CLOTHING EFFECT ON THERMAL SENSATIONS. EVALUATION BY TRANSIENT MODELLING

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INTRODUCTION

Thermal insulation of clothings is usually only expressed through the concept of "clo". This fits for steady state heat balance computations, but not for transient conditions. A model for heat and mass transfers through a one-layer clothes is presented here, taking into account water sorption and undercloth ventilation by "pumping effect". It has been added to a human thermo-regulation software calculating local physiological parameters and thermal sensations. Several experiments have been reproduced. Satisfactory results were obtained by comparison between experimental and calculated skin temperatures and thermal sensations [2].

METHOD

• ***Human model.***

Thermo-physiological parameters (skin temperatures, wettedness...) and reactions (sweating,...) of the body are computed by a 25-node human model called MARCL or by the 2-node Gagge's model [4].

• ***Thermal sensations.***

The thermal sensations model TRIM [4] associates physical variables and thermophysiological parameters of the body to local or global sensations, that are expressed on a 7-point scale from "very cold to "very hot".

• ***Clothing model.***

Figure 1 represents heat and mass exchanges between skin and environment through the fabric. The corresponding electrical representation and equations, added to the human model, are given in table 1. Clothes are simplified to few number of parameters : h - transfer coefficients, m - mass, C - heat capacitance, wich are calculated owing to the characteristics of fabrics and cloth insulation and permitivity.

Indices are following :

sk : skin	*θ* : undercloth climate
cl : clothing	a : air
o : convection and radiation	e : evaporation

Heat transfers. Sensible heat exchanges from the body ($\dot{q}_s$) depend on the undercloth temperature (T_θ) which is strongly linked to ambiance by ventilation flow rate ($\dot{m}_a$) through the fabric or the openings (cuff, collar,...). This flow rate is an effect of clothing fitting, textile permitivity, activity... [1]. T_θ also depends on cloth temperature (T_{cl}), i. e. on cloth physical properties.

Mass transfers. Latent exchanges ($\dot{q}_l$) on skin are linked to mass transfers through clothes. It depends on local vapor pressure (P_θ), which is in turn linked to outside conditions (Pa) by ventilation and clothing properties (specially permeability, regain,...).

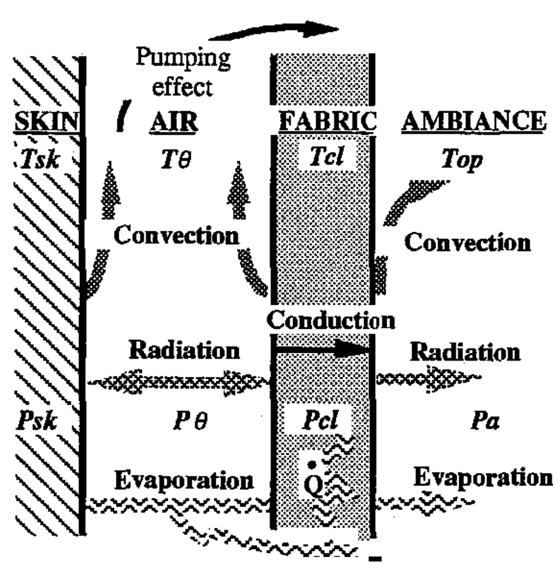
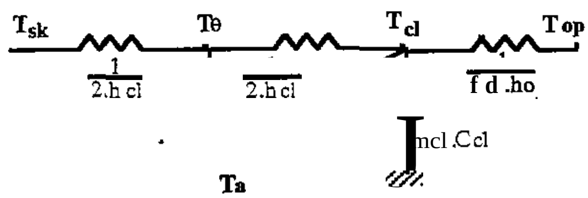
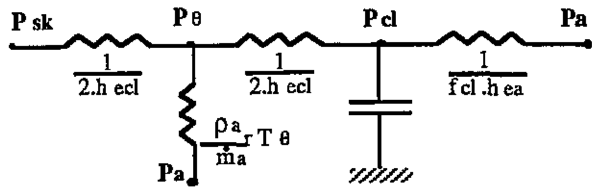


Figure 1. Representation of heat and mass transfers.

Heat transfers are linked to mass transfers by latent heat of water absorbed or desorbed by fibers ($\dot{Q}$). This depends on the variation rate (dM/dt) of the total mass of water in clothing (M) raking into account vapor trapped between fibres and absorbed by fibres. When the vapor pressure is under saturation, it can be considered that there is no liquid water and that regain is a linear function of P_{cl} [3]. It can be written : $M = M_{max}(P_{cl} / P_{scl})$

Table 1 : **Electrical** representation and equations of beat and mass transfers.

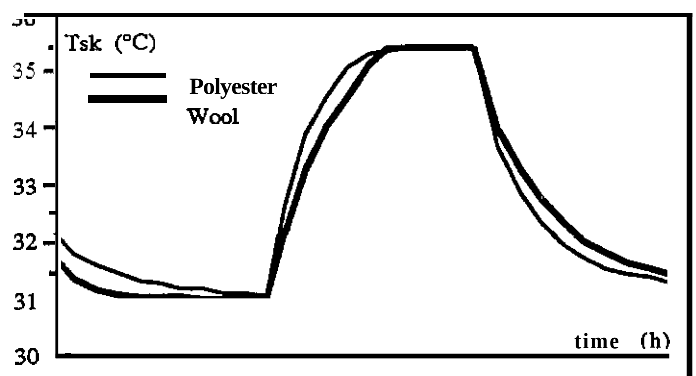
Heat transfers	*Mass transfers*
	
$\dot{q}_s = 2\, h_{cl}\, (T_{sk} - T_\theta)$	$\dot{q}_l = H_e\, \dot{m}_{sk}$ with $\dot{m}_{sk} = 2\, h_{ecl}.(P_{sk}-P_\theta)$
$T_\theta = \frac{\dot{m}_a C_a T_a + 2h_{cl}\,(T_{sk}+T_{cl})}{\dot{m}_a C_a + 4h_{cl}}$	$P_\theta = \frac{(\dot{m}_a/\rho_a r T_\theta)\, P_a + 2h_{ecl}\,(P_{sk}+P_{cl})}{(\dot{m}_a/\rho_a r T_\theta) + 4h_{ecl}}$
$\frac{dT_{cl}}{dt} = -a\, T_{cl} + b$; $a = \frac{h_{cleq}+f_{cl}h_o}{m_{cl}C_{cl}}$; $b = \frac{2h_{eq}T_{eq}+f_{cl}h_oT_{op}+\dot{Q}}{m_{cl}C_{cl}}$	$\frac{dP_{cl}}{dt} = a'\, P_{cl} + b'$; $a' = (2h_{eeq}+f_{cl}h_{ea})\frac{P_{scl}}{M_{max}}$; $b' = (2h_{eeq}P_{eq} + f_{cl}h_{ea}P_a)\frac{P_{scl}}{M_{max}}$
$T_{eq} = \frac{\dot{m}_a C_a\ T_a + 2h_{cl}\ T_{sk}}{\dot{m}_a C_a\ + 2h_{cl}}$	$P_{eq} = \frac{(\dot{m}_a/\rho_a r T_\theta)P_a + 2h_{ecl}\, P_{sk}}{(\dot{m}_a/\rho_a r T_\theta) + 2\, h_{ecl}}$
$h_{eq} = \frac{2h_{cl}\,(\dot{m}_a C_a\ + 2h_{cl})}{\dot{m}_a C_a\ + 4h_{cl}}$	$h_{eeq} = \frac{2h_{ecl}\,((\dot{m}_a/\rho_a r T_\theta) + 2\, h_{ecl})}{(\dot{m}_a/\rho_a r T_\theta) + 4\, h_{ecl}}$

RESULTS

Influence of cloth parameters

The model presented here is a rougb representation of cloth complexity. Nevertheless influence of clothing characteristics can be seen. Fig.2 shows an example of mean skin temperature variations of a man dressed with two different materials and going from a cold ambiance to a warmer one and coming back.

Differences between the two cases appear during transients. Wool delays the moment of stationnary state, that will lead to



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4. Thellier F., Moncboux F., Cordier A., Serin G., Galéou M. 1992, "Des Logiciels pour l'Analyse et la Gestion du Confort Tbermique" *Promoclim Avril/Mai.*, Tome 23, No 3, 169-175.