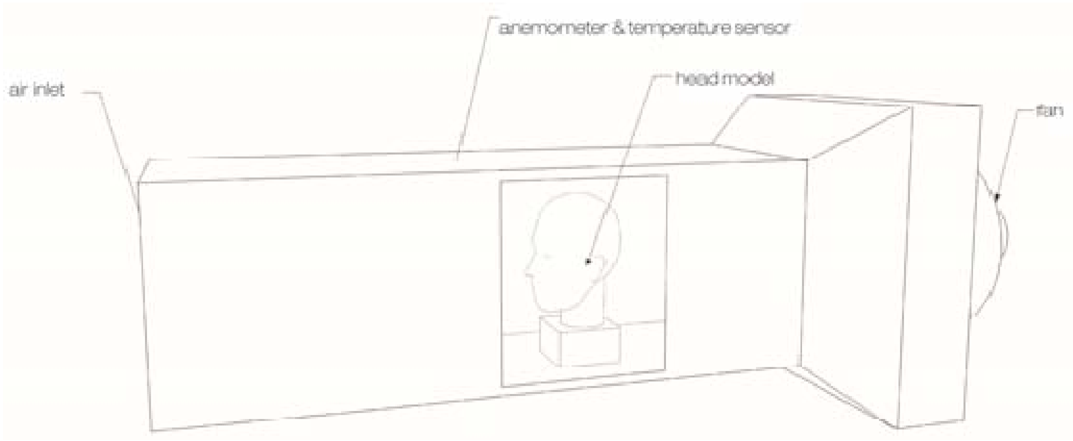

Figure 2. The measuring setup in wind tunnel. Air inlet was filled with 16 mm diameter and 50 cm long plastic tubes and fan was set on sucking air. Air velocity and temperature sensor was placed 30 cm in front of the head form.

2.1 The helmets

Two basic but in principle similar helmet mock-ups were prepared under the design process. There was used similar air channels system as RP - one of the best ventilating helmets from previous studies, though more foam and larger covering area was used to ensure safety. These mock-ups were alternately tested and modified. The tested alternatives differed by air inlet and outlet positions, their size and shape, and number of air channels, their cross section and position. Figure 1 shows the alternatives of the design helmets with arrows showing the inlet and outlet locations and the expected flow paths.

Figure 3. a) The head model as it is, with a wig and with a textile "skin" for "sweating" tests, and b) the tested helmets available on the market.

In total there were 2 new concept mock-ups with 13 modifications all together (Figure 1), 2 helmets from the market tested for reference (Figure 3b), and 4 selected helmet mock-ups from previous study (Figure 4). The tested reference helmets were: Etto - tested by Aljaste et al. [2] and Kuklane et al. [3]; H5 - from a study by Brühwiler et al. [8]; LLn - LL modified by padding lifting the shell in order to create the air channels under the open shell structure; PUn3 - last modification of PU by further expanding the air channels on top of the support structure of the shell; RP; and SSn - SS with additional material reducing inlet and outlet size by vertical bars in order to manage impact test for curb stone. Head model without any helmet (Figure 3a) was tested as reference point in the selected conditions, too.

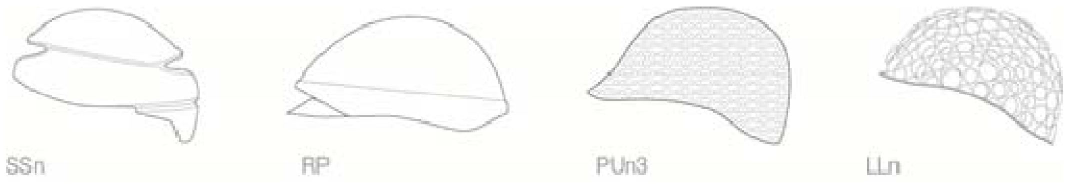

Figure 4. Helmets' mock-ups from the previous studies.

2.2 The head form

The head form (Figure 3a) consisted of six measurements sections: face, forehead, skull, neck, left and right ear. The head form was heated to a constant surface temperature of 34 °C, and placed upright (0° tilt angle) into the wind tunnel at room temperature (Figure 2).

2.3 Conditions for insulation testing

Air velocity was set to 1.6 m/s corresponding to bicycling with pedestrian speed (about 6 km/h) with and without hair (a wig), and to 6.0 m/s as speedy bicycling (about 22 km/h) with a wig. Each test lasted for at least 70 minutes. After choosing the air velocity and donning the helmet, the situation was allowed to settle. Stabilization time was about 40 minutes. The last 20 minutes of the stable state were used to record an average heating power to each section, and calculate insulation. More ventilation would lead to lower insulation and better head cooling, and vice versa. Forehead, skull and total insulation were selected for comparison.

2.4 Conditions for evaporative resistance testing

A saturated, wet textile skin was applied to the head in order to act as a water supply (Figure 3a) General settings and the helmets (Figures 1-4) were the same as for insulation tests; however, in this case the thermal testing conditions were different. The helmets were tested in the wind tunnel placed in a climatic chamber at 34 °C and 40 % relative humidity (water vapour pressure in the air 2200 Pa) with the air velocity set to 1.6 m/s (≈6 km/h). Differently from the previous test series [2,3] where only conditions without a wig were used, the tests this time were performed additionally also on the head model with a wig. Evaporative resistance was calculated from heat loss corrected for the difference in head surface to textile skin temperature [9].

3 RESULTS AND DISCUSSION

3.1 Insulation

Forehead, skull and total insulation (m^2K/W) are compared in Figures 5-7 below. The results in the diagrams were sorted by total insulation in ascending order. Total included all zones except neck that was considered as a guard zone here.

The best ventilating helmets with wind speed 1.6 m/s and bald head were the ones from previous studies SSn, LLn, RP and Pun3 (Figure 5). One of the best ventilating helmets on the market H5 stayed in the middle and was better than the new mock-up and its variations. New helmet mock-up's variations had less effect than expected. The best ventilating helmet of the variations on baldhead was with air velocity 1.6 m/s HA11 and the worst HA7. HA11 has wide air inlet in the front under the visor and HA7 has a bit smaller air inlet in the front. Both have 5 openings in the back, HA11's outlets have small air guidance for external airflow, which might have increased the overall ventilation.

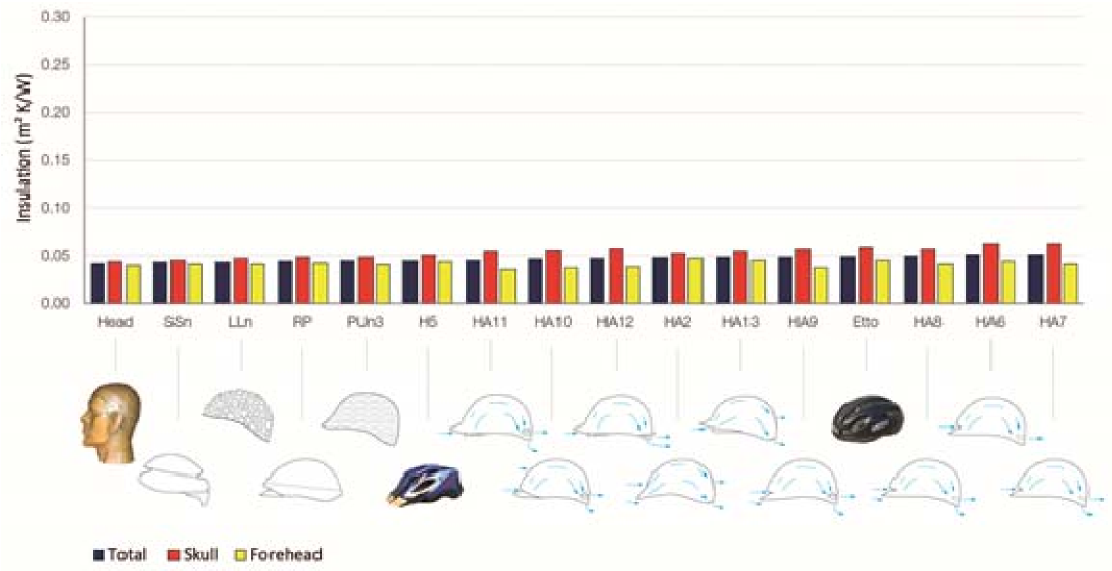

Figure 5. Helmets' insulation (m ^{2}°C/W) without a wig at air velocity of 1.6 m/s.

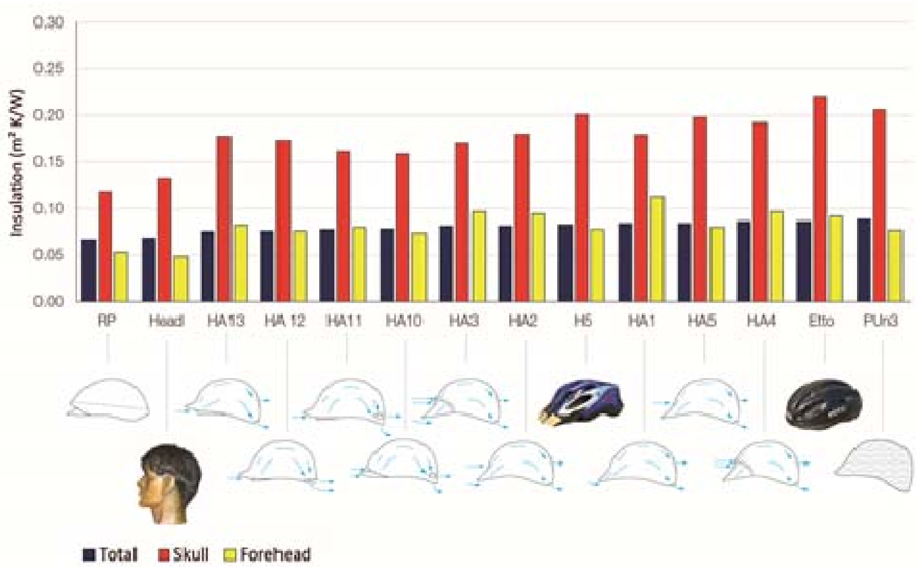

Figure 6. Helmets' insulation (m^2K/W) with a wig at air velocity of 1.6 m/s.

The experiment with the same wind speed and with a wig gave a different result (Figure 6). The best ones were RP, HA12 and HA13. H5 positioned in the middle and the most inefficient were Etto and Pun3. At 6 m/s wind and with a wig only 3 helmets were tested. There performed H5 better than HA12 and HA13 (Figure 7) that performed the best of design helmets at 1.6 m/s (Figure 6).

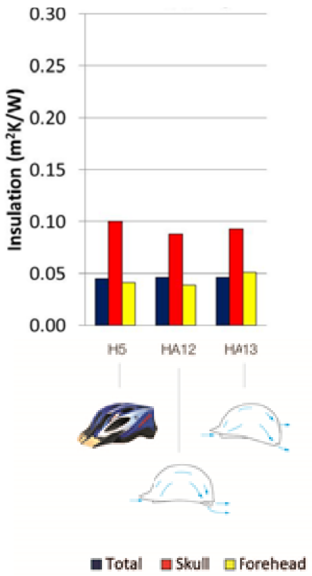

Figure 7. Helmets' insulation (m^2K/W) with a wig at air velocity of 6 m/s.

3.2 Evaporative resistance

Evaporative resistance (m^2Pa/W) of forehead, skull and total were compared and sorted by total evaporative resistance in ascending order. Wind speed was set to 1.6 m/s. The experiment on bald head showed that the most breathable helmets were Pun3 and LLn, while HA12 and HA13 showed average results while they were still cooler than H5 (Figure 8).

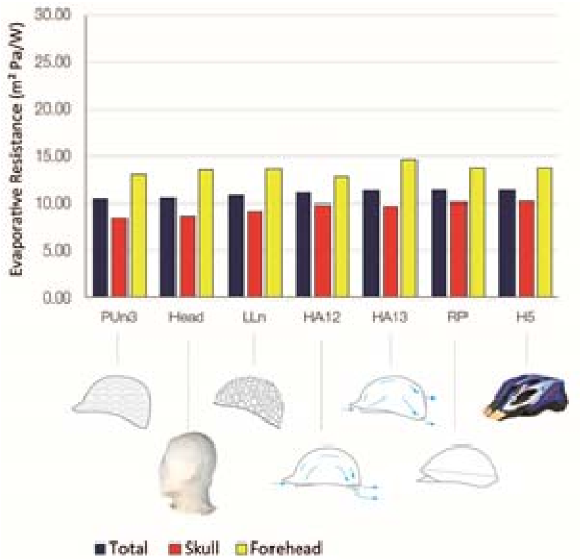

Figure 8. Helmets' evaporative resistance (m^2Pa/W) without a wig at air velocity of 1.6 m/s.

Figure 9 on the measurements of evaporative resistance with a wig showed that RP, LLn and SSn were better ventilating, and H5, HA13, HA12 were the warmest in this condition. In this case Etto performed as an average. HA12 and HA13 had a wide inlet under the visor and large air outlets. According to the results well ventilating helmet has, larger openings at the back and smaller opening at the front of the helmet that seems to create air sucking effect. Also, helmets with airy surface (LLn and PUn) seem to perform well when hair and sweating is combined, while without moisture the hair has a strong insulating effect (Figures 6, 8 and 9, see also [2,3]). This leads to strong suggestion for considering commuters bicycling habits and hairstyle for designing and selecting the helmets for best thermal comfort. Simultaneously, it may be an advantage in varying climate to have helmets that insulate when dry and support heat loss when body heat gain does grow and sweating will be induced to compensate that.

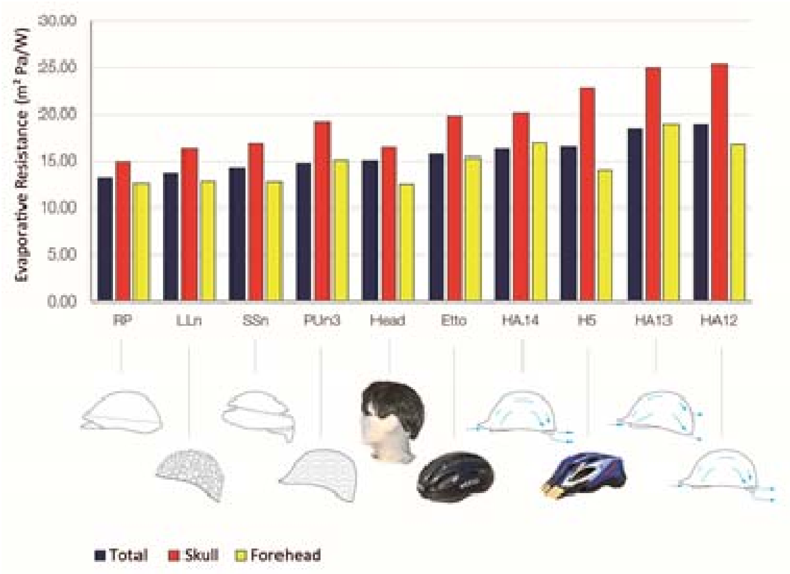

Figure 9. Helmets' evaporative resistance (m2Pa/W) with a wig at air velocity of 1.6 m/s.

4 CONCLUSIONS

On the whole, the characteristics that lead to better ventilating helmets are less contact with head and proper air channels with the strategically placed air inlets and outlets. Large openings worked much better than a several small ones, yet, the care has to be taken as too large openings reduce the helmet protective capabilities. The shape and other design related modifications of the air inlets and outlets had minimal effect on ventilation.

As various solutions worked best with different air velocities and presence of hair then it is important to consider individual characteristics and bicycling habits when designing and selecting helmets for specific population.

Further, the best solutions should be chosen, and the design work with considering of impact testing should be continued. Also, any model development of the helmet performance prediction based on design and ventilation characteristics would be of interest.

REFERENCES

[1] K. Kuklane, S.S. Heidmets and COST Action TU1101 WG4, "User friendly bicycle helmet for commuters", *Proceedings of the International Cycling Safety Conference 2013*, 20-21 November 2013, Helmond, The Netherlands, 4 pp.

[2] H. Aljaste K. Kuklane, S.S. Heidmets and COST Action TU1101 WG4, "Better Bicycle Helmets for Commuters – Evaluation of Ventilation", *Proceedings of the International Cycling Safety Conference 2014*, 18-19 November 2014, Gothenburg, Sweden, 7 pp.

[3] K. Kuklane, H. Aljaste, S.S. Heidmets and COST Action TU1101 WG4, “Evaporative resistance of newly designed bicycle helmets”, *Proceedings of the International Conference on Environmental Ergonomics 2015*, 28 June-3 July 2015, Portsmouth, UK.

[4] J. Larsson, *Cykelhjälmsanvändning i Sverige 1988-2009. Resultat från VTI:s senaste observationsstudie*, VTI report, Dnr 2009/0251-22, Linköping, 2010, http://www.vti.se/sv/publikationer/pdf/cykelhjalmsanvandning-i-sverige-19882009.pdf.

[5] D. Otte, C. Haasper and B. Wiese, ”Wirksamkeit von Fahrradhelmen bei Verkehrsunfällen von Radfahrern auf Kopfverletzungshäufigkeit und Verletzungsschwere”, *Verkehrsunfall und Fahrzeugtechnik*, **46** (2008), pp. 344-354.

[6] J. Abeysekera and H. Shahnavaz, “Adaptation to Discomfort in Personal Protective Devices: Example with Safety Helmets”, *Ergonomics* **33** (1990), pp. 137–145.

[7] X. Liu and I. Holmér, “Evaluation of evaporative heat transfer characteristics of helmets”, *Applied Human Science, Journal of Physiological Anthropology* **16** (1997), pp. 107-113.

[8] P.A. Brühwiler, M. Buyan, R. Huber, C.P. Bogerd, J. Sznitman, S.F. Graf, T. Rösgen, “Heat transfer variations of bicycle helmets”, *Journal of sports sciences* **24** (2006), pp. 999–1011.

[9] F. Wang, K. Kuklane, C. Gao, I. Holmér, ”Development and validity of a universal empirical equation to predict skin surface temperature on thermal manikins”, *Journal of Thermal Biology*, **35** (2010), pp. 197–203.