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The colder is warmer?

A pre-study for wear trials of a reference clothing ensemble for EN 342 and EN 14058 for thermal manikin calibration

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Introduction

In temperate and sub-arctic climate region about 10 % of workforce does spend at least 25 % of their working time in cold. Considerable number of indoor workers, especially, in freeze houses, food industry etc., have their occupational exposure to cold all year round. Two sets of calibration ensembles for thermal manikins are available at present for EN 342 (and 14058). These 2 sets are not fully enough as:

- statistically, 2 points give an ideal regression line that does not need to be correct for extended range;
- they do cover an insulation range of only EN 14058 and the lower end of EN 342 – the insulation range of very cold and extremely cold exposures (below -5 °C), that is the main concern of EN 342, is not covered.

Aims and objectives

The aims of the pre-test were to:

- test the equipment in extreme cold (down to -40 °C);
- suggest a metabolic rate for testing;
- settle the preliminary test conditions.

Methods

Ensemble C of Subzero project (cold store ensemble, SZC, [1]) was selected for testing (Fig. 1). Bending stiffness (Pierce's test) of the sections of clothing outer layer was measured as a function of ambient temperature.

Three subjects participated in the pre-tests for wear trials. They were walking on a treadmill at 3.5 km/h. Under the first part S1 was walking at +20 °C (with and without winter clothes) for 30 minutes, and at -2 and -36 °C with SZC for 90 minutes. So did S2 with SZC at -38 °C. At -2 °C S1 was asked to walk at 2 step rates. S3 was walking for 30-40 minutes at +10 °C in indoor clothes and in SZC, and at -10, -20 and -34 °C in SZC.

Different instruments and methods were used to analyse metabolic heat production from oxygen consumption (VO2):

- S1 and S2 used Metamax I and Metamax II and
- S3 used Metamax I and Douglas bag method.

Other recorded parameters were body weight loss, heart rate, thermal (range from +4 to -4) and pain sensation (range from 0 to 3).

Figure 1. Ensemble C of Subzero project on manikin, as items and on a subject.

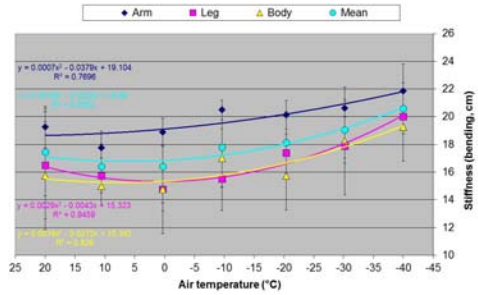

Figure 2. Bending stiffness of the garment sections as a function of ambient temperature.

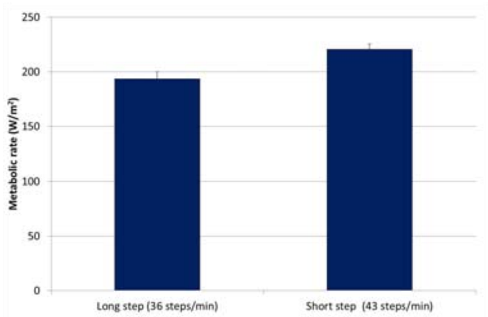

Figure 3. The effect of step rate on metabolic rate.

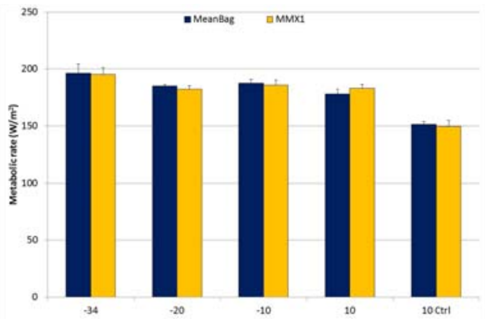

Figure 4. Metabolic rates at different test conditions. All are measured with Subzero C garment except *10 Ctrl* where indoor clothes for winter season were used.

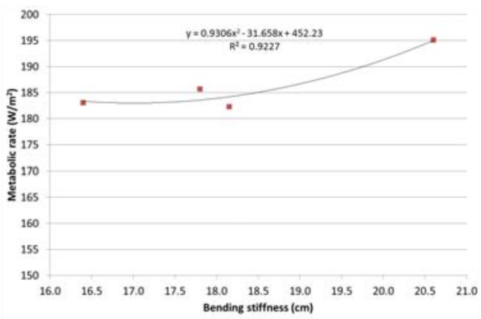

Figure 5. Metabolic rate as a function of mean temperature dependent bending stiffness.

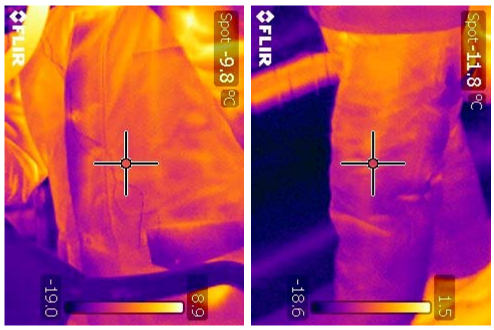

Figure 6. Infrared pictures of subject's torso and leg areas at -20 °C..

Results

The dependence of clothing bending stiffness on cold for SZC is shown in Fig. 2.

Participants were able to walk in extreme cold for 1.5 hours. Toes started feeling cold after 45 min, pain was reported at around 50-55 min, and discomfort grew with time to the end of the exposure. Estimated metabolic rate (M) according to Givoni and Goldman [2] was 140 W/m^2. Estimated M from ISO 8996 for walking without load on level and even surface (mean of 3 and 4 km/h) was 153 W/m^2. M of S1 and S3 without winter clothes was around 160 W/m^2, M for them with SZC under warm and cold conditions about 180 W/m^2, and below -30 °C for all about 200 W/m^2. Shorter steps were connected with higher metabolic rate (Fig. 3). Some unclear equipment issues were checked in S3 tests.

Based on S3 tests it was ruled out that the treadmill speed could be affected by cold by counting belt rotations. The effect of cold on measured instrument values was ruled out, too, by comparing the results of different equipment that measured VO_2 (Fig 4).

Discussion

The metabolic rate seemed to increase about 10 % at higher step rate (Fig. 3; results from 1 subject only!). Would higher step rate strengthen clothing stiffness effect? It may be possible that the garment gets stiffer in cold and thus increases motion resistance, as well (Fig. 5). Previous research suggests that clothing stiffness may affect metabolic rate by 10 % in addition to the protective clothing own effect (up to about 20 %, [3]). Considerable effect from cold seems to occur at textile temperatures below -20 °C. Outer surface temperatures of well insulating clothing stayed roughly 10 °C higher than the ambient values (Fig. 6). Temperatures inside the layers do gradually increase towards the body. It would clarify the observed effect at -30 °C and below in all subjects (Fig. 2, 4 and 5).

Conclusions

- The extreme cold may affect the instruments and measurement accuracy. However, these can be avoided by warming the sampling lines, removing ice if needed or using the Douglas bags.
- Cadence (step/min) may affect the results. If comparing the subjects and the manikin then all the subjects should be requested to walk at the same frequency, e.g. 45 double steps/min, at least under extreme cold.
- Cold affects clothing stiffness. Most probably the effect is material dependent. This may be a reason for increased energy cost in cold.
- Although the planned study was not performed, these pre-study results do define test parameters, and would allow running comparative tests with short notice.

References

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[3] Dorman L, Havenith G. The effects of protective clothing on energy consumption during different activities. European Journal of Applied Physiology, 2009, 105 (3), 463-470.

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