

LABORATORY EVALUATION OF A WATER ICE VEST

by

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## INTRODUCTION

It is unavoidable to work in adverse thermal environments in some modern manufacturing plants. Thermal stress is a problem in many industrial environments. Hot and humid environments constitute a heavy thermal stress for man because of the decreased capacity for evaporative cooling. People exposed to those environments experience elevated body temperature which can result in dehydration, fatigue, and collapse.

There are many industries in which heat strain is integral to the specific industrial process. For example, glass manufacturing, foundry, and maintenance work in steel furnaces create an environment which includes high heat and high humidity.

The general consideration of a manager or an engineer to a man working in a heat stress environment is to cool the whole environment. In fact it is unnecessary or impossible to cool the whole working environment in some situations. To protect only the individual by equipping him with a controlled microclimate is an alternative -- that is, personal cooling or individual cooling.

A device is acceptable if it makes man minimize heat gain in order to work in a reasonable time period before the reasonable heat storage is achieved. Short - term protection is possible by wearing heavily insulated clothing, but this prevents loss of metabolic heat and the man becomes uncomfortably hot after a few minutes. Some devices for body cooling must be

applied beneath the protective garment to absorb the body's heat.

Different models of personal cooling systems using dry ice, water, and air have been tried at Kansas State University in the past several years to remove environmental and metabolic heat from men working in a variety of conditions. Duncan ( 1969 ) used a water cooled hood to reduce the heat stress successfully. Byrnes ( 1970 ) found a jacket to be more effective than a hood from a physiological viewpoint. Aurora ( 1970 ) demonstrated the effectiveness of his proposed air cooled shirt utilizing dynamic insulation. Sharma ( 1970 ) used air cooled helmet to remove the heat stress. Konz, Duncan and Masud ( 1975 ) found the advantage of dry ice cooling over water cooling. Duncan ( 1975 ) tested the effects of changing the dry ice cooling garment variables of dry ice surface area facing the subjects and thermal conductance of the insulation between dry ice and subject. Wang ( 1980 ) combined a cooling vest with an air cooled hood and found the combination was more effective than a hood and a vest.

## LITERATURE REVIEW

Human Heat Exchange

Man is a heat - producing machine. His normal body temperature is about 37 C, his average skin temperature is 34 C and he produces heat by metabloism from 73 Watts to 1406 Watts, depending upon his activities. The human exchanges heat with his physical environments by three ways. These are conduction, convection and radiation.

The human thermoregulation is a closed - loop system. This heat exchange between man and his environment can be expressed by the following heat balance equation :

$$S = M - \left( \overset{+}{-} W \right) + \left( \overset{+}{-} R \right) + \left( \overset{+}{-} C \right) + \left( \overset{+}{-} E \right) + \left( \overset{+}{-} K \right)$$

where :

S = heat storage, Watts

M = metabolic rate, Watts

W = mechanical work accomplished rate, Watts

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

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

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

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

When the right side of the above equation is positive, man's average body temperature is rising; when negative, it is falling; and when zero, the body is in thermal equilibrium.

Metabolism, the chemical changes in body cells by which energy is provided for vital activities, is a process of

heat generation within the body. Metabolism furnishes fuel and oxygen to the muscles and organs.

Metabolism can be subdivided into three parts: basal metabolism, activity metabolism and digestive metabolism, technically known as specific dynamic action.

Basal metabolism is ( Konz, 1979 ) :

$$\text{BASLMT} = \text{BSMET} ( \text{WT} )$$

where :

$\text{BASLMT}$  = basal metabolism, Watts ( W )

$\text{BSMET}$  = 1.28 W/kg for males  
= 1.16 W/kg for females

$\text{WT}$  = body weight, kg

The activity metabolism factor,  $\text{ACTFMT}$ , is given in Table 1 for various tasks. Activity metabolism is ( Konz, 1979 ) :

$$\text{ACTMET} = \text{ACTFMT} ( \text{WT} )$$

where :

$\text{ACTMET}$  = activity metabolism, Watts ( W )

$\text{ACTFMT}$  = activity metabolism factor, W/kg

$\text{WT}$  = weight, kg

Digestive metabolism ( specific dynamic action ) is ( Konz, 1979 ) :

$$\text{SDAMET} = .1 ( \text{BASLMT} + \text{ACTMET} )$$

where :

$\text{SDAMET}$  = specific dynamic action, Watts

$\text{BASLMT}$  = basal metabolism, Watts

$\text{ACTMET}$  = activity metabolism, Watts

Radiation is the transfer of thermal energy between an individual and his surroundings whose surface temperature

TABLE 1

Reported Activity Cost for Various Activities. For Total Energy Cost, Add Cost of Basal Metabolism<sup>d</sup> and, if Appropriate, Specific Dynamic Action for Digestion of Foods<sup>d</sup> . 1.163 W = 1 kcal/hr.

<u>W/kg</u>	<u>Activity</u>
0.4	Crocheting, eating, reading aloud, sewing by hand, sewing by machine, sitting quietly, writing
0.6	Playing cards, standing relaxed, typing with electric typewriter
0.7	Paring potatoes, standing office work, sewing with footdriven machine, standing at attention, violin playing
0.8	Dressing and undressing, knitting a sweater
0.9	Piano playing of Mendelssohn's <u>Song Without Words</u> , singing in a loud voice
1.0	Driving car, tailoring
1.2	Dishwashing, typing rapidly
1.4	Washing floors
1.5	Cello playing, light laundry
1.6	Horseback riding ( walk ), piano play of Beethoven's <u>Appassionata</u> , sweeping bare floor with broom
1.7	Golf, organ playing ( 1/3 hand work ), painting furniture
1.9	Sweeping with hand carpet sweeper
2.3	Piano playing of Liszt's <u>Tarantella</u>
2.4	Laboratory work
2.7	Heavy carpentry

- 3.0 Cleaning windows
- 3.1 Sweeping with vacum cleaner ( upright )
- 3.3 Walking 3.2 km/hr ( 2 miles/hr )
- 3.5 Bedmaking, dancing ( Waltz )
- 4.1 Skating
- 4.5 Gardening ( Weeding )
- 4.9 Walking 4.8 km/hr ( 3 miles/hr )<sup>c</sup>
- 5.0 Horseback riding ( trot )
- 5.1 Ping pong
- 5.8 Dancing ( rhumba ), tennis
- 6.6 Sawing wood
- 7.9 Football
- 8.5 Fencing
- 11.4 Running 9.7 km/hr ( 6 miles/hr ) ( 70 kg man )<sup>d</sup>
- 11.7 Running 11.3 km/hr ( 7 miles/hr ) ( 70 kg man )<sup>d</sup>

<sup>a</sup> Basal metabolism can be approximated as 1.28 W/kg for males  
and 1.16 for females

<sup>b</sup> Digestion metabolism can be approximated as .10 ( Basal  
metabolism + Activity metabolism )

<sup>c</sup> Total energy cost of walking, W/kg, =  $2.031\ 393 + .124\ V^2$

where : V = Velocity in km/hr ( Van der Walt and Wyndham, 1973 )

<sup>d</sup> Total energy cost of running, W/kg, =  $-142.095/M + 11.045$

$490 + .039\ 678\ V^2$  where : M = body weight, kg, and V = Velocity,  
km/hr ( Van der Walt and Wyndham, 1973 )

are different from his skin temperature.

Radiant heat transfer ( Konz, 1979 ) is :

$$R = A \alpha f_{\text{eff}} f_{\text{clr}} E_{\text{clr}} e \left( T_{\text{mrt}}^4 - T_{\text{skin}}^4 \right)$$

where :

- $R$  = radiant gain ( + ), or loss ( - ), Watts
- $\alpha$  = Stefan - Boltzman constant  
 $= 5.67 * 10^{-8} \text{ Watts}/(\text{m}^2 - \text{K}^4)$
- $A$  = skin surface area, m
- $f_{\text{eff}}$  = effective skin radiation area factor ( .725 for standing, .696 for sitting )
- $f_{\text{clr}}$  = increase in radiant area due to clothing  
 $= 1 + .155 I_{\text{clo}}$
- $I_{\text{clo}}$  = insulation value of clothing, clo
- $E_{\text{clr}}$  = multiplier to radiant heat transfer coefficient to adjust for clothing barrier  
 $= 1/(1+.155 ( 5.2 ) I_{\text{clo}}^2)$ , where  $5.2 \text{ W}/(\text{m}^2 - \text{C})$  is the reference radiant heat transfer coefficient
- $e$  = emissitivity ( skin = .99 ; clothing in nonvisible radiation = .7 )
- $T_{\text{skin}}$  = temperature in K of the skin,  $K = C + 273$
- $T_{\text{mrt}}$  = mean radiant temperature in K of environment,  $K = C + 273$

The radiation energy transfer process is the consequence of energy carrying electromagnetic waves, emitted by atoms and molecules as the result of changes in their energy content.



Convection is the transfer of heat due to the movement of air past the body regardless of whether the air temperature is above or below skin temperature. When the difference of air temperature and skin temperature is zero, then convection equals zero. The convection current formed sets the fluid in motion. Convection heat transfer ( Konz, 1979 ) is :

$$C = h_c A f_{clc} ( t_{air} - t_{skin} )$$

where :

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

$h_c$  = convection heat transfer coefficient, Watts/(m<sup>2</sup> - C)  
 $= 8.3 V^{.6}$  for seated adults

$V$  = air velocity, m/s

$A$  = skin surface area, m<sup>2</sup>

$f_{clc}$  = multiplier to  $h_c$  for clothing

$= 1/(1+.155 ( 2.9^c I_{clo} ))$ , where  $2.9 \text{ W/(m}^2 - \text{C)}$  is  $h_c$  in still air (.15 m/s)

$I_{clo}$  = insulation value of clothing, clo

$t_{air}$  = air temperature, C

$t_{skin}$  = skin temperature, C

The convective component of heat transfer depends on the air velocity, available skin surface area, and temperature difference.

If a kg of sweat is evaporated from the skin, it can draw out the heat of 675 Watts. The maximum amount of evaporation heat transfer ( Konz, 1979 ) is :

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

where :

$E_{\max}$  = maximum evaporation gain ( + ), or loss ( - ), Watts

$h_e$  = evaporative heat transfer coefficient

$$h_e = 2.2 h_c$$

$h_c$  = convection heat transfer coefficient, Watts/(m<sup>2</sup> - C)

$$h_c = 8.3 V^{.6} \text{ for seated adults}$$

$V$  = air velocity, m/s

$A$  = skin surface area, m<sup>2</sup>

$W$  = fraction of skin that is wet ( Assumed = .5 )

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

$$F_{pcl} = 1 / (1 + 1.143 (2.9)^{I_{clo}}), \text{ where } 2.9 \text{ W/(m}^2 \text{ - C) is } h_c \text{ in still air (.15 m/s) for a sedentary person}$$

$I_{clo}$  = insulation value of clothing, clo

$VP_s$  = vapor pressure of water on skin ( 45 Torr if  $t_{skin} = 35 \text{ C}$  )

$VP_a$  = vapor pressure of water in air, Torr

Guyton ( 1971 ) pointed out that acclimatization could highly increase the ability for sweating of the human body. He indicated that an unacclimatized man had doubled his quantity of sweat, from 1.5 liters/hr to 3.0 liters/hr, after ten days of acclimatization.

Respiration involves warming and vaporizing moisture to the temperature of respired air. This rate of heat exchange, however, is insignificant compared with the other factors

and is usually of negligible importance.

Conduction is the gain or loss of heat through direct contact between the body and the hot or cold object. Conduction heat transfer ( Goldman, 1978 ) is :

$$K = h_k A_c ( t_{obj} - t_{skin} )$$

where :

$K$  = conduction gain ( + ), or loss ( - ), Watts

$h_k$  = conductive heat transfer coefficient, Watts/(m<sup>2</sup> - C)

$A_c$  = contact skin surface area, m<sup>2</sup>

$t_{obj}$  = object surface temperature, C

$t_{skin}$  = skin temperature, C

Because the surface area across which heat conduction occurs is limited, the magnitude of human heat transfer by conduction is generally small enough to be ignored ( but not for water cooling ).

### Influence of Heat Stress

For environmental temperature below 31 C the body can control the heat flow from the inner tissues to the skin and radiation and convection dissipate the heat. If the environmental temperature is above 31 C, the body must remove heat by the sweat evaporation mechanism.

A number of studies have shown a decrement in work performance, both physical and mental, before the limits of tolerance are reached.

Pepler ( 1959 ) exposed six subjects for 30 minutes on three occasions at 48 - hour intervals to an environment of 46.7 C dry bulb, 70% rh with an average air movement of 0.5 m/s. During the second and third exposures, the subjects worked continuously to keep a pointer aligned with a target mark as it moved erratically from side to side. Accuracy of alignment was normal at first, but deteriorated rapidly and progressively. These results were thought to indicate a growing inattentiveness to the task and general deterioration in the organization of performance.

Wyon ( 1978 ) studied the accident frequency of the workers in three munitions factories. Air temperatures were recorded in three munitions factories for a total of 27 months. The occurrence of accidents was related to the prevailing air temperature in the factory. He indicated that accident frequency increased at air temperatures above and below 20 C. The increase was more than 30% below 12 C and above 24 C.

Bell ( 1964 ) studied, for eight subjects, the effect of exposure to climatic conditions ranging in severity from 29.5 C dry bulb, 60% rh to 63 C dry bulb, 90% rh on the performance of ( 1 ) a visual and ( 2 ) an auditory vigilance task. He found that exposure time decreased with increasing climatic severity. When performance was examined in terms of the proportion of signals missed to signals given, there was no evidence of a change in vigilance with different climatic conditions; but in both experimental series, a greater proportion of signals were missed as body ( oral ) temperature increased.

For health, both heart rate and maximum body core temperature are used as criteria. The National Institute for Occupational Safety and Health ( NIOSH, 1972 ) gave 38 C as the maximum core temperature. Usually core temperature is measured as rectal temperature. At thermoneutrality rectal temperature = oral temperature + .4 C ( Konz, 1979 ).

The human body tends to protect itself. When man works in severe heat, certain physiological adjustments occur which prevent a rise in body temperature to dangerous levels. The two main physiological mechanisms responsible for the control of body temperature are, first, the secretion of sweat onto the skin surface by the sweat glands and, second, the increase in blood flow to and through the skin by means of a nervous reflex which opens small arteries in these regions. The active function of these two physiological mechanisms may, in turn, have a marked influence on other aspects of human physiology ( Wyndham, 1965 ).

Failure of either of the two main heat regulatory mechanisms mentioned above may lead to one or other of the following forms of heat illness: heat - stroke, heat collapse, heat exhaustion, acute heat fatigue, millaria and " tropical " neurasthenia. The illnesses outlined above can be attributed directly to heat exposure. There are, however, certain diseases of the cardio - respiratory organs, such as vascular degenerative disease of the coronary arteries and chronic bronchitis, which have been attributed in part to working for many years in hot, humid atmospheres ( Wyndham, 1965 ).

Both NIOSH and the Heat Stress Advisory Committee recommended the use of the Wet Bulb Globe Temperature ( WBGT ) index for monitoring of hot work environments. NIOSH recommended that 26.1 C WBGT be considered the environmental temperature at which the risk of heat disorders would start increasing, where 26.1 C is associated with a heavy work load ( 465 Watts ). At lower work rates the suggested permissible thermal levels are correspondingly higher.

There are many factors such as the rate of work, the degree of acclimatization, the duration of exposure, general health, sex, age, clothing and physical fitness which affect the physiological responses. So, the WBGT values must be modified based upon the variables listed above. For example ( Ramsey, 1978 ) gave:

( 1 ) Unacclimatized and/or not physically conditioned,

subtract 2 C from the WBGT treshhold limits

( 2 ) For shorts or semi - nude, add 2 C

( 3 ) Obese or elderly, subtract 1 to 2 C

( 4 ) Female, subtract 1 C

### Relief of Heat Stress

There are two common ways to relieve the heat stress from the human body: cool the work area, cool the worker. However, there<sup>are</sup> some situations in which it is not feasible or economic to cool the work area.

Personal cooling has been shown to be an economical and effective way of reducing heat stress and increasing productivity in hot environments ( Crockford and Lee, 1967; Konz and Duncan, 1969; Nunnely, 1970; Van Rensburg, 1972; and Wyndham, 1974 ).

The cooling mechanisms available are radiation, convection, conduction from the skin of body, and respiration. Respiratory cooling is inadequate for humans.

Skin - cooling systems that can be envisaged ( Van Graan, 1972 ) are:

1. ventilated system
2. liquid heat - absorption system
3. phase - change system

Corresponding to these three systems, the heat produced can be removed by:

1. convection and evaporation of sweat

For convection cooling, the basic problem is how to

keep the temperature of the surrounding air below skin temperature. Increasing air velocity helps in the conductive heat formula ( if air temperature is less than skin temperature ).

Still, increasing air velocity can help evaporation of sweat even if the air temperature is greater than the body's.

## 2. conduction with liquid in tubes

Water cooling has been demonstrated to be a powerful means of heat reduction since that allows direct conductive removal of body heat from the skin. The water cooling concept includes a four portion system for the garment: ( 1 ) the tubes and the garment, ( 2 ) the source of the water, ( 3 ) the lifeline, the connection between the source and the garment, and ( 4 ) the control circuit. A major disadvantage of some water cooling garments is the restricted mobility due to the lifeline connected to the remote source of water.

## 3. a process of melting or sublimation, other than the evaporation of sweat

Water ice absorbs 80 kcal/kg when it changes from solid to liquid. Dry ice absorbs 137 kcal/kg when it changes from solid to gas and 23 kcal/kg more when the gas rises from -79 C to 35 C. So, the



process of melting of water ice or sublimation of dry ice are an alternative basis for personal cooling.

## PROBLEM

A worker can feel comfortable in a thermal environment which keeps the body in a steady state of heat balance. The amount of heat storage in the human body gained from the environmental surroundings must be reduced by some cooling devices. As mentioned before, it is beneficial to cool the single individual rather than cool the whole environment.

Then we have two problems:

1. What kind of heat transport medium should be used for the most industrial utility?
2. Where should an individual be cooled for most effective results?

A liquid is used in personal cooling rather than a gas because, as shown by Burton ( 1969 ), a liquid has 1,000 to 2,000 times the heat transfer capacity for the same pumping energy requirement. Naturally, water is the ideal choice because of the following advantages:

1. it is cheap and available
2. it has high heat absorption capability
3. it is non - poisonous
4. it is easy to incorporate into a single garment.

In recent years, several studies have shown that heat removal by circulating water for men working in heat ( Gold, Zornither, 1968; Shvartz, 1970 ) and for men working in thermally isolated environments ( Webb, Annis, Troutman, 1972 ) is an excellent method for the alleviation of heat strain. However, there are

some situations where the encumbrance caused by cooling the entire body or a limited energy source reduce the practicality of individual cooling. So, cooling some part of the whole body is one practical alternative; a simplified system for cooling a limited body area may suffice.

The body consists of several regions with distinct thermoregulatory characteristics ( Hertzman and Roth, 1942 ). The cooling capacity of a given region depends upon its surface, tissue insulation, vascularity, and maintenance of thermal exchange when chilled by the cooling medium. It also has been found that cooling the surface of the head ( Hatelid, 1967; Konz and Duncan, 1969; Shvartz, 1970 ), torso ( Kaufman and Pittman, 1966 ), arms ( Gold and Zornitzer, 1968 ) or legs ( Nunneley and Troutman, and Webb, 1971 ) results in a substantial removal of body heat.

Shvartz ( 1974 ) obtained further information ( see Figure 1 ) about patterns of partial body cooling which gave a comparison of cooling ten different body regions by circulating water.

In Figure 1, efficiency is indicated by percentage of decrement in body heat storage resulting from cooling 1% of the body surface area of each region. Effectiveness is indicated by percentage of decrease in body heat storage resulting from cooling the entire surface area of each region.

From Figure 1, we know that cooling of the neck is the most efficient method because the carotid arteries are located relatively close to the skin. Cooling of the thighs is the least efficient method because the large muscle mass in this

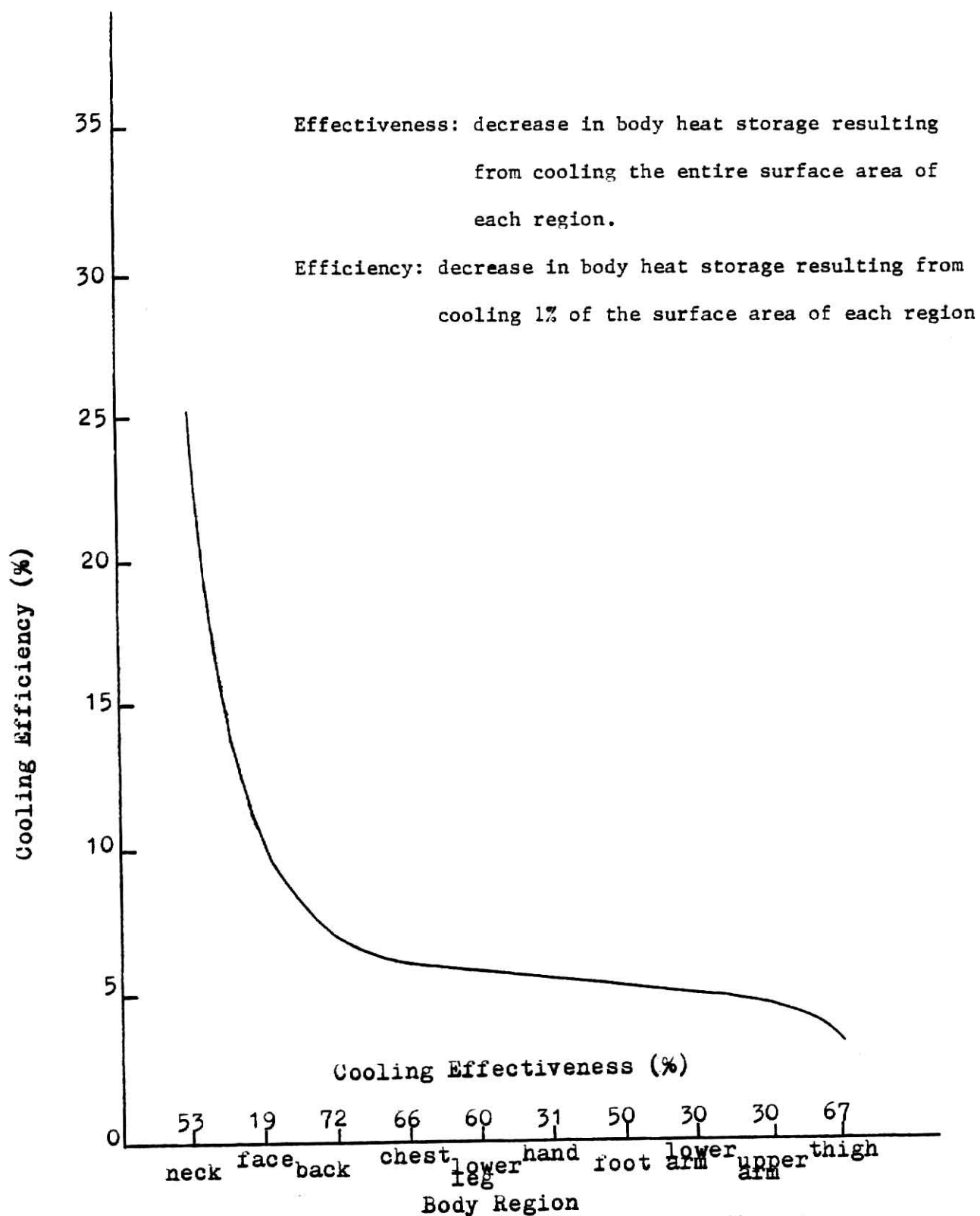


Figure 1. Effectiveness vs Efficiency of Body Cooling  
(Shvartz, 1975)

region presents a barrier between the skin and the large artery ( Shvartz, 1975 ).

Besides being effective, head cooling disturbance of the wearer's mobility is negligible. Cooling the head with a hood may make communication with others difficult.

Another body part which often is cooled locally is the torso. As mentioned above in Figure 1, cooling of the torso can reduce thermal strain up to 65%. Except for cooling effectiveness, the torso is an important site for individual cooling because the muscles in the torso contribute 55% of the total body muscle mass ( Stolwijk, 1971 ), and because it is easy to wear a cooling garment such as a shirt, vest or jacket ( Duncan and Konz, 1976 ). The torso is also a desirable location from the standpoint that a cooling garment worn on the torso can be designed to permit free movement of arms and legs and allow complete mobility to the worker ( Duncan, 1975 ).

In the study of this paper, the effectiveness of an ILC Cool Vest made by ILC Dover was tested in the following heat environment condition: 35 C dry bulb temperature, 21 mm Hg water vapor pressure ( 50% rh ), 32 radiant temperature, and air velocity < .15 m/s.

## METHOD

Task

The experiment was run in the test chamber of the Institute for Environment Research at Kansas State University. Each subject pedalled on an ergometer at:

1. 50 rpm, .5 kp
2. 50 rpm, 1.0 kp

for up to 90 minutes. For condition 1, the metabolic rate of each subject was about 215 Watts, i. e., work output = ( 50 rev/min ) ( 6 m/rev ) ( .5 kp ) = 150 ( kp - m )/min = 25 Watts. Assuming 20% efficiency, work =  $25 / .2 = 125$  W. Total energy requirements = 90 W for basal + 125 W for activity = 215 W. At condition 2, metabolic rate was  $90 + 250 = 340$  W. This was intended to simulate conditions of light work ( up to 230 Watts ) and moderate work ( 230 to 350 Watts ) for an average male.

Subject

In this study, six male Kansas State University students participated. The subjects were paid \$80.00 for the experiment. Table 2 gives their general physical characteristics. These subjects had physical fitness tests and medical examinations.

The subjects wore tennis shoes, socks, underwear, light trousers, T shirt and a long sleeve shirt during the experiment.

Cooling Device

The present cooling system we tested is a vest that is constructed from a urthane coated nylon which is mildew resistant. There is a coolant bag, battery and a pump inside. The coolant bag is capable of holding cubed or crushed ice. The battery is an 8 volt, 2.5 ampere hour lead acid battery. Under normal

TABLE 2

## General Characteristics of the Subjects

<u>Subject</u>	<u>Age(years)</u>	<u>Weight(kg)</u>	<u>Height(cm)</u>	<u>Surface Area(m)<sup>2</sup>*</u>
1	22	74	168	1.82
2	23	68	183	1.99
3	22	75	175	2.00
4	20	75	179	2.03
5	23	66	179	1.94
6	<u>23</u>	<u>64</u>	<u>170</u>	<u>1.85</u>
Mean	22	69	176	1.94

\* Surface area =  $0.208 + 0.945 \left( \left( 7.184 * 10^{-3} \right) \left( \text{Height in cm} \right)^{0.725} \right)$   
 ( Weight in kg )<sup>0.425</sup> ( Mitchell, 1971 )

use, the battery can operate up to four hours. The pump is used for circulating the water of the coolant bag through tubes. The garment is easy to don and does not hinder mobility, while the adjustable closure makes the garment comfortably fit most men.

### Procedure

Each experimental day was divided into three periods:

#### 1st period:

Each subject was weighed nude first. Nine temperature thermisters were attached to the skin of the left chest, left arm, left thigh and left leg by plastic tape ( see Figure 2 ). A rectal thermister probe was inserted into the rectum 4 to 6 cm. An EXERSENTRY was used for measuring heart rate. The subject's clothing, socks and a towel weight were taken also.

On the days that the subjects wore a water cooling vest, a pre - weighed cooling vest was put on. The 1.82 kg of cubed ice and 1,000 cc water were placed in the bag of the vest while the subject was sitting.

Then the subject was seated in the pretest room for 30 minutes. The environmental condition of the pretest room was comfortable. Its temperature was maintained at about 27 C. The skin temperature, rectal temperature and heart rate were recorded every five minutes for the last 20 minutes.

#### 2nd period:

The subject entered the conditioned rest chamber and wore the cooling garment. He began to pedal the ergometer. His





Figure 2. Sensor Locations

skin temperatures, rectal temperature and heart rate were recorded every 5 minutes. See Figure 3.

After pedalling for 90 minutes or whether the subject's rectal temperature rose 1.1 C above the basal value or heart rate exceeded 160 beats/min, he left the test chamber. During the test, the subject could drink some pre - weighed water; water temperature was approximately 10 C.

3rd period:

The subject was taken outside the test chamber into the pretest room and took off the cooling garment ( if the cooling garment had been worn ).

He stayed in the pretest room for 30 minutes. His skin temperatures, rectal temperature and heart rate were recorded every 5 minutes for the first 20 minutes. Then all his sensors were taken off and his clothing, socks, towel and nude body weight were taken again.

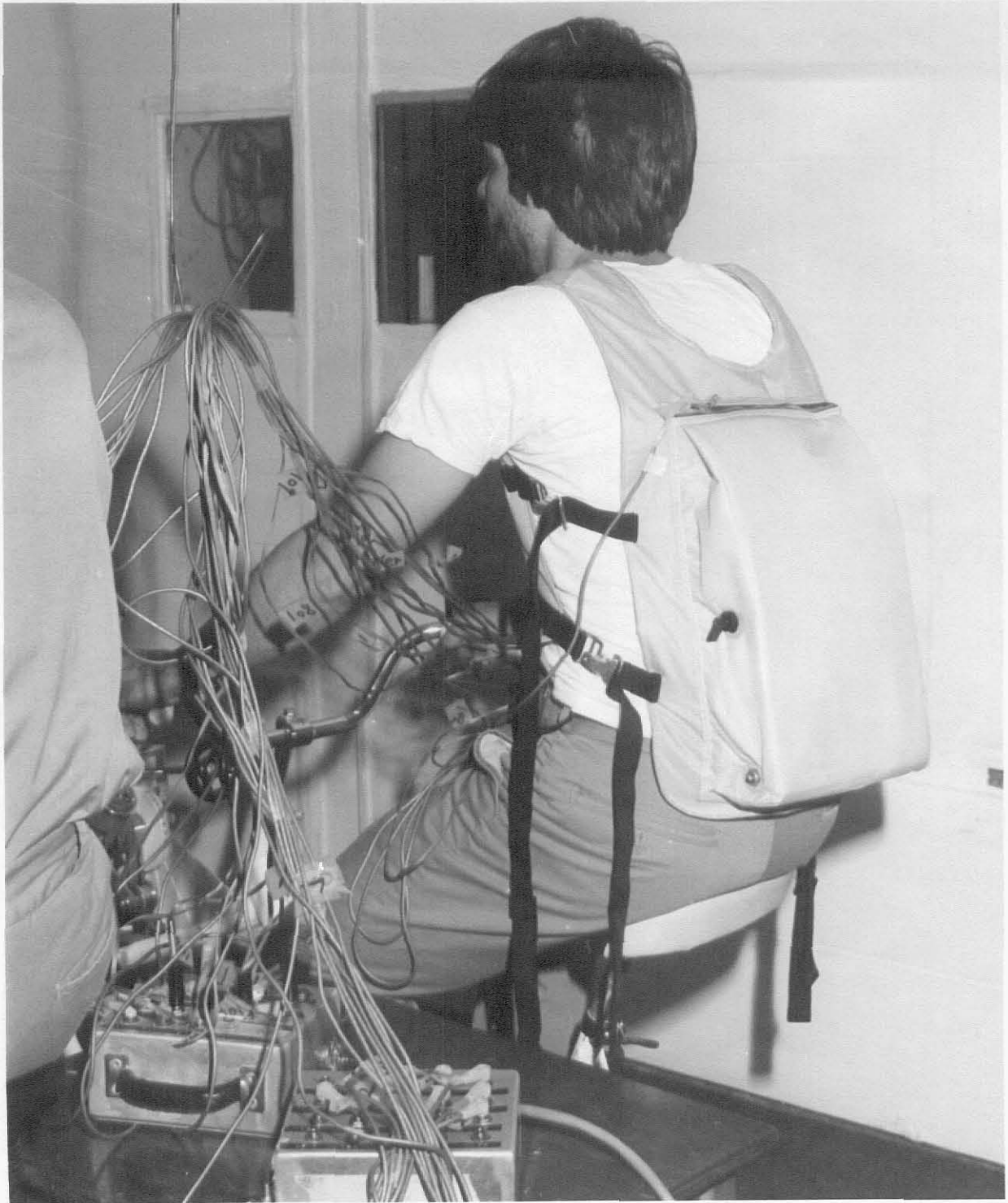


Figure 3. Subject with Cooling Vest is Pedalling the  
Ergometer in the Chamber

### Experimental Design

The experiment was divided into two stages.

The major work of the first stage for the experimenter was to get experience in operating the instruments used in the whole experimental progress and standarizing the procedure. For these purposes, a pilot study was carried out at this stage. It was really helpful for the experimenter to foresee some potential problems. For the subjects, they learned the purpose of the experiment and how to pedal the ergometer bike.

The second stage was to complete the experiment of evaluation of the water ice vest.

Table 3 shows the test schedule of each subject. Each subject was tested with and without cooling garment in the heat stress environment described before under the two conditions mentioned in task.

TABLE 3  
Test Schedule

Day	Trial	* Work	Subject						Time
			1	2	3	4	5	6	
1st	1	L	C**	N***					7:15 -- 10:00 AM
	2	L			C	N			9:45 -- 12:30 PM
	3	L					N	C	1:15 -- 4:00 PM
2nd	4	L	N	C					7:15 -- 10:00 AM
	5	L			N	C			9:45 -- 12:30 PM
	6	L					C	N	1:15 -- 4:00 PM
3rd	7	M	C	N					7:15 -- 10:00 AM
	8	M			C	N			9:45 -- 12:30 PM
	9	M					N	C	1:15 -- 4:00 PM
4th	10	M	N	C					7:15 -- 10:00 AM
	11	M			N	C			9:45 -- 12:30 PM
	12	M					C	N	1:15 -- 4:00 PM

\* Work : L - Light work (215 W) ; M - Moderate work (340 W)

\*\* C : Cooling

\*\*\* N : Non cooling

## RESULTS

There are two following objectives in the analysis of the data.

1. Effectiveness of the cooling garment
2. Difference of performance of the cooling garment in the two workloads.

The following criteria were analyzed:

1. Rectal temperature
2. Leg skin temperature
3. Torso skin temperature
4. Upper arm skin temperature
5. Heart rate
6. Sweat loss

In order to evaluate objective 1, the rise above the basal value during 90 - minute exposure to heat stress with and without cooling was analyzed by a 3 - way analysis of variance. The basal value was the average of the subject's four readings in the neutral period during the experiment. For objective 2, the decreases due to cooling in the two workloads were analyzed by a 2 - way analysis of variance.

### Rectal Temperature

There was a tendency that the subject's rectal temperature went down in the pretest room while they were waiting to enter the test chamber. Konz ( 1971 ) found the same effect. Konz stated: " it seems the subject's psychological state affected a physiological index, rectal temperature ". Sometimes it even declined in the beginning of test period. We also observed

that there was a downward trend near the end of the stress when subject was with cooling in the light work. This finding coincides with the conclusion of Aurora ( 1970 ). This effect was not observed when the subject was without cooling. The tendency of rectal temperature to continue increasing in the beginning of the recovery period found by Aurora ( 1970 ) was not observed in this experiment.

Figure 4 shows the mean rectal temperatures of the subjects under the two workloads with and without cooling. Table 4 shows the increases over the basal values during exposure to heat stress. The increase for subject 3 in the light work while cooling was negative. He benefited most from the cooling garment. A 3 - way analysis of variance showed that the average increase over the basal value ( .3 C ) with cooling was significantly (  $p < .05$  ) less than the average increase ( .5 C ) without cooling.

A 2 - way analysis of variance was used to analyze the decrease in rectal temperature due to cooling in Table 4. It showed that the average decrease ( .1 C ) due to cooling in light work was not significantly (  $p < .05$  ) different from the average decrease ( .2 C ) in moderate work. Hence, there was no difference in garment performance between light and moderate work.

#### Leg Skin Temperature

Leg skin temperature is the equally weighted average of temperatures for the lower leg and thigh. The leg is the only working member of the body during the experiment. Figure

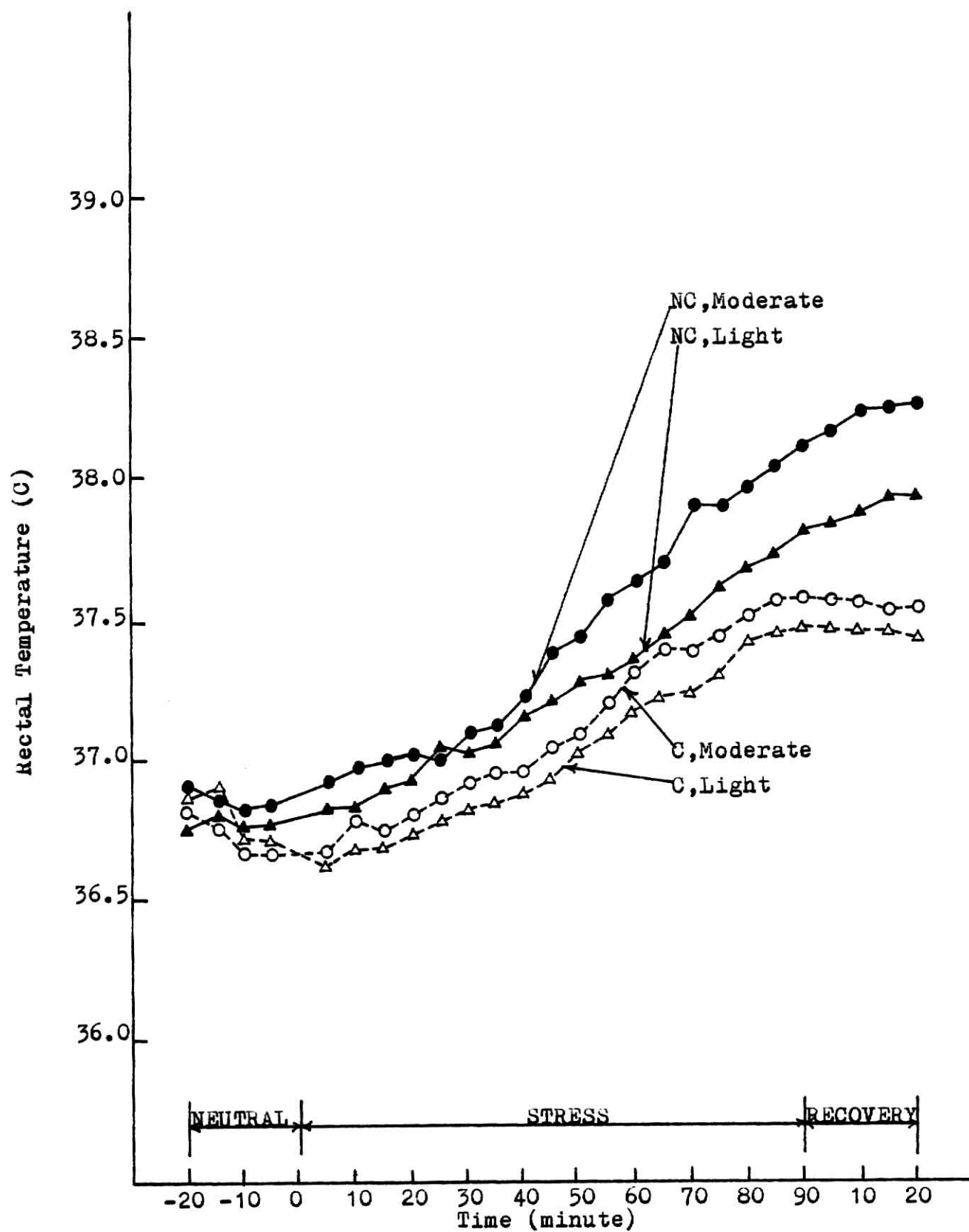


Figure 4. Mean Rectal Temperature for Light & Moderate Work



TABLE 11

Ratio of the Decrease in the Heat Storage to Heat Storage in Non Cooling Condition

Subject	WORKLOAD	
	<u>L</u>	<u>**</u> <u>M</u>
1	.79	.71
2	.76	.70
3	.78	.68
4	.74	.75
5	.69	.78
6	<u>.70</u>	<u>.68</u>
Mean	.74	.72

\* L : Light work

\*\* M : Moderate work

5 shows the subjects' leg skin temperature with and without cooling in light and moderate work. Table 5 shows the increase in leg skin temperature over the basal value due to exposure to heat stress. A 3 - way analysis of variance indicated that the average increase ( 2.3 C ) in leg skin temperature with cooling was significantly (  $p < .05$  ) lower than the average increase ( 3.1 C ) without cooling.

The decrease of the leg skin temperature due to cooling can be obtained from Table 5. A 2 - way analysis of variance showed that there was no difference between the average decrease ( .7 C ) in light work and ( .9 C ) in moderate work. It can be concluded that the performance of the cooling garment was same in these two workloads.

#### Torso Skin Temperature

Torso skin temperature is an equally weighted average of three chest and three back temperatures. The mean torso skin temperatures of the subjects with and without cooling under the two workloads are contained in Figure 6. The figure demonstrates that the subjects' mean torso skin temperature while with cooling was below the basal value. Torso skin temperature was the only skin temperature under the direct influence of the cooling device.

Table 6 gives the increase over the basal value during exposure to heat stress and the effect on torso skin temperature due to cooling. A 3 - way analysis of variance indicated that the cooling garment produced a significantly (  $p < .05$  ) lower increase ( - .8 C ) than without cooling ( 3.9 C ). Subject was a significant effect.

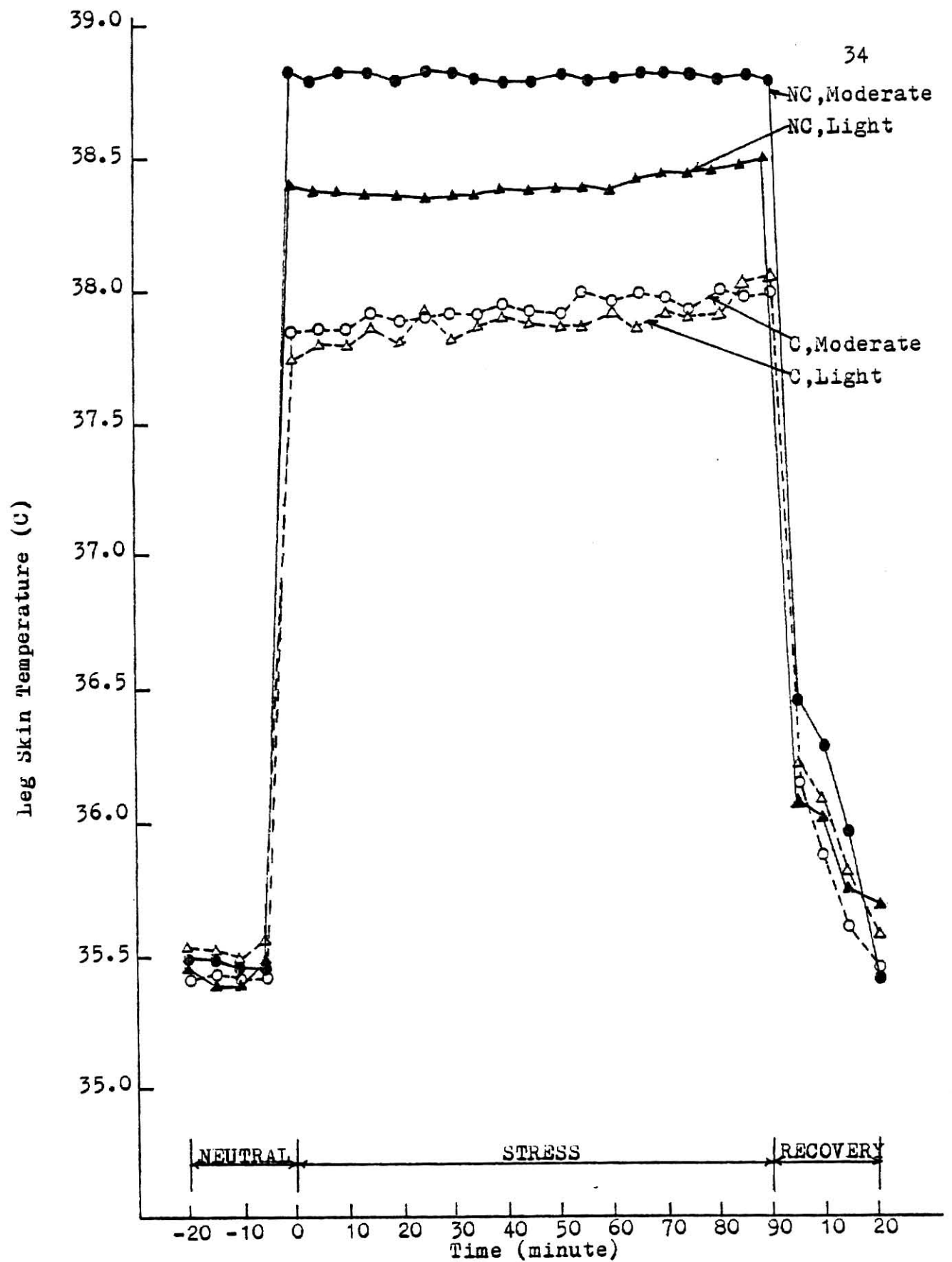


Figure 5. Mean Skin Temperature for Light & Moderate Work

TABLE 5

Increase in Leg Skin Temperature ( C ) Due to Exposure to Heat Stress

Subject	LIGHT WORK			MODERATE WORK		
	*	**		C	NC	Difference
	C	NC	Difference	C	NC	Difference
1	2.5	3.6	1.1	2.8	3.2	.4
2	2.0	2.7	.7	2.3	2.9	.6
3	1.4	2.0	.6	1.6	3.0	1.4
4	2.9	3.4	.5	2.8	3.2	.4
5	3.2	3.5	.3	2.5	3.6	1.1
6	1.7	2.6	.9	2.7	3.2	.5
Mean	2.3	3.0	.7	2.4	3.3	.9

\* : C = Cooling

\*\* : NC = Non Cooling

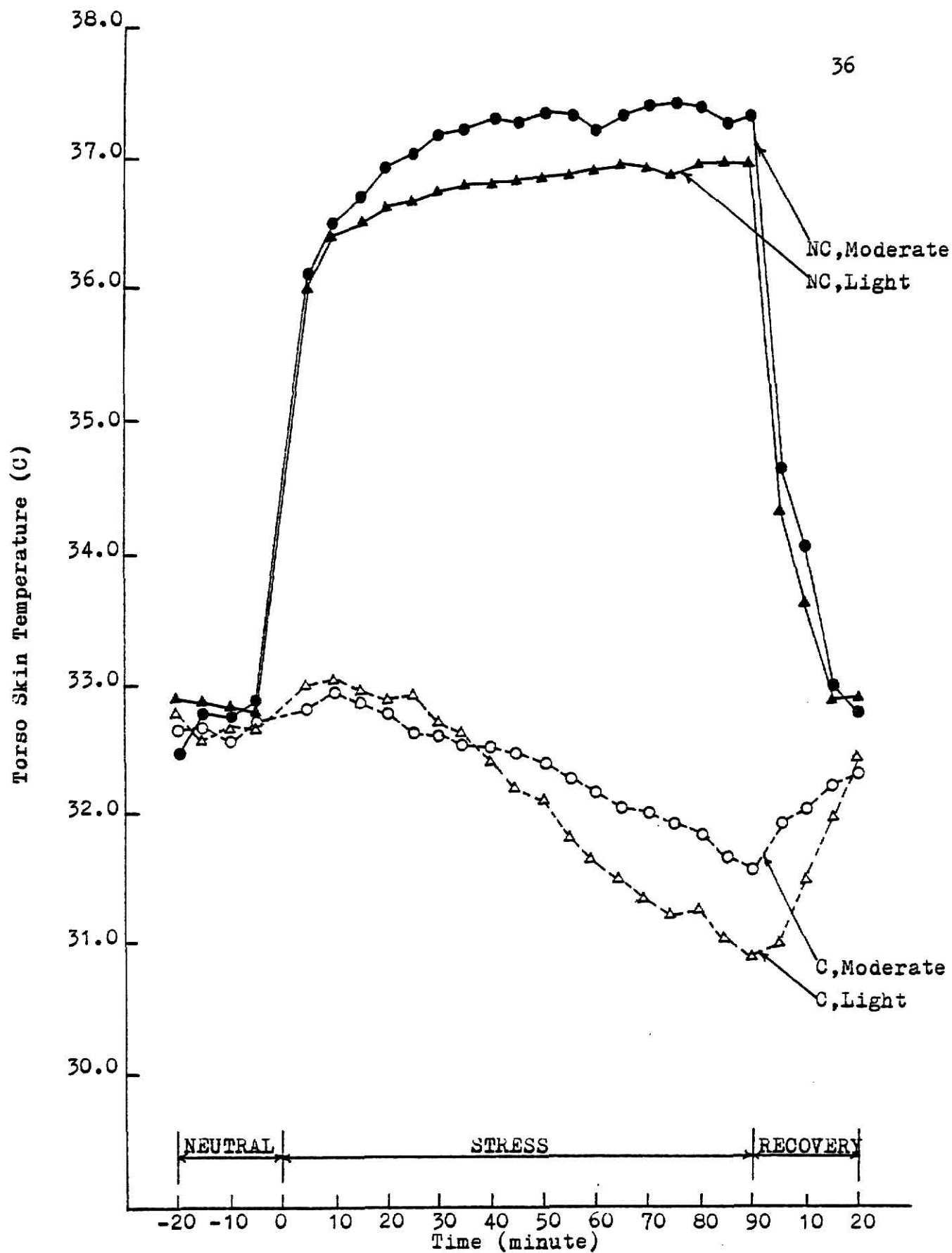


Figure 6. Mean Torso Skin Temperature for Light & Moderate Work



A 2 - way analysis of variance showed that there was no significant difference (  $p < .05$  ) between the performance of the cooling garment in light work ( 5.0 C ) and moderate work ( 4.4 C ).

#### Upper Arm Skin Temperature

Figure 7 shows the measurements of the subjects under two workloads. There were no particular characteristics worth noting from this figure. From Table 7, a 3 - way analysis of variance indicated a significant difference (  $p < .05$  ) in upper arm skin temperature between the cooling condition ( 2.2 C ) and non cooling condition ( 3.3 C ).

The decrease in upper arm skin temperature due to cooling in Table 7 was analyzed by a 2 - way analysis of variance. That showed that there were no significant difference (  $p < .05$  ) between light work ( 1.0 C ) and moderate work ( 1.1 C ).

#### Heart Rate

The electronic meter for measuring heart rate had minor troubles during the first trial, so the data for subject 1 are not available. Figure 8 shows the heart rate of the subjects. The heart rates of the subjects were very irregular in both the cooling and non cooling condition. Heart rates were very sensitive to heat stress. Table 8 shows the increases in heart rate over the basal value due to a 90 - minute exposure to heat stress and the decreases because of cooling. A 3 - way analysis of variance showed that the average increase in heart rate with cooling ( 24 beats/min ) was significantly (  $p < .05$  ) less than the average increase without cooling ( 37 beats/min ).

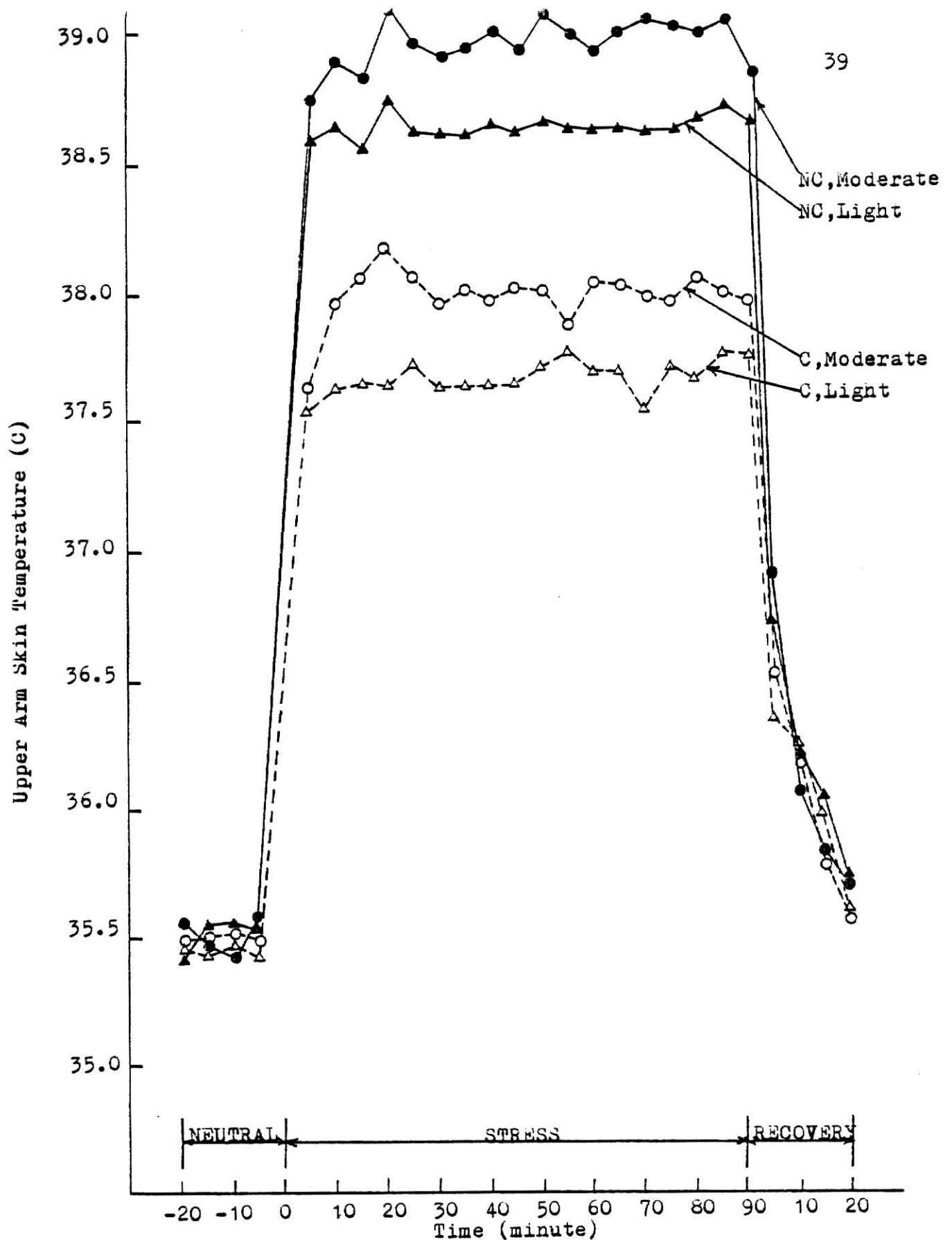


Figure 7. Mean Upper Arm Temperature for Light & Moderate work



TABLE 7

Increase in Upper Arm Skin Temperature ( C ) Due to Exposure to Heat Stress

Subject	* LIGHT WORK			MODERATE WORK		
	C	NC	Difference	C	NC	Difference
1	3.3	4.0	.7	2.4	2.8	.4
2	1.4	2.8	1.4	1.9	3.0	1.1
3	2.5	3.5	1.0	2.9	3.7	.8
4	2.8	3.8	1.1	2.2	3.5	1.3
5	2.7	3.5	.9	3.2	3.7	.5
6	1.7	1.9	.7	1.4	3.8	2.8
Mean	2.1	3.1	1.0	2.3	3.6	1.1

\* : C = Cooling

\*\* : NC = Non Cooling

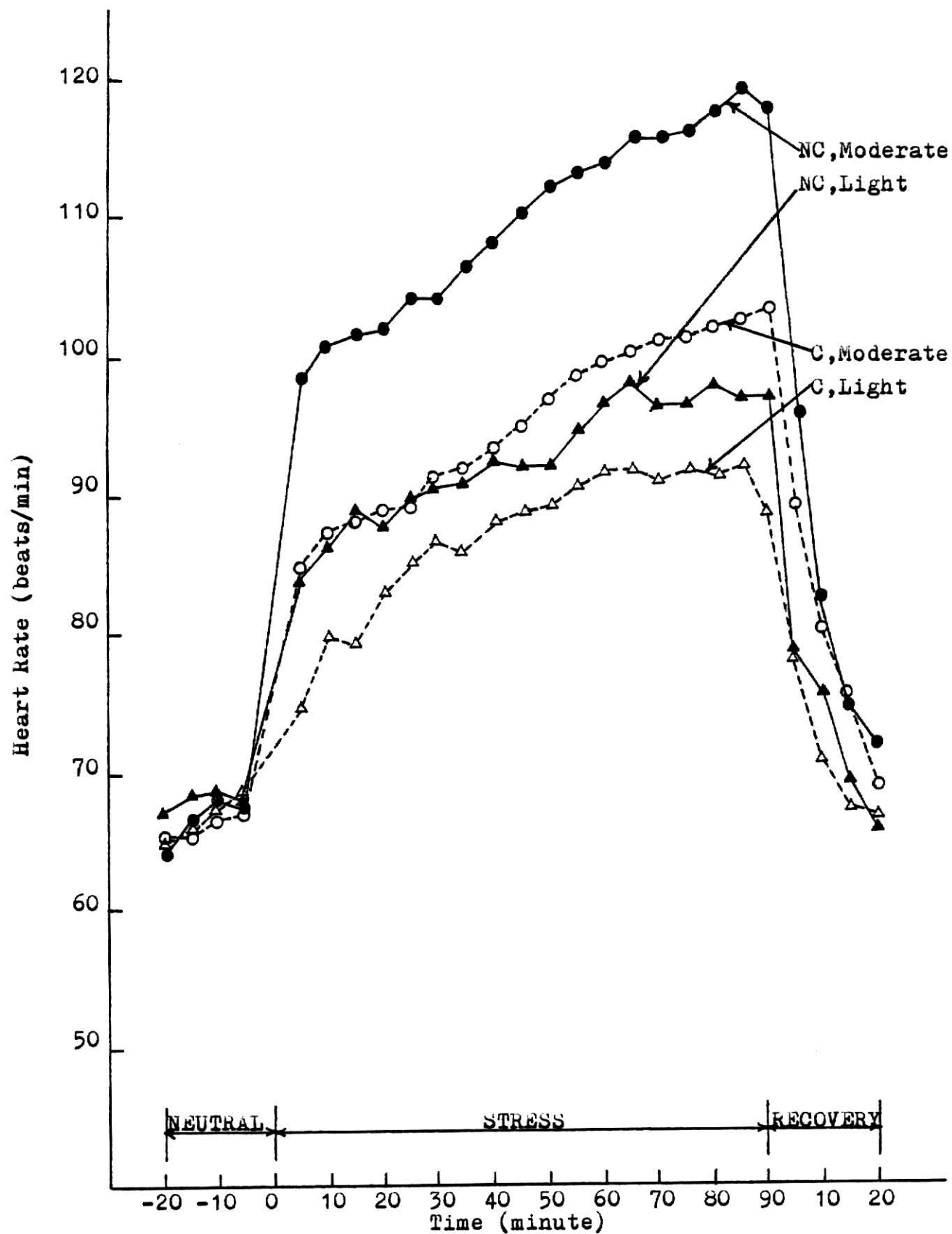


Figure 8. Mean Heart Rate for Light & Moderate Work

TABLE 8

Increase in Heart Rate ( beats/min ) Due to Exposure to Heat Stress

Subject	LIGHT WORK			MODERATE WORK		
	*	**			Difference	
	C	NC	Difference	C	NC	Difference
1	***	***	***	***	***	***
2	9	28	19	18	23	5
3	15	16	1	28	46	18
4	20	28	8	32	48	16
5	19	26	7	37	64	27
6	27	39	12	38	56	18
Mean	18	27	9	31	47	16

\* : C = Cooling

\*\* : NC = Non Cooling

\*\*\* : Data Not Available

The analysis also indicated that the workload and the subject effects also were significant (  $p < .05$  ). The average increase in heart rate in light work ( 22 beats/min ) was significantly (  $p < .05$  ) lower than the average increase in moderate work ( 39 beats/min ).

A 2 - way analysis of variance showed that the average decrease of heart rate in light work ( 9 beats/min ) was not significantly (  $p < .05$  ) less than the average decrease in moderate work ( 16 beats/min ). The performance of the cooling garment was not significantly (  $p < .05$  ) different in the light and moderate workload when using heart rate as the criterion.

#### Sweat Loss

Table 9 gives the increases in sweat loss of the subjects over their basal values due to heat stress and the reduced amount due to cooling. There was a wide variation in light work while cooling. A 3 - way analysis of variance indicated that the average increase with cooling ( 393 grams/m<sup>2</sup> of body area/hr ) was significantly (  $p < .05$  ) less than the average increase without cooling ( 986 grams/m<sup>2</sup> of body area/hr ). The effectiveness of the cooling garment was proved if sweat loss was used as the criterion.

A 2 - way analysis of variance showed that the average reduction in light work ( 542 grams/m<sup>2</sup> of body area/hr ) was not significantly (  $p < .05$  ) lower than the average reduction in moderate work ( 642 grams/m<sup>2</sup> of body area/hr ). Therefore, the cooling garment was as effective in light as moderate work.

TABLE 9  
2  
Increase in Sweat Loss ( grams/m of body area/hr ) Due to Exposure to  
Heat Stress

Subject	* LIGHT WORK **			MODERATE WORK		
	C	NC	Difference	C	NC	Difference
1	220	769	549	475	995	520
2	376	895	519	523	1143	620
3	466	1066	600	450	991	541
4	195	755	560	442	1259	817
5	418	936	518	421	1100	679
6	313	821	508	428	1107	679
Mean	331	873	542	456	1099	642

\* : C = Cooling

\*\* : NC = Non Cooling

### Heat Storage and Heat Removal from the Body

Heat storage rate was estimated by the following formula suggested by Webb ( 1969 ):

$$Q = C_p W ( .8 \Delta t_r + .2 \Delta t_s )$$

where:

$Q$  = the amount of heat stored during exposure, Watts

$C_p$  = specific heat of human body

$$C_p = .97 \text{ (W-hr)/(kg-C)}$$

$W$  = weight of the body, kg ( Table 2 )

$\Delta t_r$  = change in rectal temperature, C ( Table 4 )

$\Delta t_s$  = change in skin temperature, C, estimated from a weighted average of changes in leg ( Table 5 ), torso ( Table 6 ) and upper arm skin temperature ( Table 7 ):

$$(.37) ( t_{leg} ) + (.37) ( t_{torso} ) + (.26) ( t_{upper arm} )$$

The specific heat of human body,  $C_p$ , was .97 (W-hr)/(kg-C) ( ASHRAE Handbook, 1977 ). Table 10 gives the subjects' heat storage rate due to exposure to heat stress in the two workloads with and without the cooling garment and the removed body heat storage due to cooling. The average heat storage with cooling ( 62 Watts ) was significantly (  $p < .05$  ) lower than the heat storage without cooling ( 236 Watts ).

The average decrease due to cooling in light work ( 151 Watts ) was significantly (  $p < .05$  ) different from the average decrease in moderate work ( 197 Watts ).

The individual values as a percent of the mean ranged from 85 to 113% for light work and from 81 to 129% for moderate work.

TABLE 10

Heat Storage ( Watts ) Due to Exposure to Heat Stress

Subject	LIGHT WORK				MODERATE WORK			
	C*	NC**	Difference	% of Mean	C	NC	Difference	% of Mean
1	44	209	165	109	75	258	183	93
2	47	198	151	100	78	264	186	94
3	44	201	157	104	73	232	159	81
4	50	221	171	113	79	312	233	118
5	51	184	133	88	73	328	255	129
6	45	174	129	85	79	245	166	84
Mean	47	198	151	100	76	273	197	100

\* : C = Cooling

\*\* : NC = Non Cooling

Table 11 shows the ratio of the difference to the heat stored in the non cooling condition. For instance, for subject 1 in light work, the ratio of heat removal to heat stored in the non cooling condition =  $(209 - 44)/209 = .79$ . The average ratio of heat removal to heat stored in the non cooling condition was .73.

### Heat Extraction

The conduction heat transfer was estimated in the following way:

First, the approximation of heat extracted from the environment could be estimated from ice weight change and water temperature differential. First the garment was tested without any one wearing it in a 35 C environment for 1 hour.

$$1. \text{ Initial ice weight} = 1.82 \text{ kg}$$

$$\text{Final ice weight} = 1.17 \text{ kg}$$

$$\begin{aligned} \text{Heat absorbed from solid to liquid} &= 80 (1.82 - 1.17) \\ &= 52 \text{ kcal} \end{aligned}$$

$$2. \text{ Initial water temperature} = 18.88 \text{ C}$$

$$\text{Final water temperature} = 5.00 \text{ C}$$

$$\begin{aligned} \text{Heat into water} &= 1 (18.88 - 5.00) \\ &= 13.88 \text{ kcal} \end{aligned}$$

$$\begin{aligned} 3. \text{ Heat of melted ice from } 0 \text{ C to } 5 \text{ C} &= (1.82 - 1.17) (0 - 5) \\ &= -3.25 \text{ kcal} \end{aligned}$$

$$\begin{aligned} \text{So, heat extracted from the environment} &= 52 + 3.25 - 13.88 \\ &= 41.37 \text{ kcal/hr} \\ &= 48 \text{ Watts} \end{aligned}$$



TABLE 4

Increase in Rectal Temperature ( C ) Due to Exposure to Heat Stress

Subject	* LIGHT WORK		MODERATE WORK	
	C	NC	Difference	Difference
1	.3	.4	.1	.3
2	.4	.6	.2	.5
3	-.1	.2	.3	.4
4	.4	.5	.5	.5
5	.5	.5	.0	.4
6	.2	.4	.2	.4
Mean	.3	.4	.1	.4
				.2

\* : C = Cooling

\*\* : NC = Non Cooling

Second, heat extraction may be calculated in the experimental situation. For subject 1 in the light work,

initial ice weight = 1.82 kg

final ice weight = 0.00 kg

$$\begin{aligned} \text{heat absorption from solid to liquid} &= 80 ( 1.82 - 0.00 ) \\ &= 145.6 \text{ kcal} \\ &= 97.1 \text{ kcal/hr} \\ &= 112.6 \text{ Watts} \end{aligned}$$

initial water temperature = 18 C

final water temperature = 5.35 C

$$\begin{aligned} \text{heat into water} &= 1 ( 18 - 5.35 ) \\ &= 12.65 \text{ kcal} \\ &= 8.43 \text{ kcal/hr} \\ &= 9.78 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{heat of melted ice from 0 C to 5 C} &= ( 1.82 - 0 ) ( 0 - 5.35 ) \\ &= - 9.74 \text{ kcal} \\ &= - 6.49 \text{ kcal/hr} \\ &= - 7.53 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{So, conduction heat loss in environment} &= ( 112.6 + 7.53 - 9.78 ) \\ &= 110.35 \\ &= 62.35 \text{ Watts} \\ &\approx 62 \text{ Watts} \end{aligned}$$

Table 12 shows calculations for the other conditions.

Convection heat transfer of subjects with cooling was estimated from the formula on p. 8:

$$C = h_c A f_{clc} ( t_{air} - t_{skin} ) \text{ Watts}$$

TABLE 12

Potential Heat Losses ( Watts ) by Conduction, Convection, Radiation and Evaporation of Sweat

Subject	Work	Conduction	Radiation	Convection	Evaporation of Sweat	Total
1	L*	62	19	25	28	134
2	L	61	18	20	33	132
3	L	59	15	18	29	121
4	L	60	19	28	40	147
5	L	61	11	19	35	126
6	L	61	16	24	34	135
Mean		61	16	22	33	133
1	M**	64	17	27	95	203
2	M	65	16	24	112	217
3	M	64	17	22	76	173
4	M	65	17	16	101	199
5	M	66	13	17	81	177
6	M	66	15	24	78	123
Mean		65	13	22	91	182

\* L : Light work

\*\* M : Moderate work

where:

$$h_c = 8.3 V_c^{.6} = 8.3 ( .15 )^{.6} = 2.66 \text{ W/(m}^2 - \text{C)}$$

A = subjects' DuBois body area, m<sup>2</sup>, can be found from

Table 2

$$f_{clo} = 1/(1+.155 (2.9) I_{clo}) = .79, I_{clo} = .60$$

$$t_{air} = 35 \text{ C}$$

t<sub>skin</sub> = skin temperature of a subject with cooling, C,

estimated from  $t_{skin} = (.3) (t_{skin \text{ under garment}}) + (.7) (t_{skin \text{ not under garment}})$ , assumed 80% of torso skin was cooled by cooling garment.

The evaporation loss can be estimated from the formula on

p.9:

$$E_e = h_c A W F_{pcl} (VP_s - VP_a) \text{ Watts}$$

where:

$$h_e = 2.2 h_c = 2.2 * 2.66 = 5.85 \text{ W/(m}^2 - \text{C)}$$

A = subjects' body area, m<sup>2</sup>

W = fraction of skin that is wet = 0.5

F<sub>pcl</sub> = decrease in evaporative efficiency for permeable clothing

$$F_{pcl} = 1/(1+.143 (2.9) I_{clo}) = .801$$

VP<sub>s</sub> = vapor pressure of water on skin, mm Hg

VP<sub>a</sub> = vapor pressure of water in air = 21 mm Hg

Thus, the rough estimate of evaporation loss was:

$$E = 2.35 A (VP_s - 21) \text{ Watts}$$

The vapor pressure of water on skin, VP<sub>s</sub>, was the saturation pressure at the skin temperature from the psychrometric

tables ( ASHRAE Handbook, 1977 ). Skin temperature can be estimated from:  $(.3) (t_{\text{skin under garment}}) + (.7) (t_{\text{skin not under garment}})$ .

Radiation heat transfer can be estimated from the formula on p.7:

$$R = A \alpha f_{\text{eff}} f_{\text{clr}} E_{\text{clr}} e (T_{\text{mrt}}^4 - T_{\text{skin}}^4) \text{ Watts}$$

where:

$A$  = skin surface area,  $\text{m}^2$

$\alpha$  = Stefan - Boltzman constant =  $5.67 \times 10^{-8} \text{ W/(m}^2 \text{ - K}^4)$

$f_{\text{eff}}$  = effective skin radiation area factor = .70

$f_{\text{clr}}$  =  $1 + .155 I_{\text{clo}}$  = 1.09

$E_{\text{clr}}$  =  $1 / (1 + .155 (5.2) I_{\text{clo}})$  = .67

$e$  = emissitivity = .70

$T_{\text{mrt}}$  = mean radiant temperature in K of environment,

$K = 273 + C = 308$

$T_{\text{skin}}$  = temperature in K of skin,  $T_{\text{skin}} = (.3) (t_{\text{skin under garment}}) + (.7) (t_{\text{skin not under garment}})$

For male subject,  $f_{\text{eff}}$  was assumed to be .70 ( Fanger, et al, 1970 ) and emissivity of the skin to be .70 ( Slonium, 1974 ).

So, the estimate of radiation loss can be obtained from:

$$R = 2.03 \times 10^{-8} A ( 9.0 \times 10^9 - T_{\text{skin}}^4 ) \text{ Watts}$$

From Table 12 and heat balance equation on p.3, the heat storage of the subjects could be obtained ( see Table 13 ). For instance, for subject 1 in the light work, the heat storage ( S ) = metabolic heat ( M ) - Work output ( W ) - ( Conductive loss ( K ) + Radiative loss ( R ) + Convective loss ( C ) + Evaporative loss ( E ) ) =  $215 - 25 - ( 62 + 19$

TABLE 13

Total Heat Storage ( Watts ) by Subject

<u>Subject</u>	<u>Light</u>	<u>Moderate</u>
1	56	87
2	58	73
3	69	117
4	43	91
5	64	113
6	<u>55</u>	<u>167</u>
Mean	58	108

+ 25 + 28 ) = 56 W. From Table 10, for subject 1 the actual heat storage in the light work was 44 W; thus the two techniques of heat storage differed by 12 W. From Table 13, the average heat storage in light work and moderate work were 58 W and 108 W respectively, while the Table 10 estimates were 47 W and 76 W. The most probable error in Table 12 is in the conduction calculation and the skin wettedness assumption of 0.5 for the evaporation calculation.

#### Subject Evaluation

The subjects were given a questionnaire form as shown in Appendix A to evaluate the performance of the cooling garment. Four of the six subjects felt comfortable in light work and moderate work. Subject 1 and 6 felt slightly cool in these two workloads. Hence, from the subjects' opinion, the cooling effectiveness is good.

## DISCUSSION

The two primary objectives of this study were to investigate the effectiveness of the ILC model 19 Cool Vest in two workloads ( 215 W and 340 W ) in a heat stress environment ( 35 C, 50% rh ).

In general, the proposed cooling device is a good design. The total weight of the cooling garment ( including 1.82 kg ice and one liter water ) is about 5.5 kg. The garment can provide a flow rate of 53 kg/hr through 840 cm<sup>2</sup> cooling area for removing heat from the human body. There were only 48 W heat losses to the heat stress environment, so the insulation material ( urethane ) is relatively effective. From Table 10, there were quite significant individual differences in heat reduction. For light work, it ranged from 15% below to 13% above average. For moderate work, it ranged from 16% below to 29% above average. This suggests closeness of garment fit should be improved.

The increase from basal values in leg and upperarm skin temperature with the vest were found to be significantly lower than without the vest. There was no significant difference in the performance of the garment in light and moderate work with these temperatures as the criteria. But, the cooling vest worked a little better in the moderate workload.

Torso skin temperature was the equally weighted average of three chest and three back skin temperatures. There were large individual variations in the change of the subjects' torso skin temperatures. The possible reason may be that the



subjects adjusted the temperature control valve on the cooling vest quite irregularly. It was observed that the torso skin temperature of subject 1 and 6 went down about 2 C when they wore the cooling garment during exposure to heat in the test chamber. The torso skin temperature decreased -0.8 C from basal value with cooling compared to increased 3.9 C without cooling. The significance of the effect of subjects showed that different subjects reacted differently to the garment. The performance of the cooling vest was better in the light workload but the difference between light and moderate work was not statistically significant.

The subjects' rectal temperatures declined before they wore the cooling vest. It is concluded that psychological emotion is one of the variables that decide the effectiveness of the cooling garment. The vest decreased the rectal temperature 0.1 C. The performance of the cooling vest was better ( but not significantly ) under the condition of moderate work.

The sweat loss of the subjects with the garment was only 48% of that without the garment.

The effect of emotion on heart rate that Konz ( 1971 ) found did not appear in this study. The cooling garment kept the average increase in heart rate to 24 beats/minute as compared to 39 beats/minute without the garment. There was no statistical difference in the two workloads with heart rate as the criterion.

Although some subjects complained about the weight of the

coolant bag, all of them were satisfied with the cooling device and the task tested.

## CONCLUSION

The effectiveness of the proposed cooling system has been demonstrated. The cooling device made all the subjects' physiological responses, that is, torso skin temperature, rectal temperature, upperarm skin temperature, leg skin temperature, heart rate and sweat loss much below the non cooling condition.

The performance of the cooling garment in light work ( 215 W ) and moderate work ( 340 W ) was not significantly different.

Of course, the garment is not the final design. According to subjects' suggestion, the following two modifications could be made:

1. evenly distribute the ice weight, for instance, half of the weight in front and half of the weight in back.

Pulling on neck muscles can be avoided.

2. improve the straps, so that they can fit the cooling garment tighter with the body.

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## APPENDIX A

## Subject Questionnaire Form

Subject Name: \_\_\_\_\_

Date: \_\_\_\_\_

Workload:    Light (    )                      Moderate (    )

A. Classify your opinion about the cooling vest you have used on the following scale ( mark one ):

1. COLD
2. COOL
3. SLIGHTLY COOL
4. COMFORTABLE
5. WARM
6. HOT

B. What modifications do you think should be made in the design of cooling vest?

## APPENDIX B

## Subject Consent Form

I, the undersigned, realize that I will be asked to begin a test of 90 minutes. My rectal and skin temperatures will be recorded as well as my heart rate.

I will be asked to pedal the ergometer according to one of the two conditions: 1) 50 rpm, .5 kp; 2) 50 rpm, 1.0 kp in a hot test chamber ( 35 C, 50% rh ). In each condition, I will be with a cooling garment one day and without cooling garment another day.

I may have to endure some discomfort due to the heat stress. A nurse will be present during the experiment. She will remove me from the chamber: a) when 90 minutes are completed, b) if she feels the stress is too much for me, c) if my rectal temperature rises more than 1.1 C ( 2 F ), d) if my heart rate exceeds 160 beats/min or e) if I feel too ill to continue. However, if I choose not to complete the experiment, I will forfeit my \$80.

I will receive \$80 for completing the four sessions. Being removed due to the reasons above is considered completion of a session.

My name will be kept confidential.

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Signature

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Date



LABORATORY EVALUATION OF A WATER ICE VEST

by

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Diploma, Industrial Engineering, Taipei Institute  
of Technology, 1978

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AN ABSTRACT OF A MASTER'S THESIS

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## ABSTRACT

An water cooling vest supplied with 58 kg/hr flow rate through 840 cm<sup>2</sup> cooling area was evaluated in a heat stress environment of 35 C dry bulb, 50% rh and air velocity less than .15 m/s on six male subjects. Each subject pedalled the ergometer in the heat stress under two workloads: 50 rpm and .5 kp ( metabolic rate = 215 W; light work ), 50 rpm and 1.0 kp ( metabolic rate = 340 W; moderate work ). Each subject was exposed to the heat stress under one workload once with the vest and once without the vest. Heart rate, rectal temperature, upperarm temperature, leg temperature and torso temperature were recorded during 20 minutes in a neutral environment, 90 minutes in heat stress and 20 minutes in the neutral environment again.

The vest removed heat storage in the body by 174 W. The vest decreased the rectal temperature by .1 C, leg temperature .8 C, torso temperature 4.7 C, upper arm temperature 1.0 C, heart rate 12 beats/min, and sweat losses by 48% when compared to the non cooling condition. The above criteria were kept significantly (  $p < .05$  ) lower with the vest. There was no significant difference in performance between light and moderate work.

Some further improvements in the design, especially fit, of the cooling device can increase its efficiency.