12.5 #4587

CONVECTIVE HEAT LOSSES FROM SEGMENTS OF THE HUMAN BODY

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Introduction

The convective heat transfer between every segment of the human body and its environment is an important subject and there have been a number of investigations in this area, see Rapp (1973), Chang (1988), Homma (1988) and Nishi (1970). It is also important that human beings feel comfortable under the environmental conditions in which they live and work. Thermal comfort is connected with the heat losses from segments of the human body.

Because heads and arms are often bare when people stay indoors (sometimes even when they are outside), it is helpful to separate the segments into two parts. These are (i) the head and arms and (ii) the rest of the segments of the human body.

Previous investigations have shown that the comfort air velocities can not be too high. This means ... veen free and forced convective heat transfer should be considered.

A series of experiments has been carried out to obtain the convective heat transfer coefficient in different air velocities, and with varing temperature differences between the segments and their environment. A new type of interpolation equation has been used for the segment of human body.

Experiment and results

A nude full-scale manikin was used to measure the convective heat transfer coefficients for different segments. It was divided into seven segments, i.e. head, trunk, arms, hands, thighs, legs and feet. During the measurement, the manikin was placed in the wind tunnel. The measurements taken were

- o the surface temperature of manikin
- o the ambient air temperature
- o the surrounding temperature
- o the air velocities for every segment
- o the total heat production for every segment.

For more detailes on the measurement techniques, see Wang (1990a), (1990b). The experimental results are given in Tables 1 to 4.

Table 1. Air velocity, m/s, temperature difference, °C, and convective heat transfer coefficients for trunk, W/m$^2\cdot$°C.

v = 0,6	$\Delta\theta_{s-a}$	3,8	5,1	6,7	8,4	6,6	9,4
(m/s)	α_c	13,5	13,4	13,5	13,8	13,8	14,4
v =0,57	$\Delta\theta_{s-a}$	6,8	8,3	10,0	9,2		
	α_c	13,1	13,3	13,5	13,3		
v =0,26	$\Delta\theta_{s-a}$	12,6	8,8	3,9	10,2	11,4	12,5
	α_c	8,6	9,1	7,7	9,0	8,8	8,8
v =0,38	$\Delta\theta_{s-a}$	11,6	7,1	7,7	8,6	9,3	10,3
	α_c	9,5	8,6	9,3	9,5	10,0	10,0
v =0,09	$\Delta\theta_{s-a}$	8,8	10,9	12,6	14,1	15,6	
	α_c	5,7	6,4	6,9	6,8	6,8	
v =0,63	$\Delta\theta_{s-a}$	5,0	4,8	5,7	7,1	8,8	11,0
	α_c	5,2	9,6	12,0	12,7	12,3	12,4

Table 2. Air velocity, m/s, temperature difference, °C, and convective heat transfer coefficients for thighs, $W/m^2 \cdot °C$.

v = 0,57	$\Delta\theta_{s-a}$	5,3	6,7	5,6	7,6		
(m/s)	α_c	21,8	22,1	22,4	22,2		
v =0,60	$\Delta\theta_{s-a}$	4,2	5,5	6,6	8,3	4,8	7,6
	α_c	21,0	20,1	20,0	21,0	21,0	20,9
v =0,22	$\Delta\theta_{s-a}$	10,6	4,6	7,6	8,8	9,8	11,0
	α_c	13,7	12,8	13,9	13,8	13,6	13,9
v =0,26	$\Delta\theta_{s-a}$	9,9	6,4	7,2	8,0	8,8	
	α_c	15,2	14,6	14,6	15,2	14,8	
v =0,08	$\Delta\theta_{s-a}$	3,8	5,4	6,9	9,3	12,3	13,5
	α_c	10,0	9,7	10,8	10,3	10,9	11,0
v =0,40	$\Delta\theta_{s-a}$	4,9	6,3	7,9	9,6		
	α_c	17,2	18,2	17,7	18,0		

Table 3. Air velocity, m/s, temperature difference, °C, and convective heat transfer coefficients for legs, $W/m^2 \cdot °C$.

v = 0,87	$\Delta\theta_{s-a}$	5,1	6,7	8,4	2,5	6,8	9,0
(m/s)	α_c	16,7	17,3	17,4	16,9	17,4	17,7
v =0,85	$\Delta\theta_{s-a}$	2,7	4,9	6,4	7,9	9,6	8,7
	α_c	17,4	17,6	17,3	17,4	17,8	8,3
v =0,26	$\Delta\theta_{s-a}$	12,7	5,2	6,9	9,0	3,6	10,3
	α_c	11,1	10,6	11,2	11,3	10,9	11,2
v =0,34	$\Delta\theta_{s-a}$	11,5	6,6	7,5	8,6	9,5	10,5
	α_c	12,2	11,6	11,9	12,0	12,2	12,0
v =0,12	$\Delta\theta_{s-a}$	4,7	6,6	9,0	11,6	10,1	15,7
	α_c	7,5	7,4	7,4	7,5	7,7	7,7
v =0,55	$\Delta\theta_{s-a}$	5,8	7,4	9,1	11,2		
	α_c	14,4	4,8	14,5	14,7		

hence equation (4) becomes

$$\alpha_c{}^n = (A \cdot \Delta\theta_{s\text{-}a}{}^{m_1})^n + C \quad (6)$$

Introducing

$$Y = \alpha_c{}^n \quad (7)$$

$$X = \Delta\theta_{s\text{-}a}{}^{m_1 n} \quad (8)$$

$$D = A^n \quad (9)$$

and combining equations (6) to (9) give

$$Y = D \cdot X + C \quad (10)$$

In order to get coefficients C and D, the multiply linear regression analysis is employed. Equation (10) gives

$$f(X) = \sum_{i=1}^{k} (Y_i - D \cdot X_i - C)^2 \quad (11)$$

where

k is the number of experiments for a certain velocity

X_i, Y_i are the experimental values.

For a certain exponent n, if $\frac{\partial f}{\partial C} = 0$, a better correlation equation can be obtained. And the best value of the exponent n is the one which yields the smallest value for the mean square relative errors, see Table 6.

It was shown by Wang (1990b) that a value of 2 for the exponent n gave the best fit for the head and arms. And from Table 6, it appears that the best value of the body is also around 2. Therefore $n = 2$ was chosed for the further calculations.

For a certain air velocity, we have equation (5)

$$C = (B \cdot v^{m_2})^n = \text{Const}$$

The calculated C values are shown in Tables 7 to 10, for $n = 2$

Table 6. Mean square relative errors for different exponent.

Body segment			n		
	1	1,5	2,0	2,5	3,0
Trunk	0,0263	0,0205	0,0188	0,0185	0,0187
Thighs	0,0186	0,0153	0,0161	0,0172	0,0179
Legs	0,0133	0,0152	0,0116	0,0118	0,0187
Feet	0,0335	0,0303	0,0290	0,0284	0,0281

Table 7. C values for different air velocities for trunk, $n = 2$.

				v, m/s		
	0,60	0,57	0,26	0,38	0,09	0,63
C	173,0	158,3	57,6	71,2	20,1	134,9