45 Simple relationships among current vapor permeability indices of clothing with trapped-air layer

T. Oohori, L.G. Berglund,[1] and *A.P. Gagge*[1] Hokkaido Institute of Technology, Sapporo, Japan [1]John B. Pierce Foundation Laboratory, New Haven, Connecticut, USA

The purpose of this paper is to analyze and compare four current indices and models of evaporative heat transfer through clothing layer.

The effective dry heat transfer coefficient (h') over the temperature gradient $\Delta T=(T_{sk}-T_a)$ is $DRY/\Delta T=hF_{cl}$ or $1/(I_a + I_{cl})$ where h is the sum of h_r and h_c; $I_a(=1/h)$ and I_{cl} are the thermal resistances of the outer-air and clothing respectively; F_{cl} is the Burton's thermal efficiency factor, that is, the ratio of the dry heat loss when clothed and when unclothed i.e. $F_{cl}=I_a/(I_a+I_{cl})=1/(1+hI_{cl})$. Analogous to the dry heat exchange, the effective evaporative heat transfer coefficient (h'_e) of a fully wet surface over the vapor pressure gradient $\Delta P=(P^*_{sk}-P_a)$ is $EV/\Delta P=h_eF_{pcl}$ or $1/(I_e+I_{cle})$, where h_e is the evaporative heat transfer coefficient of the outer-air layer; $I_e(=1/h_e)$ and I_{cle} are the evaporative resistances of the outer-air and clothing respectively; F_{pcl} is the Nishi's permeation efficiency factor, namely, the ratio of the evaporative heat loss when clothed and when unclothed: $F_{pcl}=I_e/(I_e+I_{cle})=1/(1+h_eI_{cle})$.

Several vapor permeability indices were defined which related dry and evaporative heat transfer through clothing layer:

1) Lewis relation (1922) for the non-radiative air layer:
$L=h_e/h_c=2.2$ in °K/Torr

2) Permeation index for the outer-air layer (1984):
$i_a=h_e/2.2h=h_c/h$

3) Permeation index for the clothing layer (1983):
$i_{cl}=h_{cle}/2.2h_{cl}=I_{cl}/2.2\ I_{cle}$

4) Permeation index for the total clothing-air layer (Woodcock 1962):
$i_m = h'_e/2.2\ h' = h_e\ F_{pcl}/2.2\ h\ F_{cl} = (I_a+I_{cl})/2.2\ (I_e+I_{cle})$

The simple relationships among the above permeability indices may be written as follows:

1) $1/i_m=F_{cl}/i_a+(1-F_{cl})/i_{cl}$

2) $F_{pcl}=(I_a/i_aL)/[(I_a/i_aL)+(I_{cl}/i_{cl}L)]=1/(1+h_cI_{cl}/i_{cl})$

3) $(1/F_{cl}-1)i_a=(1/F_{pcl}-1)i_{cl}$

4) $i_m=F_{pcl}i_a+(1-F_{pcl})i_{cl}$.

Our definition of I_{cl}, i_{cl} and I_{cle} all include the trapped-air between the skin surface and fabric. In a case of low activity, like sedentary, with one-layer clothing, the dry heat may be transferred through the trapped air by conduction and radiation, namely, the effective thermal resistance of clothing is: $I_{cl}=I^*_{cl}+I_{at}$, where I^*_{cl} and $I_{at}(=1/(h_{rt}+h_{ct}))$ are the intrinsic resistances of fabric itself and the trapped-air respectively. Similarly, the effective evaporative resistance of clothing is: $I_{cle}=I^*_{cle}+I_{et}$, where I^*_{cle} and I_{et} are the evaporative resistances of fabric itself and the trapped-air respectively. Introducing new permeation indices i^*_{cl} and i_{at}, the effective permeation index (i_{cl}) can be expressed as the average of i^*_{cl} and i_{at}, weighted by new efficiency factors F_{at} and $(1-F_{at})$:

$1/i_{cl}=F_{at}/i^*_{cl}+(1-F_{at})/i_{at}$,

where $i^*_{cl}=I^*_{cl}/I^*_{cle}L$, $i_{at}=I_{at}/I_{et}L=h_{ct}/(h_{ct}+h_{rt})$ and F_{at} is the thermal efficiency factor of the trapped-air:

$$F_{at}=I^*_{cl}/I_{cl}=I^*_{cl}/(I^*_{cl}+I_{at}).$$

46 **Design of functional work clothing for butchers**

R. Ilmarinen, , E. Korhonen [1], E. Tammela [1] and P. Haivaoja [2] Department of Physiology, Institute of Occupational Health [1] Department of Occupational Safety, Institute of Occupational Health [2] University of Industrial Arts, Helsinki, Finland

The requirements of modern food hygiene and maintaining the quality of foodstuff both involve the handling and storing of food at low temperatures. Usually the temperature of fresh meat during the cutting of carcasses varies between +2°C and +7°C, and the air temperature of a cutting room between +8°C and +12 °C, respectively.

The requirements for cold cutting rooms have increased thermal discomfort and cold stress among butchers. Radiant asymmetry, cold draft, elevated air humidity, and low floor temperatures are common complaints. In addition, the lack of sufficient thermal insulation of the hands is a special problem in the work of butchers, which is compounded by the static nature of the work associated with quite a low overall metabolic heat production.

It is known that the clothing has a great potential to minimize thermal discomfort and unwanted effects of local cooling on the worker. However, the clothing normally worn by butchers, a white cotton workcoat and trousers, is thermally defective and a common cause for complaint: excessive local cooling of neck, shoulder, ankles, and lower back are typical. The body fluids of slaughtered animals and moist work conditions wet the clothing, particularly in the abdominal area. This decreases the thermal insulation of clothing and causes extra discomfort.

This study was aimed to design new, functional work clothing for butchers, especially paying attention to the metabolic requirements of the work and the thermal and general working conditions in slaughterhouses.

On the basis of the results of the pilot study (review of the literature, questionnaires and interviews, work analysis, physiological measurements) different types of work clothing were designed for prolonged use during normal work in meat cutting. Physical material tests and measurements of thermal insulation values; and the follow-up of clothing maintenance were carried out. Further modifications and evaluations of work clothing were based on the opinions of butchers and on the physiological trials in slaughterhouses including e.g., the measurements of metabolic rate, rectal and different skin temperatures, thermal sensation and comfort votings.

The final assembly of work clothing chosen consists of three pieces (CO/PE): an apron, trousers with extra insulation in lower back, and a workcoat with extra insulation in the neck and shoulders, and at the wrists. The sleeves are protected against moisture by special textile material. The thermal insulation of this new set of work clothing together with underwear (long sleeves and long legs) is 1.3 clo and it proved to be sufficient for thermal comfort in moderate work in an air temperature of 10°C.

Close co-operation between butchers, safety officers, slaughterhouse employers, research workers and designers was the basis for the success of the project. Now the new clothing set is accepted for general use in Finland and the results show that the functional work clothing has positive effects of thermal comfort in cold work.