COOLING WITH FANS IN HOT AND HUMID WORKING ENVIRONMENTS

by

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Abstract

In hot and humid working conditions where it is economically not feasible to control the environmental temperature by air conditioning, fan cooling can be used. The air velocity required to maximize heat dissipation was determined analytically and experimentally. Air from a fan was directed on the subjects from the side. Air velocities used were 0.13, 0.4, 0.8, 1.6 and 3.2 m/s with the dry bulb temperature at 32 C, wet bulb temperature of 24.5 C, and 55 % rh. The mean radiant temperature was the same as dry bulb temperature; vapor pressure was 19 mm Hg. Two standing subjects worked continuously for 120 minutes, pedaling with their hands an ergometer placed on a table; it maintained their total metabolism at 190 W. Skin and rectal temperatures, heart rate, sweat rates, comfort votes and thermal sensations were recorded. Air velocity had no effect on the work output in 120 minutes by the two subjects. Higher air velocities of 1.6 and 3.2 m/s maintained lower skin temperatures, lower rectal temperatures and heart rates, the subjects sweated less and considered it "cooler" and more "pleasant."

INTRODUCTION

There are situations where it is not economical to cool a work environment by air conditioning. Yet, if a worker is to maintain thermo-neutrality, minimize heat gain or, at the very least, be able to work a reasonable time period before the allowable heat storage is achieved, protective measures must be taken. One feasible alternative is to cool the man with a fan.

Cooling is achieved primarily by evaporation of sweat. Evaporation of sweat can be limited by the man or by the environment. Evaporation is usually environmentally limited due to the lack of air movement. This is remedied by increasing air velocity. The cheapest way to increase velocity is to use a fan with the fan air directed on the worker. The question is how much air flow is required to maximize the heat dissipation.

Human Heat Transfer: The man exchanges heat with his environment by radiation, convection and evaporation. Conductive heat transfer is negligible unless a large porportion of the body surface is in contact with solid material at a temperature very different from skin temperature. In a given environment, radiant heat transfer is fixed if skin temperature and body posture are fixed. But evaporative heat transfer is not fixed. The amount of water on the skin surface depends on the sweat rate, and sweat rate is controlled by body temperature. Thus, in response to heat stress, more sweat is produced. Evaporative heat transfer is then maximum for that environment. Evaporative heat transfer is a function of environmental parameters and skin temperature only (Mitchell and Whillier, 1971).

Evaporation is by far the most powerful avenue of body cooling so that body cooling in hot environments will be maximum when evaporation is maximum. Maximum cooling power (Q_{max}) for any particular environment is:

Q_{max} = Radiant cooling + Convective cooling + Maximum evaporative cooling.

Konz (1978) stated that sweating to remove heat is not considered "comfortable."

Fanger (1973) reported that during comfort:

$$T_{skin} = 35.7 - 0.276\ M$$

and $E_{sweat} = 0.42\ (M - 58)$

where: T_{skin} = mean skin temperature

M = metabolic rate, W/m^2

E_{sweat} = evaporative sweating rate, W/m^2

Air Velocity: Mitchell and Whillier (1971) showed that raising air velocity beyond 2 m/s had little effect on evaporation on nude men. However, achieving 2 m/s at the skin is difficult as air velocity drops off very rapidly with departure from the fan's axis and rapidly even along the fan's axis (Konz, 1977). To be useful a fan must be pointed directly at a worker and be close. Clothing, since it reduces air velocity next to the skin, hinders evaporation as well as convection. In addition, evaporation from clothing instead of the skin gives a cooling to the person as low as 250 kcal/kg instead of 480 kcal/kg (Konz, 1977).

Evaporation can be increased also by decreasing water vapor pressure in the air. But this dehumidification process is expensive and not economically feasible in all industries.

Heat Stress and Skin Temperature: An individual is able to reach thermal equilibrium with the environment if the rate at which he or she rejects heat to the environment is equal to the rate of metabolic production of heat. The rate of metabolic production of heat, in turn, is equal to the rate of energy consumption, which is determined by the oxygen consumption, less whatever energy leaves the body in the form of external work. The criterion for thermal equilibrium is therefore that maximum cooling power should exceed, or at least equal.

If skin temperature rises because of failure of the body to attain equilibrium in hot environments, the circulation of blood between muscle and skin is increased, if possible, to minimize the core temperature rise. Increasing the blood circulation results in increasing circulatory strain, which usually manifests itself as a high heart rate. Thus increases in skin temperature in the heat are associated with increases in core temperature, or in circulatory strain, or both. The higher the work rate, the greater the amount of heat required to be transported between core and periphery, and therefore, the greater the disadvantage of a high skin temperature. It therefore is beneficial to the worker to keep his skin temperature as low as possible.

Acclimatization: Acclimatized individuals working in thermal equilibrium in the heat seem to maintain their skin temperatures at or below about 35 C irrespective of air temperature, humidity, wind speed or work rate (Mitchell, Wyndham and Hemp, 1971). It should be noted that acclimatized men are able to sweat considerably more than those who are unacclimatized.

It is impossible for any individual to sweat at a rate which exceeds their maximum sweating limit. Beyond this limit, heat storage begins.

Small Individuals: For individuals doing the same work, those with small body surface areas have a higher metabolic heat production per unit area. Thus they require a higher rate of cooling. Low surface area probably contributes largely to the poor performance of small individuals working in heat.

Human Thermoregulation: Figure 1 depicts the human thermoregulatory system as a closed loop system. This model was introduced by Stolwijk and Hardy in 1966. In this figure the feedback control system is divided into a regulated system and the regulating system (regulator). The regulated system (body heat capacitance) can be subjected to a disturbance from environmental heat or cold or metabolic heat. The disturbance causes a change in the controlled variable which is measured

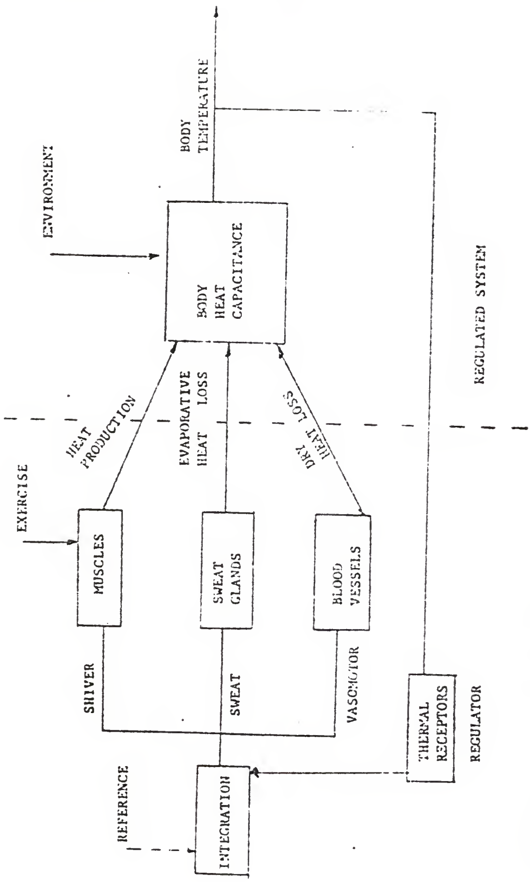

FIGURE 1. HUMAN THERMOREGULATION, A CLOSED-LOOP SYSTEM

by thermal receptors. This information, the feedback, is compared with reference information. The difference between the feedback and the reference, termed the error, is a measure of the effect of the disturbance on the controlled variable. The error activates a control center which provides a control action in such a way as to oppose the effect of disturbance. In thermoregulation, the control actions are means of modifying heat loss, heat production, or heat conservation by sweating, shivering or vasomotor activity.

The key equation is the heat balance equation.

$$S = M - (\pm W) + (\pm R) + (\pm C) + (\pm E) + (\pm K)$$

where:

S = heat storage rate, Watts

M = metabolic rate, Watts

W = mechanical work accomplished rate, Watts (walk up steps = +; down = -)

R = radiation rate, Watts (gain = +; loss = -)

C = convection rate, Watts (gain = +; loss = -)

E = evaporation rate, Watts (gain = +; loss = -)

K = conduction rate, Watts (gain = +; loss = -)

A hypothetical subject has the following characteristics:

Age: 24 years

Sex: Male

Weight: 65 kg

Height: 170 cm

I_{clo}: Insulation value of clothing, clo

= 0.55 for subject wearing pants, shirt, socks, and shoes and wearing gloves

Total metabolism = 190 Watts

He works for 2 hours in the following environment: Mean radiant temperature of environment = MRT = 32 C, dry bulb temperature = DBT = 32 C, and relative humidity = rh = 55 %. The following temperatures were assumed: core temperature of body = 37.2 C and skin temperature = 36 C.

Human body heat storage rate can be calculated from either the equation above or from the following equation.

$$S = 1.15\ m\ C_p\ (MBT_f - MBT_i)/t$$

where S = storage, watts

m = mass of body, kg

C_p = 0.83, specific heat of body

MBT_f = final mean body temperature, C

$= 0.33\ (\text{skin temp}_f) + 0.67\ (\text{core temp}_f)$

$= 0.33\ (\ 36.0\ ) + 0.67\ (\ 37.2\ )$

$= 36.8$

MBT_i = initial mean body temperature, C

$= 0.33\ (\text{skin temp}_i) + 0.67\ (\text{core temp}_i)$

$= 0.33\ (\ 32\ ) + 0.67\ (\ 37.2\ )$

$= 35.5$

t = time, hours

$= 2$ hours

Substituting:

$$S = 1.15 \times 65 \times 0.83\ (36.8 - 36.5)/2$$

$$= 40 \text{ Watts}$$

Hence, with the assumptions made, the heat storage rate is 40 Watts.

The National Institute of Occupational Safety and Health says that heat storage must be kept so that maximum core temperature does not exceed 38 C.

<u>Radiation</u>: Radiant heat transfer is:

R $= \alpha\ A\ f_{eff}\ f_{clr}\ F_{pcl}\ e\ (T^4_{mrt} - T^4_{skin})$

R = radiant gain (+) or loss (-), Watts

α = 5.67×10^{-8} Watts/(m^2 - K^4) = Stefan - Boltzman constant

A = skin surface area, M^2

= 0.208 + 0.945 (DBSA)*

DBSA = DuBois surface area, m^2

= $0.007184\ (HT)^{0.725}\ (WT)^{0.425}$

HT = height, in cm = 170 cm

WT = weight = 65 kg

DBSA = $0.007184\ (170)^{0.725}\ (65)^{0.425}$

= 1.7536 m^2

A = 0.208 + 0.945 (1.7536)

= 1.865 m^2

f_{eff} = effective radiation factor = 0.725 (for standing) (Fanger <u>et al</u>., 1970)

f_{clr} = increase in area due to clothing

= 1 + 0.15 (I_{clo})

I_{clo} = insulation value of clothing, clo

= 0.55 for subject wearing pants, shirt, socks and shoes and working gloves

f_{clr} = 1 + 0.15 (0.55)

= 1.0825

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*Correcting for inaccuracies in the DuBois prediction (Mitchell <u>et al</u>., 1971).

F_{pcl} = decrease in evaporative efficiency for permeable clothing = 1/(1 + 0.143 (2.9) Iclo) where 2.9 W/$(m^2$ - C) is h_e in still air (0.15 m/s) for a sedentary person

e = emissitivity (skin = 0.99; clothing in nonvisible radiation = 0.7)

T_{skin} = temperature of skin, K = C = 273

= 35 C, K = 35 + 273 = 308

T_{mrt} = mean radiant temperature of environment, K = C + 273

= 32 C, K = 32 + 273 = 305

Substituting values, we have:

$$R = \frac{5.67}{10^8} \times 1.865 \times 0.725 \times 1.0825 \times 0.814 \times 0.7\ (305^4 - 308^4)$$

= 16 Watts

<u>Convection</u>: Convective heat transfer (Konz, 1977) is:

$$C = h_c\ A\ f_{clr}\ F_{pcl}\ (t_{air} - t_{skin})$$

C = convection gain (+) or loss (-), Watts

h_c = convective heat transfer coefficient, Watts/$(m^2$-C)

= 4.2 W/$(m^2$-C) for still air

But, for moving air:

$$h_c = K_1 V^{0.6}$$

where K_1 = 8.6 for standing nude adults

V = air velocity, m/s

$$h_c = 8.6 \times V^{0.6}$$

A = skin surface area = 1.865 m^2

f_{clr} = 1.0825

F_{pcl} = decrease in evaporative efficiency for permeable clothing

t_{air} = air temperature = 32 C

t_{skin} = 35 C

$$C = 4.2 \times 1.865 \times 1.0825 \times 0.814\ (32 - 35) = -25.44$$

so, $C = h_c \times 1.865 \times 1.0825 \times 0.814\ (32 - 35)$

The above equation shows that convective heat transfer is directly proportional to the air velocity. The following values for convective heat transfer are obtained.

V, m/s	0.2	0.4	0.8	1.6	3.2
$(V)^{0.6}$	0.38	0.58	0.87	1.33	2.00
h_c	3.85	5.44	7.69	10.88	15.38
C, Watts	19	27	37	54	76

Evaporation: Evaporation heat transfer is:

$E = h_e\ A\ W\ F_{pcl}\ (VP_a - VP_s)$

where

E = evaporative gain (+) or loss (-), Watts

h_e = evaporative heat transfer coefficient = $2.2\ h_c$

A = skin surface area, m^2

W = fraction of skin that is wet

F_{pcl} = decrease in evaporative efficiency for permeable clothing

I_{clo} = insulation value of clothing, clo

VP_s = vapor pressure of water on skin, mm Hg
= 43 mm Hg, for 35 C skin temperature at 100 % rh

VP_a = vapor pressure of water in air, mm Hg
= 19 mm Hg, for 32 C DBT at 55 % rh

Substituting, we have

$E = 2.2\ h_c \times 1.865 \times W \times 0.814\ (19 - 43)$

V, m/s	0.2	0.4	0.8	1.6	3.2
h_c	3.85	5.44	7.69	10.88	15.38
E, Watts	(308)W	(436)W	(616)W	(872)W	(1233)W
E_{max} (W=1)	308	436	616	872	1233

<u>Conduction</u>: Conductive heat transfer is negligible in the case of a worker in a factory as his body is not in contact with any solid material which is at a temperature very different from the skin temperature. Hence conduction is not considered in this paper.

<u>Theoretical Analysis of Effect of Air Velocity</u>: Consider a hypothetical subject with a weight of 65 kg and height of 170 cm with a skin surface area of 1.86 m^2. Figure 2 shows that while the heat loss due to radiation is constant, convection and evaporation rise linearly as air velocity increases.

As metabolic rate increases a greater amount of heat is required to be removed by evaporation. Figure 3 shows that for the specified atmospheric conditions, a greater air velocity is required to achieve thermal equilibrium.

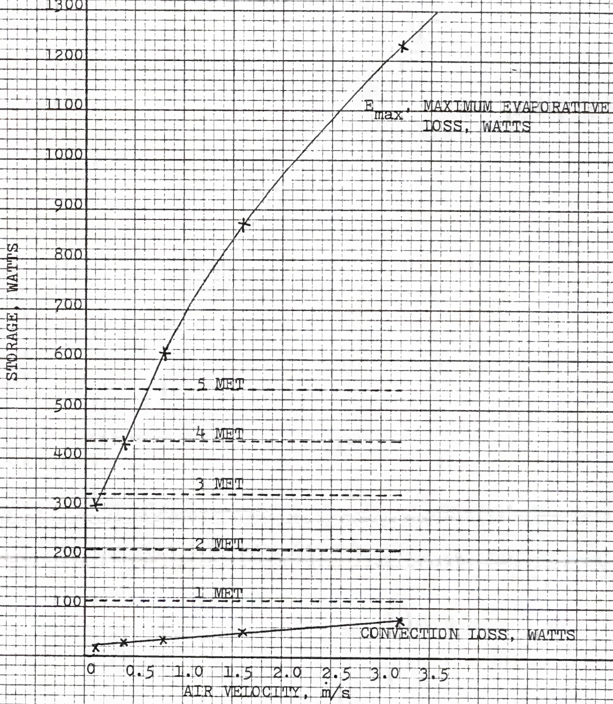

FIGURE 2. AIR VELOCITY VS HEAT LOSS BY CONVECTION AND EVAPORATION

1 MET = 58 WATTS/m^2

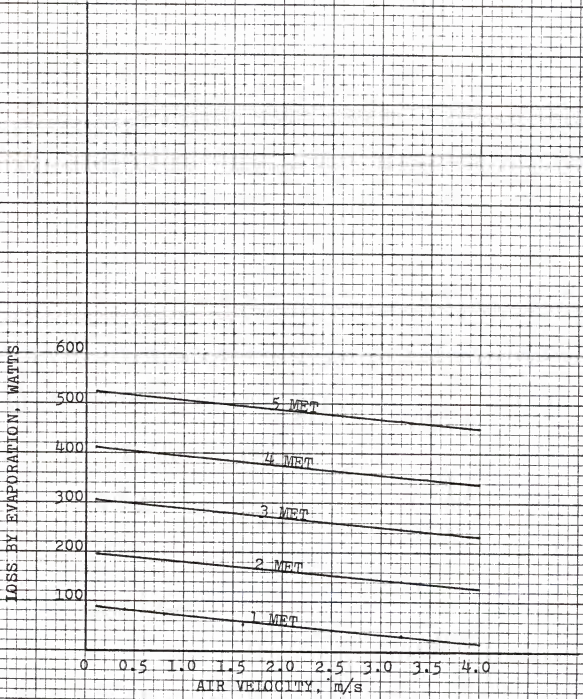

FIGURE 3. AMOUNT OF HEAT TO BE REMOVED BY EVAPORATION, AT VARIOUS METABOLIC RATES

METHOD

Task

The experiments were conducted in an environmental chamber of the Institute for Environmental Research at Kansas State University. The task first was performed under "control conditions" where DBT of 25 C, WBT 18.5 C and 55 % rh were maintained, conforming to the ASHRAE standard comfort zone for seated sedentary work. The standing, arm-pedalling task was performed in still air (0.13 m/s).

This was used as a reference point to compare the data obtained under experimental heat stress conditions, in which the environmental chamber was maintained at 32 C DBT and 24.5 C WBT with relative humidity at 55 %. The mean radiant temperature was the same as the dry bulb temperature. Air velocity was "still air" (0.13 m/s), 0.4, 0.8, 1.6 and 3.2 m/s. The subject wore light cotton underwear, socks and shoes, pants, half sleeves shirt and cotton working gloves (estimated clo = 0.55). The standing subject pedalled an erogometer, placed on a table, with his hands, at 50 rev/min at 0.5 kg load to maintain a metabolic rate of 190 W while working. See Figure 4. There were no scheduled rest periods during the 120 minute test period. However, the subjects rested when they desired. The distance pedalled, recorded on the tachometer, was a direct measure of work done.

Subjects

Two male subjects were paid $5.00 for every 3000 revolutions pedalled. The subjects had their physical fitness

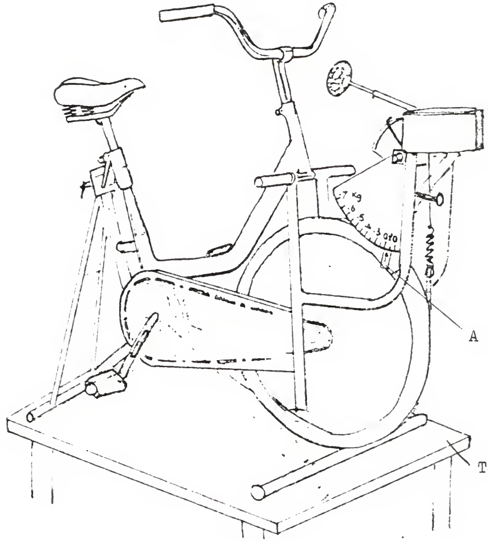

FIGURE 4. DRAWING OF BICYCLE ERGOMETER

A. Tension on flywheel was adjusted to maintain the hanging pendulum steady at 0.5 kg load, as shown on the semicircular scale, while pedalling at a speed of 20 km/hr.

tests taken prior to the experiment at the Institute for Environmental Research. Physical characteristics of the subjects are listed in Table 1.

Measurements, Procedure and Experimental Design

Air Velocity: Air from a propellor fan was directed from the left side of the subject. Wind speed was measured at five points distributed over a square of 30 cm x 30 cm at the head of the subject. A model 60 Anemotherm anemometer was used to measure air velocity. Air velocity used was "still air" (0.13 m/s), 0.4 m/s, 0.8 m/s, 1.6 m/s and 3.2 m/s. The sequence of air velocities used for the experiment is in Appendix III.

Skin Temperature: Skin temperature was measured by means of eight temperature thermisters (four 400 series and four 700 series). Each thermister was held in position by taping it securely on the skin with Micropore paper tape. The sites of the thermocouples are shown in Figure 5. The thermisters were connected to three Digitec temperature recorders.

Comfort Votes: Four ballots were used to obtain the dependent measures. See Appendix IV. The first was the thermal sensation ballot which on a listing of numbers from 1 to 7 described cold to hot sensations. The second ballot, which was designed to measure the subjects' responses to the air movement, consisted of a seven-point adjective rating. The third, designed to measure the responses of the subjects to sound, also consisted of a seven point rating. The fourth

TABLE 1. PHYSICAL CHARACTERISTICS OF SUBJECTS

Characteristic	Subject 1	Subject 2
Sex	Male	Male
Age, yr	23	21
Height, cm	183.0	167.6
Weight, kg	89.40	74.27
Percentage body fat*	13.8	5.0
Lean body weight, kg	77.0	70.6
Cardiovascular fitness**	Fair	Good
DuBois surface area, m^2	2.21	1.94

*For males, $\left(\frac{4.570}{\text{body density}} - 4.142\right) 100$

where,

Body density = (1.1017 - ((arm skinfold x 0.000883) + (chest skinfold x 0.000736) + (umb. skinfold x 0.000282)))

**Based on a maximum oxygen consumption of 39.4 ml/kg min for subject 1 and 46.7 ml/kg min for subject 2. This was estimated from heart rate for both subjects of 120 b/min, pedalling 5 min with a 7.5 kpm load.

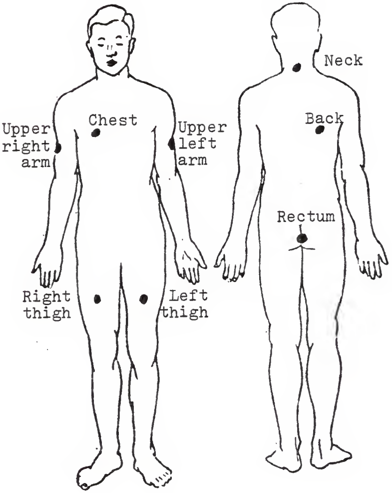

FIGURE 5. LOCATION OF TEMPERATURE THERMISTORS

was Borg's perceived exertion vote (Borg, 1962) which contained a listing of numbers and adjectives describing perceived exertion.

Heart Rate: Heart rate was measured with a stethoscope for 30 seconds. The subject stood without pedalling during the 30 seconds the reading was taken.

Weight: Weight of the subjects was taken with the clothing and without, both before and after the experiment.

Practice Periods: Four days before commencing the experimental study, both subjects underwent four practice sessions pedalling the ergometer for twenty minutes each day. This was to tone up the arm muscles for this particular activity.

Procedure: The subject was weighed with his clothes on and the clothing weighed separately, both before and after the experiment. The thermistors were attached in the environmental chamber. About 10 minutes after entering the chamber the initial physiological data and votes were recorded. The subject then commenced pedalling, maintaining the tachometer speed at 20 km/hr. The sound level in the chamber was measured by a sound level meter. Music was played over the radio. Physiological data was recorded every 10 minutes for 120 minutes on a data sheet. See Appendix VI. The subject recorded his thermal and comfort sensations, his exertion vote, his noise vote and air velocity vote every 30 minutes. However, during the last 20 minutes of the experiment, the air was directed from 45^{o} from the back for 10 minutes and votes were recorded and then the fan was moved 45^{o} to the front and after 10 minutes votes were recorded. This was done to determine the preference of the subjects to the direction of air. This movement of the fan from the side to the front or back also was randomized.

The subject was not given any scheduled rest but could take a rest whenever he desired. However, he was not allowed to sit down during the rest. The amount of cycling performed was recorded from the tachometer. The distance pedalled was a direct measurement of work done. The subject was not allowed to eat or drink during the test period.

RESULTS

Analysis and Discussion

An analysis of variance was performed on the data obtained with the aid of a computer program called "AARDVARK." The analysis of variance model is given by:

$$\text{OBSV} = S\ (I) + C\ (J) + T\ (K) + SC\ (IJ) + ST\ (IK) + CT\ (JK) + E\ (IJK).$$

where,

S = subjects, I = 2

C = conditions, J = 6

T = times, K = 13

This analysis of variance was carried out for 13 sets of data:

1. Neck temperature
2. Chest temperature
3. Back temperature
4. Left arm temperature
5. Right arm temperature
6. Rectal temperature
7. Right leg temperature
8. Left leg temperature
9. Heart rate
10. Noise vote
11. Air movement vote
12. Thermal sensation vote
13. Exertion vote.

All F ratios are shown in Tables 2 - 5.

TABLE 2. ANALYSIS OF VARIANCE OF TEMPERATURES

VARIABLES

Sources of variation	d.f.	Neck temperature		Chest temperature		Back temperature		Left arm temperature		Right arm temperature	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F	Mean square	F
Subjects	1	148.4	80.9**	98.1	135.8**	143.1	306.1**	44.7	144.5**	108.4	546.2**
Conditions	5	17.4	9.5**	25.7	35.5**	18.5	39.6**	22.7	73.5**	35.5	178.9**
Times	12	14.2	7.8**	1.2	1.7	2.1	4.6**	6.6	21.4**	4.3	21.7**
(Subject)(condition)	5	6.1	3.3*	10.6	14.7**	11.3	24.3**	3.8	12.2**	1.6	7.9**
(Subject)(time)	12	0.6	0.3	2.8	3.9*	0.3	0.5	0.3	0.9	0.2	0.9
(Condition)(time)	60	2.7	0.3	1.1	1.6	0.5	1.1	0.9	2.9	0.5	2.6
Error	60	1.8		0.7		0.5		0.3		0.2	
Total	155										

*$\alpha < 0.05$

**$\alpha < 0.01$

TABLE 3. ANALYSIS OF VARIANCE OF TEMPERATURES VARIABLES

Sources of variation	d.f.	Left leg temperature		Right leg temperature		Rectal temperature	
		Mean square	F	Mean square	F	Mean square	F
Subjects	1	53.4	114.2**	257.5	264.0**	2.4	45.4**
Conditions	5	80.8	172.8**	106.0	108.7**	2.7	50.9**
Times	12	1.2	2.7	1.1	1.2	0.8	15.2**
(Subject)(condition)	5	9.4	20.1**	23.0	23.6**	0.8	15.8**
(Subject)(time)	12	0.2	0.5	0.4	0.5	0.1	1.7
(Condition)(time)	60	0.4	0.9	0.8	0.8	0.0	0.6
Error	60	0.5		0.9		0.05	
Total	155						

$^*\alpha < 0.05$

$^{**}\alpha < 0.01$

TABLE 4. ANALYSIS OF VARIANCE OF VOTES

VARIABLES

Sources of variation	d.f.	Exertion vote		Thermal sensation		Noise vote		Air movement vote	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Subjects	1	66.1	65.2**	3.3	8.3**	8.1	59.0**	60.0	170.6**
Conditions	5	2.0	2.0	4.3	11.0**	0.2	1.4	4.9	13.8**
Times	4	154.5	152.3**	4.6	11.6**	0.1	0.5	4.3	12.2**
(Subject)(condition)	5	2.2	2.2	0.8	2.1	0.2	1.4	3.2	8.9**
(Subject)(time)	4	2.5	2.5	0.4	1.1	0.1	0.5	0.0	0.1
(Condition)(time)	20	0.5	0.5	0.3	0.7	0.1	1.0	0.3	0.9
Error	20	1.01		0.4		0.1		0.4	
Total	59								

$^{*}\alpha < 0.05$

$^{**}\alpha < 0.01$

TABLE 5. ANALYSIS OF VARIANCE OF HEART RATE

Sources of variation	d.f.	Heart rate	
		Mean square	F
Subjects	1	17715.9	408.5**
Conditions	5	866.6	19.9**
Times	4	1096.7	25.3**
(Subject)(condition)	5	354.5	8.2**
(Subject)(time)	4	138.6	3.2*
(Condition)(time)	20	55.1	1.3
Error	20	43.3	
Total	59		

*$\alpha<0.05$

**$\alpha<0.01$

Neck Temperature: Subjects, conditions and times were significant, as well as the subjects by conditions interaction. In the following figures, the mean values for the experiment are plotted, that is, the effect of time is ignored. Figure 6 shows the surprising result that neck temperature at low air velocities of 0.4 m/s and 0.8 m/s rises from that at the "still air" condition. Higher air velocities of 1.6 m/s and 3.2 m/s drive the temperature down.

Chest Temperature: Subjects and conditions were significant as well as the subjects by conditions and conditions by times interactions. Figure 7 shows us that chest temperature is lowest at "still air" condition. A low air velocity of 0.4 m/s increases the temperature. A high air velocity of 3.2 m/s again brings the temperature down.

Back Temperature: Subjects, conditions and times were significant, as well as the subjects by conditions interaction. Figure 8 shows that back temperature rises at a low air velocity of 0.4 m/s from "still air" (0.13 m/s) condition. The temperature is lower whe the task is performed at higher air velocities.

Left Arm Temperature: Subjects, conditions and times were significant, as well as the subjects by conditions interaction. Figure 9 shows that the left arm temperature is higher at "still air" or at a low air velocity of 0.4 m/s. Higher air velocities tend to lower the temperature.

Right Arm Temperature: Subjects, conditions and times were significant, as well as the subjects by conditions interaction. Figure 10 shows that higher air velocities of 1.6 m/s

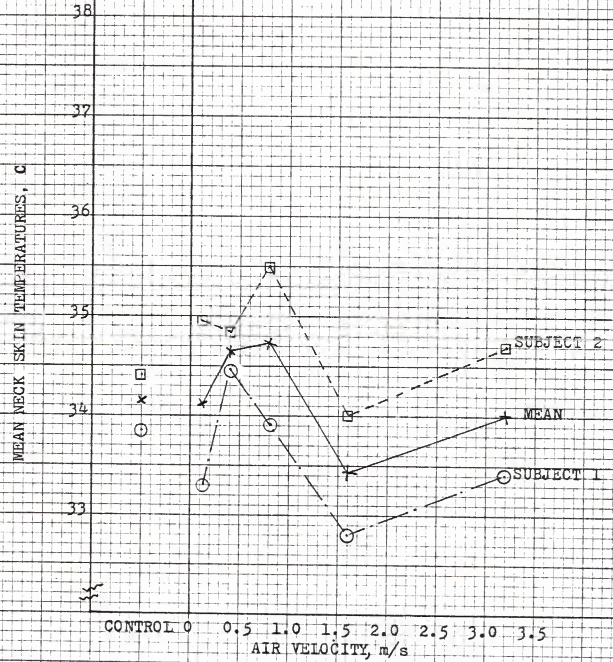

FIGURE 6. MEAN NECK SKIN TEMPERATURE VS AIR VELOCITY

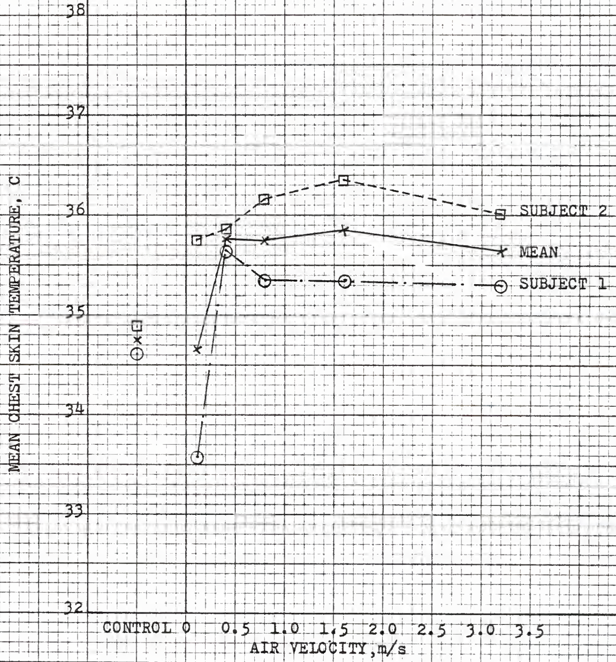

FIGURE 7. MEAN CHEST SKIN TEMPERATURE VS AIR VELOCITY

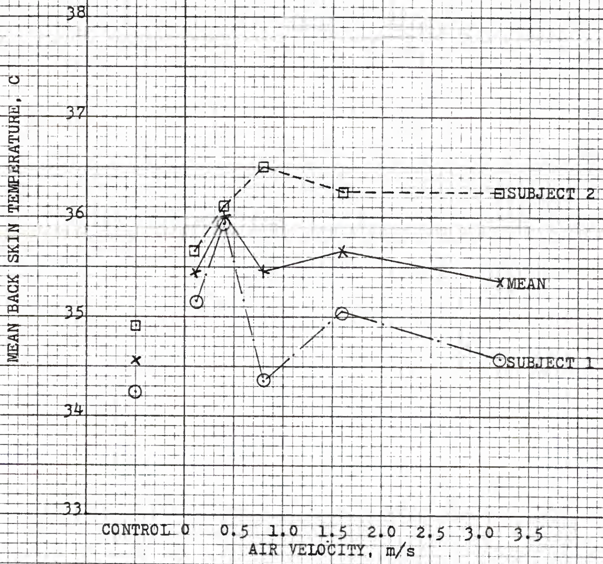

FIGURE 8. MEAN BACK SKIN TEMPERATURE VS AIR VELOCITY

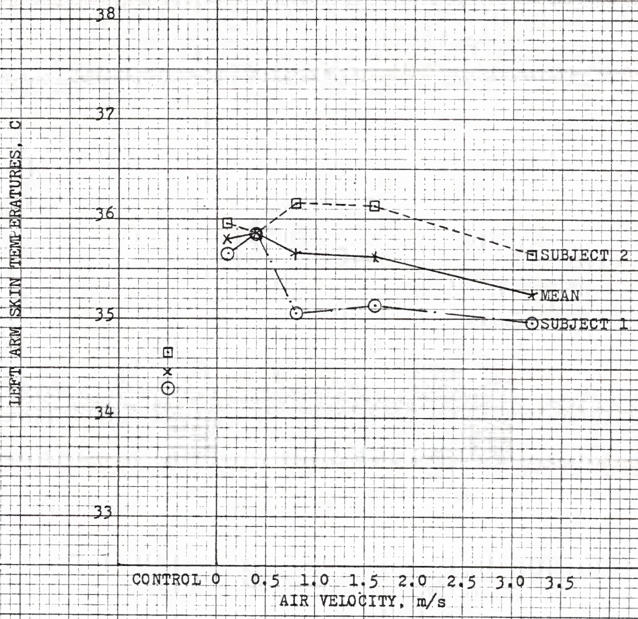

FIGURE 9. MEAN LEFT ARM SKIN TEMPERATURES VS AIR VELOCITY

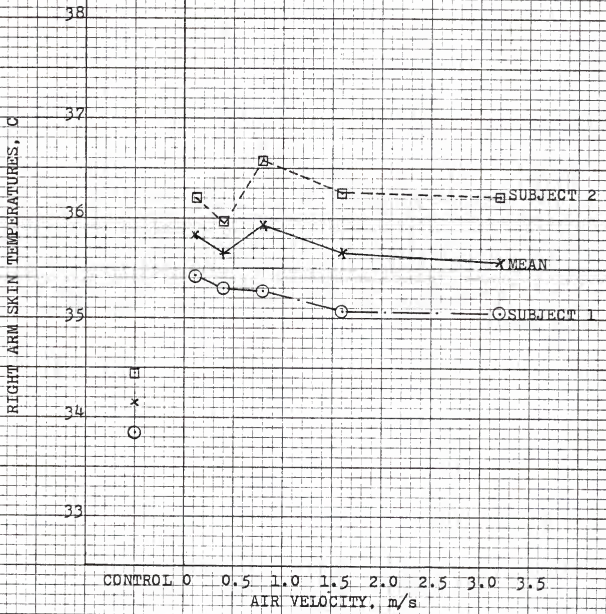

FIGURE 10. RIGHT ARM SKIN TEMPERATURES VS AIR VELOCITY

and 3.2 m/s result in lower right arm temperatures. As air was directed from the left side of the subject, the right arm, unlike the left arm, did not get direct air from the fan. Left and right arm temperatures did not differ significantly. Low air velocities (still air, 0.4 m/s and 0.8 m/s) result in higher temperatures.

Left Leg Temperature: Subjects and conditions were significant as well as the subjects by conditions interaction. Figure 11 shows the variations of left leg temperatures with respect to air velocities. As the subjects wore pants, no direct air from the fan reached the legs. The different leg temperatures were responses to the air being directed on the upper half of the body. Air velocities of 0.8 m/s and 1.6 m/s resulted in lower temperatures as compared to "still air" or 0.4 m/s or 3.2 m/s.

Right Leg Temperatures. Subjects and conditions were significant as well as the subjects by conditions interaction. Figure 12 shows no conclusive relationship between air velocity and right leg temperatures. However, high air velocity of 3.2 m/s tends to reduce the temperature. The right leg was significantly higher than left leg temperature.

Rectal Temperature: Subjects, conditions and times were significant, as well as the subject by condition interactions. Figure 13 shows that low air velocities of 0.4 m/s and 0.8 m/s tend to result in higher rectal temperatures. Higher air velocities of 1.6 m/s and 3.2 m/s drive down rectal temperature.

Heart Rate: Subjects, conditions and times were significant as well as the subject by condition and subject by time interactions. Figure 14 shows that higher air velocities of

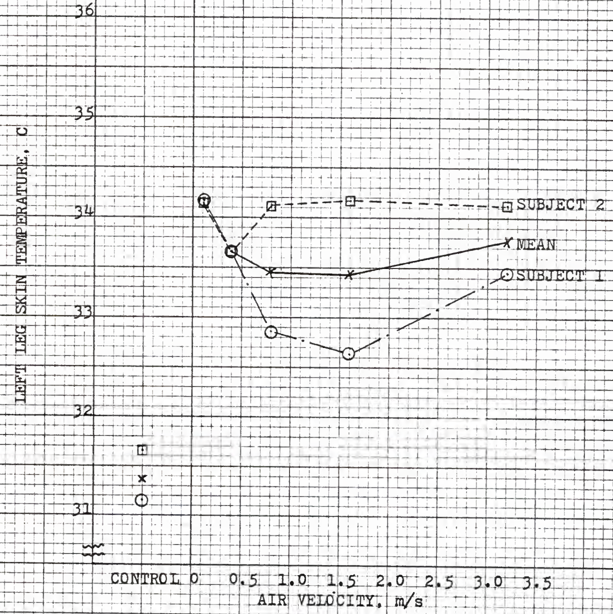

FIGURE 11. LEFT LEG SKIN TEMPERATURES VS AIR VELOCITY

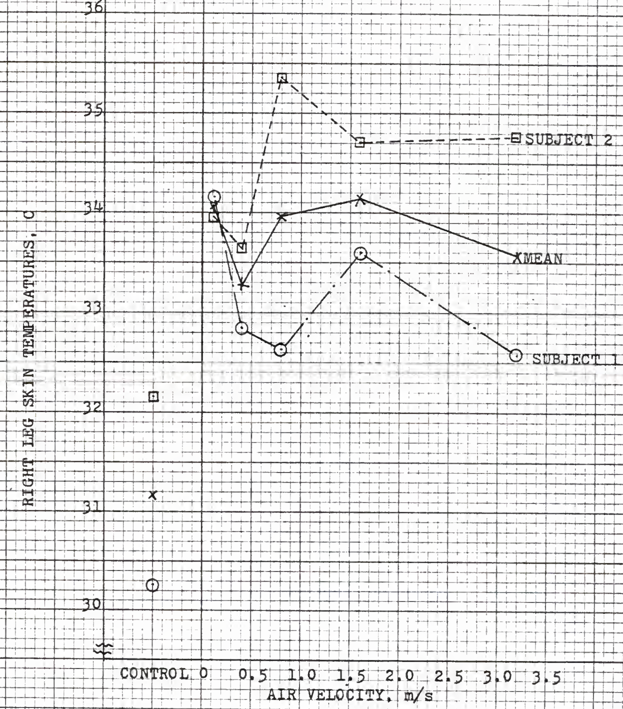

FIGURE 12. MEAN RIGHT LEG SKIN TEMPERATURES VS AIR VELOCITY

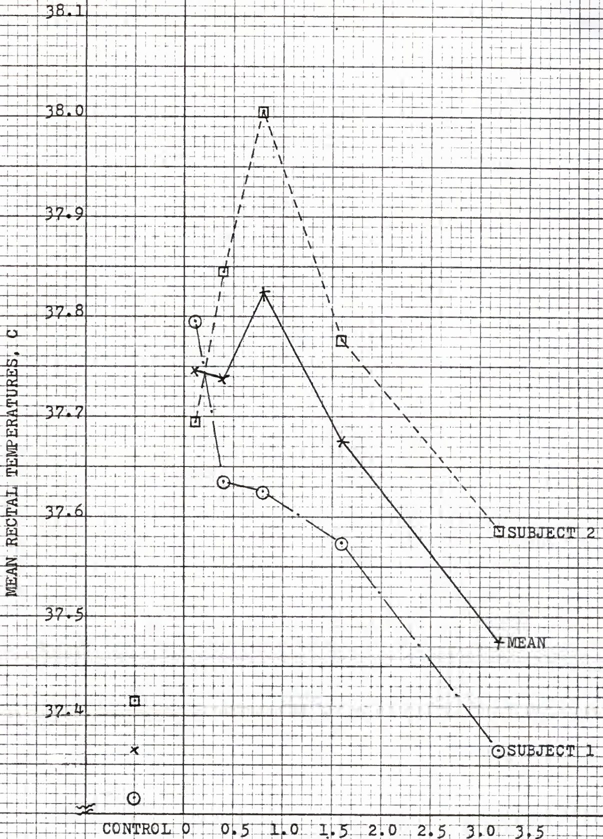

FIGURE 13. MEAN RECTAL TEMPERATURE VS AIR VELOCITY

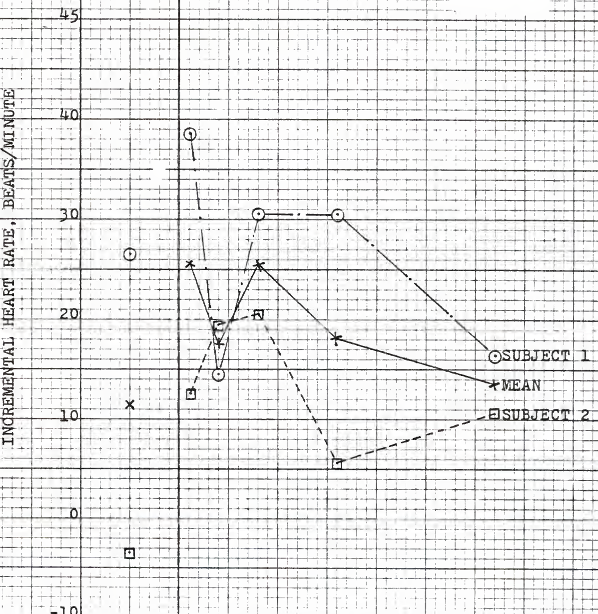

FIGURE 14. INCREMENTAL HEART RATE VS AIR VELOCITY
SUBJECT 1: MEAN RESTING HEART RATE = 96.2 b/min
SUBJECT 2: MEAN RESTING HEART RATE = 73.3 b/min

1.6 m/s and 3.2 m/s result in lower heart rates. This is in keeping with the earlier results of skin temperatures. Higher skin temperatures at lower air velocities result in a higher heart rate, as the heart beats faster to transfer the heat from the muscular layer of the body to the environment.

Exertion Vote: Subjects and times were significantly different. Figure 15 shows surprising results again. Subjects recorded a lower exertion vote at "still air" conditions as compared to air being blown on them. However, they felt that they were exerting a higher exertion at lower air velocities of 0.4 m/s and 0.8 m/s. They registered lower exertion votes at higher air velocities of 1.6 m/s and 3.2 m/s. Note that even though the task remains the same, the subjects recorded a lower exertion vote at higher air velocities and they registered a lower heart rate simultaneously. The mean heart rate was about 105 beats/min, while the perceived exertion vote predicted a heart rate of about 130 beats/min. This implies that the perceived exertion vote overestimated the heart rate during heat. Since the original perceived exertion work by Borg was for comfort conditions it may not be accurate to use the perceived exertion vote in heat stress conditions.

Thermal Sensation: Subjects, conditions and times were significant. Figure 16 shows that subjects preferred higher velocity air to be blown on them. The higher the air velocity the cooler they felt.

Noise Vote: Subjects alone was significant. Figure 17 shows us that air velocity has no effect on their noise vote. The noise level ranged from 70 to 75 dBA for all the experiments.

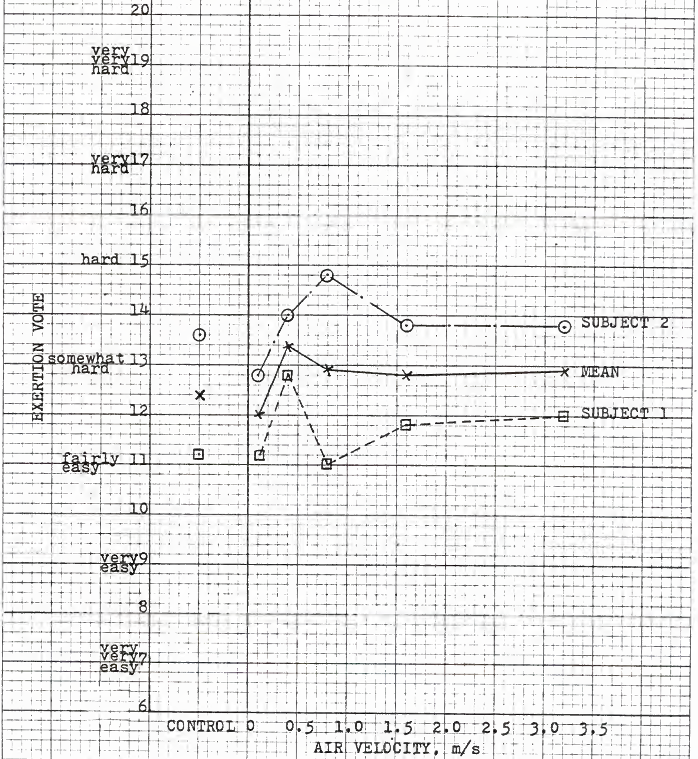

FIGURE 15. EXERTION VOTE VS AIR VELOCITY

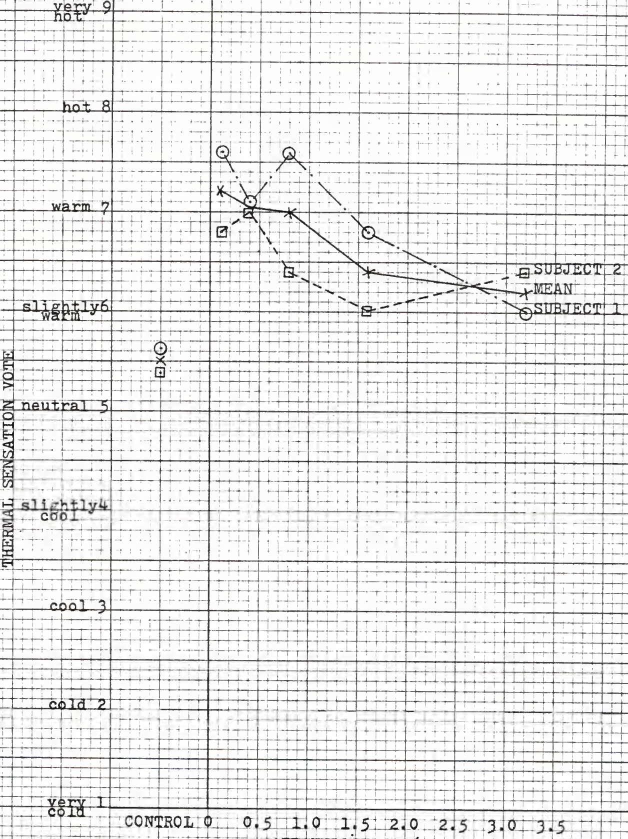

FIGURE 16. THERMAL SENSATION VOTE VS AIR MOVEMENT

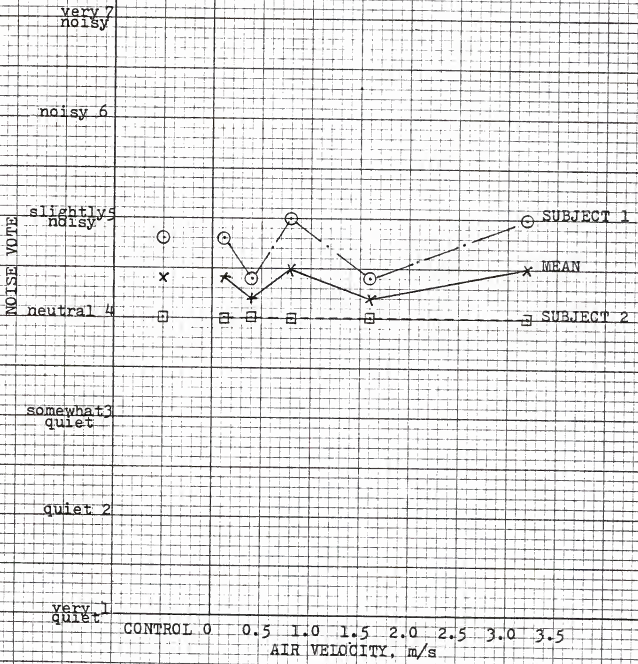

FIGURE 17. MEAN NOISE VOTE VS AIR VELOCITY

Air Movement Vote: Subjects, conditions and times were significant as well as the subject by condition interaction. Figure 18 shows that subjects felt that higher air velocities were more pleasant. The "still air" condition was recorded as "unpleasant." The higher air velocities were preferred in this environment. Subjects also showed preference of air to be directed from the front or side but not from the back. See Appendix V.

Work Done: Figure 19 shows distance pedalled in kilometers in 120 minutes versus air velocity. For these two subjects, air velocity was not a factor that determined the distance they pedalled. The mean plot shows that the maximum distance was pedalled in "still air" conditions. The lowest was at 0.4 m/s air velocity.

Sweat Evaporation by Subjects: Weight of the subjects and weight of the clothing they wore during the experiment, taken before and after the experiment, were used to calculate the weight of sweat evaporated. See Table 6 and Figure 20.

Figure 20 shows maximum sweat loss occurred at 0.4 m/s air velocity. Sweat loss was lowest at 1.6 m/s air velocity.

Comparisons of Actual Data With Computer Predictions

The experimental data was compared with the Kansas State University computer model (Konz, Hwang, Dhiman, Duncan and Masud, 1977).

Model Description: The body is divided into 6 segments (head, trunk, arms, hands, legs and feet) each of which is subdivided into core, muscle, fat and skin for a total of 24

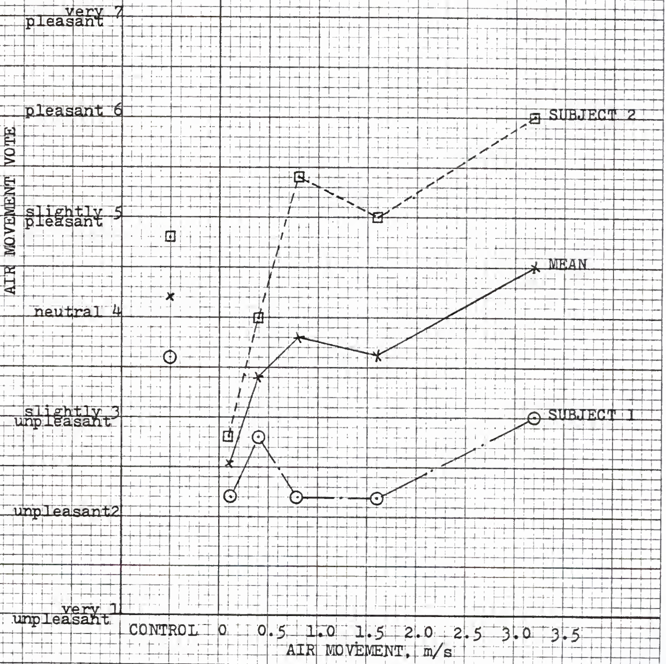

FIGURE 18. AIR MOVEMENT VOTE VS AIR VELOCITY

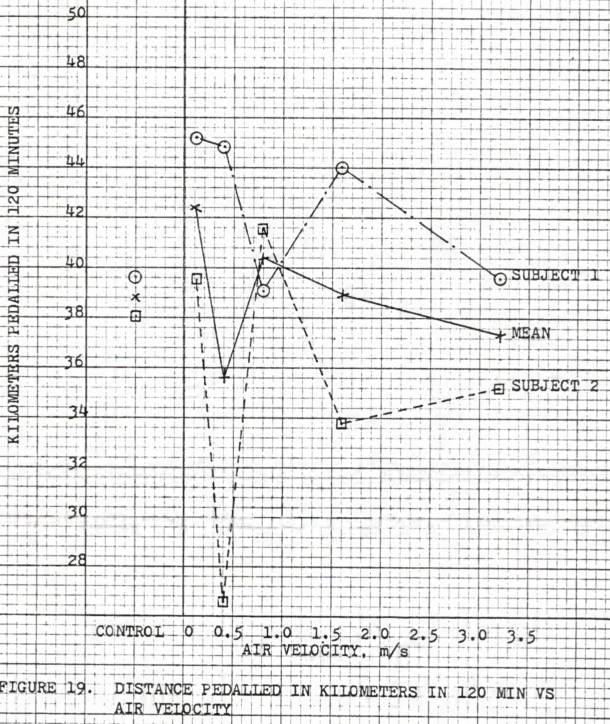

FIGURE 19. DISTANCE PEDALLED IN KILOMETERS IN 120 MIN VS AIR VELOCITY

TABLE 6. SWEAT EVAPORATION BY SUBJECTS

Air velocity m/s	Subject 1		Subject 2	
	g/h	g/(h - m^2)	g/h	g/(h - m^2)
Control condition	300	135	188	96
0.13	499	225	359	185
0.4	545	246	490	252
0.8	493	223	386	198
1.6	415	187	295	152
3.2	470	212	334	172

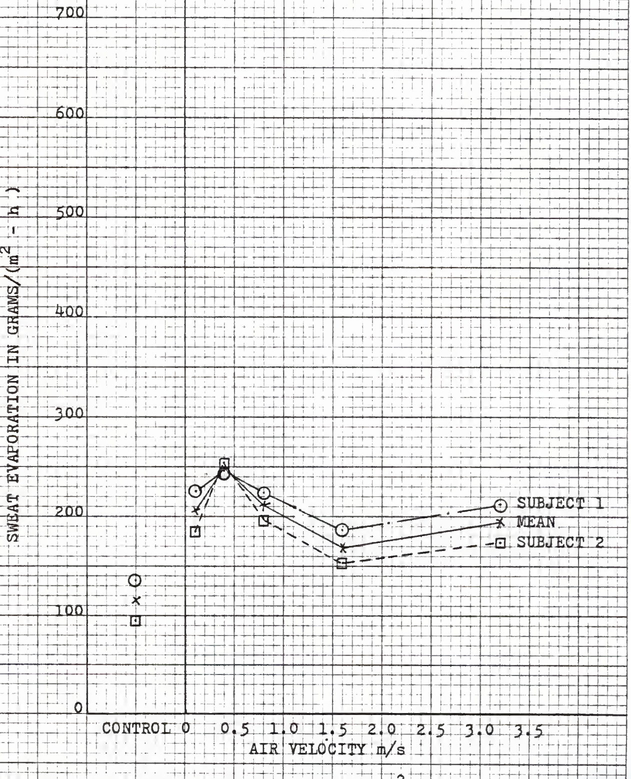

FIGURE 20. SWEAT EVAPORATION IN GRAMS/(m^2 - h) VS AIR VELOCITY

elements. Blood flow between the cores of the 6 segments is through a hypothetical "central blood compartment" so there are 24 + 1 = 25 elements in all. Periodically the program computes a heat balance for each of the 25 elements.

The heat balance at each element is composed of heat generation (metabolism), heat input, and heat output.

Metabolism is composed of basal metabolism and activity metabolism. For the three interior layers (core, muscle and fat), heat input and output are through conduction and convection (blood flow). The outer layer (skin) has, in addition, heat exchange with the environment through evaporation, convection and radiation.

As mentioned before, the key concept is the controlling system which uses temperature of each of these 25 elements as input to modify sweat rate on the skin, blood flow rate in the skin layer, and heat production rate (shivering) in the muscle layer.

Experimental information used for the computer simulation is given in Appendix VII. The simulation was plotted only for subject 1 at 0.8 m/s.

The following comparisons were made:

1. Rectal temperature
2. Head temperature
3. Trunk temperature
4. Arm temperature
5. Leg temperature
6. Sweat rate

7. Heart rate

8. Comfort votes.

The experimental values and computer predictions are listed for the above 8 comparisons in Tables 7 to 21.

Rectal Temperature: Plots for experimental values and computer calculations for the rectal temperature for subject 1 are shown in Figure 21 and Table 7. Computer values are lower than the experimental readings at 0.8 m/s. The experimental data shows a gradual rise to the stabilizing temperature. The computer value drops suddenly initially and makes a steeper rise to the stabilizing temperature. The computer data for the control condition is 0.5 C lower on the average as compared to the experimental data.

Head Temperature: Figure 22 and Table 9 show that the experimental (neck) data for the control condition first overshoots and then decreases while the computer (head) value, after a slight fall, gradually rises until it crosses the experimental value after 100 minutes of simulation. The experimental data for 0.8 m/s first falls rapidly and gradually reaches a stable value after 80 minutes of experimentation. The computer values for this condition slowly ascend and then slowly fall, but are always higher than the experimental temperatures.

Trunk Temperature: Figure 23 and Table 11 give the data. Experimental data (av. of chest + back) for both the control condition and 0.8 m/s first rise steeply and then gradually fall to a steady state temperature of 34.5 C. The control condition computer values are lower than the experimental data throughout the simulation.

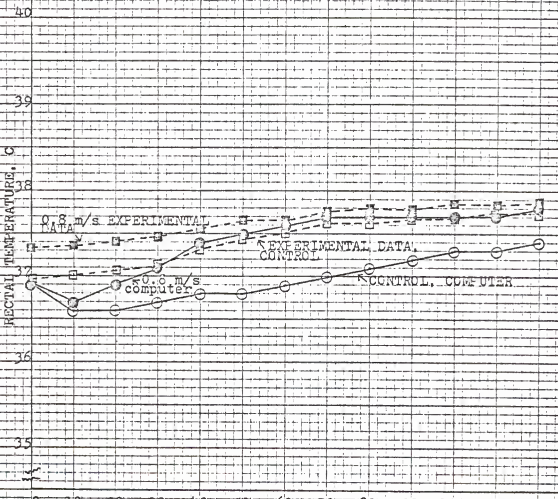

FIGURE 21. RECTAL TEMPERATURE VS TIME - SUBJECT 1

TABLE 7. SUBJECT 1-RECTAL TEMPERATURE, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	36.95	36.9	+0.05	37.56	36.9	0.66	37.26	36.9	0.36	37.33	36.9	0.43	37.29	36.9	0.39	37.08	36.9	0.18
10	37.00	36.6	0.40	37.72	36.7	1.02	37.34	36.7	0.34	37.36	36.7	0.66	37.26	36.7	0.56	37.05	36.7	0.35
20	37.06	36.6	0.46	37.72	36.9	0.82	37.38	36.9	0.48	37.40	36.9	0.50	37.34	36.9	0.44	37.14	36.9	0.24
30	37.11	36.7	0.41	37.78	37.1	0.68	37.47	37.1	0.37	37.47	37.1	0.37	37.53	37.1	0.43	37.22	37.1	+0.11
40	37.31	36.8	0.51	37.83	37.4	0.43	37.58	37.4	0.18	37.54	37.4	0.14	37.57	37.4	0.17	37.34	37.4	-0.06
50	37.42	36.8	0.62	37.83	37.5	0.33	37.65	37.5	0.15	37.65	37.5	0.15	37.61	37.5	0.11	37.42	37.5	-0.08
60	37.50	36.9	0.60	37.83	37.6	0.23	37.67	37.6	+0.07	37.64	37.6	0.04	37.67	37.6	0.07	37.44	37.6	-0.16
70	37.61	37.0	0.61	37.83	37.7	0.13	37.69	37.7	-0.01	37.75	37.7	0.05	37.69	37.7	-0.01	37.50	37.7	-0.20
80	37.61	37.1	0.51	37.83	37.7	0.13	37.76	37.7	+0.06	37.80	37.7	0.10	37.68	37.7	-0.02	37.53	37.7	-0.17
90	37.68	37.2	0.48	37.83	37.7	0.13	37.84	37.7	0.14	37.79	37.7	0.09	37.68	37.7	-0.02	37.52	37.7	-0.18
100	37.69	37.3	0.39	37.83	37.7	0.13	37.86	37.7	0.16	37.83	37.7	0.13	37.72	37.7	+0.02	37.52	37.7	-0.18
110	37.72	37.3	0.42	37.84	37.7	0.14	37.84	37.7	0.14	37.82	37.7	0.12	37.76	37.7	+0.06	37.51	37.7	-0.19
120	37.72	37.4	0.32	37.88	37.8	0.08	37.91	37.8	0.11	37.88	37.8	0.03	37.72	37.8	-0.08	37.50	37.8	-0.30

Ex = experimental value C = computer prediction value

TABLE 8. SUBJECT 2-RECTAL TEMPERATURE, C

Time min	Control condition			. 0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	37.20	36.8	+0.40	37.30	36.9	+0.40	38.04	36.9	+1.14	37.43	36.9	+0.53	37.68	36.9	+0.78	37.27	36.9	+0.37
10	37.12	36.5	+0.62	37.41	36.8	+0.61	38.02	36.8	+1.22	37.61	36.8	+0.81	37.68	36.8	+0.88	37.32	36.8	+0.52
20	37.22	36.6	+0.62	37.51	37.0	+0.51	38.00	37.0	+1.00	37.73	37.0	+0.73	37.69	37.0	+0.69	37.40	37.0	+0.40
30	37.26	36.7	+0.56	37.62	37.3	+0.32	37.94	37.3	+0.64	37.89	37.3	+0.59	37.76	37.3	+0.46	37.51	37.3	+0.21
40	37.31	36.8	+0.51	37.72	37.5	+0.22	37.93	37.5	+0.43	37.99	37.5	+0.49	37.76	37.5	+0.26	37.56	37.5	+0.06
50	37.34	37.0	+0.34	37.83	37.6	+0.23	37.87	37.6	+0.27	38.11	37.6	+0.51	37.81	37.6	+0.21	37.64	37.6	+0.04
60	37.34	37.2	+0.14	37.83	37.6	+0.23	37.85	37.6	+0.25	38.17	37.6	+0.57	37.78	37.6	+0.18	37.69	37.6	+0.09
70	37.34	37.3	+0.04	37.85	37.7	+0.15	37.81	37.7	+0.11	38.18	37.7	+0.48	37.78	37.7	+0.08	37.69	37.7	-0.01
80	37.36	37.4	-0.04	37.84	37.7	+0.14	37.78	37.7	+0.08	38.22	37.7	+0.52	37.78	37.7	+0.08	37.69	37.7	-0.01
90	37.36	37.5	-0.14	37.83	37.7	+0.13	37.75	37.7	+0.05	38.25	37.7	+0.55	37.82	37.7	+0.12	37.72	37.7	+0.02
100	37.38	37.5	-0.12	37.78	37.8	-0.02	37.67	37.8	-0.13	38.23	37.8	+0.45	37.84	37.8	+0.04	37.69	37.8	-0.11
110	37.38	37.6	-0.22	37.73	37.8	-0.07	37.65	37.8	-0.15	38.24	37.8	+0.44	37.86	37.8	+0.06	37.71	37.8	-0.09
120	37.39	37.6	-0.21	37.75	37.8	-0.05	37.63	37.8	-0.17	38.21	37.8	+0.41	37.91	37.8	+0.11	37.72	37.8	-0.08

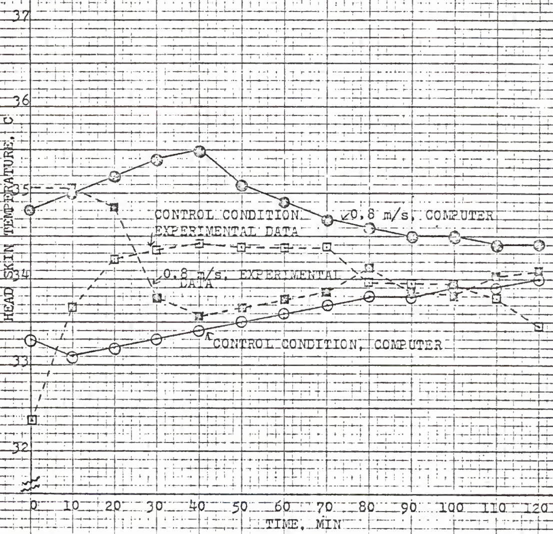

FIGURE 22. SUBJECT 1 - HEAD SKIN TEMPERATURE VS TIME

TABLE 9. SUBJECT 1-HEAD TEMPERATURES, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	32.34	33.3	-0.96	34.67	34.8	-0.13	34.97	34.8	+0.17	35.06	34.8	+0.26	34.87	34.8	+0.07	34.61	34.8	-0.19
10	33.67	33.1	+0.57	35.33	35.0	+0.33	35.39	35.0	+0.39	35.07	35.0	+0.07	34.89	35.0	-0.11	34.31	35.0	-0.69
20	34.22	33.2	+1.02	35.39	35.2	+0.19	35.41	35.2	+0.21	34.82	35.2	-0.38	34.33	35.2	-0.87	33.95	35.2	-1.25
30	34.32	33.3	+1.02	35.22	35.4	-0.18	35.09	35.4	-0.31	33.79	35.4	-1.61	34.00	35.4	-1.40	33.64	35.4	-1.76
40	34.02	33.4	+0.62	35.06	33.5	-0.44	34.60	35.5	-0.90	33.58	35.5	-1.92	33.87	35.5	-1.63	33.45	35.5	-2.05
50	34.36	33.5	+0.86	34.72	35.1	-0.38	34.37	35.1	-0.73	33.68	35.1	-1.42		35.1		33.18	35.1	-1.92
60	34.36	33.6	+0.76	34.50	34.9	-0.40	34.37	34.9	-0.53	33.55	34.9	-1.35		34.9		33.37	34.9	-1.53
70	34.36	33.7	+0.66	34.24	34.7	-0.46	34.42	34.7	-0.28	33.84	34.7	-0.86		34.7		33.21	34.7	-1.49
80	33.97	33.8	+0.17	34.20	34.6	-0.40	34.20	34.6	-0.40	34.11	34.6	-0.49		34.6		33.13	34.6	-1.47
90	33.96	33.8	+0.16	34.34	34.5	-0.16	34.37	34.5	-0.13	33.04	34.5	-1.46		34.5		33.42	34.5	-1.08
100	33.91	33.9	+0.01	34.17	34.5	-0.33	34.17	34.5	-0.33	33.82	34.5	-0.68		34.5		33.30	34.5	-1.14
110	33.77	33.9	-0.13	33.60	34.4	-0.8	33.56	34.4	-0.84	34.03	34.4	-0.37		34.4		32.85	34.4	-1.55
120	33.44	34.0	-0.56	33.60	34.4	-0.8	33.19	34.4	-1.21	34.10	34.4	-0.30		34.4		32.70	34.4	-1.7

TABLE 10. SUBJECT 2-HEAD TEMPERATURES, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	33.63	33.3	+0.33	35.57	34.8	+0.77	35.70	34.8	+0.90	35.59	34.8	+0.79	35.33	34.8	+0.53	35.81	34.8	+1.01
10	34.03	33.1	+0.93	36.04	35.0	+1.04	35.74	35.0	+0.74	36.04	35.0	+1.04	35.73	35.0	+0.73	35.87	35.0	+0.87
20	34.35	33.3	+1.05	35.69	35.3	+0.39	35.42	35.3	+0.12	36.02	35.3	+0.72	35.53	35.3	+0.23	35.82	35.3	+0.52
30	34.51	33.5	+1.01	35.26	35.4	-0.14	34.52	35.4	-0.88	35.82	35.4	+0.42	35.63	35.4	+0.23	35.67	35.4	+0.27
40	34.57	33.6	+0.97	34.55	34.9	-0.35	34.62	34.9	-0.28	35.46	34.9	+0.56	34.97	34.9	+0.07	35.64	34.9	+0.74
50	34.56	33.7	+0.86	34.75	34.6	+0.15	33.99	34.6	-0.61	35.63	34.6	+1.06	33.69	34.6	-0.91	35.19	34.6	+0.59
60	34.59	33.8	+0.79	34.85	34.5	+0.35	33.37	34.5	-1.13	35.29	34.5	+0.79	33.25	34.5	-1.25	35.12	34.5	+0.62
70	34.74	33.9	+0.84	35.02	34.3	+0.72	33.93	34.3	-0.37	35.33	34.3	+1.03	33.26	34.3	-1.04	35.11	34.3	+0.81
80	34.54	33.9	+0.64	35.06	34.3	+0.76	35.02	34.3	+0.72	35.21	34.3	+0.91	32.84	34.3	-1.46	34.8	34.3	+0.50
90	34.49	33.7	+0.79	34.55	34.2	+0.35	34.57	34.2	+0.37	35.39	34.2	+1.19	33.19	34.2	-1.01	34.8	34.3	+0.50
100	34.41	33.6	+0.81	34.43	34.2	+0.23	35.14	34.2	+0.94	35.11	34.2	+0.91	32.79	34.2	-1.41	34.5	34.2	+0.30
110	34.52	33.6	+0.92	34.43	34.2	+0.23	35.48	34.2	+1.28	35.11	34.2	+0.91	33.92	34.2	-0.28	34.4	34.2	+0.20
120	34.69	33.5	+1.19	34.53	34.2	+0.33	35.13	34.2	+0.93	35.18	34.2	+0.98	32.34	34.2	-1.86	34.4	34.2	+0.20

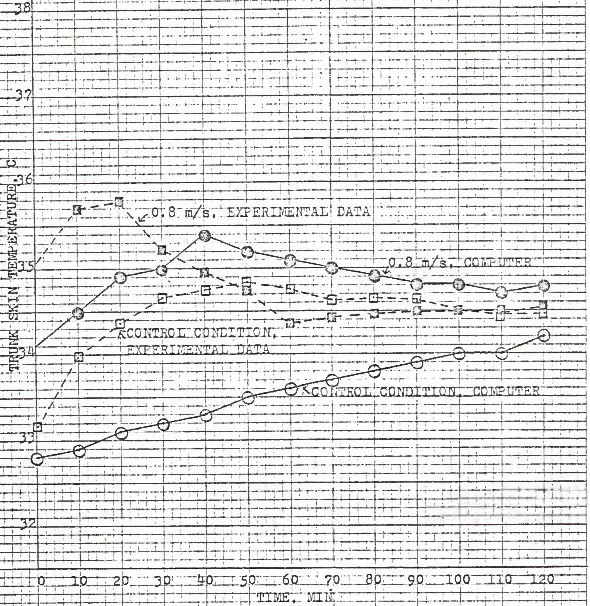

FIGURE 23. SUBJECT 1 - TRUNK SKIN TEMPERATURE VS TIME

TABLE 11. SUBJECT 1–TRUNK TEMPERATURE, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	33.13	32.8	+0.33	34.00	34.1	-0.90	35.54	34.1	+1.44	35.09	34.1	+0.99	34.85	34.1	+0.75	35.08	34.1	+0.98
10	33.97	32.9	+1.07	34.83	34.5	+0.33	35.73	34.5	+1.23	35.70	34.5	+1.20	35.12	34.5	+0.62	35.15	34.5	+0.65
20	34.35	33.1	+1.25	35.14	34.9	+0.24	35.77	34.9	+0.87	35.78	34.9	+0.88	35.21	34.9	+0.31	35.15	34.9	+0.25
30	34.66	33.2	+1.46	35.33	35.0	+0.33	35.74	35.0	+0.74	35.21	35.0	+0.21	35.43	35.0	+0.43	35.04	35.0	+0.04
40	34.44	33.3	+1.14	35.25	35.4	-0.15	35.53	35.4	+0.13	34.96	35.4	-0.44	35.21	35.4	-0.19	34.81	35.4	-0.59
50	34.83	33.5	+1.33	35.03	35.2	-0.17	35.54	35.2	+0.34	34.73	35.2	-0.47	35.16	35.2	-0.04	34.55	35.2	-0.65
60	34.74	33.6	+1.14	33.89	35.1	-1.21	35.71	35.1	+0.61	34.75	35.1	-0.35	34.98	35.1	-0.12	34.80	35.1	-0.30
70	34.61	33.7	+0.91	33.56	35.0	-1.44	35.79	35.0	+0.79	34.34	35.0	-0.66	35.01	35.0	+0.01	34.38	35.0	-0.62
80	34.68	33.8	+0.88	34.06	34.9	-0.84	35.72	34.9	+0.82	34.41	34.9	-0.49	35.16	34.9	+0.26	34.70	34.9	-0.20
90	34.63	33.9	+0.73	34.08	34.8	-0.72	36.13	34.8	+1.33	34.60	34.8	-0.20	35.23	34.8	+0.43	34.92	34.8	+0.12
100	34.50	34.0	+0.50	33.50	34.8	-1.30	35.99	34.8	+1.19	34.49	34.8	-0.31	35.26	34.8	+0.46	35.05	34.8	+0.25
110	34.45	34.0	+0.45	33.92	34.7	-0.78	36.10	34.7	+1.40	34.49	34.7	-0.21	35.29	34.7	+0.59	35.08	34.7	+0.38
120	34.47	34.2	+0.27	34.19	34.8	-0.61	36.03	34.8	+1.23	34.55	34.8	-0.25	35.62	34.8	+0.82	35.23	34.8	+0.43

$$\text{*Trunk temperature} = \frac{\text{chest temperature + back temperature}}{2}$$

TABLE 12. SUBJECT 2-TRUNK TEMPERATURE, C

Time	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
min	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	32.77	33.3	-0.53	35.35	34.2	+1.15	36.09	34.2	+1.89	35.41	34.2	+1.21	35.70	34.2	+1.5	35.54	34.2	+1.34
10	33.78	33.4	+0.38	35.78	34.8	+0.98	36.35	34.8	+1.55	36.23	34.8	+1.43	36.12	34.8	+1.32	36.18	34.8	+1.38
20	34.41	33.5	+0.91	35.96	35.1	+0.86	36.31	35.1	+1.21	36.45	35.1	+1.35	36.48	35.1	+1.38	36.33	35.1	+1.23
30	34.90	33.7	+1.20	35.98	35.4	+0.58	36.06	35.4	+0.66	36.62	35.4	+1.22	36.57	35.4	+1.17	36.31	35.4	+0.91
40	35.06	33.9	+1.16	35.76	35.2	+0.56	36.07	35.2	+0.87	36.61	35.2	+1.41	36.40	35.2	+1.20	36.17	35.2	+0.97
50	35.23	34.0	+1.23	35.72	35.0	+0.72	35.98	35.0	+0.98	36.63	35.0	+1.63	36.44	35.0	+1.44	36.35	35.0	+1.35
60	35.33	34.1	+1.23	35.63	35.0	+0.63	35.82	35.0	+0.82	36.39	35.0	+1.39	36.28	35.0	+1.28	36.27	35.0	+1.27
70	35.16	34.3	+0.86	35.88	34.9	+0.98	35.74	34.9	+0.84	36.28	34.9	+1.38	36.14	34.9	+1.24	36.29	34.9	+1.39
80	35.28	34.5	+0.78	35.78	34.8	+0.98	35.72	34.8	+0.92	36.16	34.8	+1.36	36.28	34.8	+1.58	36.21	34.8	+1.41
90	35.36	34.5	+0.86	35.81	34.8	+1.01	35.84	34.8	+1.04	36.25	34.8	+1.45	36.34	34.8	+1.54	36.16	34.8	+1.36
100	35.40	34.4	+1.0	35.58	34.8	+0.78	35.81	34.8	+1.01	36.26	34.8	+1.46	36.35	34.8	+1.55	36.05	34.8	+1.25
110	35.49	34.4	+1.09	35.32	34.8	+0.52	36.01	34.8	+1.21	36.36	34.8	+1.56	36.49	34.8	+1.69	35.93	34.8	+1.13
120	35.57	34.4	+1.17	35.57	34.8	+0.77	36.15	34.8	+1.35	36.64	34.8	+1.84	36.43	34.8	+1.63	36.04	34.8	+1.24

*Experimental values, trunk temperature = $\frac{\text{chest temperature + back temperature}}{2}$

The computer temperature slowly rises throughout the simulation. At 0.8 m/s the computer values slowly rise and then gradually fall. Note that trunk temperature for experimental data is the mean of the chest and back temperature.

Arm Temperature: The experimental data is considerably higher than the computer values, see Figure 24 and Table 13. This is because the subject's arms were doing work and consequently were at a higher temperature. The figure shows us that the final temperature of the experimental data for both control and 0.8 m/s conditions is quite high. The computer values are low because the computer model assumes the work to be done with the legs, i.e., the pedalling of the ergometer is done with legs.

Leg Temperature: Figure 25 and Table 15 show the differences in computer model temperature and experimental values. The experimental leg temperature plotted is the mean of the left leg and right leg temperatures.

Sweat Rate: Cumulative losses in 120 minutes through respiration and sweating, in grams of water for both subjects, for all conditions as compared with the computer predictions are shown in Table 17. Figure 26 shows us that, from experimental data, maximum sweat losses occur at 0.4 m/s air velocity and subjects sweat the least at 1.6 m/s air velocity. Subject 1 sweated more than subject 2. The computer simulation shows that subject 2 sweated more than subject 1. Both cases register a gradual drop in sweat losses as air velocity increases from 0.13 m/s to 3.2 m/s. The computer prediction is only about 50% of the experimental values.

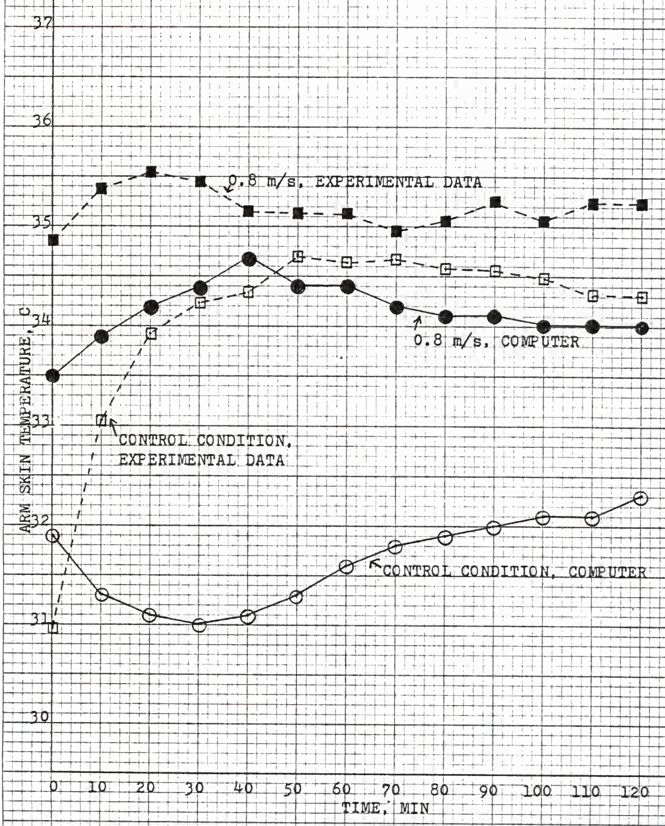

FIGURE 24. SUBJECT 1 - ARM SKIN TEMPERATURE VS TIME

TABLE 13. SUBJECT 1-ARM TEMPERATURE, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	30.96	31.9	-0.94	34.11	33.5	+0.61	35.22	33.5	+1.72	34.86	33.5	+1.36	33.93	33.5	+0.43	34.45	33.5	+0.95
10	33.05	31.3	+1.75	34.81	33.9	+0.91	35.29	33.9	+1.39	35.38	33.9	+1.48	34.50	33.9	+0.60	34.87	33.9	+0.97
20	33.91	31.1	+2.81	35.22	34.2	+1.02	35.55	34.2	+1.35	35.54	34.2	+1.34	34.83	34.2	+0.63	35.02	34.2	+0.82
30	34.21	31.0	+3.21	35.47	34.4	+1.07	35.56	34.4	+1.16	35.43	34.4	+1.03	35.14	34.4	+0.74	34.95	34.4	+0.55
40	34.33	31.1	+3.23	35.69	34.7	+0.99	35.25	34.7	+0.55	35.15	34.7	+0.45	35.08	34.7	+0.38	34.86	34.7	+0.16
50	34.70	31.3	+3.40	35.50	34.4	+1.10	35.69	34.4	+1.29	35.11	34.4	+0.71	35.13	34.4	+0.73	34.85	34.4	+0.45
60	34.62	31.6	+3.02	35.69	34.2	+1.49	35.51	34.2	+1.31	35.11	34.2	+0.91	35.19	34.2	+0.99	35.04	34.2	+0.84
70	34.68	31.8	+2.88	35.50	34.1	+1.40	35.66	34.1	+1.56	34.96	34.1	+0.86	35.27	34.1	+1.17	34.76	34.1	+0.66
80	34.58	31.9	+2.68	35.50	34.1	+1.40	35.56	34.1	+1.46	35.06	34.1	+0.96	35.40	34.1	+1.30	35.04	34.1	+0.94
90	34.54	32.0	+2.54	35.89	34.0	+1.89	35.95	34.0	+1.96	35.26	34.0	+1.26	35.43	34.0	+1.43	35.29	34.0	+1.29
100	34.49	32.1	+2.39	35.94	34.0	+1.94	35.79	34.0	+1.79	35.07	34.0	+1.07	35.40	34.0	+1.40	35.23	34.0	+1.23
110	34.30	32.1	+2.20	36.05	33.9	+2.15	35.74	33.9	+1.84	35.23	33.9	+1.33	35.44	33.9	+1.54	35.29	33.9	+1.39
120	33.61	32.3	+1.31	36.21	34.0	+2.21	35.72	34.0	+1.72	35.22	34.0	+1.22	35.64	34.0	+1.64	35.13	34.0	+1.13

*Experimental value, arm temperature = $\frac{\text{left arm temperature + right arm temperature}}{2}$

TABLE 14. SUBJECT 2-ARM TEMPERATURE, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	32.12	31.9	0.22	34.86	33.6	1.26	35.73	33.6	2.13	34.91	33.6	1.31	35.42	33.6	1.82	34.73	33.6	1.13
10	33.58	31.4	2.18	35.95	34.0	1.95	36.14	34.0	2.14	36.08	34.0	2.08	36.05	34.0	2.05	35.65	34.0	1.65
20	34.40	31.3	3.1	36.14	34.3	1.84	36.26	34.3	1.96	36.38	34.3	2.08	36.28	34.3	1.98	35.95	34.3	1.65
30	34.71	31.4	3.31	36.26	34.6	1.66	36.14	34.6	1.54	36.77	34.6	2.17	36.50	34.6	1.90	36.22	34.6	1.62
40	34.79	31.7	3.09	36.33	34.4	1.93	36.05	34.4	1.65	36.57	34.4	2.17	36.27	34.4	1.87	36.14	34.4	1.74
50	34.79	31.9	2.89	36.33	34.2	2.13	35.96	34.2	1.76	36.48	34.2	2.28	36.22	34.2	2.02	36.14	34.2	1.94
60	35.12	32.0	3.12	36.19	34.0	2.19	35.59	34.0	1.59	36.56	34.0	2.56	36.29	34.0	2.29	35.89	34.0	1.89
70	34.72	32.1	2.62	36.26	34.0	2.26	35.60	34.0	1.60	36.36	34.0	2.36	36.17	34.0	2.17	35.93	34.0	1.93
80	34.90	32.4	2.5	36.20	33.9	2.30	35.65	33.9	1.75	36.42	33.9	2.52	36.26	33.9	2.36	35.88	33.9	1.98
90	35.08	32.7	2.38	36.20	33.9	2.30	35.85	33.9	1.95	36.49	33.9	2.59	36.15	33.8	2.35	35.87	33.9	1.97
100	34.98	32.8	2.18	36.02	33.9	2.12	35.91	33.9	2.01	36.40	33.9	2.50	36.24	33.9	2.34	36.08	33.9	2.18
110	35.11	32.8	2.31	36.18	33.9	2.28	35.89	33.9	1.99	36.51	33.9	2.61	36.31	33.9	2.41	35.89	33.9	1.99
120	35.04	32.8	2.24	36.30	33.9	2.40	36.10	33.9	2.20	36.56	33.9	2.66	36.18	33.9	2.28	35.88	33.9	1.98

*Experimental value, arm temperature = $\frac{\text{left arm temperature + right arm temperature}}{2}$

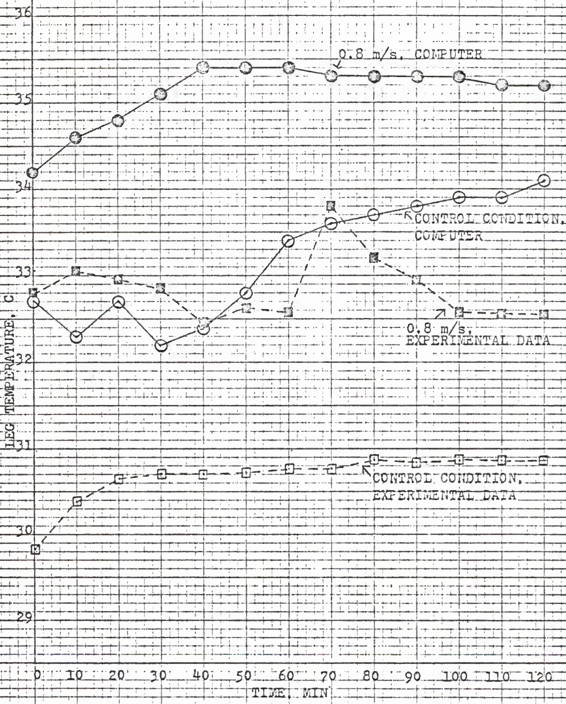

FIGURE 25. LEG TEMPERATURE VS TIME - SUBJECT 1

TABLE 15. SUBJECT 1-LEG TEMPERATURES, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	29.81	32.7	-2.89	33.47	34.2	-0.73	33.02	34.2	-1.18	33.05	34.2	-1.15	33.03	34.2	-1.17	32.86	34.2	-1.34
10	30.39	32.3	-1.91	33.69	34.6	-0.91	33.46	34.6	-1.14	33.04	34.6	-1.56	33.41	34.6	-1.19	33.39	34.6	-1.21
20	30.65	32:7	-2.05	34.25	34.8	-0.55	33.43	34.8	-1.37	32.96	34.8	-1.84	33.63	34.8	-1.17	33.81	34.8	-0.99
30	30.70	32.2	-1.50	34.47	35.1	-0.63	33.19	35.1	-1.91	32.82	35.1	-2.28	33.90	35.1	-1.20	33.38	35.1	-1.72
40	30.70	32.4	-1.70	34.64	35.4	-0.76	32.74	35.4	-2.66	32.45	35.4	-2.95	33.60	35.4	-1.80	33.25	35.4	-2.15
50	30.71	32.8	-2.09	34.42	35.4	-0.98	33.16	35.4	-2.24	32.62	35.4	-2.78	33.04	35.4	-2.36	33.10	35.4	-2.30
60	30.78	33.4	-2.62	34.42	35.4	-0.98	32.93	35.4	-2.47	32.59	35.4	-2.81	32.65	35.4	-2.75	32.92	35.4	-2.48
70	30.79	33.6	-2.81	34.08	35.3	-1.22	32.99	35.3	-2.31	33.77	35.3	-1.53	32.68	35.3	-2.62	32.57	35.3	-2.73
80	30.88	33.7	-2.82	33.97	35.3	-1.33	32.76	35.3	-2.54	33.20	35.3	-2.10	32.80	35.3	-2.50	32.71	35.3	-2.59
90	30.83	33.8	-2.97	34.22	35.3	-1.08	33.26	35.3	-2.04	32.96	35.3	-2.34	32.82	35.3	-2.48	32.73	35.3	-2.57
100	30.88	33.9	-3.02	34.08	35.3	-1.22	33.20	35.3	-2.10	32.58	35.3	-2.72	32.75	35.3	-2.55	32.88	35.3	-2.42
110	31.05	33.9	-2.85	33.97	35.2	-1.23	32.93	35.2	-2.27	32.55	35.2	-2.65	32.78	35.2	-2.42	32.86	35.2	-2.34
120	30.85	34.1	-3.25	34.22	35.2	-0.98	32.82	35.2	-2.38	32.55	35.2	-2.65	32.97	35.2	-2.23	32.85	35.2	-2.35

*Experimental value = $\frac{\text{left leg temperature + right leg temperature}}{2}$

TABLE 16. SUBJECT 2-LEG TEMPERATURES, C

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)	Ex*	C	(Ex-C)
0	30.84	32.8	-1.96	34.10	34.3	-0.2	33.78	34.3	-0.52	34.13	34.3	-0.17	34.12	34.3	-0.18	34.07	34.3	-0.23
10	31.62	32.5	-0.88	34.63	34.8	-0.17	34.24	34.8	-0.56	34.85	34.8	+0.05	34.50	34.8	-0.30	34.52	34.8	-0.28
20	31.94	32.5	-0.56	34.44	35.1	-0.66	34.26	35.1	-0.84	34.83	35.1	-0.27	34.35	35.1	-0.60	34.59	35.1	-0.51
30	32.22	32.8	-0.58	34.14	35.4	-1.26	33.80	35.4	-1.60	35.14	35.4	-0.26	34.64	35.4	-0.76	34.64	35.4	-0.76
40	32.16	33.3	-1.14	33.96	35.4	-1.44	33.80	35.4	-1.60	34.90	35.4	-0.50	34.38	35.4	-0.72	34.55	35.4	-0.85
50	32.08	33.6	-1.52	33.83	35.3	-1.47	33.46	35.3	-1.84	34.79	35.3	-0.51	34.33	35.3	-0.97	34.61	35.3	-0.69
60	32.07	33.8	-1.73	33.94	35.3	-1.36	33.33	35.3	-1.97	34.63	35.3	-0.67	34.51	35.3	-0.79	34.48	35.3	-0.82
70	31.71	33.9	-2.19	33.74	35.2	-1.46	33.30	35.2	-1.90	34.46	35.2	-0.74	34.23	35.2	-0.97	34.48	35.2	-0.72
80	31.89	34.2	-2.31	33.69	35.2	-1.51	33.29	35.2	-1.90	34.61	35.2	-0.59	34.38	35.2	-0.82	34.68	35.2	-0.52
90	32.02	34.3	-2.28	33.86	35.2	-1.34	33.49	35.2	-1.71	34.73	35.2	-0.47	34.36	35.2	-0.84	34.37	35.2	-0.83
100	31.84	34.3	-2.46	33.98	35.2	-1.22	33.28	35.2	-1.92	34.70	35.2	-0.50	34.33	35.2	-0.87	34.17	35.2	-1.03
110	32.03	34.3	-2.27	34.11	35.2	-1.09	33.56	35.2	-1.64	34.88	35.2	-0.32	34.89	35.2	-0.31	34.29	35.2	-0.91
120	31.96	34.3	-2.34	34.15	35.2	-1.05	33.65	35.2	-1.55	35.01	35.2	-0.19	34.76	35.2	-0.44	34.28	35.2	-0.92

*Experimental value = $\frac{\text{left leg temperature + right leg temperature}}{2}$

TABLE 17. CUMULATIVE LOSSES IN 120 MINUTES THROUGH RESPIRATION AND SWEATING, IN GRAMS OF WATER

Air velocity, m/s	Subject 1		Subject 2	
	Exp	Computer	Exp	Computer
Control conditions	600	110	376	136
0.13	998	293	718	336
0.4	1090	288	980	332
0.8	986	283	772	327
1.6	830	278	590	321
3.2	940	274	668	315

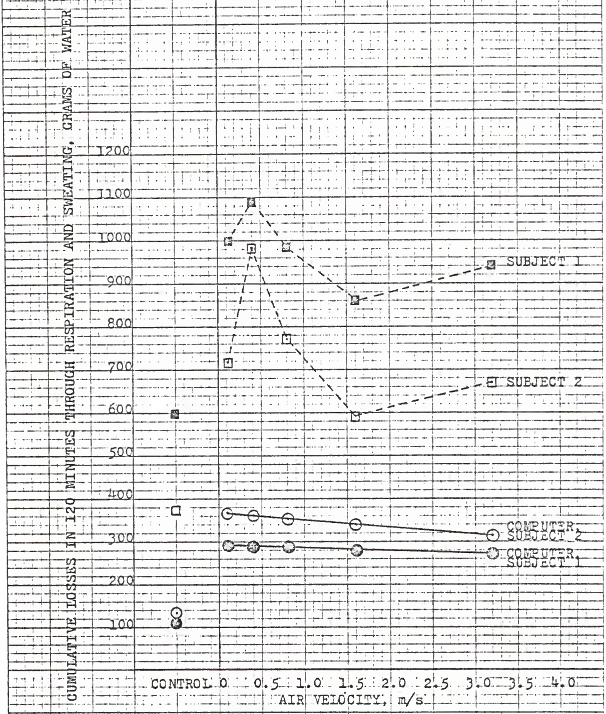

FIGURE 26. CUMULATIVE LOSSES IN 120 MIN THROUGH RESPIRATION AND SWEATING VS AIR VELOCITY

Heart Rates: Tables 18 and 19 show us the comparison between actual heart rates and computer predictions. Figure 27 shows that the actual heart rates of subject 1 are considerably higher than the computer predictions, especially for the 0.8 m/s condition. Figure 28 shows that experimental data for the control condition falls below the computer prediction while the experimental data for the 0.8 m/s condition is higher than the computer values. The actual increase from control to heat conditions was about 30 b/min for both subjects, whereas for the computer this was only 10 b/min.

Comfort Votes: Tables 20 and 21 show us the comparison between actual thermal sensation votes recorded by the two subjects during the experiment and the computer comfort predictions. The subjects actually feel much warmer than the computer prediction. The computer comfort vote is similar to the thermal sensation vote, a nine point scale ranging from very cold to very hot. See Appendix IV. The low computer prediction is a result of the low computer predicted sweat rate.

TABLE 18. SUBJECT 1-HEART RATES, BEATS/MIN

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	82	77	5	100	81	19	94	81	13	94	81	13	101	81	20	106	81	25
30	94	87	7	132	90	42	117	90	27	130	90	40	138	90	48	114	90	24
60	100	90	10	156	95	61	112	95	17	130	95	35	128	95	33	114	95	19
90	118	89	29	140	96	44	120	96	24	138	96	42	130	96	34	106	96	10
120	106	90	16	146	98	48	112	98	14	141	98	43	136	98	38	122	98	24

TABLE 19. SUBJECT 2-HEART RATE, BEATS/MIN

Time min	Control condition			0.13 m/s			0.4 m/s			0.8 m/s			1.6 m/s			3.2 m/s		
	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)	Ex	C	(Ex-C)
0	64	73	- 9	72	76	- 4	80	76	+ 4	80	76	+ 4	72	76	- 4	72	76	- 4
30	70	86	-16	82	90	- 8	92	90	+ 2	98	90	+ 8	82	90	- 8	84	90	- 6
60	71	87	-16	92	95	- 3	98	95	+ 3	98	95	+ 3	74	95	-21	96	95	+ 1
90	72	89	-17	92	96	- 4	92	96	- 4	98	96	+ 2	80	96	-16	84	96	-12
120	74	90	-16	90	96	- 6	102	96	+ 6	104	96	+ 8	88	96	- 8	84	96	-12

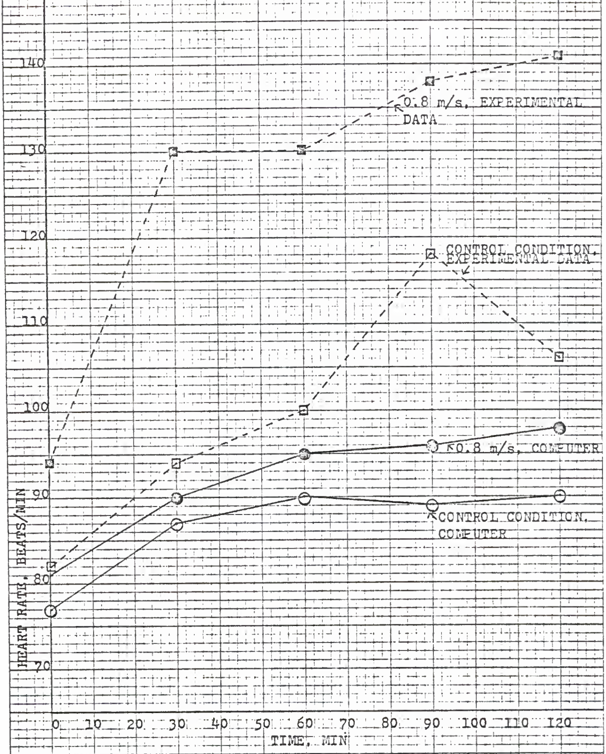

FIGURE 27. SUBJECT 1 - HEART RATE VS TIME

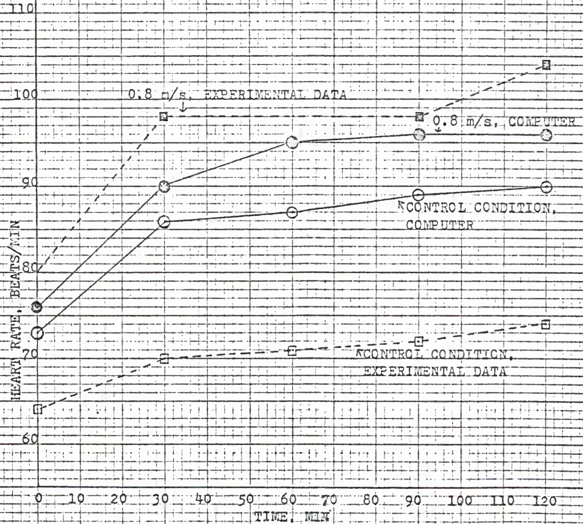

FIGURE 28. SUBJECT 2 - HEART RATE VS TIME

TABLE 20. SUBJECT 1-COMFORT VOTES

Time min	Control condition		0.13 m/s		0.4 m/s		0.8 m/s		1.6 m/s		3.2 m/s	
	Ex	C	Ex	C	Ex	C	Ex	C	Ex	C	Ex	C
0	slightly cool	neutral	warm	neutral	slightly warm	neutral	slightly warm	neutral	neutral	neutral	slightly warm	neutral
30	neutral	neutral	warm	neutral	warm	neutral	hot	neutral	hot	neutral	slightly warm	neutral
60	slightly warm	neutral	hot	slightly warm	warm	slightly warm	hot	slightly warm	hot	neutral	slightly warm	neutral
90	slightly warm	neutral	hot	slightly warm	hot	slightly warm	hot	slightly warm	hot	slightly warm	slightly warm	neutral
120	warm	neutral	hot	slightly warm	hot	slightly warm	warm	slightly warm	hot	slightly warm	slightly warm	neutral

TABLE 21. SUBJECT 2-COMFORT VOTES

Time min	Control condition		0.13 m/s		0.4 m/s		0.8 m/s		1.6 m/s		3.2 m/s	
	Ex	C	Ex	C	Ex	C	Ex	C	Ex	C	Ex	C
0	slightly cool	neutral	slightly warm	neutral	warm	neutral	neutral	neutral	neutral	neutral	slightly warm	neutral
30	neutral	neutral	warm	neutral	warm	neutral	slightly warm	neutral	warm	neutral	slightly warm	neutral
60	slightly warm	neutral	warm	slightly warm	warm	slightly warm	warm	slightly warm	slightly warm	neutral	warm	neutral
90	slightly warm	neutral	warm	slightly warm	warm	slightly warm	warm	slightly warm	slightly warm	slightly warm	slightly warm	neutral
120	slightly warm	slightly warm	warm	slightly warm	warm	slightly warm	warm	slightly warm	slightly warm	slightly warm	warm	neutral

CONCLUSIONS

1. From the preceding analysis, in the given environmental conditions of 32 C DBT and 24.5 WBT with 55 % rh, air velocity had no effect on the work output in 120 minutes by the two subjects.

2. Both subjects not only performed better in terms of distance pedalled in 120 minutes under "still air" conditions, but also recorded lower skin temperatures as compared to low air velocity conditions of 0.4 m/s and 0.8 m/s. High air velocities of 1.6 m/s and 3.2 m/s better maintained low skin temperature.

3. Both subjects recorded lower rectal temperatures at higher air velocities.

4. Both subjects registered lower heart rates at higher air velocities.

5. Both subjects sweated less at higher air velocities of 1.6 m/s and 3.2 m/s.

6. Both subjects preferred the highest air velocity of 3.2 m/s as being "pleasant" and "cooler" on the air movement and thermal sensation voting scales. Air velocity had no effect on their exertion vote or noise vote.

7. Subjects preferred air to be directed from the front or side, but not from the back.

8. a. Computer predictions were quite accurate for rectal temperatures.

b. Head and trunk temperatures showed that experimental data reached stable temperature in 55 minutes, while the computer took 120 minutes.

c. Leg and arm temperatures differed due to the actual pedalling with the arms, while the computer model assumed leg pedalling.

d. The computer predicted lower sweat losses as against actual data and needs an upward revision.

e. Comfort vote comparisons show that computer votes recorded were much "cooler" as against actual votes and need revision. This is related to the inadequate sweat rate.

f. Heart rate recorded by the computer was quite different from the actual data collected for both subjects.

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Appendix I

WRITTEN INSTRUCTIONS

Stand behind the cycle. Pedal the bicycle with your hands at a steady rate of 20 km/hr as indicated on the tachometer. You may use both hands or one hand for pedalling. You are required to pedal at this steady rate for 120 minutes. No rest period has been scheduled. You may rest as and when you so desire, but you should not sit down during the rest period. The time you pedal is regarded as "work" time. The time you rest is regarded as "idle" time. You will be paid for the "work" done at a rate of $5.00 for every 3,000 revolutions.

Record your comfort rate on the given comfort scales every 30 minutes. Also record your perceived exertion rate on the exertion scale every 30 minutes.

You cannot eat or drink anything during the 120 minute test period.

"Cooling with fans in hot and humid working environments."

SUBJECT CONSENT FORM

I, the undersigned, realize that in this experiment I am required to work continuously for 120 minutes, pedalling a bicycle with my hands at 50 revolutions per minute.

I am aware of the discomfort that I may have to endure due to the environment temperature of 32 C. I realize that I can rest at any time during the experiment or can discontinue my participation in this study at any time.

I further understand that all the data is confidential and I agree to allow publication of any or all of the data collected if presented in a coded form.

Signature

Date

Appendix III

Sequence of air velocities used for the experiment

Session number	Subject 1 air velocity, m/s	Subject 2 air velocity, m/s
1	0.13	0.8
2	1.6	0.4
3	Control	1.6
4	0.8	Control
5	3.2	3.2
6	0.4	0.13

Appendix IV

a. Exertion Scale

Vote No: __________ Test No: __________

Name and No: __________________________

____

Circle the number beside the adjective that describes how you feel you are working.

6	
7	very very light
8	
9	very light
10	
11	fairly light
12	
13	somewhat hard
14	
15	hard
16	
17	very hard
18	
19	very very hard
20	

b. Noise Scale

Vote No: __________ Test No: __________

Name and No: ___________________________

____

Circle the number beside the adjective that describes the noise level.

7 very noisy
6 noisy
5 slightly noisy
4 neutral
3 somewhat quiet
2 quiet
1 very quiet

c. Air Movement Vote

Vote No: __________ Test No: __________

Name and No: ___________________________

____

Circle the number beside the adjective that describes how you feel.

7 very pleasant
6 pleasant
5 slightly pleasant
4 neutral
3 slightly unpleasant
2 unpleasant
1 very unpleasant

Appendix IV

d. Thermal Sensation Vote

Vote No: __________ Test No: __________

Name and No: ____________________________

____

Circle the number beside the adjective that describes how you feel.

9	very hot
8	hot
7	warm
6	slightly warm
5	neutral
4	slightly cool
3	cool
2	cold
1	very cold

e. Computer comfort vote scale

greater than +3.5	very hot
+2.5 to +3.5	hot
+1.5 to +2.5	warm
+0.5 to +1.5	slightly warm
+0.5 to -0.5	neutral
-0.5 to -1.5	slightly cool
-1.5 to -2.5	cool
-2.5 to -3.5	cold
less than -3.5	very cold

Appendix V

AIR MOVEMENT VOTES - DIRECTION OF AIR

Subject 1

Air velocity m/s	Vote	Direction of air Side	45° Back	45° Front
0.4	air movement	unpleasant	unpleasant	unpleasant
	thermal sensation	hot	hot	hot
0.8	air movement	unpleasant	unpleasant	unpleasant
	thermal sensation	warm	hot	hot
1.6	air movement	neutral	unpleasant	neutral
	thermal sensation	slightly warm	slightly warm	slightly warm
3.2	air movement		Not studied	
	thermal sensation			

Subject 2

Air velocity m/s	Vote	Side	45° Back	45° Front
0.4	air movement	neutral	slightly unpleasant	neutral
	thermal sensation	warm	hot	warm
0.8	air movement	neutral	slightly unpleasant	neutral
	thermal sensation	warm	hot	warm
1.6	air movement	slightly pleasant	neutral	slightly pleasant
	thermal sensation	slightly warm	warm	warm
3.2	air movement	pleasant	slightly pleasant	pleasant
	thermal sensation	slightly warm	warm	slightly warm

Appendix VI Data Sheet

Subject No. Air Velocity = m/s

Cooling With Fans

Time min	Ex	Ts	N	W	Rect	Chest	Back	LArm	RArm	LLeg	RLeg	Head	Heart rate b/min	WBT
0														
10														
20														
30														
40														
50														
60														
70														
80														
90														
100														
110														
120														

Tachometer Readings
Initial =
Final =

	Initial	Final
Wt of Clothes =		
Wt of Subject + Clothes =		

DBT =
WBT =

Appendix VII

INFORMATION USED FOR COMPUTER SIMULATION

		Subject 1	Subject 2
Sex (male = 1)		1.	1.
Age, yr		23.	21.
Weight, kg		89.40	75.00
Height, cm		183.0	167.60
TBFYM, % fat		13.8	5.
Fitness		3.	2.
Acclimitization, %		0.00	0.00
Environment, heat stress conditions			
Barometric pressure		740.	740.
DBT		32.2	32.2
TRV, radiant temperature		32.2	32.2
VV, air velocity	a.	0.13	0.13
	b.	0.4	0.4
	c.	0.8	0.8
	d.	1.6	1.6
	e.	3.2	3.2
RHV, relative humidity		0.55	0.55
Environment, control			
Barometric pressure		740.	740.
DBT		25.0	25.0
TRV, radiant temperature		25.0	25.0
VV, air velocity		0.13	0.13
RHV, relative humidity		0.55	0.55
Task			
WORKV, total metabolic rate			
first 10 min (not plotted)		085.	085.
next 120 min		190.	190.
Clothing			
head		0.0	0.0
torso		0.23	0.23
arms		0.0	0.0
hands		0.1	0.1
legs		0.12	0.12
feet		0.1	0.1

Appendix - continued

	Subject 1	Subject 2
JOBV	2	2
END TIME, min	0130.	0130.
INTERVAL, min	010.	010.

COOLING WITH FANS IN HOT AND
HUMID WORKING ENVIRONMENTS

by

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requirements for the degree

MASTER OF SCIENCE

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1978

COOLING WITH FANS IN HOT AND HUMID WORKING ENVIRONMENTS

Abstract

In hot and humid working conditions where it is economically not feasible to control the environmental temperature by air conditioning, fan cooling can be used. The air velocity required to maximize heat dissipation was determined analytically and experimentally. Air from a fan was directed on the subjects from the side. Air velocities used were 0.13, 0.4, 0.8, 1.6 and 3.2 m/s with the dry bulb temperature at 32 C, wet bulb temperature of 24.5 C, and 55 % rh. The mean radiant temperature was the same as dry bulb temperature; vapor pressure was 19 mm Hg. Two standing subjects worked continuously for 120 minutes, pedaling with their hands an ergometer placed on a table; it maintained their total metabolism at 190 W. Skin and rectal temperatures, heart rate, sweat rates, comfort votes and thermal sensations were recorded. Air velocity had no effect on the work output in 120 minutes by the two subjects. Higher air velocities of 1.6 and 3.2 m/s maintained lower skin temperatures, lower rectal temperatures and heart rates, the subjects sweated less and considered it "cooler" and more "pleasant."