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REMOVAL OF METABOLIC HEAT FROM MAN WORKING IN A PROTECTIVE SUIT*

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INTRODUCTION

Although water-cooled Apollo EVA space suits with a single, controlled inlet temperature proved to be relatively simple and quite effective in maintaining acceptable thermal conditions, they did have certain short-comings (refs. 1, 2, 3). Among these was the limitation of the minimum inlet temperature by the most sensitive part of the body. This present work was undertaken primarily to explore the feasibility of independently cooling separate regions of the body. Specific purposes included (1) determination of preferred coolant inlet temperatures and the amounts of heat removed at each region, and (2) the order of cooling or warming preferences at different metabolic rates. The subject's own sense of comfort was the criterion used in each case.

EXPERIMENTAL SETUP

A water-cooled suit was constructed for the purpose of testing the characteristics of the proposed differential scheme of cooling the body. The suit consisted of 16 individual pads made of 3/32-in. i.d. by 5/32-in. o.d. Tygon tubes running parallel, 5/8-in. apart. The cooling pads covered the head (2)[1], front and back, upper and lower torso (4), upper and lower, right and left arms (4), right and left thighs (4), and right and left lower legs (2). The face, neck, hands, and feet were not covered with cooling tubes. Table 18.1 gives pertinent dimensions of the cooling pads and the whole suit. All the pads, excluding the ones for the head, were stitched on the inside of a man's thermal union underwear garment. The cooling hood was made of a snow suit hood with the cooling tubes stitched onto the inside,

The body was divided into six regions for cooling purposes:

Head
Upper torso
Lower torso
Arms
Thighs
Lower legs

These regions were supplied with water mixed from cold and hot headers. Before entering the suit, the two streams were mixed separately for each region, thus allowing for continuous regulation of water inlet temperatures. These temperatures were measured by interchangeable, multipurpose No. 401 Yellow Springs Co. thermistors and a Tele-Thermometer. The difference between outlet

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[1]Numbers in parentheses represent number of pads.

Table 18.1 *Data on the cooling garment.*

Pad	*Number of pads*	*Number of tube rows in pad*	*Area covered by pad* in^2	cm^2	*Total area covered by pads* in^2	cm^2	*Percent area covered*
Head	2	12	65	419	130	838	9.6
Front and back, upper and lower torso	4	14	111	716	444	2864	33.0
Upper arms	2	11	62	400	124	800	9.2
Lower arms	2	12	60	387	120	774	8.9
Upper thighs	2	7	83	535	166	1070	12.3
Lower thighs	2	10	96	619	192	1238	14.2
Lower legs	2	16	86	555	172	1110	12.8
Total	16	–	–	–	1348	8694	100

	Cooling garment		*Insulating suit*		*Cooling hood*		*Insulating hood*		*Total*	
	kg	*lb*	*kg*	*lb*	*kg*	*lb*	*kg*	*lb*	*kg*	*lb*
Weight, dry	4.41	9.72	0.80	1.61	0.25	0.55	0.31	0.68	5.77	12.56
Weight, wet	4.88	10.77	–	–	0.30	0.66	–	–	6.29	19.33

and inlet temperatures of each pad was measured by thermopiles consisting of five 30-gage copper-constantan thermocouples. The temperatures were continuously recorded on a recording potentiometer. Water flow rates through each of the regions were measured by a rotameter. Figure 18.1 shows a schematic diagram of the cooling pads and the control, supply, and measuring systems.

Over the underwear garment, the subjects wore an insulating suit that thermally isolated them from the environment. A heavily furred hood was used for the same purpose on the head. All test subjects wore tennis shoes.

An A.R. Young treadmill was used for the walking sessions. The speed of the belt was controlled to correspond to the desired level of activity and was timed with a stop watch.

For metabolic measurements, expired air samples were taken with metalized Douglass bags (ref. 4). The bags were placed inside a tightly sealed Plexiglas chamber that was under a vacuum of about 5 mmHg (ref. 5). One-minute sampling was used. Air volumetric flow rates were measured by means of a Parkinson–Cowan dry gas meter. Inlet and outlet air temperatures were measured by two

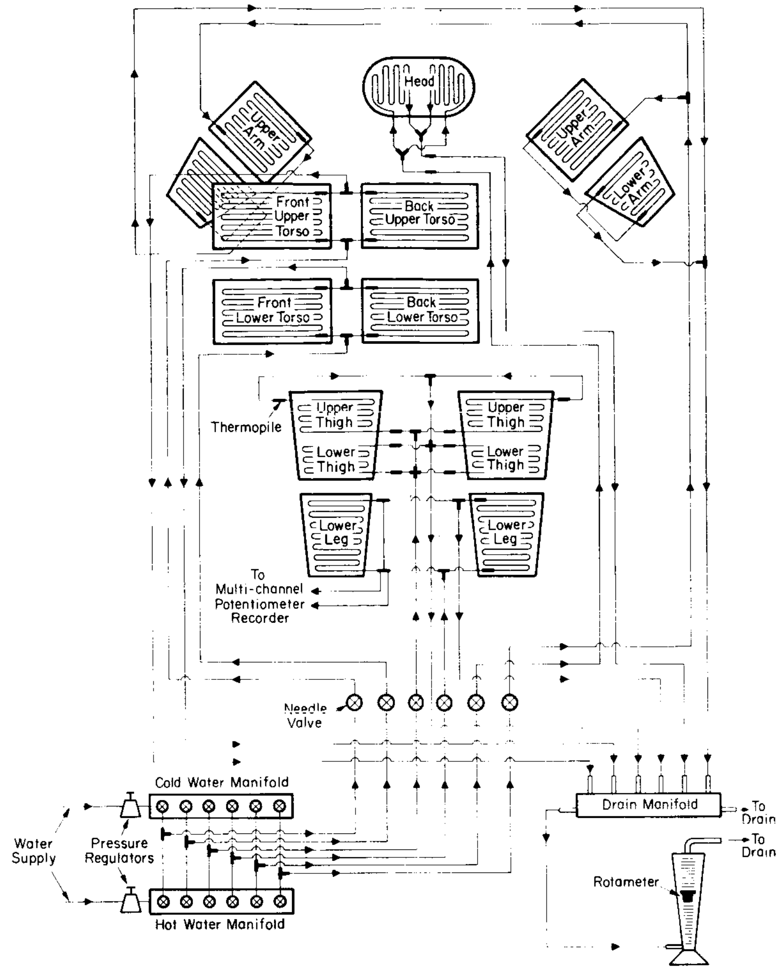

Figure 18.1 *The cooling garment and the control, supply, and measuring systems.*

interchangeable, multipurpose No. 401 Yellow Springs Co. thermistors and a Tele-Thermometer. Air samples were analyzed for carbon dioxide and oxygen content. A Godard-Mijnhardt carbon dioxide thermal conductivity meter, Pulmo Analysor Type 44-A-2 and a Beckmann Paramagnetic oxygen analyzer, Model C2, were used. These data were used to evaluate energy expenditure (refs. 6,7).

The temperature of the ear canal was taken as a measure of deep body temperature. For this purpose a No. 510 Yellow Springs Co. ear thermistor was inserted approximately 1/2 in. into the ear canal and was held in place by a specially prepared ear plug made of medical grade silicone rubber. The outside ear was covered by a piece of polyurethane foam to exclude possible effects of the cooling tubes. Measurement of the temperature of the ear canal rather than the more commonly used rectal temperature was more convenient for walking, and it gave a closer indication of the hypothalamic temperature regulated by the body. Figure 18.2 shows a general view of the setup with a test subject dressed in the cooling and insulating suits, but without shoes, walking on the treadmill.

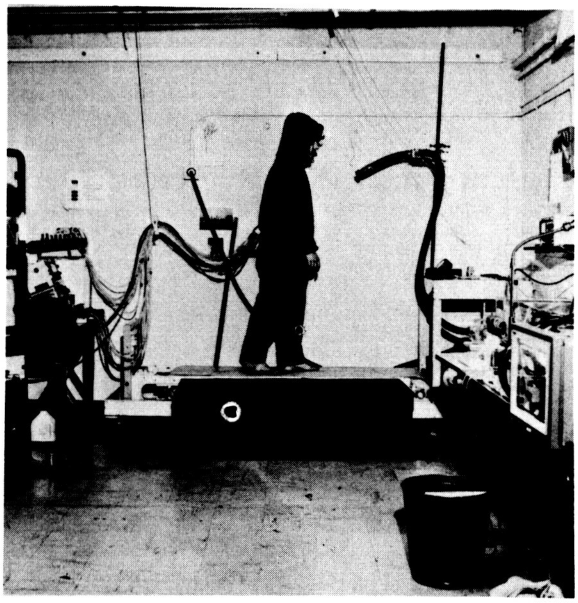

Figure 18.2 *The experimental setup. A test subject is shown dressed in the complete cooling suit walking on the treadmill. He wears no tennis shoes here and the ear canal thermistor is not connected.*

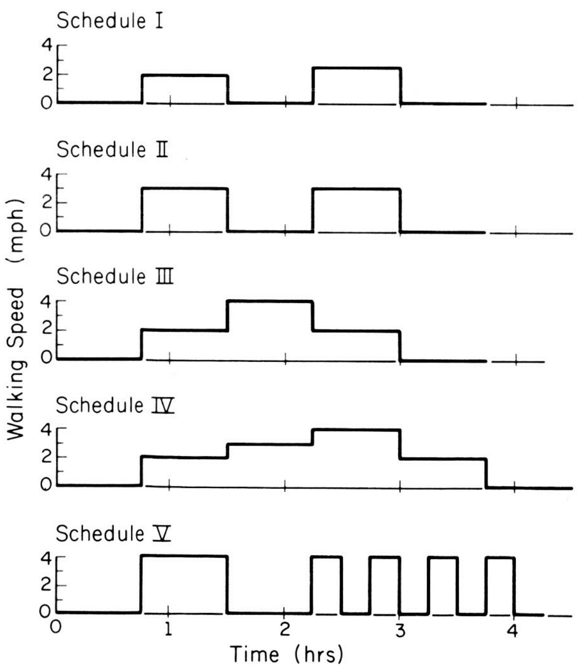

Figure 18.3 *Activity schedule used for the experiments with the cooling suit.*

A Buffalo special physiological beam scale was used to determine weight losses during the experiments. The sensitivity of this scale was estimated at ±0.25g.

EXPERIMENTS WITH THE COOLING SUIT

Activity Schedules

Five different activity schedules were used for all test subjects. The schedules consisted of alternate periods of standing and level walking on the treadmill with or without the cooling suit. The various levels of activity were chosen to cover a variety of different activity loads. The steady state and, to some extent, transient characteristics of the cooling suit were studied under those conditions. Each of the schedules started with the subject standing still for at least 45 min. During this period water inlet temperatures were adjusted to correspond to the subject's own sense of comfort. The duration of each of the standing and walking sessions (except the second part of Schedule V) was 45 min. It was assumed that after 45 min from the onset of a new activity level the subjects reached a thermal quasisteady state.[2] Figure 18.3 illustrates the details of the five activity schedules.

Schedule I, with the lowest activity levels, consisted of four step changes: standing, walking at 2 mph, standing, walking at 2.5 mph, and standing. Once the subject's comfort was achieved while standing, no deliberate changes were made in water inlet temperatures; although small changes did occur because of the instability of the water supply system. The purpose was to test the cooling capacity of the suit at higher metabolic rates while operating at the temperature levels that were considered comfortable at the lower metabolic rate.

Schedule II was designed to compare the effect of changing the water inlet temperature at the same activity level. It consisted of two identical, periodic step changes: standing,

[2]Quasisteady state was defined as the state when no significant changes in the difference between outlet and inlet water temperatures were noticeable.

walking at 3 mph, standing, again walking at 3 mph, and standing. During the first walking session no adjustments in water inlet temperatures were permitted. During the second cycle, however, the water temperatures were adjusted to correspond to the subject's comfort.

Schedule III consisted of four step changes: standing, walking at 2 mph, walking at 4 mph, walking at 2 mph, and standing. The purpose of this schedule of activities was to study the characteristics of the suit at moderately high activity levels (approximately 1650 Btu/hr, 480 W). The intermediate 2 mph walking sessions were used to allow a gradual change to the high activity level and condition the subjects for the relatively high speed that was also included in the last two schedules. Adjustments of water inlet temperatures were permitted throughout the entire duration of the experiment.

Schedule IV was almost identical to Schedule III, but it included an additional walking session at 3 mph immediately preceding the 4 mph walking period. This was done to study the effect of a more gradual change in activity levels.

Schedule V was used to examine the performance of the suit with a direct step change from standing to the moderately high activity level and determine the characteristics of the suit with thermal transients produced by identically repeated activity levels. This schedule consisted of standing, walking at 4 mph, and standing followed by four short, identical, periodic sessions of walking at 4 mph and standing. The duration of each of the short walking and standing sessions was 15 min. Readjustments in water inlet temperatures were permitted throughout this entire schedule.

Test Subjects

Five male students, aged 18 to 29 years, served as test subjects. They represented a variety of physical fitnesses from poor to athletic. The physical characteristics of the test subjects are summarized in table 18.2. Surface areas were determined from the Dubois height/weight formula. All but one subject completed all five experiments. One did not complete Schedule V because of a cramped thigh muscle.

Table 18.2 *Characteristics of the test subjects.*

Subject	*Age*	*Height*		*Weight*		*Surface area*		*Percent area covered by cooling pads*
		cm	*in*	*kg*	*lb*	m^2	ft^2	
A. SGP	20	173	68	65.7	144.8	1.78	19.2	48.8
B. SKB	22	170	67	61.1	134.7	1.71	18.4	50.8
C. HNT	27	170	67	64.2	141.5	1.74	18.7	50.0
D. RET	18	169	66.5	64.2	141.5	1.74	18.7	50.0
E. PF	29	161	63.5	55.8	123.0	1.58	17.0	55.0
Means	23.2	169	66.4	62.2	137.1	1.71	18.4	50.9

Experimental Procedure

All experiments were performed at the Laboratory for Ergonomics Research, University of Illinois at Urbana–Champaign. This laboratory is air conditioned at about 73° F (23° C) and 60 percent relative humidity. A total of 29 experiments were run of which 24 were performed with the cooling suit. Five comparison runs were performed by subject SKB repeating the regular activity schedules without the suit. During these comparison runs the subject wore tennis shoes, shorts, and a light T-shirt. All subjects started with Schedule I and, in order, completed the other schedules. They were permitted to listen to the radio and read while standing; but no eating, drinking, or smoking was allowed during the experiments.

At the beginning and end of each experiment the subjects were weighed, and their oral temperature and blood pressure was taken. The last two measurements were taken only as precautionary measures against any acute effects of the experiment on the subject. During the experiments the following data were collected: ear canal temperature, water inlet temperatures, differences between water outlet and inlet temperatures at each of the six regions of the body, water flow rates, respiratory volumetric rates, and temperature of the expired air. During Schedule V and the runs without the suit, pulse rates were also taken. All measurements were taken at the end of each activity in the schedule and were assumed to represent the quasisteady state.

After the preliminary measurements the subject donned the cooling garment. Then the thermally insulating suit was put over the cooling garment. Next the ear thermistor was inserted into the ear and was covered by thermal insulation. Finally the water flow and all measuring systems were started. Figures 18.4 and 18.2 show one of the subjects in various stages of dressing.

During the first standing period the water inlet temperatures were adjusted to conform to the subject's sense of comfort. After 45 min, when a thermal quasisteady state was reached, the subject started to walk on the treadmill. Subsequent activities were as described before.

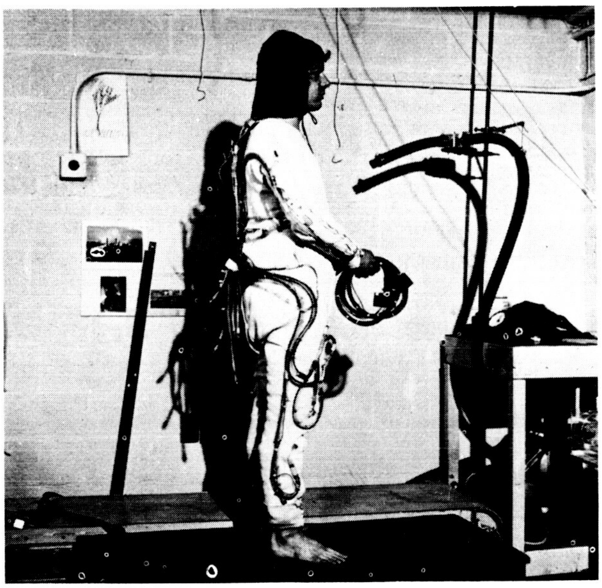

Figure 18.4 *The cooling garment.*

Measured, Recorded, and Calculated Quantities

The following quantities were measured, recorded, or calculated from measured data.

1. Total metabolic rate was calculated from volumetric flow rate of the expired air and the carbon dioxide content obtained from the gas analysis. The caloric value of oxygen was assumed at 5.0 kcal/liter (ref. 6). Although slightly high, this value conformed well with the respiratory quotients found in most of the runs. Maximum deviation from the actual caloric value was estimated to be about 4 percent.
2. Rate of heat removed by the suit in each region was taken as the product of the difference between water outlet and inlet temperatures, specific heat and mass flow rate of the cooling water.

3. Rate of heat lost by respiration was calculated from the flow rate, temperature, and enthalpy of the expired air, assuming it to be saturated.
4. Weight loss during the experiment was the difference between the initial and final weights of the subject.
5. Ear canal temperature was measured with an ear thermistor, as discussed before.
6. Water inlet temperatures to each region were measured with thermistors in the water streams.
7. Order of preferred changes in water inlet temperatures to the different regions was recorded for the purposes of identifying those zones of the body that require such changes and establishing this order as a function of activity level.
8. Comfort vote was based on the subject's own evaluation of three choices: slightly cold, comfortable, slightly warm.
9. Pulse rate was measured only during Schedule V and the comparison runs without the suit. The pulse rate was assumed to be an index of the metabolic and cardiac costs of physical work. Pulse rate was not taken during the other schedules because they were considered to represent quasisteady states.

DISCUSSION

Most of the results were averaged for all subjects and are presented in this form. Wherever feasible, entire ranges of individual variations are also shown.

Figure 18.5 shows mean values of metabolic rates and of the heat removed by the suit and by respiration during Schedule II. These results are typical for all schedules. Also shown are the ranges of metabolic rates included in the mean values. It is seen that during the standing sessions most of the heat produced in the body was removed by the cooling suit. In many cases the heat removed by the suit even exceeded slightly the total metabolic rate. This phenomenon is believed to be due to possible thermal transients indicated by a decrease of "deep body" temperature following a change in activity from walking to standing (fig. 18.6) and also to cumulative measurement errors.

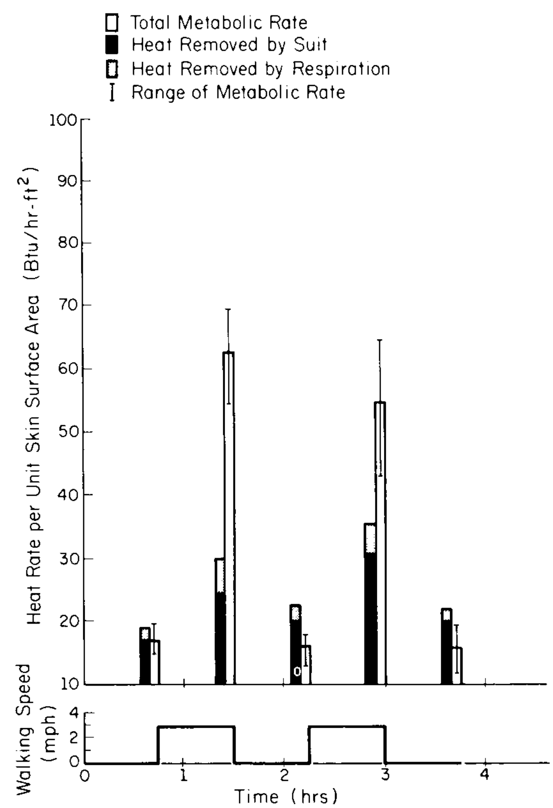

Figure 18.5 *Mean values of metabolic rates and of the amounts of heat removed by the cooling suit and by respiration for Schedule II.*

During all of the walking sessions the relative amount of heat removed by the suit dropped significantly. At best it was only about 70 percent of the total metabolic rate; but it was usually closer to 50 percent. Possible reasons to account for the portion of the total metabolic rate that was not removed by the cooling suit follow.

1. Thermal transients with heat still being stored inside the body were indicated by an increase in "deep body" temperature (fig. 18.6)
2. Heat dissipated to the environment from the uncovered surfaces (e.g., face, forehead, and hands)
3. Heat removed by respiration

4. Heat removed by perspiration evaporated by the air that was pumped under the somewhat loose insulating suit by movement of the subject
5. Work done by the muscles
6. Heat lost to the environment through the clothing
7. Measurement errors and inaccuracies

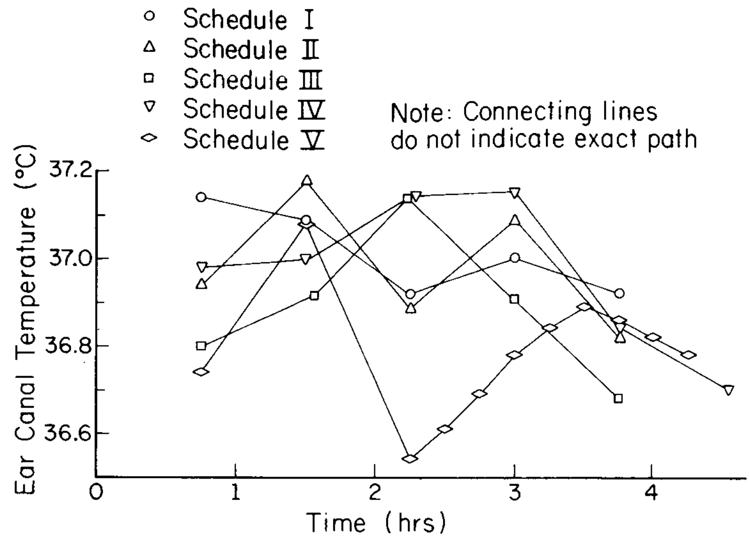

Figure 18.6 *Average ear canal temperatures for the various schedules.*

Among these, only the contribution of item 3 (i.e., respiration) was estimated. This alone amounted from 7.3 to 14.8 percent of the total metabolic rate. These values are consistent with those reported by Bazett (ref. 8). With the increase in metabolic rate the amount of heat carried away by respiration also increased. However, the relative amount of heat removed by the exhaled air decreased. The remaining, unaccounted for portion of the metabolic rate was assumed to have been removed by the other means mentioned above.

From the comfort standpoint, the cooling system was found to be insufficient to accommodate metabolic rates in excess of about 1200 Btu/hr (350 W). The subjects felt consistently too warm at the moderately high activity levels. This insufficiency was due primarily to two reasons: too small a contact area between the skin and the cooling tubes, and too high water inlet temperatures. The actual contact area was estimated to be about 10 percent of the total skin surface area. The lowest water inlet temperature obtained in most of the experiments was about 61° F (16° C). Increasing the contact area between the skin and the cooling tubes or lowering the water inlet temperatures or both would improve the cooling capacity of the suit. This conclusion is supported by the results obtained by Webb and Annis (ref. 9). They estimated that 22 percent of the total skin surface area was in contact with the cooling tubes in their experiments. All of their subjects were reported to have been comfortable with the lowest water inlet temperature of 61° F (16° C) and high metabolic rates of 2400 Btu/hr (700 W) for 2 hours.

During the second part of the experiments in Schedule V, no quasisteady state was ever reached. This finding was true for the metabolic rates and amounts of heat removed by the cooling suit as well as for the heart rates and ear canal temperatures (fig. 18.7). These quantities show a clear trend of increase with time, at least during the 2 hours of the short 15-min alternate changes in levels of activity. The amount of heat removed by respiration, however, seems to have reached a quasisteady state within 15 min from the onset of a change in exercise level. This result indicates that the transient time of the respiratory system is much shorter than that of the thermal system of the human body within the investigated range.

During the second part of Schedule V, heart rates not only showed a trend to increase with time, but also exceeded the values found in the first part (fig. 18.6). This observation indicates possibly a fatigue effect that was supported by the feelings of all subjects. It is also indicative of a lack of steady state.

During the experiments of Schedules III, IV, and V, the effects of gradual and abrupt step changes from standing to walking at 4 mph were considered. No significant differences were found in total metabolic rates and amounts of heat removed by the cooling suit. Of these two quantities, only the cooling effectiveness, the fraction of the total metabolic heat removed by the suit, seemed to have changed during Schedule IV. This result may mean that during Schedule IV the thermal steady state of the moderately high activity level was more nearly attained because of the two intermediate step changes preceding it. However, there were differences in the temperature of the ear canal. It was lower by about 0.5° C when a step change from standing to walking at 4 mph was introduced without any intermediate changes (fig. 18.6). There were no major differences between the temperatures of the ear canal measured during Schedules III and IV that involved gradual changes. This observation may indicate that the transient time until a complete thermal steady state is reached in the human body is longer than 45 min and is more likely to be of the order of 2 hours.

Figures 18.8 through 18.12 show the relative amounts of heat removed by the suit at the various regions of the body during the different schedules of activity. Based on these data, the following observations were made.

1. The relative amount of heat removed from the arms was the lowest in most cases. It ranged from 1.7 to 7.2 percent of the total heat removed by the suit and was usually around 3 to 4 percent. This occurred despite the fact that the arm pads covered about 18 percent of the total skin surface area covered by the suit. This finding can be attributed, in part, to the nature of the activities used in

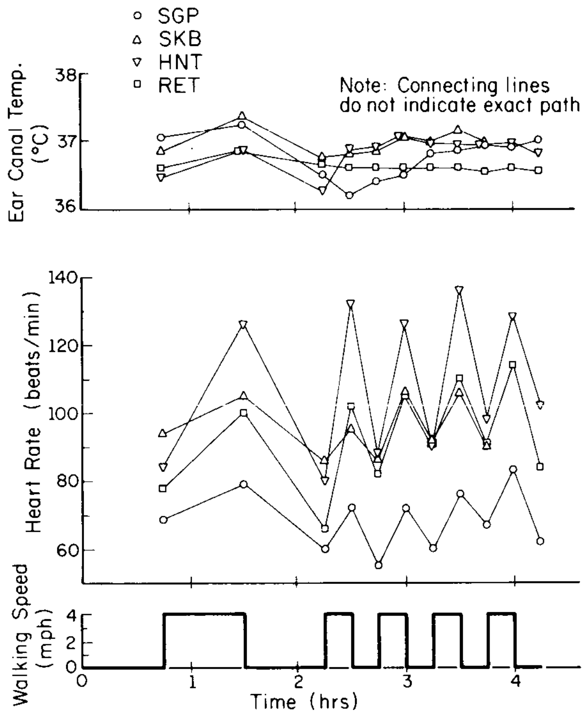

Figure 18.7 *Individual variations in ear canal temperatures and heart rates for Schedule V.*

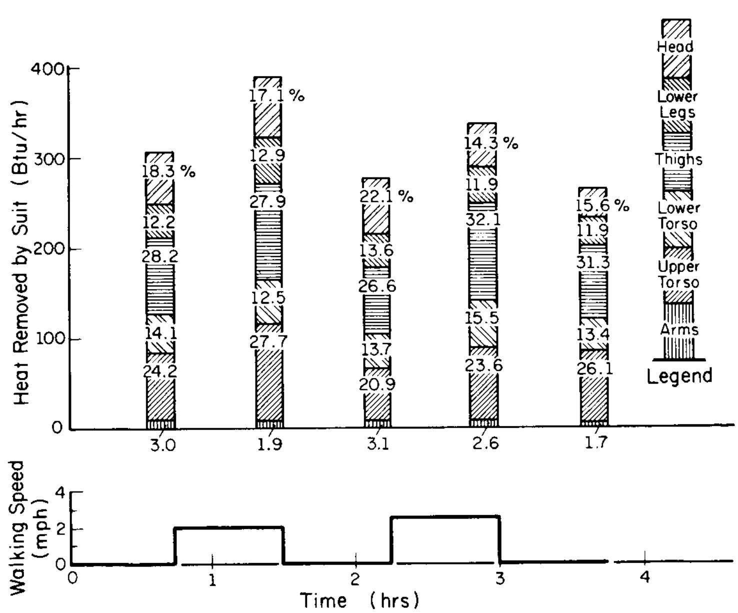

Figure 18.8 *Mean values of the amounts of heat removed by the cooling pads for Schedule I.*

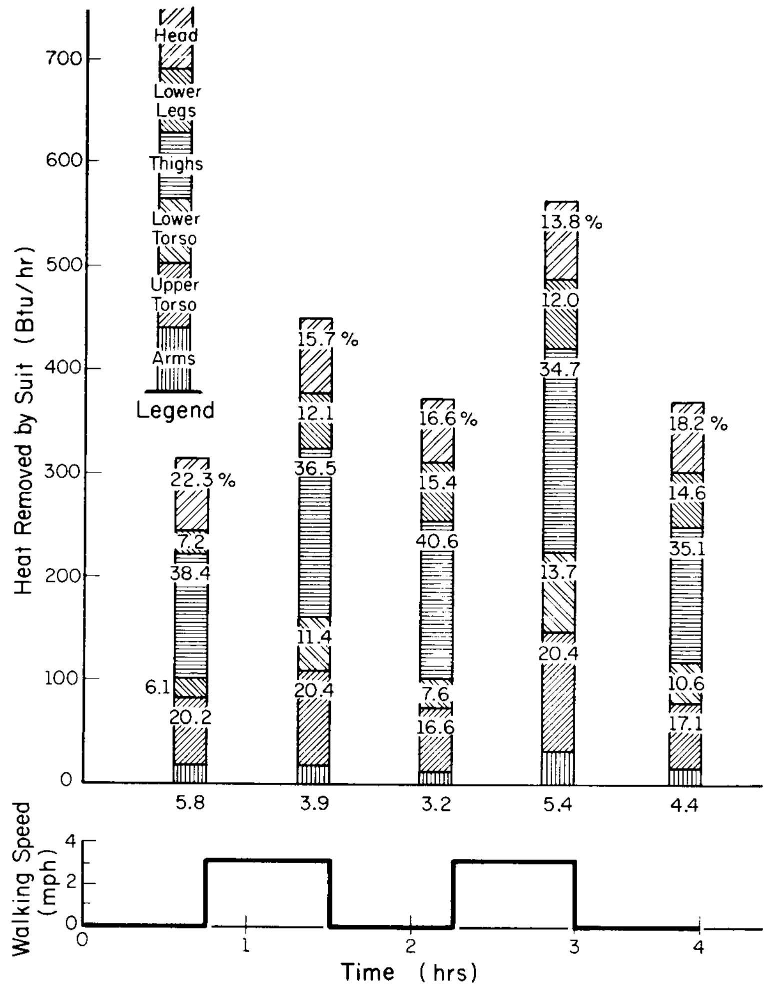

Figure 18.9 *Mean values of the amounts of heat removed by the cooling pads for Schedule II.*

this study; these were composed primarily of work of the leg muscles and did not involve much arm work. This assumption is supported by the fact that the relative value of the heat removed at the arms increased during the walking sessions when the subjects were swinging their arms.

2. The largest amount of heat removed by the suit from a single region came from the thighs. It ranged from a low of 25.8 percent, while standing, to a high of 41.7 percent, while walking at 3 mph, of the total heat removed by the suit. As the metabolic rate exceeded the upper limit that could be accommodated by the suit, the relative amount of heat removed from the thighs decreased. Because of the limits imposed by the minimum water inlet temperature and the contact area between the skin of the thighs and the cooling tubes, heat was probably carried away from the thighs by the blood stream to be dissipated elsewhere. Also the "deep body" temperature increased and sweating was enhanced, as indicated by higher weight losses.

3. A relatively high percentage of the total heat removed by the suit came from the head, which constituted only about 7 percent of the total surface area. It ranged from 10.3 to 36.9 percent. The highest values were obtained during the second part of Schedule V (fig. 18.12). Thus

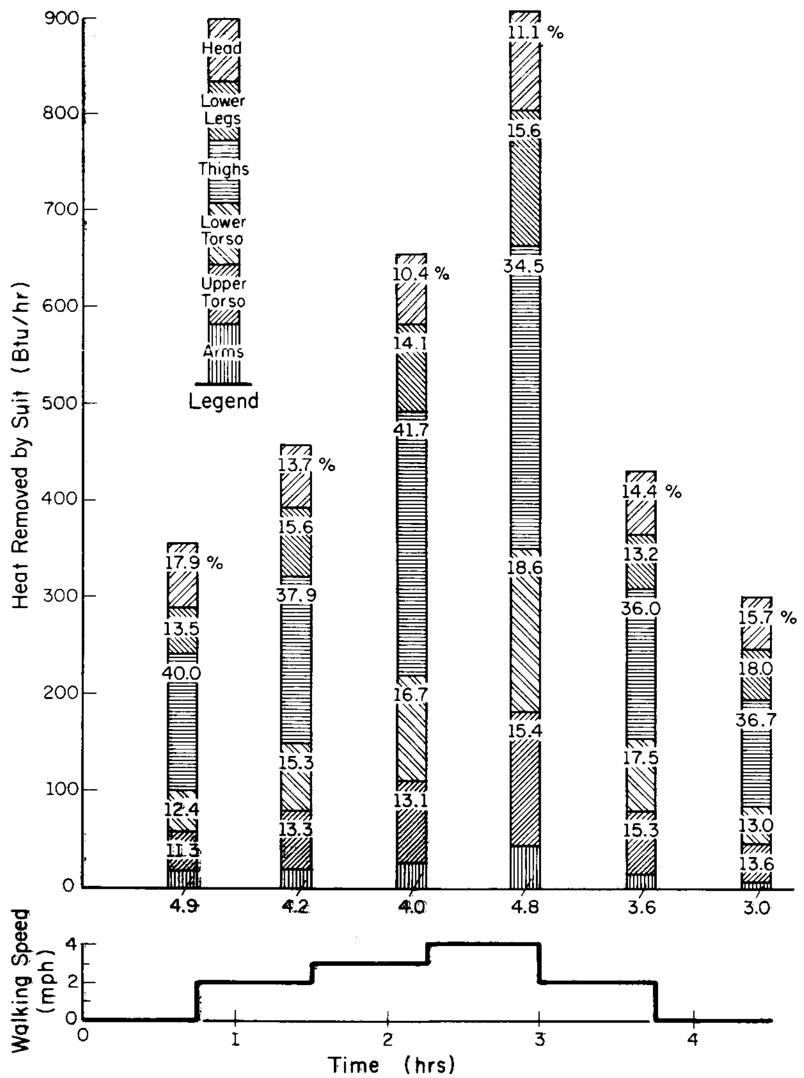

Figure 18.10 *Mean values of the amounts of heat removed by the cooling pads for Schedule III.*

thermal transients seem to enhance heat removal from the head. According to Nunneley (ref. 10), up to 40 percent of the total metabolic rate was removed from the head during resting and steady states by a cap with cooling tubes. Nunneley however, did not use a cooling suit along with the cap. Shvartz (ref. 11), in a study with a cooling suit that included a cooling hood, found that during steady states the hood removed about 40 percent of the total removed by the cooling suit assembly. However, 12 percent of the total surface area was covered by the hood in his studies as compared to only about 5 percent in the present study.

4. During Schedule I more heat was removed by the cooling suit during the first walking session at 2 mph than during the second at 2.5 mph (fig. 16.8). The reason was the unexpected drop in "deep body" temperature as indicated in figure 18.6 by the temperature of the ear canal. Since no readjustments in water inlet temperatures were permitted during these experiments,

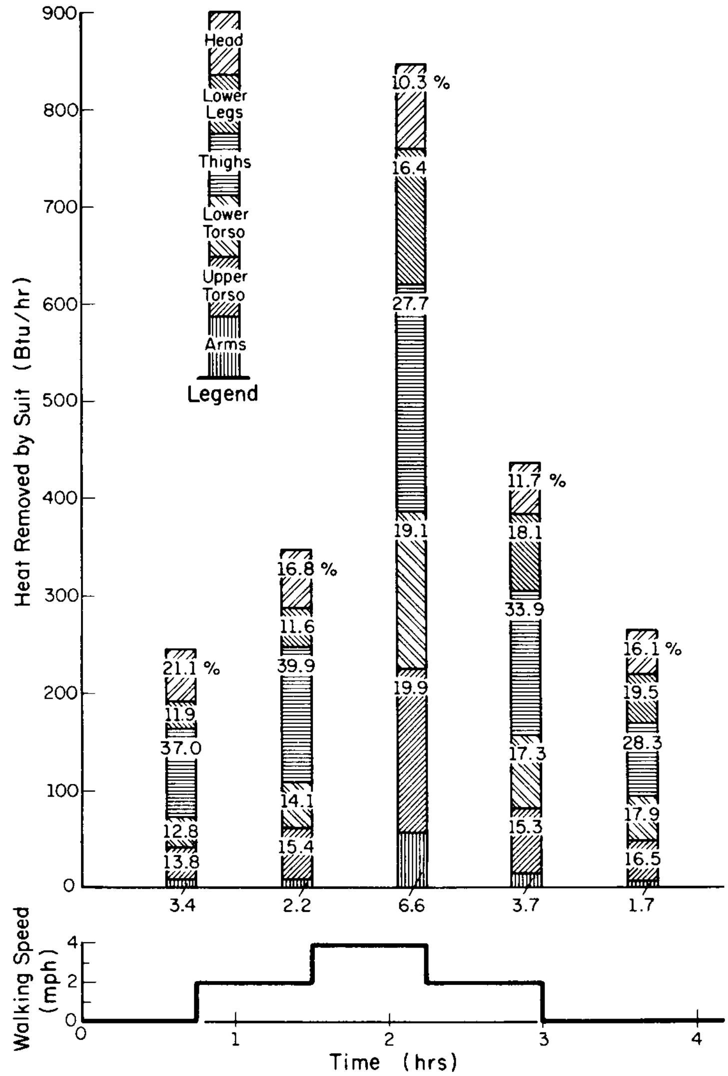

Figure 18.11 *Mean values of the amounts of heat removed by the cooling pads for Schedule IV.*

this phenomenon of less heat removed by the suit at a higher metabolic rate is not considered to have any physiological meaning.

5. During Schedule II, readjustments of the water inlet temperatures at the same level of activity caused the following changes.

   The total metabolic rate decreased (fig. 18.5)

   The amount of heat removed by the cooling suit increased (fig. 18.9)

   The temperature of the ear canal dropped (fig. 18.6)

   Consequently, the cooling effectiveness of the suit increased from 0.39 to 0.56. Also, adjustments of the water inlet temperatures actually diminished the subject's heat strain.[3] This

[3] Heat strain is often referred to as the physiological response in consequence of a heat load (ref. 12). It should be distinguished from the heat stress used to denote the heat load imposed on man (ref. 12). A commonly used index to assess physiological strain was developed by Craig (ref. 13) and modified by others (ref. 14). It is a linear combination of heart rate, rise in rectal temperature, and sweat production rate.

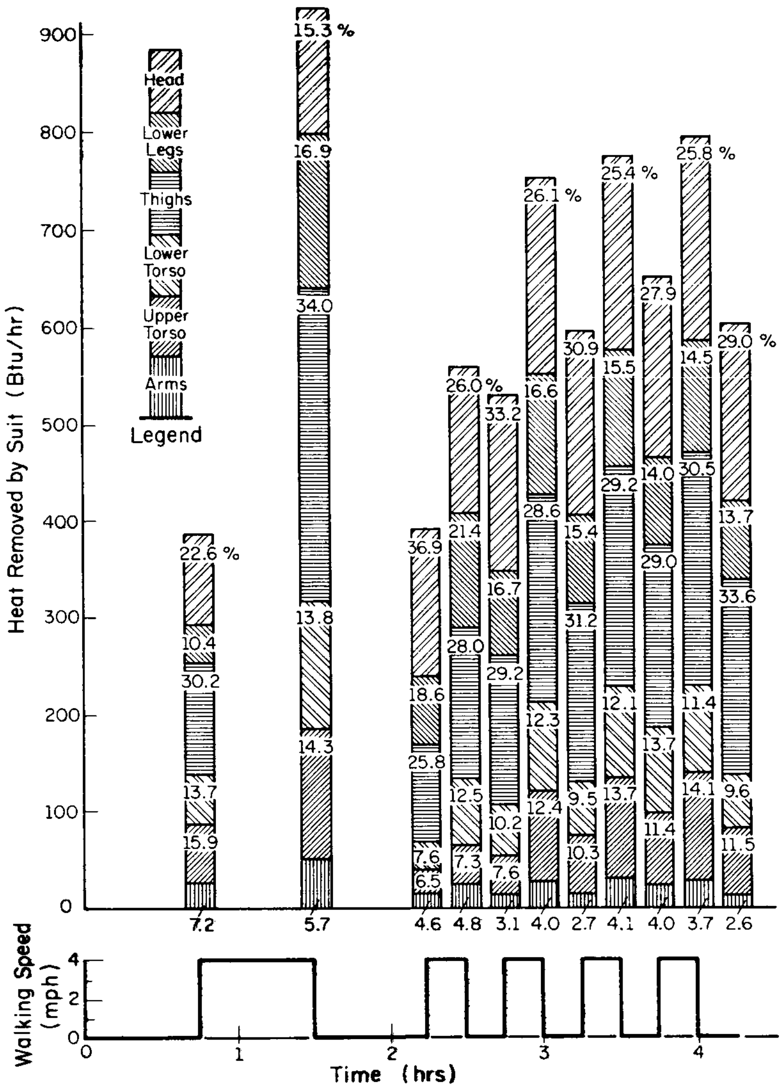

Figure 18.12 *Mean values of the amounts of heat removed by the cooling pads for Schedule V.*

reduction of heat strain occurred even though a consistent comfort vote of "comfortable" was obtained through the entire Schedule II. These findings indicate that additional cooling provided by some artificial means, such as a cooling suit, may reduce the heat strain beyond that considered comfortable by human subjects. A similar conclusion was also reached by Gold and Zornitzer (ref. 15).

Figure 18.13 shows the average water inlet temperatures at the various regions of the body for Schedule II. This schedule was selected for comparative presentation because (1) the effect of additional cooling at the same level of activity was studied during these experiments, and (2) the metabolic rates encountered during this schedule never exceeded the cooling capacity of the suit.

During the initial standing session most of the subjects preferred an almost uniform temperature over the entire body (fig. 18.13(a)). This situation did not change during the first walking session where no additional cooling was permitted (fig. 18.13(b)). Immediately following the first walking session, the restriction on additional cooling was removed. A decrease in most water inlet temperatures was requested by all subjects (fig. 18.13(c)). The average changes requested were 1.2 to 1.3° C for the arms and thighs and 0.2 to 0.6° C for the head and upper and lower torso. The highest decrease in water inlet temperature, 2.3° C, was requested for the lower legs. During the second walking session at 3 mph (fig. 18.13(d)) the requests for decreases in water inlet temperatures were arms, upper torso, and thighs 3.4 to 3.8° C, head 1.4° C, and lower torso 2.5° C. The highest decrease, 4.7° C, was for the lower legs. During the last standing period the requested changes in water inlet temperatures were such that they essentially reproduced the situation that prevailed during the second standing session with only minor differences (fig. 18.13(e)).

As a consequence of the results presented in the preceding section, the following observations were made.

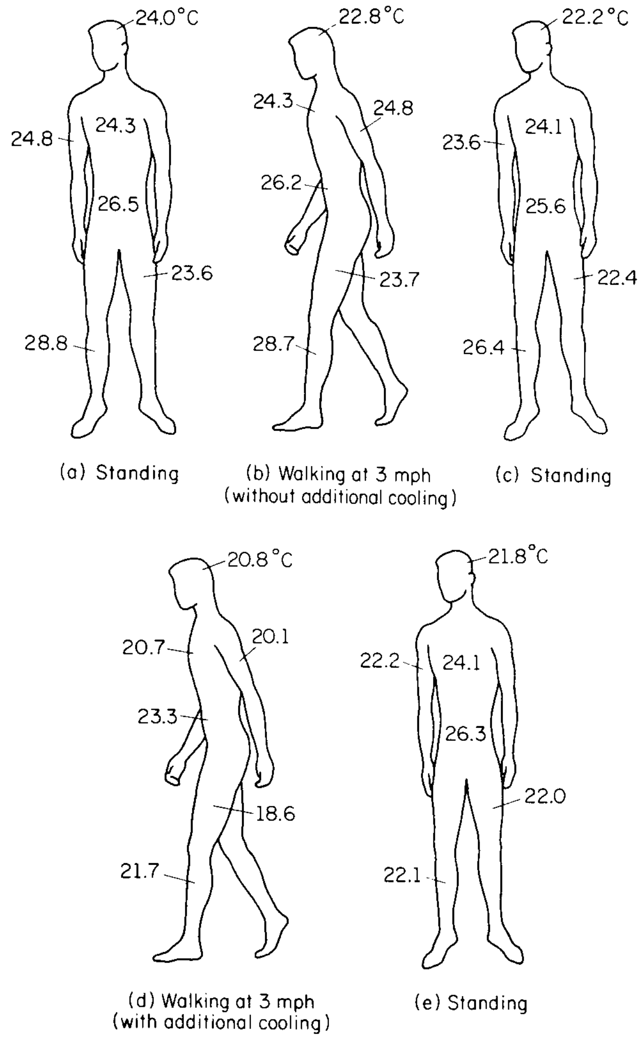

Figure 18.13 *Mean water inlet temperatures at the various regions of the body for Schedule II.*

1. The working muscle (i.e., thighs and lower legs) exhibited the highest variability in water inlet temperatures, as expected.
2. While the changes in water inlet temperatures to the head were the smallest, they were also, on the average, starting from the lowest temperature level among all the water inlet temperatures. Thus, cooling the head seems to have a profound effect on the sensation of comfort, as noted also by Nunneley (ref. 10) and Shvartz (ref. 11).

There did not seem to be any consistency in the order of changes requested in water inlet temperatures by different subjects. Many more experiments with more subjects are needed to identify those regions in the body that require faster cooling or warming as a result of a change in the level of activity (ref. 7).

The mean values of weight losses ranged from 65 gm/hr in Schedule I to 118 gm/hr in Schedules III and IV. These values, although slightly higher, are consistent with those reported by Webb and Annis (ref. 9). In four out of five cases the heat rates were higher during the runs without the suit as compared to the runs with the suit. No fundamental explanation was found for the exception, Schedule III; it may have been due to a measurement error.

Examining the results of the comparative experiments with and without the cooling suit reveals that the total metabolic rate was generally higher during the experiments with the suit. This finding is probably due to the fact that there was a certain energy cost in wearing the suit. At the same time, the temperature of the car canal seemed to have been only slightly lower during the experiments without the suit. Also (fig. 18.14) the heart rate was usually lower during at least the comparative experiments of Schedule V with the suit. The lower heart rates with only slightly higher "deep body" temperatures seem to indicate reduced heat strain during the experiments with the cooling suit.

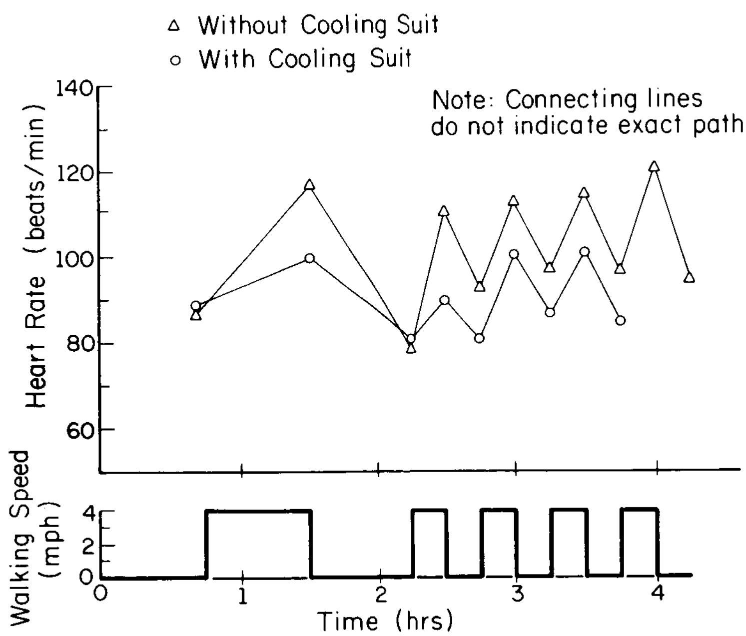

Figure 18.14 *Heart rates of the test subject during the comparative experiments with and without the cooling suit for Schedule V.*

The large amount of data gathered was reported in detail in reference 7, and was not repeated here except as needed.

SUMMARY AND CONCLUSIONS

A water cooled garment was constructed and used to study the characteristics of independent regional cooling of the body in contrast to the current practice of uniform cooling. The cooling pads in the garment were grouped to provide independent control of water inlet temperatures and flow rates to six regions: head, upper torso, lower torso, arms, thighs, and lower legs. Experiments with and without the cooling suit were conducted with five test subjects standing and walking on a treadmill on selected schedules. Steady state and, to a lesser extent, transient characteristics were obtained.

Based on the experiments with the cooling suit, the following conclusions were reached.

1. Some regions of the body require more cooling during walking than others (e.g., thighs, head, and lower legs).
2. During standing an almost uniform water inlet temperature was requested for all regions of the body by the subjects but the situation changed significantly during exercise. Conclusions 1 and 2 indicate that independent regional cooling may be more effective than the present scheme of uniform cooling.
3. Cooling of the head during exercise affects comfort profoundly.
4. Transient times for reaching a thermal steady state from the onset of a new exercise level are of the order of two hours. This transient time, however, includes a relatively slow, active response of the human thermoregulatory system to changes in exercise rate (i.e., the shifting of the deep body temperature).
5. During exercise the thermal effectiveness of the cooling suit decreased as compared to the values obtained for standing.
6. Intermediate changes in the level of activity between an initial and final level do not have a noticeable effect on the thermal state so long as sufficient time is allowed for reaching a steady state corresponding to the final level of activity.
7. The cooling suit seemed to actually diminish the heat strain of the test subjects beyond what was considered comfortable by them.
8. No regional order of preferred changes in water inlet temperatures could be determined. More experiments are required to determine if there are regions of the body that require faster cooling or warming than others.

Based on the comparative experiments with and without the cooling suit, the following observations were made.

1. Metabolic rates were, in most cases, higher during the experiments with the cooling suit, indicating that additional energy cost was associated with wearing the suit.
2. Ear canal temperatures were usually slightly lower during the experiments without the cooling suit.
3. Heart rates were lower during the experiments with the cooling suit.
4. Weight losses were usually lower during the experiments with the suit.

Thus, the cooling suit seems to have reduced the heat strain even though the heat stress was increased slightly.

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