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AN EVALUATION OF THE AIR VENTILATED SUIT FOR USE BY CH-124 FLIGHT CREWS

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AN EVALUATION OF THE AIR VENTILATED SUIT FOR USE BY CH-124 FLIGHT CREWS

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TABLE OF CONTENTS

SUMMARY

This report describes an evaluation of the Beaufort Mk2C Air Ventilated Suit worn under the Beaufort Mk10 Immersion Suit in alleviating the degree of heat stress experienced by CH-124 flight personnel. Tests were conducted in a conditioned room at temperatures of 65°F, 70°F, 75°F, 80°F and 85°F with a relative humidity of 85%. It was found that this clothing ensemble does not confer any protection from heat stress in these conditions.

LIST OF ABBREVIATIONS

The following abbreviations appear in this report.

a	amperes
AVS	Air Ventilated Suit
DB	Dry Bulb Temperature
DCIEM	Defence and Civil Institute of Environmental Medicine
hp	horsepower
hz	hertz
MBT	mean body temperature
Mk	Mark
pf	picofarad
ph	picohenry
RH	Relative Humidity
rpm	revolutions per minute
T_R	rectal temperature
$\overline{T_S}$	mean skin temperature
USAF	United States Air Force
v	volt
WB	Wet Bulb Temperature
WBGT	Wet Bulb Globe Temperature
^oC	degrees Centigrade
^oF	degrees Fahrenheit
ΔMBT	change in mean body temperature
ΔT_R	change in rectal temperature
$\Delta \overline{T_S}$	change in mean skin temperature

AN EVALUATION OF THE AIR VENTILATED SUIT FOR USE BY CH-124 FLIGHT CREWS

INTRODUCTION

Background

During operations in the spring and fall, CH-124 flight crews are subject to serious discomfort from heat stress as a result of relatively high ambient air temperatures and the wearing of unventilated Mk.10 immersion suits over their thermal underwear. This clothing ensemble is required to ensure the safety of a crew member if immersed accidentally in the relatively cold sea water over which many of the operations are conducted. It is worn for the entire duration of the flight which may last up to 4.5 hours.

It has been suggested that the use of an air ventilated coverall worn under the immersion suit would alleviate the heat load sustained by the CH-124 flight crews (1) and the Defence and Civil Institute of Environmental Medicine was requested (1, 2) to investigate the feasibility of this suggestion. The effectiveness of the MK2C air ventilated suit when worn under a Mk 10 immersion suit in reducing heat stress in subjects was examined at temperatures of 65, 70, 75, 80 and 85°F and humidity of 85% RH and the results are presented in this report.

METHOD

Equipment Under Test

The immersion suit used in this study was a Beaufort Immersion Suit Mk 10 and the air ventilated coverall used was a Beaufort Air Ventilated Suit Mk 2C. The latter was connected to a CH-124 blower motor (a 400 hz AC motor, serial PN938D7431, 0.12 hp, 0.6a, 0.7 pf, 200 v, 23000 rpm, 3 ph, continuous duty) via a USAF PT345 connector with an infinitely variable manual flow control.

General Methodology

The experiments were conducted in the Tropical Room at DCIEM during the months of October and November, 1972. Three healthy male Caucasian volunteers in the age range of 20 to 45 years and height range of 5'6" to 5'11" were used as subjects. Two subjects were examined simultaneously in each experimental session. In the control condition the (control) clothing worn was as follows:

(a) light underwear and wool socks,
(b) unventilated Mk 10 immersion suit,
(c) immersion socks,
(d) flying gloves,
(e) type 411 helmet,
(f) Bauer Mk 2 life jacket, and
(g) dingy back pack.

In the experimental conditions the control clothing was worn plus an air ventilated suit (AVS) over the underwear and under the immersion suit. The AVS hose was passed through the chest opening which was closed tightly by the waterproof sliding fastener. The AVS hose then protruded from the left side of the subject. Such an arrangement was practically air tight but not water tight. With the following exceptions, the subjects were equipped in the same manner as typical CH-124 flight personnel. Originally it was intended that the subjects wear thermal underwear (string vest and underpants) but since these items could not be obtained the subjects wore light underclothing. It was also intended that the subjects wear flying boots over their immersion socks but this procedure was abandoned after the first experiment due to pain caused by the tight fit of the boots on the immersion socks. Immersion boots were not available for this study.

Subjects were tested in pairs, one wearing the control ensemble and the other wearing the experimental ensemble. Each of the pair was tested twice, once with each ensemble. The experimental sessions were held in five ambient room temperatures and consequently there were 2 x 5 or 10 experimental sessions*.

Both subjects were seated and strapped in ejection seats (facsimiles of the CH-124 seats) with shoulder harnesses and lap belts for a period of 3.5 hours. The subject wearing the AVS connected the AVS hose with a short corrugated rubber hose to the blower motor located on the floor near the left side of his seat. In every session the flow control of the hose-blower

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* The same two subjects were employed for the first eight sessions. One was then no longer available and he was replaced by a third subject in the last two sessions.

connector was kept maximally open in order to determine the maximum effectiveness of the AVS. The air supply to the blower motor was taken from the ambient air in the Tropical Room.

The blower motor itself received its power supply from an RCAF 5P/44 Metallic Power Supply (Type TS 376CB).

The protocol for each test was as follows:

(a) At 0730 hours the subjects were weighed nude. Skin thermistors and ECG leads were then fixed to the subjects. After donning the experimental attire they were reweighed. Sensor leads were passed out of the clothing ensemble via the chest opening.

(b) The subjects then entered the Tropical Room and were quickly seated and strapped into the ejection seats. The skin thermistors and ECG leads were then connected to recorders. At approximately 0800 hours the experimental measurements began and the blower in the AVS system was activated.

(c) During the session the subjects were permitted to talk, read or play cards (made possible by having the two seats facing each other). An observer remained with the subjects during the entire session to monitor the physical state of each subject and to terminate the experiment should conditions warrant this action. Subjects were not permitted water or beverages during the course of a session.

(d) Every 15 minutes during the experiment the heart rate, the rectal temperature and seven skin temperatures of each subject were recorded as well as the ambient air temperature and humidity of the room. The subjective feeling of thermal comfort of each subject was also recorded according to the following scale:

(1) hot
(2) warm
(3) comfortably warm
(4) comfortable
(5) comfortably cool
(6) cool

(e) At 1130 hours the session was terminated and the subjects were weighed fully equipped and then in the nude to assess the degree of water loss. By 1200 hours, subjects were free to leave the experimental area. The duration of each session was 3.5 hours, approximately the length of time of most CH-124 operational flights.

TABLE 1

ENVIRONMENTAL CONDITIONS IN THE DCIEM TROPICAL ROOM

CONDITION	DB	WB	WBGT	TIME TO 50% CASUALTIES*
1 (Mild)	65°F	62.1°F	63.0	Indefinite
2	70	66.7	67.7	"
3	75	71.6	72.6	"
4	80	76.5	77.6	"
5 (Severe)	85	81.1	82.3	"

* For lightly clothed sedentary men(3).

Instrumentation

The skin temperature of each subject was monitored throughout each experimental session at seven locations:

(a) forehead (T_1)

(b) left forearm (T_2)

(c) back of left hand (T_3)

(d) sole of left foot (T_4)

(e) left calf (T_5)

(f) left thigh (T_6)

(g) abdomen (T_7)

These temperatures were used to obtain the mean skin temperatures of each subject from the formula(4):

$$\text{Mean Skin Temperature} = \overline{T_S} = 0.07\ T_1 + 0.14\ T_2 + 0.05\ T_3 + 0.07\ T_4 + 0.13\ T_5 + 0.19\ T_6 + 0.35\ T_7$$

The probes used to obtain these temperatures were YSI series 400 thermister probes attached to the skin with adhesive electrode collars.

The rectal temperature of each subject was monitored throughout the experiment with YSI rectal probe inserted prior to the session. The eight thermister leads from each subject were connected to a YSI telethermomiter calibrated in ^{o}C. All the thermistor probes were calibrated before use. The rectal and mean skin temperatures were combined to give the mean body temperature (MBT)(14):

$$MBT = 0.67\ T_R + 0.33\ \overline{T_S}$$

where T_R is the rectal temperature.

Heart rates were recorded with a Sanborn 500 Viso-Cardiette electrocardiograph.

The wet bulb (WB) and dry bulb (DB) temperatures of the Tropical Room were monitored with a sling psychrometer concurrently with the physiological parameters. From these two temperatures, values of humidity were obtained from psychrometric charts and values of the Wet Bulb Globe Temperature (WBGT) index were calculated from the equation(5):

$$WBGT = 0.7\ WB + 0.3\ DB$$

RESULTS AND DISCUSSION

Error Analysis

The accuracy of the temperature sensors used in determining the rectal, mean body and mean skin temperatures was of the order $\pm 0.1^{o}C$. Those thermometers used to measure the wet bulb and dry bulb temperatures were accurate to $\pm 0.1^{o}F$. The weighing scale had an accuracy of $\pm \frac{1}{4}$ lb.

The calculated maximum errors in the determinations of mean skin temperature were $\pm 0.7^{o}C$ and those for the mean body temperature were $\pm 0.8^{o}C$. The maximum errors of measurement in the determinations of WBGT was $\pm 0.2^{o}F$.

Survey of Results

The results are presented in Figures 1 to 10, each figure representing all the measurements made during one experimental session. The figures are arranged in chronological order and each consists of five graphs of physiological or environmental variables plotted against the same time axis. The first graph in each figure shows the time-variation of mean skin temperatures, rectal temperatures and mean body temperatures of the two subjects. The second graph shows the heart rates of the two subjects and the third one shows their response on the subjective index of comfort. Below these are located two graphs, one showing the humidity variation and the other the variation of dry bulb temperature and WBGT index. In all figures the broken lines represent the experimental (AVS) ensemble.

Table 2 shows the average environmental conditions obtained for each experiment.

TABLE 2

AVERAGE ENVIRONMENTAL CONDITIONS IN THE AVS STUDY

Experimental Session No.	Desired Conditions			Observed Conditions		
	DB	Humidity	WBGT	DB	Humidity	WBGT
1	65.0°F	85%	63.0°F	67.4	66	62.3
2	65.0	85	63.0	67.7	63	62.1
3	70.0	85	67.7	70.8	65	65.2
4	70.0	85	67.7	70.2	72	66.1
5	75.0	85	72.6	76.0	77	72.3
6	75.0	85	72.6	74.8	81	71.8
7	80.0	85	77.6	79.8	84	77.1
8	80.0	85	77.6	81.4	84	78.8
9	85.0	85	82.3	85.3	81	82.0
10	85.0	85	82.3	86.7	85	84.0

From Table 2 and the figures it can be seen that good control was maintained over the dry bulb temperatures in the Tropical Room during these experiments but that control over the humidity was poor (presumably due to the faulty action of the room's humidity sensing apparatus). The oscillations of humidity produced corresponding oscillations in WBGT but of markedly less relative amplitude. Despite these oscillations, the degree of heat stress in the chamber did not deviate sufficiently from desired and intended values to invalidate any of the conclusions reached.

Some recording difficulties occurred during certain sessions. For example, no heart rate was recorded for the AVS assembly in Session 1 and only a partial heart rate was obtained for the control ensemble in Session 2. No rectal temperature was obtained for the AVS in session 2 and hence no mean body temperature could be calculated for this case. Poor and intermittent performance of the blower motor was observed in session 10 and the corresponding figure is marked accordingly. The difficulty seemed to stem from the destructive action of high temperatures and long running times on the bearings in the motor.

Any effectiveness of the AVS would be revealed by its ability to suppress a rise in $\overline{T_S}$, MBT and/or T_R of the subject in comparison with the control during the same experiment.

The effectiveness of the suit would also be shown in the comparison of the physiological responses of the same subject wearing the AVS with himself without the AVS in similar conditions. Table 3 represents a qualitative appraisal of the 10 figures.

TABLE 3*

EXPERIMENTAL SUMMARY

Experiment No.	Average WBGT	$\overline{T_S}$	T_R	MBT	Heart Rate	Subjective Response
1	62.3°F	S > N	S > N	S > N	--	S > N
2	62.1	S > N	--	--	S < N	S > N
3	65.2	S > N	S = N	S > N	--	S > N
4	66.1	S > N	S < N	S < N	S < N	S > N
5	72.3	S > N	S < N	S < N	S < N	S < N
6	71.8	S > N	S = N	S = N	S > N	S = N
7	77.1	S < N	S = N	S < N	S > N	S > N
8	78.8	S > N	S < N	S < N	S < N	S > N
9	82.0	S < N	S < N	S < N	S > N	S > N
10	84.0	S > N	S < N	S < N	S < N	S > N

S = AVS N = control

* S > N represents the fact that the level of measurement attained for the AVS exceeds that of the control. S < N means the converse. S = N mean that the levels attained in both ensembles were equivalent.

In most cases, the differences in $\overline{T_S}$, T_R or MBT between the two subjects were less than 1^{o}C and hence of relatively little physiological import. In the course of this experiments, neither subject was ever severely heat stressed. Though there was some tendancy of the AVS to provide higher levels of skin and body temperatures for the wearer in the mild heat stress conditions and slightly lower levels for the higher heat stress conditions (Table 3), there was little evidence to suggest any alleviation of heat stress due to the wearing of the AVS. From the Subjective Response column in Table 3 it can be seen that the subject wearing the AVS in almost all cases gave verbal evidence of feeling warmer than the control subject. This was true even for cases in which the values of $\overline{T_S}$ and T_R for the AVS were less than the control. This suggests that the feeling of comfort or discomfort when wearing the AVS may be due to other variables besides temperature.

The ability of either clothing ensemble to suppress the rise in $\overline{T_S}$, T_R or MBT was further examined by subtracting the first recorded measurements in the session from the values at the end of 3.5 hours (Table 4).

TABLE 4

CHANGES IN PHYSIOLOGICAL TEMPERATURES DURING EXPERIMENTAL SESSIONS

	S	N	
1 (65^{o}F)*			S = #1
ΔT_R	-0.8^{o}C	-0.4	
ΔMBT	-0.3	-0.4	
$\Delta\overline{T_S}$	+0.5	-0.1	
2 (65^{o}F)			S = #2
ΔT_R		-0.6	
ΔMBT		-0.3	
$\Delta\overline{T_S}$	+0.8	+0.1	
3 (70^{o}F)			S = #1
ΔT_R	-0.3	-0.2	
ΔMBT	+0.2	-0.3	
$\Delta\overline{T_S}$	+1.3	-0.3	
4 (70^{o}F)			S = #2
ΔT_R	-0.2	-1.0	
ΔMBT	+0.7	-0.3	
$\Delta\overline{T_S}$	+3.6	+1.5	

	S	N	
5 (75°F)			S = #2
ΔT_R	-0.2	+0.3	
ΔMBT	+0.4	+1.3	
$\Delta \overline{T_S}$	+1.8	+3.1	
6 (75°F)			S = #1
ΔT_R	-0.3	-0.1	
ΔMBT	+0.5	+0.5	
$\Delta \overline{T_S}$	+2.1	+0.9	
7 (80°F)			S = #1
ΔT_R	-0.1	-0.1	
ΔMBT	+0.5	+0.8	
$\Delta \overline{T_S}$	+1.5	+2.4	
8 (80°F)			S = #2
ΔT_R	+0.1	0	
ΔMBT	+0.7	+0.1	
$\Delta \overline{T_S}$	+1.7	+0.4	
9 (85°F)			S = #1
ΔT_R	+0.2	0	
ΔMBT	+0.3	+0.3	
$\Delta \overline{T_S}$	+0.3	+1.4	
10 (85°F)			S = #3
ΔT_R	+0.6	+0.1	
ΔMBT	+0.9	+0.4	
$\Delta \overline{T_S}$	+1.7	+1.5	

* Temperatures in brackets indicate desired dry bulb temperatures in the Tropical Room.

In sessions 1 and 2 (65^{o}F DB), the skin temperature of the subject wearing the AVS increased significantly and his rectal temperature decreased relative to the control assembly. This was also true for the 70^{o}F DB sessions in which the subject wearing the AVS gained heat compared with the one wearing the control assembly. No significant differences in change of temperatures occured in the other sessions. The conclusion to be reached from this analysis is that the AVS is of little benefit to the wearer in this experiment.

Table 5 shows the changes in weight for the two subjects in the course of the sessions. The numbers in the table represent the mean difference between the final weights and the initial weights.

TABLE 5

WEIGHT CHANGES (lb) OF SUBJECTS DURING AVS EXPERIMENTAL SESSIONS

Session No.	AVS Subject	Control Subject
1	0	0
2	0	0
3	-0.25	-0.75
4	-0.50	-0.75
5	0	-0.50
6	-0.50	0
7	-1.0	-0.50
8	-0.50	-1.25
9	-2.00	-1.0
10	-1.75	-1.25

For the 80^{o}F DB and 85^{o}F sessions the AVS resulted in slightly more weight loss than the control. For the other conditions there were no significant differences in weight change between the two.

Discussion

Several observations were made on the use of the AVS with the immersion suit:

(a) When air is forced into the AVS from the blower motor, the immersion suit is blown up to its maximum extent due to the fact that there is no easy egress of the air from the suit. Air is lost through seepage through the zippered fastener, the cuffs and the collar areas. This pressurized suit constitutes a resistance against which the blower motor must labour and the back pressure may reduce the effective flow of air into the AVS.

(b) Due to the action of the blower motor, the ambient air of the Tropical Room was further heated in passage through the motor, thereby tending to nullify any beneficial aspect of the forced air in the AVS. The lack of air egress from the suit causes the suit to become a resevoir of warm slightly presurized air. Convective cooling of a subject is proportional to the square root of air velocity over the body as well as the temperature differential between the mean skin temperature and the air temperature. The action of the pressurized immersion suit is to reduce the effect of the former and the action of the heating of the blower motor is to reduce the effect of the latter.

(c) One beneficial aspect of the pressurized immersion suit was that the sensation of weight of the clothing on the wearer was reduced. A significant lightening effect was noted.

CONCLUSIONS

It is concluded that:

(a) The Beaufort Mk 2C Air Ventilated Suit did not provide any significant alleviation of heat stress occurring in these experiments when worn under a Mk 10 immersion suit. (65 - 85^{o}F, 85% RH, 3.5 hours exposure).

(b) At low conditions of heat stress (65^{o}F, 85% RH) the above-mentioned ensemble was warmer to wear than the same ensemble without the AVS. In nearly all conditions, the subject wearing the AVS felt as subjectively warm or warmer than the control subject, even when measurements showed that he was cooler.

RECOMMENDATIONS

It is recommended that the Beaufort Mk 2C air ventilated suit should not be used underneath the Mk 10 immersion suit as specified in Reference (1) to reduce the heat stress of CH 125 flight personnel. It might be effective if supplied with cooled air from an air conditioning unit and if the immersion suit were altered to permit air egress from the clothing ensemble.

ACKNOWLEDGEMENTS

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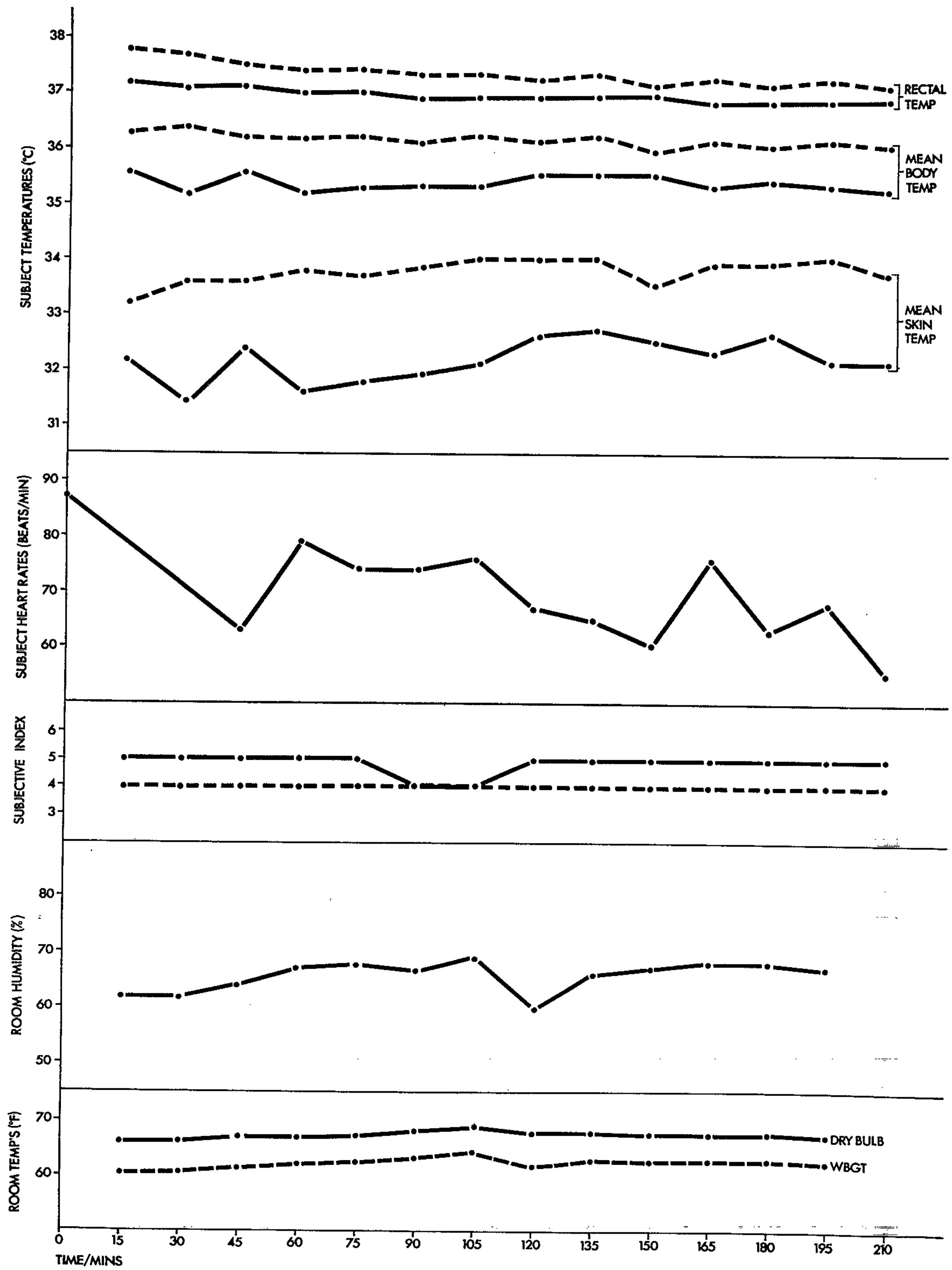

Figure 1. Results obtained in the first session at 65°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

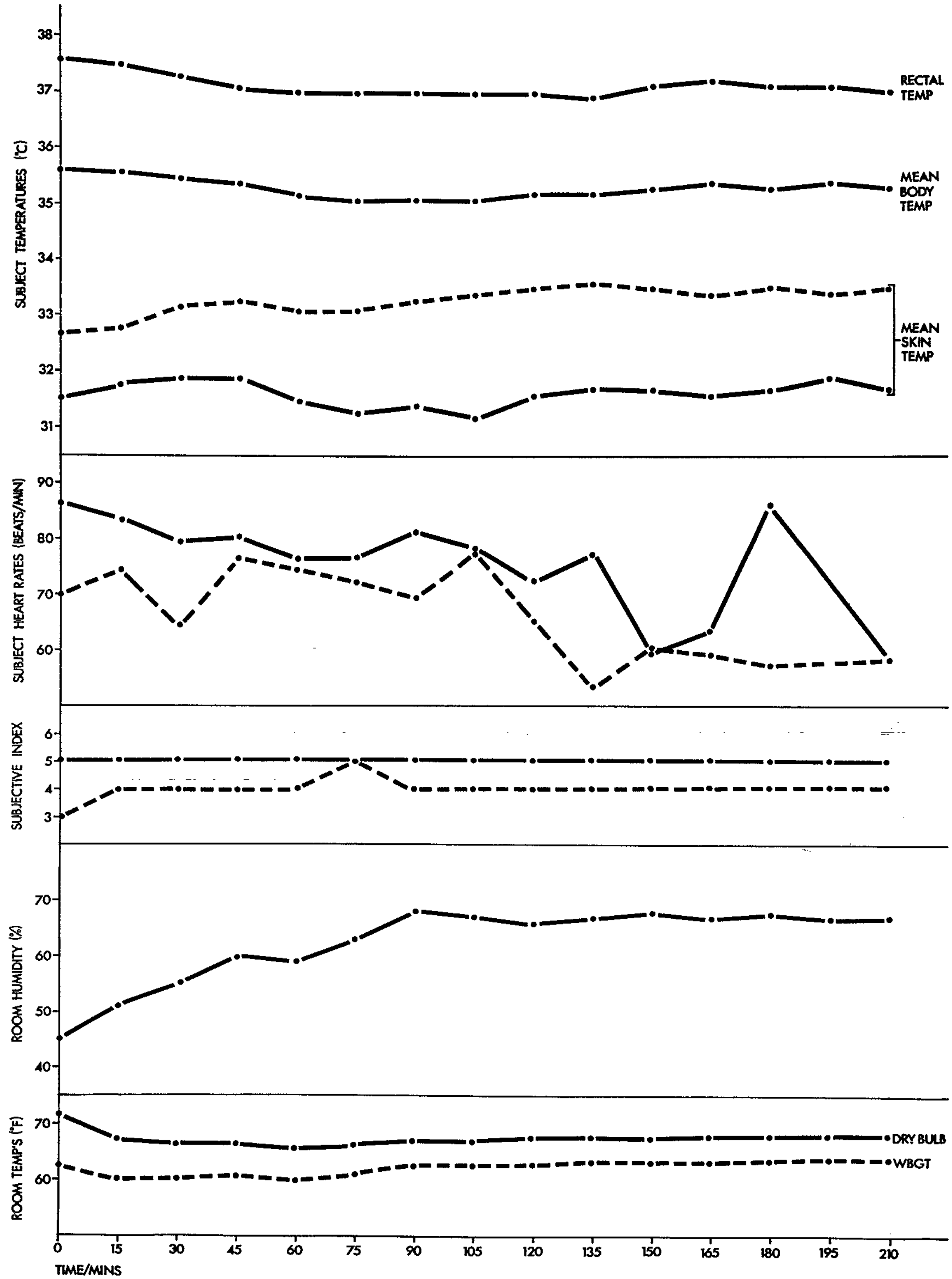

Figure 2. Results obtained in the second session at 65°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

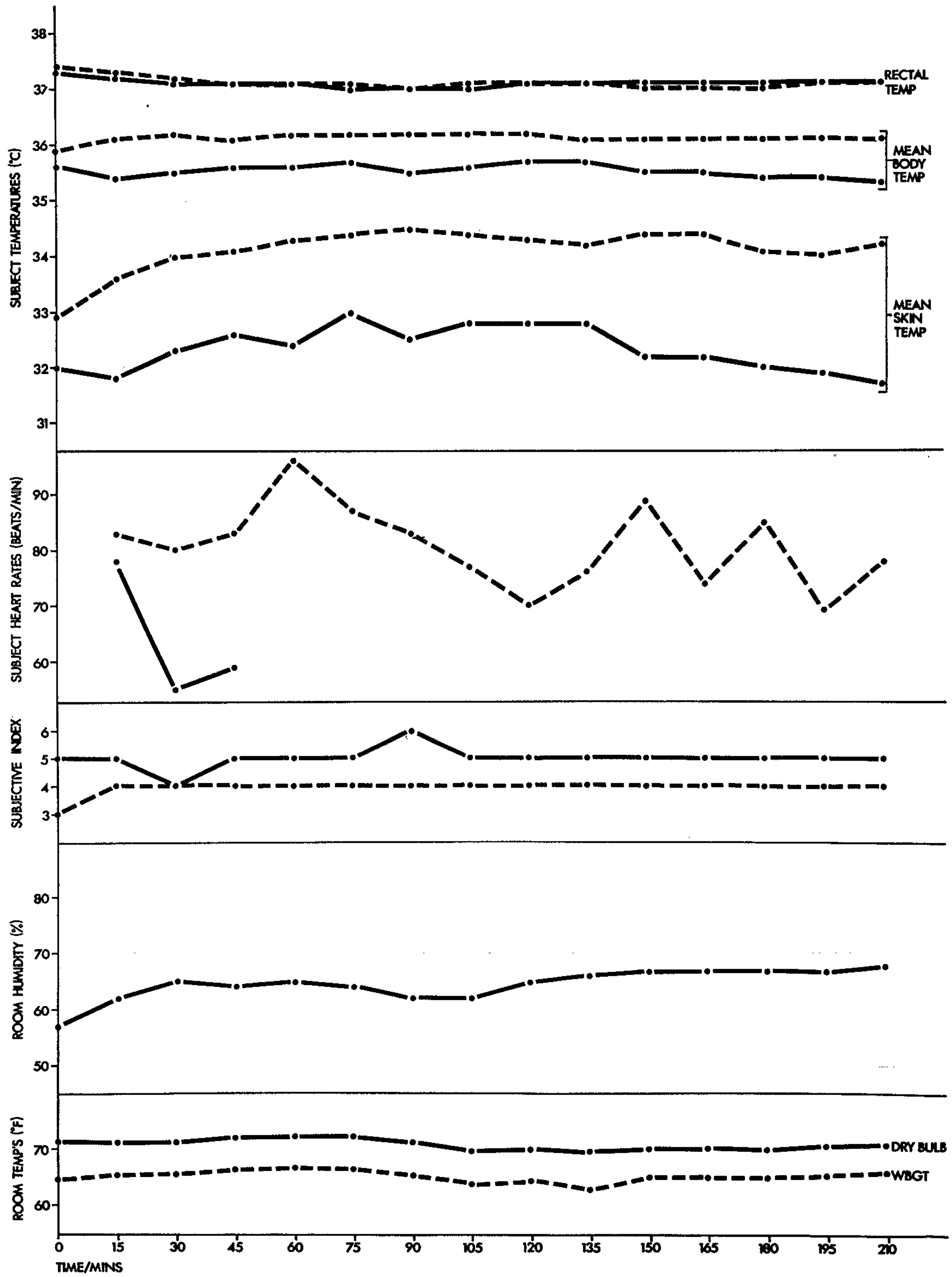

Figure 3. Results obtained in the first session at 70°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

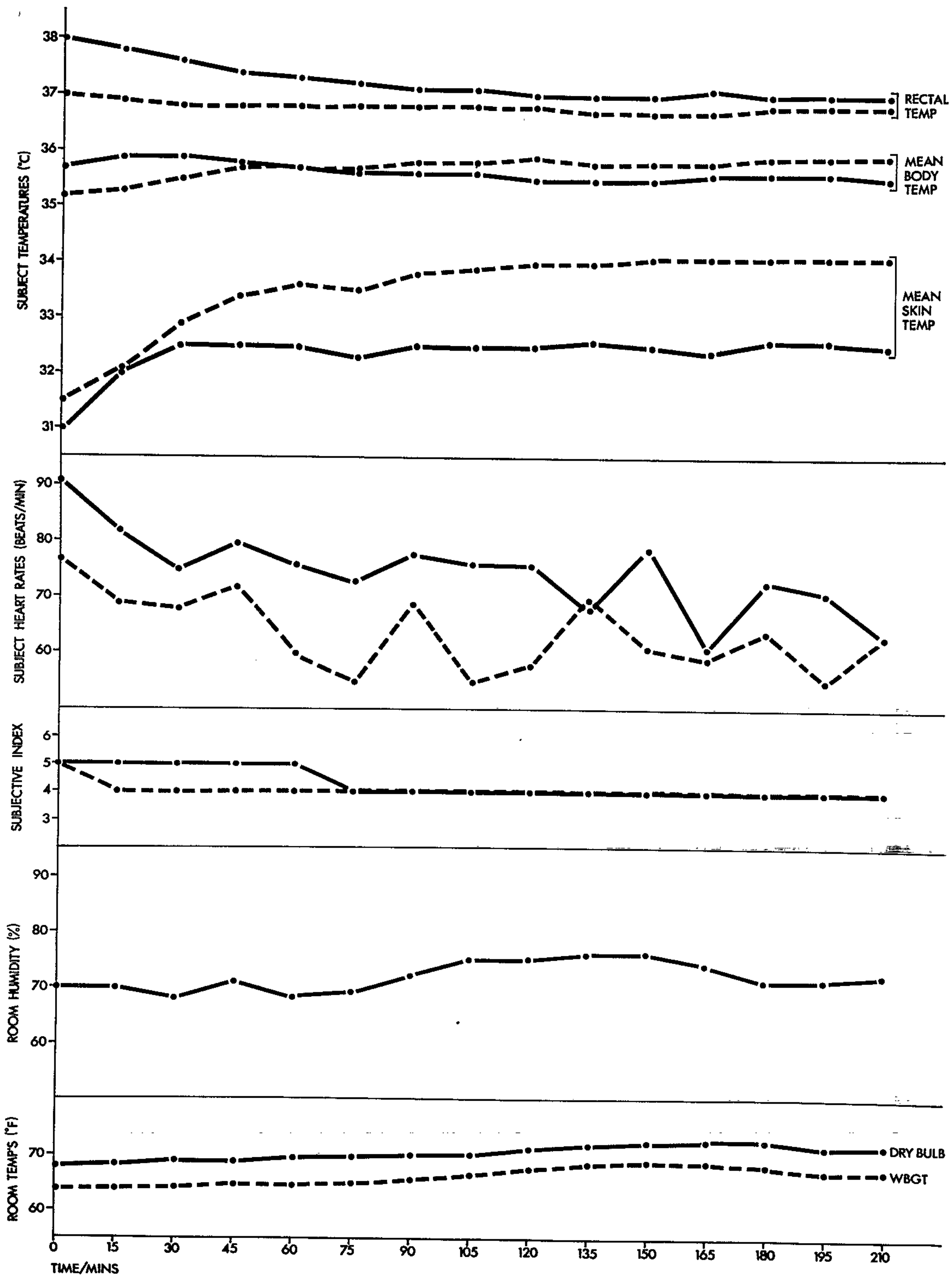

Figure 4. Results obtained in the second session at 70°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

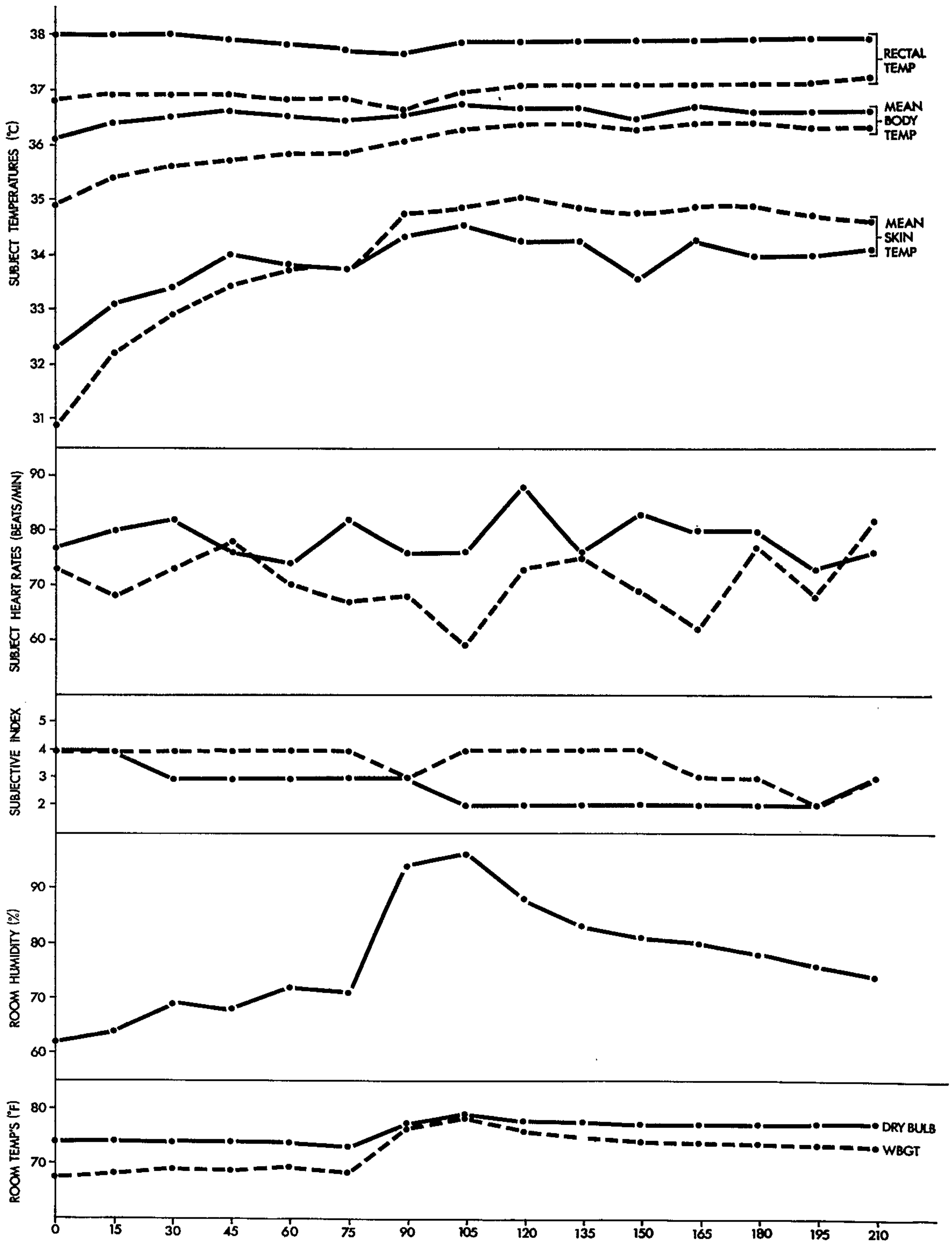

Figure 5. Results obtained in the first session at 75°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

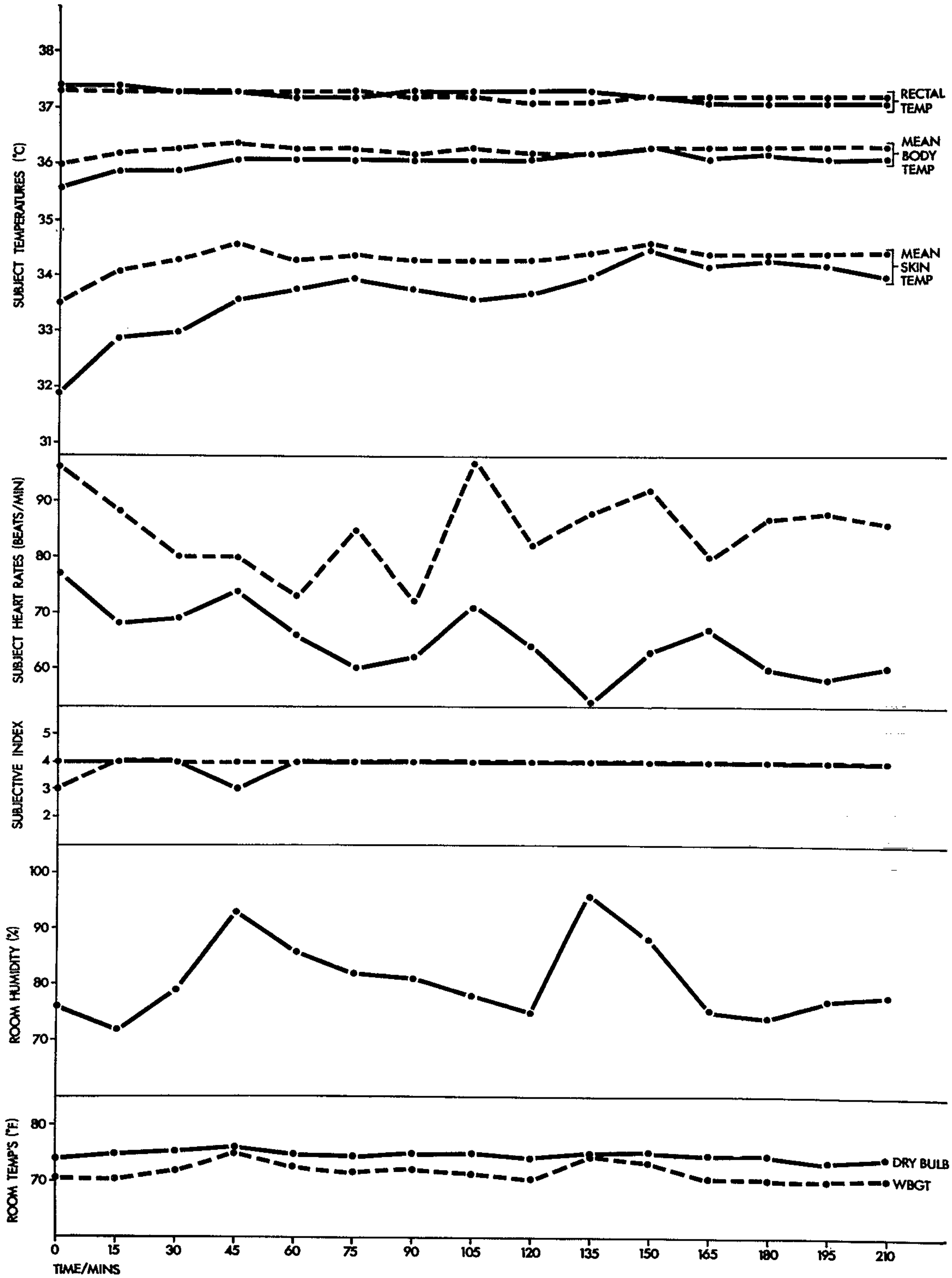

Figure 6. Results obtained in the second session at 75°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

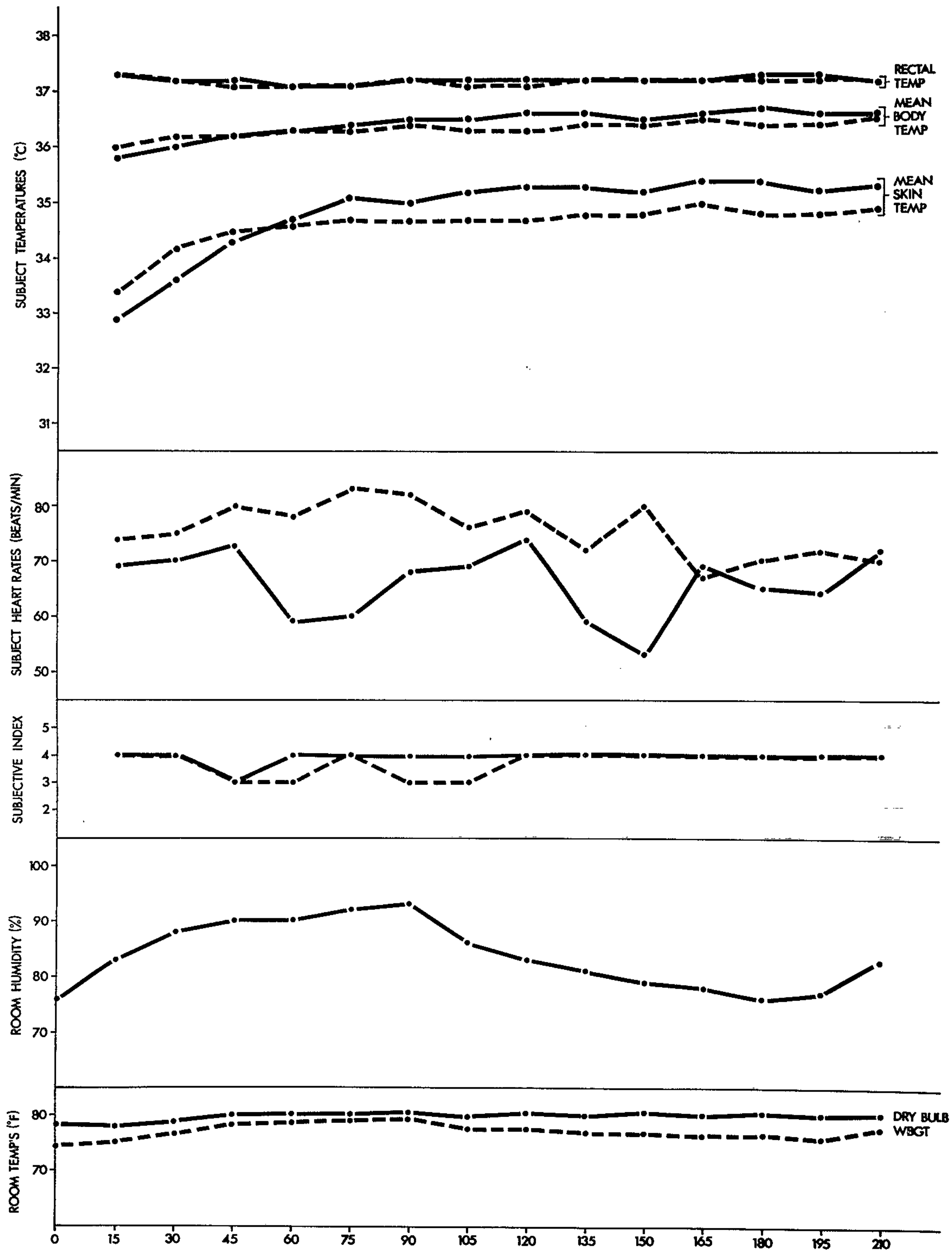

Figure 7. Results obtained in the first test at 80°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

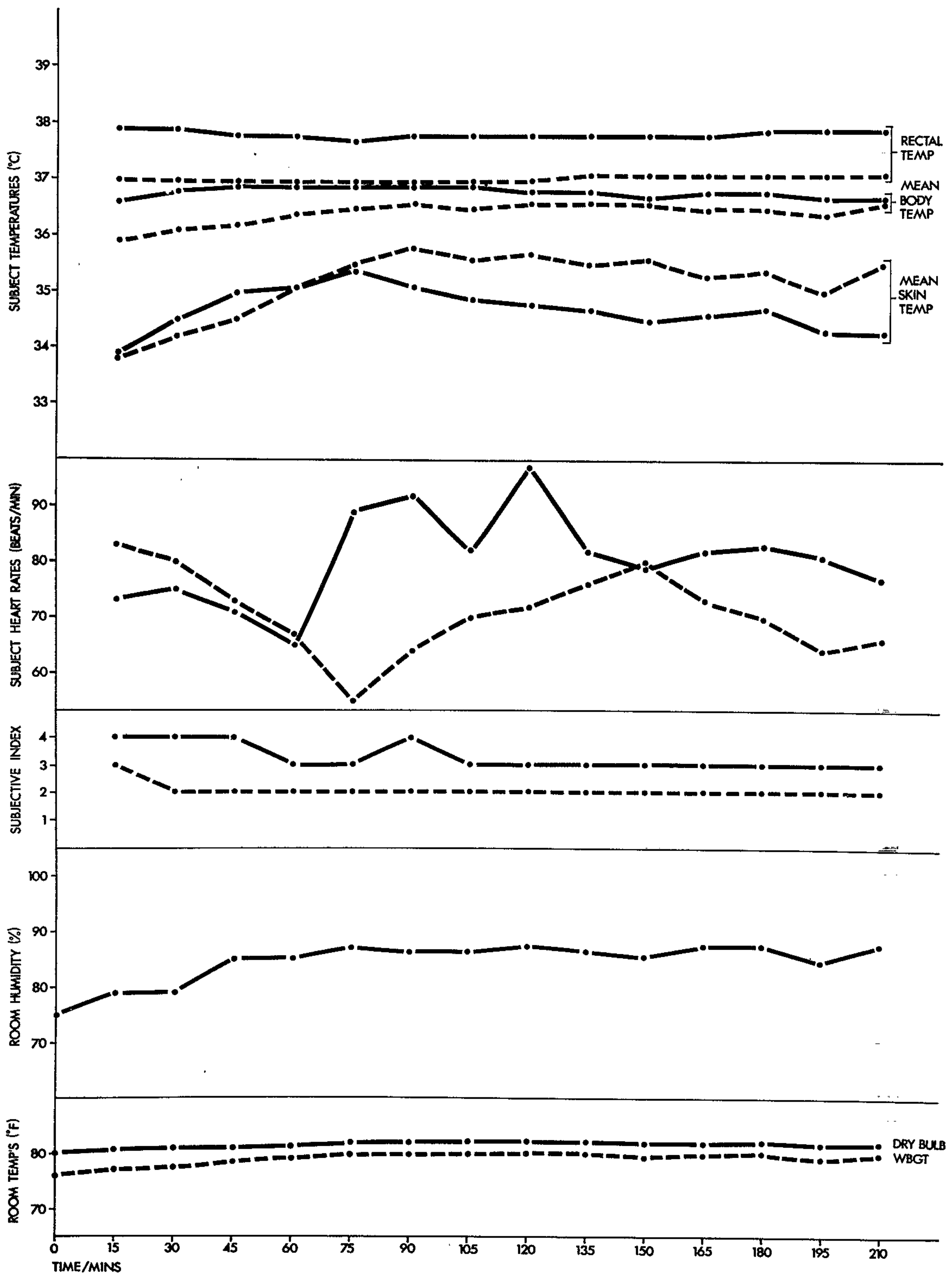

Figure 8. Results obtained in the second session at 80°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

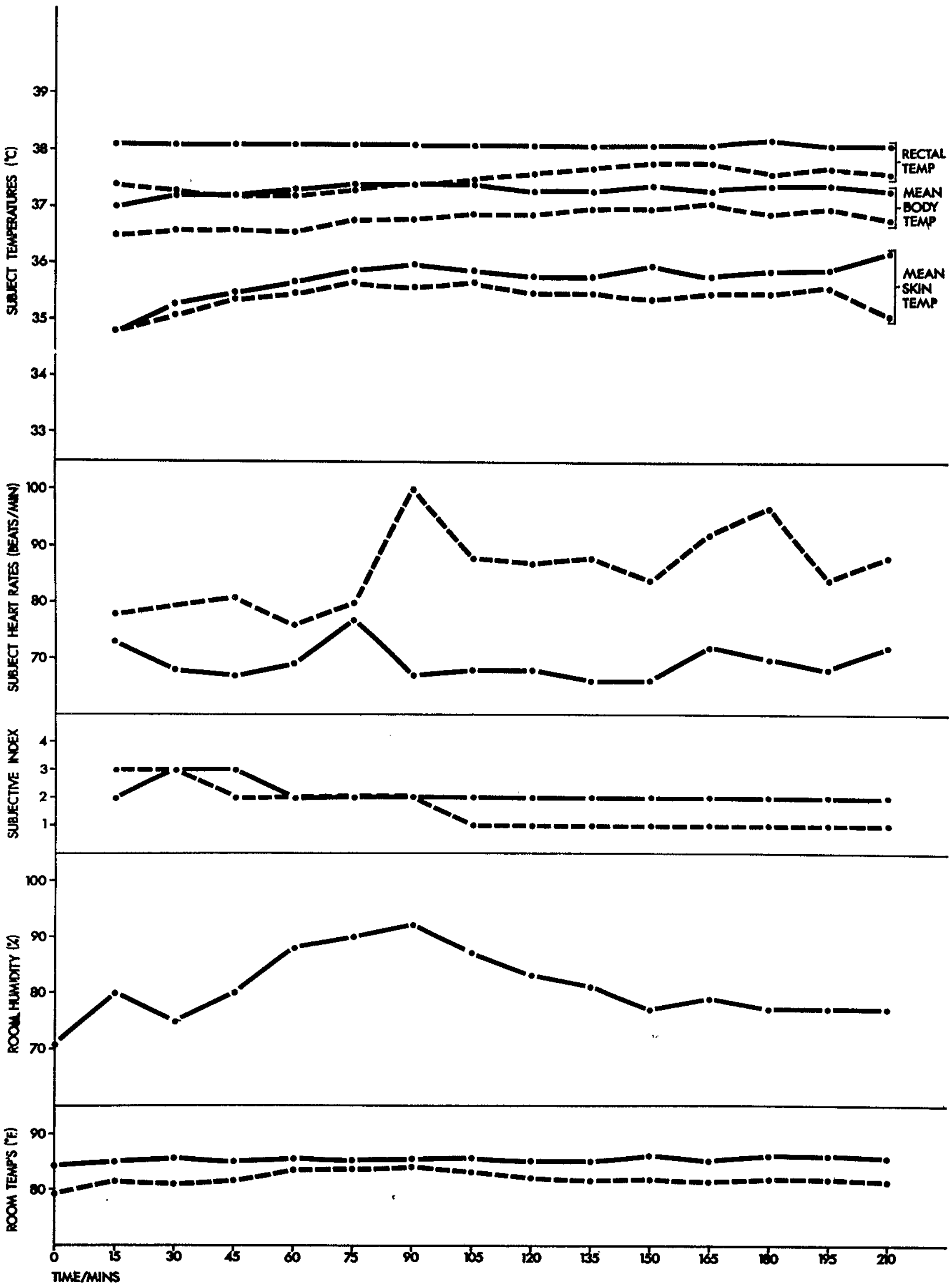

Figure 9. Results obtained in the second session at 85°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

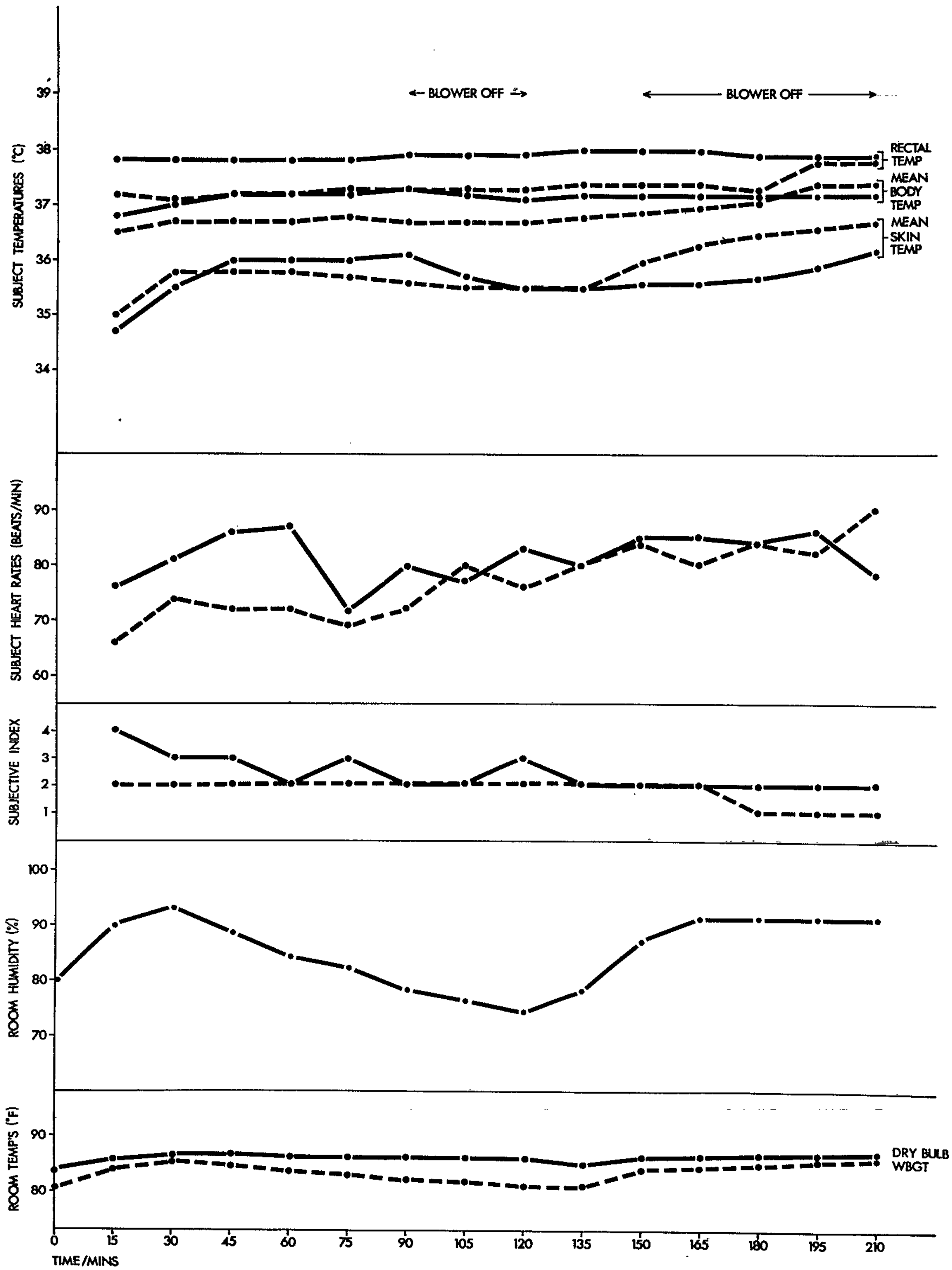

Figure 10. Results obtained in the second session at 85°F DB and 85% relative humidity. In the upper three graphs the subject wearing the AVS assembly is represented by a broken or dashed line; the subject wearing the control assembly is represented by a solid line.

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13. ABSTRACT

This report describes an evaluation of the Beaufort Mk2C Air Ventilated Suit worn under the Beaufort Mk10 Immersion Suit in alleviating the degree of heat stress experienced by CH-124 flight personnel. Tests were conducted in a conditioned room at temperatures of 65°F, 70°F, 75°F, 80°F and 85°F with a relative humidity of 85%. It was found that this clothing ensemble does not confer any protection from heat stress in these conditions.

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