REPRESENTATION OF THE EFFECTS OF MOVEMENT AND WIND ON CLOTHING VAPOR RESISTANCE IN ISO STANDARDS

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INTRODUCTION

In heat stress standards, as ISO 7933, two problems arise in relation to input values for evaporative resistance. The first is that in contrast to data on clothing insulation for dry heat loss, little data are available on evaporative resistances of clothing systems. The second is that even less is known on how this evaporative resistance changes with posture changes, movement or wind. In order to assist the user of such standards, lists with evaporative resistances of clothing ensembles should be compiled, and the effects of movement, etc. should be investigated and translated into practical correction equations. The latter type of work is currently performed within the Biomed 2 research project "Assessment of the risk of heat disorders encountered during work in hot conditions (Heat Stress)," and initial results are represented here.

Currently, ISO 7933 and 9920 refer to two methods for the determination of evaporative resistance of clothing ensembles (R_T): (1) the use of F_{pcl}, a reduction factor for evaporative heat loss with clothing compared to the nude person and (2) the use of im, the permeability index of clothing, which provides a relationship between evaporative and dry heat resistance of clothing items or systems. In this paper these approaches will be discussed in light of the effects that movement and wind have on clothing heat and vapor resistance.

The use of F_{pcl}:

ISO 7933 suggests the use of F_{pcl} as a reduction factor for latent heat exchange:

$$R_T = \frac{1}{(h_e \cdot F_{pcl})} \qquad (1)$$

where h_e is the evaporative heat transfer coefficient, given by

$$(W \cdot m^{-2} \cdot kPa^{-1}) \qquad (2)$$

h_c = convective heat transfer coefficient and

$$F_{pcl} = \frac{1}{1 + 2.22\, h_c \left(I_{cl} - \frac{\left(1 - \frac{1}{f_{cl}}\right)}{(h_c + h_r)} \right)} \qquad (3)$$

with I_{cl} = intrinsic clothing insulation and f_{cl} = clothing surface area factor

Usually in the application of ISO 7933, I_{cl} is derived from a list with basic clothing insulation values, derived in a standing, no wind condition, without a correction for movement or wind. In Table 1, some example calculations are presented, which show the relationship between F_{pcl} and R_T on one hand and wind speed (v_a) on the other.

Table 1. Determination of F_{pcl} and R_T according to ISO 7933, with wind as changing parameter.

v_a $m\,s^{-1}$	h_c $W m^{-2} °C^{-1}$	I_{cl} $m^2 °C W^{-1}$	f_{cl} n.d.	h_r $W m^{-2} °C^{-1}$	F_{pcl} n.d.	h_e $W m^{-2} kPa^{-1}$	R_T $m^2 kPa W^{-1}$
0.2	4.54	0.16	1.3	5.0	0.431	75.8	0.031
0.5	6.10	0.16	1.3	5.0	0.355	101.9	0.028
2.0	13.19	0.16	1.3	5.0	0.194	220.2	0.023
4.0	19.99	0.16	1.3	5.0	0.134	333.8	0.022

Table 1 shows that an increase in wind speed results in a decreasing F_{pcl}, which, according to the textual definition of F_{pcl} (a reduction factor for evaporative heat loss), is contrary to expectations. Only due to the sharp increase in he, the value for R_T decreases with wind. Taking the general Fpcl definition:

$$F_{pcl} = \frac{R_a}{R_a + R_{cl}} = \frac{R_a}{R_T} \qquad (4)$$

one can understand that F_{pcl} decreases with wind, as R_a is reduced to a greater extent by wind than is R_T.

As described in other papers (1,3) it is now possible to provide correction equations for the effect of movement and wind on I_{cl}. Using this corrected I_{cl} instead of a constant one in equation 3 should improve predictions of R_T.

As was expected, using the corrected I_{cl}, F_{pcl} increases compared to that using a constant I_{cl}. This is illustrated in Table 2. For the calculations with a constant I_{cl}, a decrease in R_T of 29% at 4 $m \cdot s^{-1}$ wind is observed (Table 1). For a decreased I_{cl} (29%; Δ I_{cl} 42%), the decrease in RT amounts to 48%. Though this is substantially more than in the current practical use of ISO 7933, it is still less than observed by Havenith et al. (2).

Table 2. Determination of F_{pcl} and R_T according to ISO 7933, with wind and I_a as changing parameters

v_a ms^{-1}	h_c $Wm^{-2}{}^oC^{-1}$	I_{cl} $m^2{}^oCW^{-1}$	f_{cl} n.d.	h_r $Wm^{-2}{}^oC^{-1}$	F_{pcl} n.d.	h_e $Wm^{-2}kPa^{-1}$	R_T m^2kPaW^{-1}
0.2	4.54	0.14	1.3	**5.0**	0.45	75.8	0.029
0.5	6.10.	0.13	1.3	5.0	0.40	101.9	0.025
2.0	13.19	0.11	1.3	**5.0**	0.25	220.2	0.018
4.0	19.99	0.10	1.3	5.0	0.20	333.8	0.015

Approach through I_t

In ISO 9920 the derivation of R_T using the permeability index im is described

$$R_T = \frac{I_T}{i_m \cdot L} = \frac{0.06}{i_m} \cdot \left(\frac{I_a}{f_{cl}} + I_{cl} \right) . \tag{5}$$

ISO 9920 also provides **im** values for typical clothing configurations, with a rule of thumb **im** of 0.38 for one- or two-layer permeable garments. Using this approach for the determination of RT in ISO 7933, the change in clothing insulation would directly be reflected in the change in RT: a change in the total clothing insulation (Itot = Icl + Ia/fcl) would result in an equivalent change in the vapor resistance. For the example in Table 2, at 4m.s-1 wind, the 42% reduction in Itot would give a 42% reduction in RT. This reduction too is much smaller than observed in experiments by Havenith et al. (2), however. They observed a stronger decrease in RT then in Itot (Figure 1) and showed that there is a theoretical basis for such a relation. Their data indicate that im, as used here, is not a constant value but will increase in movement and wind conditions. Though im values obviously differ between garments or ensembles, reanalysis of Havenith et al.'s data showed that when im was expressed relative to the value measured

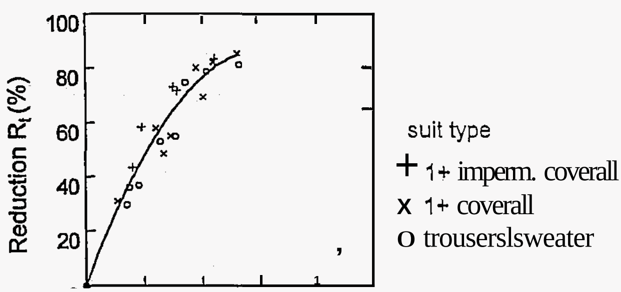

Figure 1. Relationship between the reduction in vapor resistance RT and that in heat resistance (Itot) for three ensembles.

in the standing, no wind condition, the change in im due to movement and wind in relation to the change in clothing insulation for the same conditions was very similar for very different types of clothing (Figure 2). This then implies that an empirical description of this relationship would actually accommodate the gen-

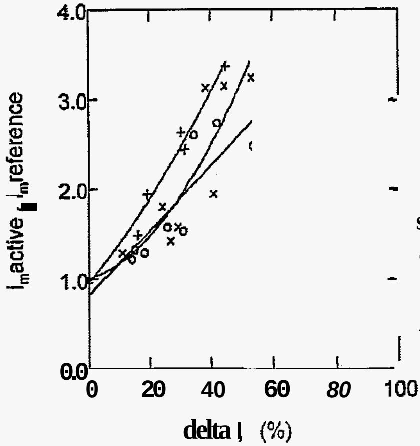

Figure 2. Relationship between Im, expressed relative to the reference at no wind, standing and the change in heat resistance.

eral correction of clothing ensembles' vapor resistance for effects of movement and wind. This approach would then provide reductions in evaporative resistance for clothing than are experimentally observed, which is higher than for the other given approaches (Fpcl and constant im).

CONCLUSION

The use of the reduction factor for evaporative heat transfer, Fpcl, does not provide proper corrections of clothing vapor resistance for conditions where the wearer is moving or exposed to wind. Also, although mathematically correct, it changes in the opposite direction than users expect, given its description. As it is observed that the change in the clothing permeability index, im, due to movement and wind is similar for different garment types, it is suggested that this parameter be used for the description of these effects in future standards.

REFERENCES

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