Heat stress prediction for simulated wildland firefighting

L. M. G. Jacobs[1], A. M. H. Klomp[1], H. A. M. Daanen[1], K. Kuklane[2,3*]

[1]Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, Netherlands
[2]Team Fire Service Science, Netherlands Academy of Crisis Management and Fire Service Science, Netherlands Institute for Public Safety (NIPV), Arnhem, The Netherlands
[3]Chair of Biosystems Engineering, Institute of Forestry and Engineering, Estonian University of Life Sciences, Tartu, Estonia
*Correspondence: kalev.kuklane@emu.ee

Abstract. Predicted heat strain model (PHS, ISO 7933) utilizes clothing, environment and activity data in calculations. Online tool versions from FAME Lab (PHS-FL) and Lund University (PHS-LU) allow input of intermittent conditions and data input outside the validity range of the model. The study aimed to validate both algorithms for intermittent firefighter scenarios. This paper compares results from wildland firefighting simulations in laboratory conditions (WLF). It has to be noted that some of the used environmental conditions, activity levels and clothing properties were outside the validity range of the standard. Also, PHS- FL had no input for clothing evaporative resistance, and might have used instead insulation and evaporative resistance relationships and utilized permeability index of normal clothes (0.38). Four firefighters dressed in turnout gear performed intermittent activities in a climate-controlled room (Ta = 30.4 ± 1.0 °C, RH = 28.4 ± 11.0 %, va<0.15 m/s). The work load was simulated by walking on treadmill at 2.1, 3.5 and 4.5 km/h, corresponding on average to metabolic rates of 145, 187 and 226 W/m2. In each test, each activity level was performed twice, with planned exercise start and end with 2.1 km/h. However, all test persons did quit exercise before the intended heat exposure time (90 minutes), and the last exercise at 2.1 km/h was missing or incomplete. For the whole exposure radiation load of 1 kW/m2 was applied at the right shoulder level simulating solar load. Between minutes 25 and 55, the radiation load was increased to 3 kW/m2 for 2 minutes at the start of each 5 minutes, i.e., for 12 minutes in total. As PHS_FL did not allow for enough timesteps for each radiation change, then a time weighed radiation load for this period was calculated and utilized in predictions in both model versions. After quitting the heat, the test persons removed jacket, helmet and gloves and followed 30 minutes recovery period at room temperature (Ta = 18.5 ± 3.3 °C, RH = 44.6 ± 15.4 %). Measured exposure parameters and clothing properties were used as the PHS models' input data. Rectal (Trec) and mean skin temperatures (Tsk), and body water loss (mwl) were compared with PHS predictions. Predictions were made for each individual test person and then the average predicted values were calculated. Both online tools showed significant differences with the measured data. The discrepancies in temperatures increased over time being statistically not significant in the first half of the test periods and becoming statistically significant ($p < 0.05$) in Trec towards the end of heat exposure and recovery (PHS-FL) or within recovery period (PHS-LU), Predicted values stayed always lower than the measured values, and difference reached finally above 1 °C. Differences were statistically significant for Tsk in the middle of heat exposure and reached 2.6 °C as the highest during recovery with the predicted values being lower than the measured ones. At the same time differences in measured and predicted mwl did not reach statistical significance, in spite of observably higher predicted values ($p>0.05$). Expected higher mass loss in predictions may be a reason also for lower predicted skin and rectal temperatures. Other clearly noticeably differences in measured and predicted values were lower start Trec in predictions or when using real Trec as input, forcing Trec initially to drop; slower Trec increase in predictions; higher predicted Tsk at start; considerably quicker predicted Tsk changes at the start and stop of radiation that then quickly levelling off; and considerably quicker predicted Tsk drop at the start of recovery. The behaviour of predicted Tsk may indicate that the model does not count with mass and thermal inertia of the protective clothing system, and in this way affects also Trec. At the same time quicker initial changes of predicted Trec and diminished raise later maybe also indicating poor consideration of human body mass and thermal inertia, too. Neither PHS tool gave a good prediction in WLF scenario. More tests are needed to suggest adjustments of ISO 7933 or support a need for a dedicated user standard for intermittent heavy work in protective gear.

Key words: firefighter, protective clothing, thermal insulation, predicted heat strain, model validation.

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