PHYSIOLOGICAL RESPONSES TO INTERMITTENT HEAT STRESS

by

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INTRODUCTION

In spite of the amazing technical progress achieved during this century, many people still must work in hot environments to earn their living. The strain shown by the workers to the stress of the hot environments is indicated by increased heart rate, sweating, skin temperature, and core temperature (usually measured as rectal temperature). Therefore workers often take breaks, either on a formal or informal schedule, to recover from the heat stress.

Numerous experiments have been performed to determine the physiological effects on the human body of hot work environments. However most of them use non-acclimatized subjects exposed to continuous heat for one or two hours.

In 1943, for the first time, Robinson, et al. investigated the period of acclimatization to hot environments (T_{db} 40° C, rh 23%, ET* 35.5°C) and loss of acclimatization after exposure ceased. They found that, by measuring heart rate, average skin temperature and rectal temperature, men were acclimatized rapidly during about seven days and thereafter slowly up to 23 days, and that men lost acclimatization during about 21 days after exposure ceased. Robinson (1949) also investigated variations of rectal and skin temperature of one highly acclimatized subject. The subject was exposed to increasing effective temperature from ET 17°C to ET 38°C while resting (110 Watts) and walking on a treadmill maintaining his metabolic rate at 440 Watts. He found that both skin temperature and rectal temperature, which were measured at the end of two hour exposure, increased smoothly while resting, but sharply while walking as environmental temperature increased beyond ET 30°C. Robinson, et al. (1965) found that, using four out of the five subjects of the experiment in 1943, older men, ages 40-60, showed about the same degree of strain during work in the heat as they did 22 years earlier and acclimatized as well.

Ellis (1960) investigated heat acclimatization of 12 men with alternated rest (66.7%) and work (step-climbing) in a hot chamber (Tdb 38°C, rh 83%, ET* 44°C) for two hours/day (first three days), three hours (next three days), and four hours (last six days) after a 6-day training period. During the acclimatization, heart rate changed most rapidly, then sweat rate and finally rectal temperature (six, seven, and ten days respectively for acclimatization).

Brouha (1967a) investigated the duration of the rest periods between working periods for five minute bicycle ergometer rides. Metabolic rate was 600 Watts for males and 400 Watts for females. Four different environments were used. The mean recovery times from the maximal work level to a heart rate of 110 beats/min were significantly affected by environmental conditions. For ten cycles of the work, the mean recovery times were 0.16 min/cycle in 15.6°C, 0.36 min/cycle in 22.2°C, 1.70 min/cycle in 32.2°C, and 2.14 min/cycle in 37.8°C. Brouha (1967b) also investigated workers' heart rate through eight hours in two work-rest environments. At mean environmental temperature of 4.5°C, the workers were able to perform eleven full cycles (25 min/cycle) of work without an abnormally high reaction (over 110 beats/min). However at a mean environmental temperature of 28°C, the number of cycles were reduced from eleven to eight, giving the workers longer rest periods. Very high reactions (up to 150 beats/min) were observed during the afternoon, indicating a progressive accumulation of fatigue.

Gisofi and Robinson (1969) studied the relation between physical training and heat acclimatization in a 50°C, 17% rh, 39.6 ET* environment. Six weeks of training had improved the heat tolerance of the subjects, but not fully acclimatized them. Before the training, rectal temperature, mean skin temperature, and heart rate after 80 minutes work were 39.6°C, 37.7°C, and 162 beats/min respectively. After the training, after 80 minutes work, rectal temperature and mean skin temperature were lowered about one degree; heart rate was lowered about 20 beats/min.

Recently, Kamon (1979) investigated scheduling work-rest cycles for hot ambient conditions using six heat acclimatized male subjects. Schedule of work and rest periods were designed for work at 40% $\dot{V}_{O_2}$ max and 60% $\dot{V}_{O_2}$ max (540 Watts and 800 Watts). Each was under two work environments, warm-humid (T_{db} 36°C, rh 71%, ET* 40°C) and hot-dry (T_{db} 50°C, rh 12.5%, ET* 38.8°C), and two resting environments, neutral ambient condition (T_{db} 23°C, rh 50%, ET* 23°C) and the same as the work environment. Table 1 shows the physiological responses, highest values for rectal temperature and heart rate, under each work-rest environment. He found that the work and rest periods were adequate (rectal temperature of 38°C and heart rate of 180 beats/min were considered safe for the activities involved in regular industrial tasks) for hot-dry ambient conditions irrespective of the resting environments, but were adequate for the warm-humid conditions only when resting periods were under the neutral ambient condition.

Krajeski, Kamon, and Avellni (1979) studied scheduling rest for consecutive light and heavy work loads under hot ambient conditions using six heat acclimatized subjects (three for each sex) with the same ambient con-

Table 1. Work-rest environments and physiological responses (Kamon, 1979).

Work	Work Env.	Rest Env.	Physiological responses							
			Rectal Temp(°C)		Heart rate (b/min)		Mean skin temp.(°C)		Sweat evaporative heat loss (w/m^2)	
			Work	Rest	Work	Rest	Work	Rest	Work	Rest
40% $\dot{V}O_2$ max 20 min work 20 min rest (4 cycles)	Tdb 36°C rh 71% ET* 40°C	Tdb 23°C rh 50%	37.8	37.9	140	84	36.1 $\pm$0.6	35.9$\pm$0.5	203	172
		Tdb 36°C rh 71%	38.3	38.2	152	105	35.6$\pm$ 0.5	33.6$\pm$ 0.5	201	111
	Tdb 50°C rh 12.5% ET* 38.8°C	Tdb 23°C rh 50%	37.8	37.2	125	80	34.9$\pm$0.7	35.6$\pm$0.6	387	245
		T_{db} 50°C rh 12.5%	37.8	37.7	129	93	34.8$\pm$0.5	33.6$\pm$0.6	389	64
60% $\dot{V}O_2$ max 10 min work 20 min rest (5 cycles)	Tdb 36°C rh 71% ET* 40°C	Tdb 23°C rh 50%	38.1	38.1	172	86	36.9$\pm$0.7	36.6$\pm$0.8	262	250
		Tdb 36°C rh 71%	38.6	38.5	183	116	35.9$\pm$0.5	34.3$\pm$1.3	269	211
	Tdb 50°C rh 12.5% ET* 38.8°C	Tdb 23°C rh 50%	37.7	37.7	159	80	35.3$\pm$1.0	35.4$\pm$0.8	565	267
		Tdb 50°C rh 12.5%	38.0	37.9	167	100	34.5$\pm$0.8	33.3$\pm$0.6	519	103

ditions for working and resting area as in the previous study (Kamon 1979). The task was 25 minutes of walking at 30% V_{O_2} max (230 Watts for women and 420 Watts for men) and 5 minutes of carrying a load uphill at 75% V_{O_2} max (660 Watts for women and 1190 Watts for men). Resting periods (30 min/cycle) during the 3 work-rest cycles for 180 minutes were adequate, rectal temperature of 38°C and heart rate of 180 beats/min were set for limit levels, when the resting periods were under neutral ambient conditions. The mean skin temperatures for the women were significantly higher than for the men with rest under neutral ambient conditions. This was due to their smaller capacity of sweating than men. However, most of the experiments mentioned above also were conducted in less than four hours, or used non-acclimatized subjects without much concern with clothing. The purpose of this experiment was to find physiological responses of the human body in different work environments through approximately six hours with a lunch break.

METHOD

Task

The experiments were done in the KSU-ASHRAE Environmental Test Chamber at Kansas State University. Each subject, with the standard KSU uniform (0.6 clo), was tested in the eight different conditions. Metabolic rate, chosen to be representative of industrial environments, was maintained at 300 Watts (See Appendix). They alternated 3 minutes standing (112 Watts) and 2 minutes step task (572 Watts) over a set of two 23 cm (19 inch) steps (See Figure 1) through the work hours. The following criteria were measured from four male subjects through eight different conditions.

(1) Mean skin temperature (See Figure 2 for the location of skin sensors)

(2) Rectal temperature

(3) Oral temperature

(4) Heart rate

(5) Blood pressure

(6) Evaporative weight loss

See Figure 3 for a sketch of the experimental conditions. Table 2 shows the environmental conditions for the work-rest periods and the sequence of the experiment. Work-rest schedules for the two work-rest levels are shown on Figure 4.

Subjects

Four male subjects were used after they passed a physical examination by a physician. Subjects were paid $400 for their participation. Each subject's physical characteristics are listed in Table 3.

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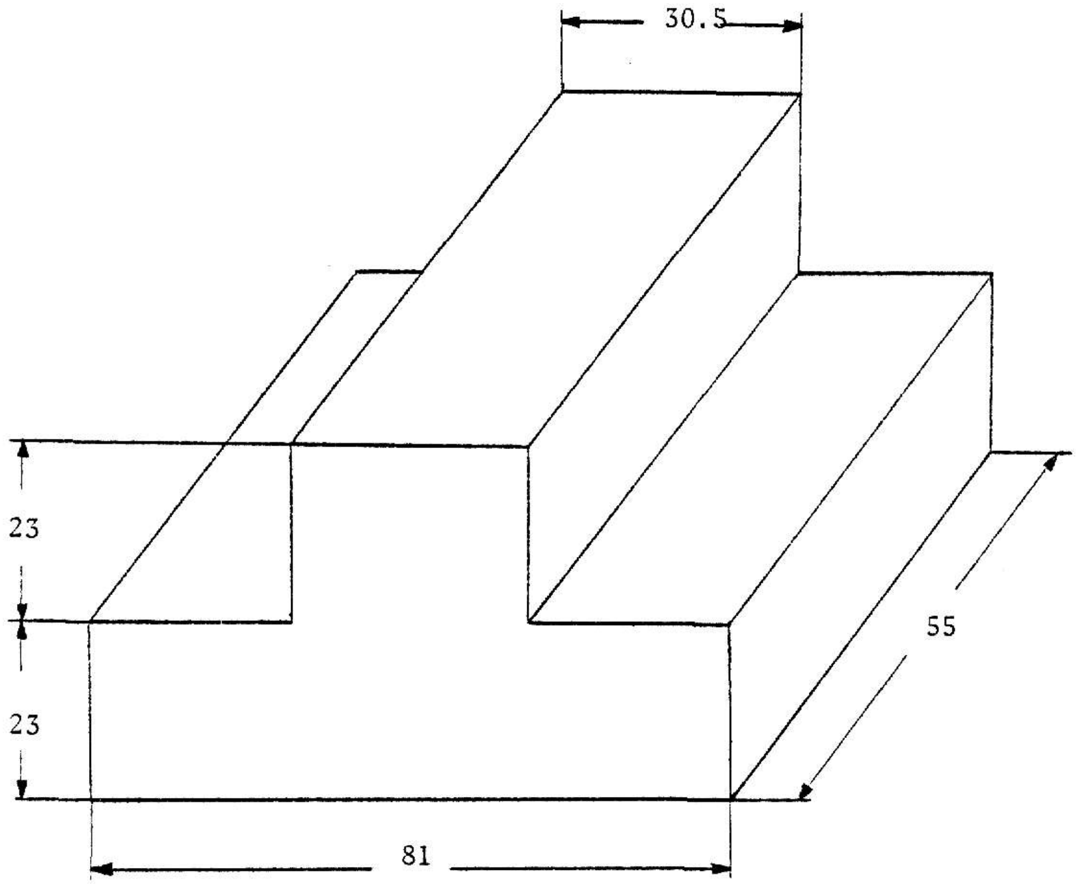

Figure 1. Dimension of step (cm)

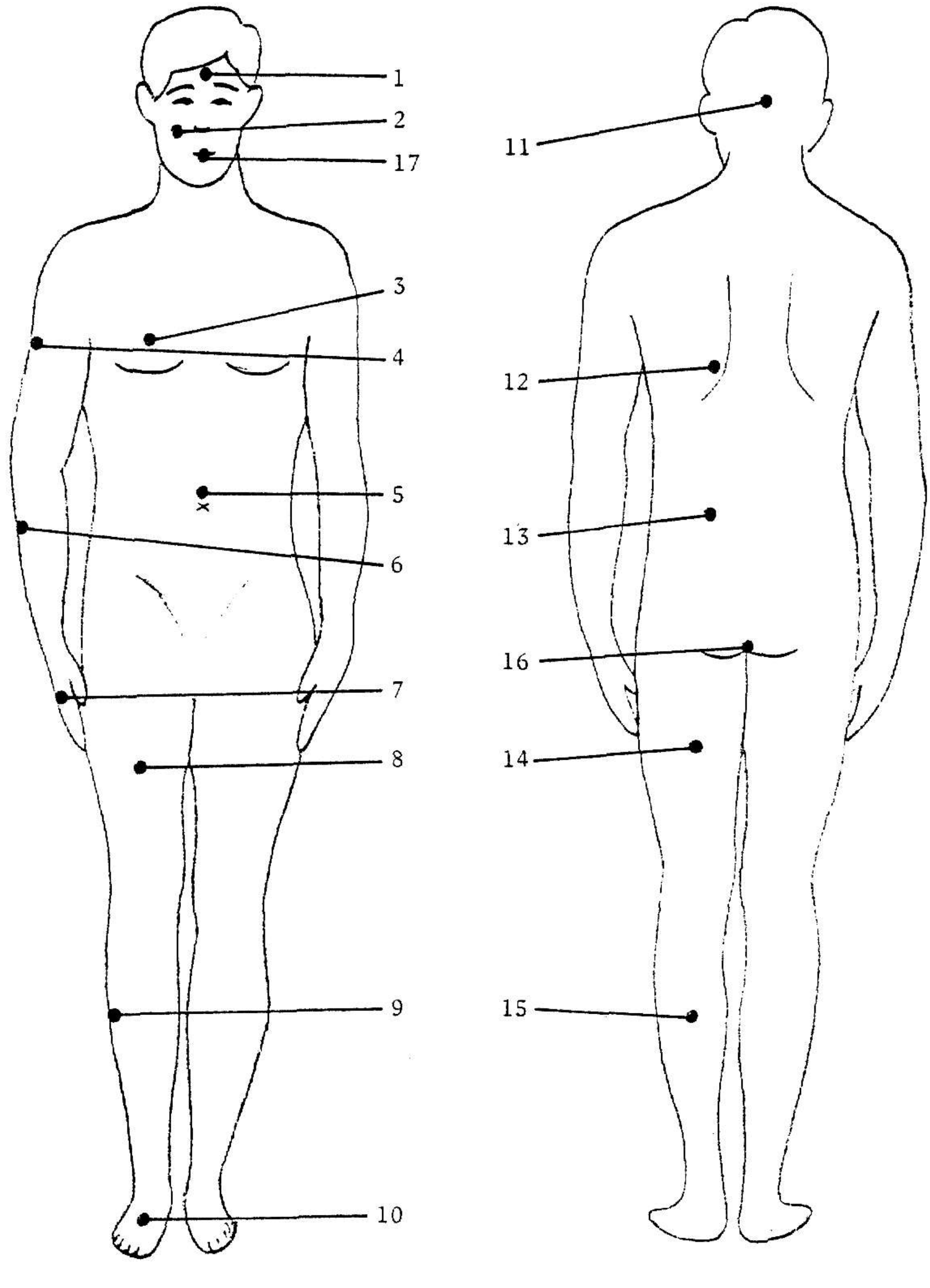

Figure 2. Location of skin sensors (location 16 and 17 designate the rectal and oral temperature respectively).

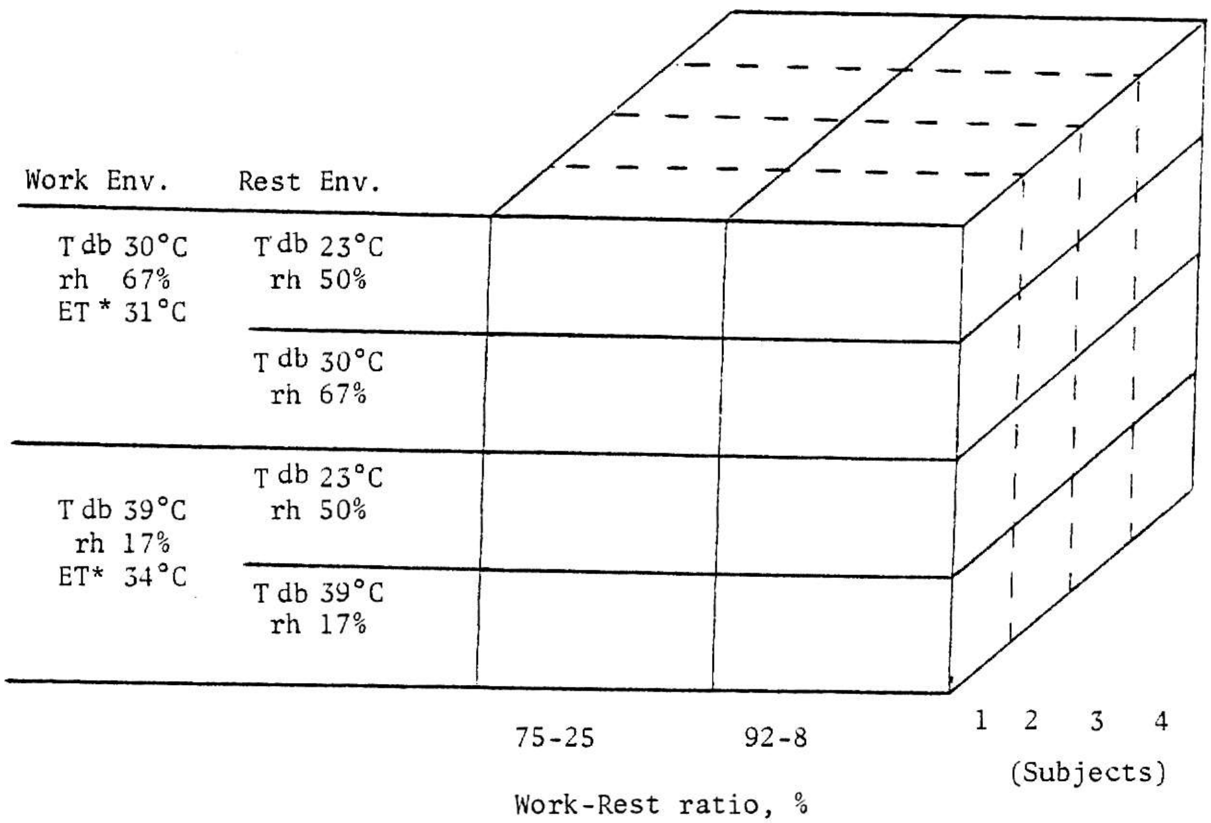

Figure 3. The experimental conditions (See Table 2)

Table 2. Environmental conditions and sequence of conditions.

Work-Rest ratio, %	Work Env.	Rest Env.	Sequence
75-25	Tdb 30°C rh 67% ET* 31°C (warm-humid)	Tdb 23°C rh 50%	1
		Tdb 30°C rh 67%	7
	T db39°C rh 17% ET* 34°C (hot-dry)	Tdb 23°C rh 50%	4
		Tdb 39°C rh 17%	8
92-8	Tdb 30°C rh 67% ET* 31°C (warm-humid)	Tdb 23°C rh 50%	6
		Tdb 30°C rh 67%	3
	Tdb 39°C rh 17% ET* 34°C (hot-dry)	Tdb 23°C rh 50%	5
		Tdb 39°C rh 17%	2

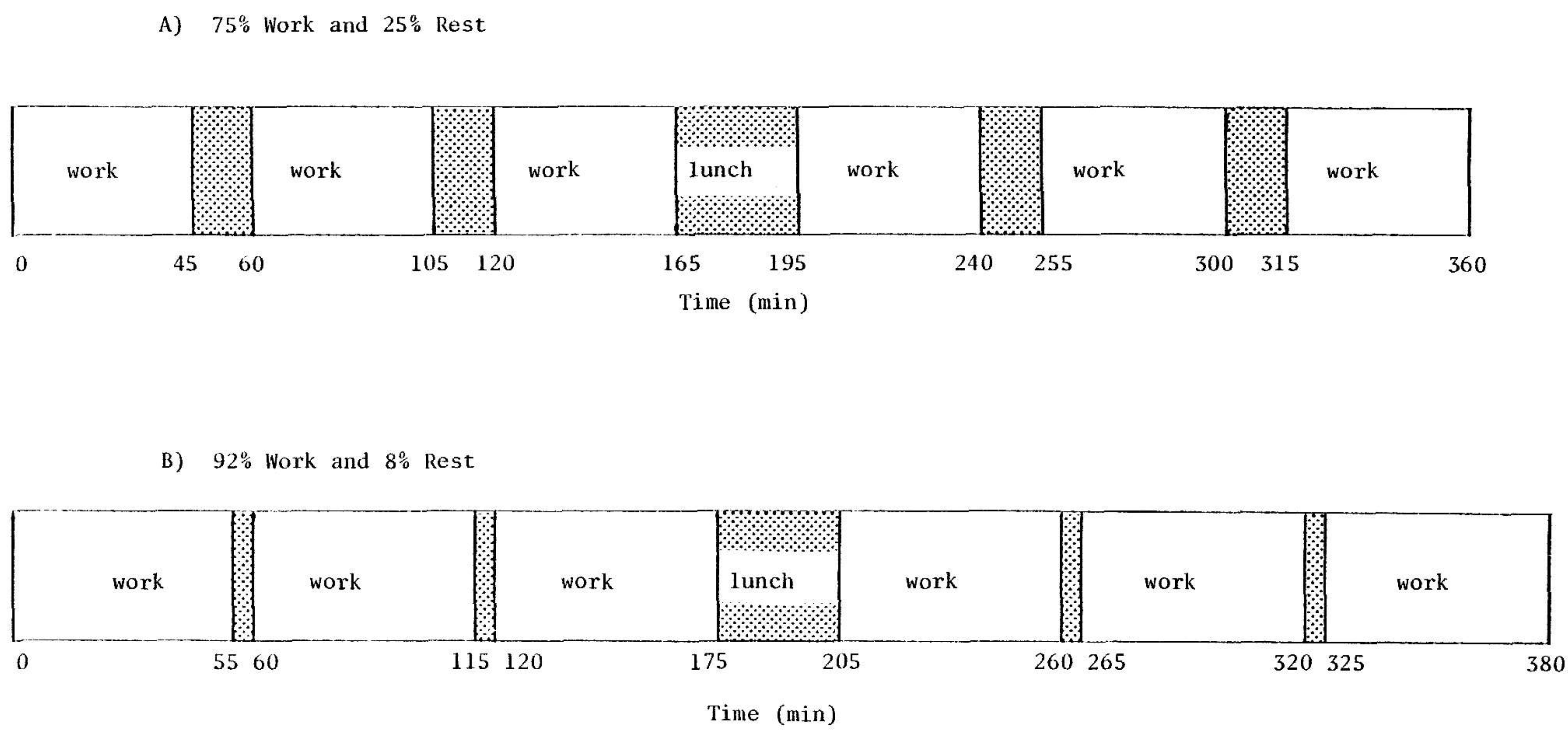

Figure 4. Work-Rest schedules.

Table 3. Physical characteristics of subjects

Characteristics	Subjects 1	2	3	4
Age (yrs)	20	20	20	21
Weight (kg)	78.2	76.4	79.1	80.3
Height (cm)	179	190	188	187
DuBois Surface Area (m^2)	2.07	2.13	2.15	2.15
Basal Blood Pressure (mmHg)				
Systolic	120	120	110	120
Diastolic	70	60	70	70

Experimental Procedure

One subject (#4) missed the whole first day of the experiment. Each experiment was conducted for three hours before the 30 minute lunch in the cool rest area and three hours after lunch. The subjects were in one condition each day; the experiment was performed for eight days. Before an experiment in each condition, each subject's weight was measured. After the Exersentry with belt was fixed on each subject for the heart rate, 15 YSI 409 thermistors were attached and held in position. A YSI 709 rectal thermistor probe and a YSI 703 oral thermistor probe were inserted before entering the chamber. After entering the chamber, the subjects were seated for ten minutes to get a steady state for initial data. The subjects started work by alternating 3 minutes standing and 2 minutes stepping, pacing the step task 5 seconds per trip (walk up one side of the steps and down the other). During the test, skin temperature, oral temperature, and rectal temperature were recorded every 5 minutes on magnetic tapes. Heart rate was detected by the Exersentry continuously. Each subject was asked to read his heart rate as soon as the stepping was over every five minutes. Weight and blood pressure were measured after each work session. The thermal sensation vote and seven-pair comfort vote were obtained at the end of each work session. Cold water or a soft drink was allowed during the work hours; the amount and time were recorded. The amount of urine also was measured each time they urinated. Subjects were not allowed to lie down during the rest. Light music was played in the work area over the radio to reduce the subjects' boredom from the simple standing and step task. The criteria to remove subjects from the work session were set as 38.5°C for rectal temperature, 180 beats/min,(90% of their predicted maximum (heart rate maximum = 220-age), for heart rate, 200 mmHg for systolic blood pressure, 110 mmHg for diastolic blood pressure, nurse's decision, and the subject's request. The subjects stopped work when their systolic blood pressure exceeded 150 mmHg, and resumed work when the systolic blood pressure dropped to 130 mmHg. However, none of the subjects were removed from the chamber.

About 10% of the data of oral temperature were interpolated, particularly during the rest time, due to the sore mouth caused by the oral thermistor probe. Evaporative weight loss had resolution errors of ± 80 g/m^2 - h for the first four experiments, and $\pm$ 20 g/m^2 - h for the last four experiments due to changing scales.

RESULTS

The results were analyzed by the general linear model procedure using SAS. For the ANOVA and Duncan's multiple range test, data were collected at the end of each work period. Tables 4, 7, 9, 12, and 15 show the analysis of variance; Tables 5, 6, 8, 10, 11, 13, 14, 16, and 17 show Duncan's multiple range test of mean skin temperature, rectal temperature, oral temperature, heart rate, evaporative weight loss, blood pressure (systolic and diastolic), thermal sensation vote, and seven-pair comfort vote.

Mean skin temperature

Mean skin temperature (Table 4) was significant for ratio (34.7°C for 25% rest and 35.0°C for 8% rest), work temperature (34.1°C for warm-humid and 35.7°C for hot-dry), time (34.9°C, 34.8°C, 34.7°C, 34.7°C, 34.9°C, and 35.1°C in order of work period), and subject (34.4°C, 34.9°C, 35.0°C, and 35.1°C). Due to the moderate metabolic work rate in the work environment, however, mean skin temperature tended to increase slightly by the end of the time. Figures 14-21 in Appendix III show the trend of mean skin temperature of the four subjects for the eight conditions which were made by the combination of ratio, work temperature, and rest temperature. Means of skin temperature of the eight conditions were significantly different (Table 5). Figure 5 shows mean skin temperature for the two rest ratios. Rest ratio was significant for mean skin temperature in the condition of hot-dry work and rest.

Rectal temperature

Rectal temperature (Table 4) was significant for ratio (37.6°C for 25% rest and 37.8°C for 8% rest), work temperature (37.6°C for warm-humid and 37.8°C for hot-dry), rest temperature (37.6°C for cool, 37.6°C for hot-

Table 4. Analysis of Variance of skin and rectal temperature

Source	d.f.	Skin temperature Mean square	Skin temperature F	Rectal temperature Mean square	Rectal temperature F
Ratio (R)	1	3.40	31.25 **	0.71	6.36 *
Work-Temp. (WT)	1	57.05	523.59 **	1.66	14.79 **
Rest-Temp. (RT)	2	0.21	1.91	1.06	9.45 **
Time (T)	5	0.62	5.69 **	0.22	1.95
Subject	3	4.18	38.39 **	1.70	15.11 **
R * WT	1	0.38	3.50	3.30	29.41 **
R * RT	2	3.96	36.38 **	1.75	15.57 **
R * T	5	0.31	2.87 *	0.05	0.41
WT * T	5	0.09	0.83	0.06	0.54
RT * T	10	0.09	0.81	0.06	0.54
Error	150	0.11		0.11	
Total	185				

* $\alpha < 0.05$

** $\alpha < 0.01$

Table 5. Multiple range test for mean skin temperature

Condition	Mean (C°)		
HD-work, 8% HD-rest (2)	36.09	A	
HD-work, 25% C-rest (4)	35.68	B	
HD-work, 8% C-rest (5)	35.56	B	
HD-work, 25% HD-rest (8)	35.21	C	
WH-work, 8% WH-rest (3)	34.24	D	
WH-work, 25% C-rest (1)	34.19	D	
WH-work, 25% WH-rest (7)	34.03	D	E
WH-work, 8% C-rest (6)	33.81		E

WH: warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

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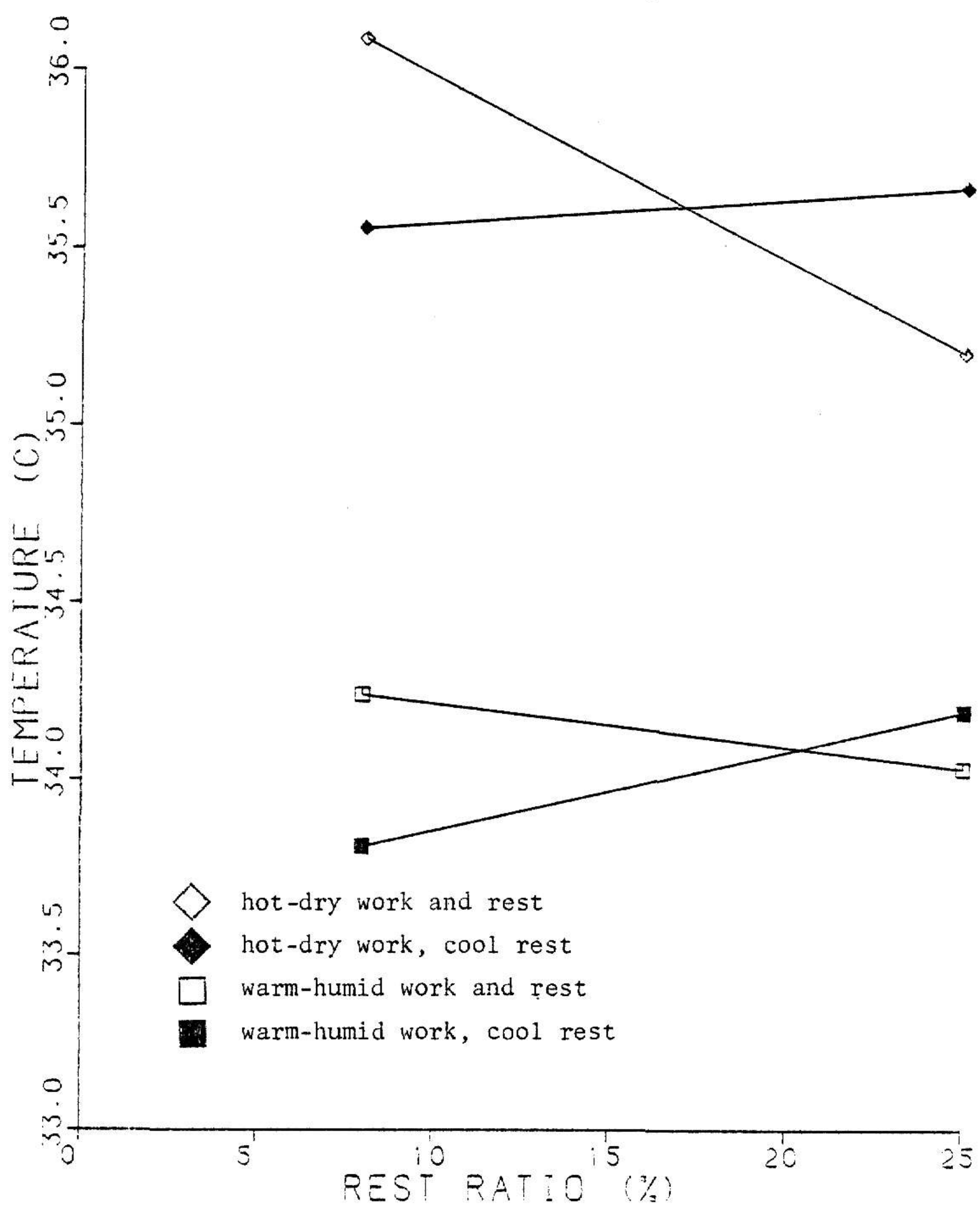

Figure 5. Mean skin temperature vs rest ratio

dry, and 37.9°C for warm-humid), and subject (37.5°C, 37.6°C, 37.7°C, and 37.9°C). Due to the moderate metabolic work rate, rectal temperature tended to increase slightly (37.3°C to 37.8°C) by the end of the time. Figures 22-29 show the trend of rectal temperature for the eight conditions. Means of rectal temperature of the eight conditions were not significantly different, except one condition (work at warm-humid and 25% rest in cool), which one subject missed, by Duncan's multiple range test (Table 6). Figure 6 shows rectal temperature for the two rest ratios. Rest ratio was significant for rectal temperature in the condition of warm-humid work and cool rest. This might be due to one subject's values because his mean rectal temperature was higher than any of the other subjects.

Oral temperature

Oral temperature (Table 7), many data of which were interpolated due to sore mouths, was significant for ratio (35.3°C for 25% rest and 35.8°C for 8% rest) and subject (35.1°C, 35.5°C, 35.6°C, and 36.1°C). Figures 30-37 show the trend of oral temperature for the eight conditions. Means of oral temperature of the eight conditions were significantly different (Table 8). Figure 7 shows oral temperature for the two rest ratios. Rest ratio was significant for oral temperature in the condition of hot-dry work and rest. Due to the subjects' cold drink intake during their work performances, however, oral temperature (mean = 35.6°C), which they usually measure for body temperature in hospitals, was much lower than rectal temperature (mean = 37.7°C). This probably indicates that the results of oral temperature in this experiment are not so meaningful as those of the other criteria.

Table 6. Multiple range test for rectal temperature

Condition	Mean (C°)	
HD-work, 8% HD-rest (2)	37.85	A
WH-work, 25% WH-rest (7)	37.78	A
WH-work, 8% C-rest (6)	37.78	A
HD-work, 25% C-rest (4)	37.76	A
WH-work, 8% WH-rest (3)	37.71	A
HD-work, 25% HD-rest (8)	37.68	A
HD-work, 8% C-rest (5)	37.67	A
WH-work, 25% C-rest (1)	37.10	B

WH: warm-humid (30°Cdb rh 67%)

HD: hot-dry (39° db, rh 17%)

C : cool (23°C db rh 50%)

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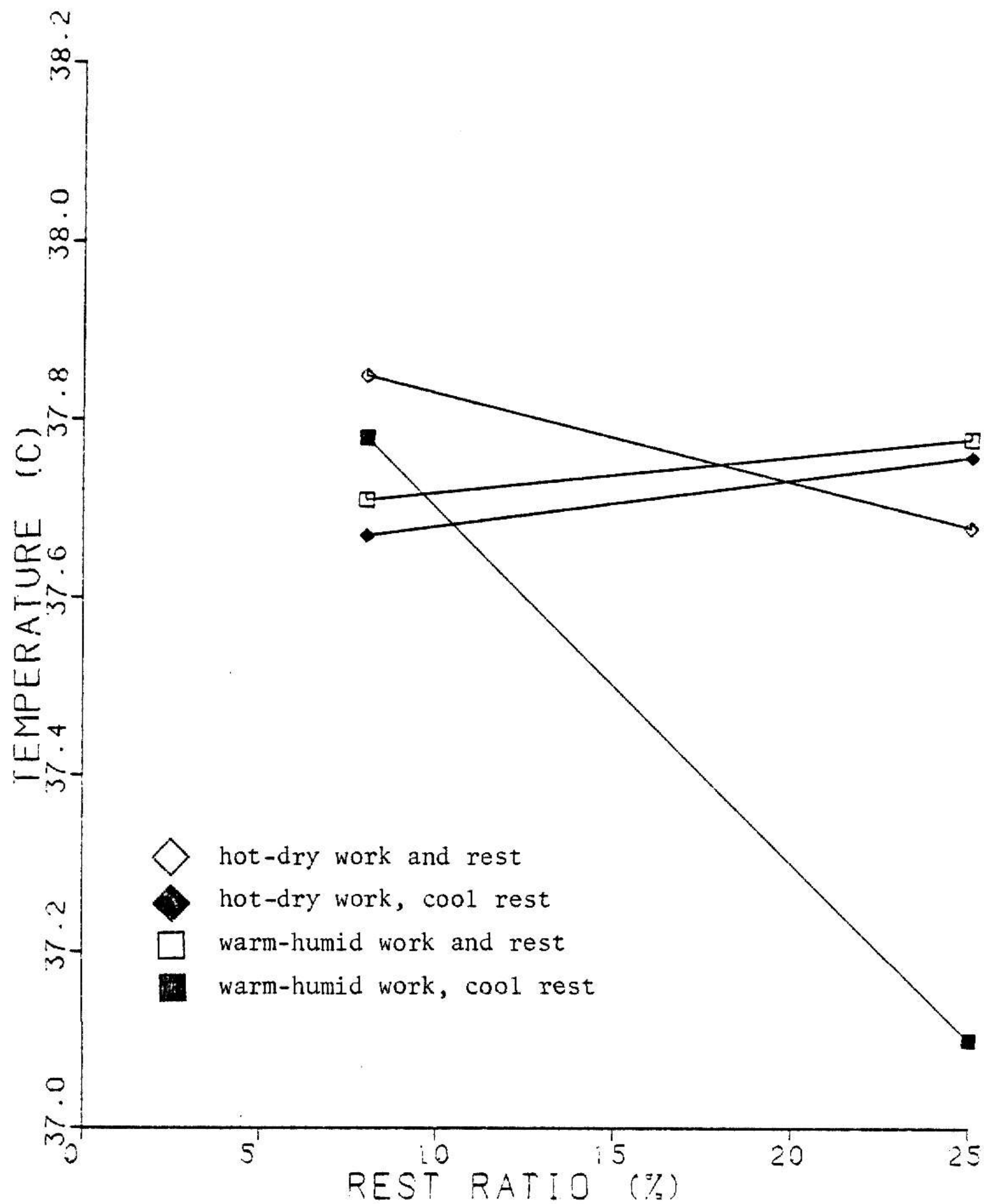

Figure 6. Rectal temperature vs rest ratio

Table 7. Analysis of Variance of oral temperature

Source	d.f.	Mean square	F
Ratio (R)	1	10.60	10.16**
Work-Temp. (WT)	1	0.02	0.02
Rest-Temp. (RT)	2	0.61	0.59
Time (T)	5	1.77	1.70
Subject	3	6.91	6.62 **
R * WT	1	0.42	0.41
R * RT	2	2.98	2.85
R * T	5	1.24	1.19
WT * T	5	1.20	1.15
RT * T	10	1.03	0.99
Error	150	1.04	
Total	185		

** $\alpha < 0.01$

Table 8. *Multiple range test for oral temperature*

Condition	Mean (°C)		
HD-work, 8% HD-rest (2)	35.99	A	
WH-work, 8% C-rest (6)	35.89	A	B
HD-work, 8% C-rest (5)	35.75	A	B
WH-work, 8% WH-rest (3)	35.71	A	B
WH-work, 25% WH-rest (7)	35.65	A	B
HD-work, 25% C-rest (4)	35.52	A	B
WH-work, 25% C-rest (1)	34.85	C	B
HD-work, 25% HD-rest (8)	34.85	C	

WH: warm-humid (39°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

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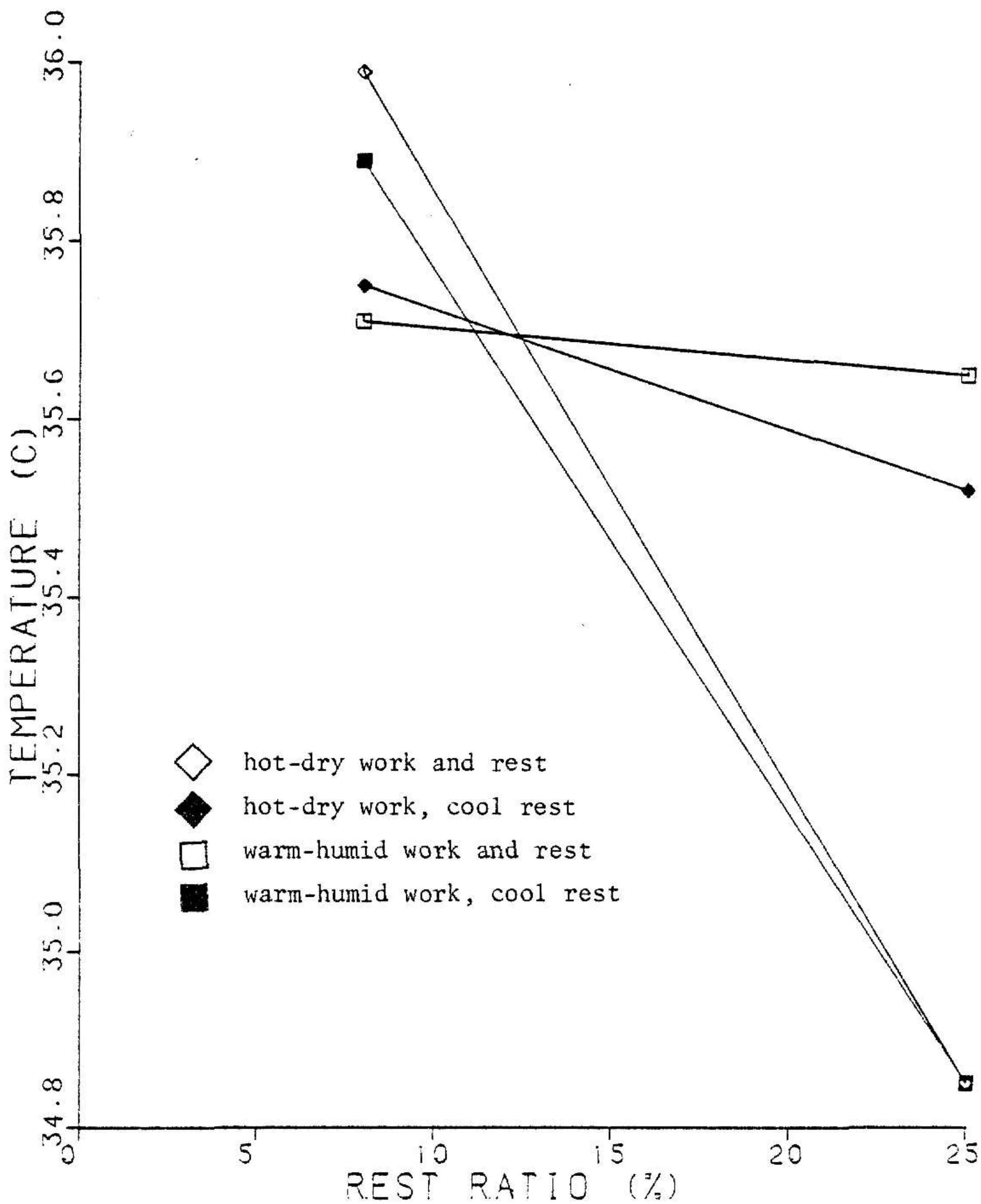

Figure 7. Oral temperature vs rest ratio

Heart rate

Heart rate (Table 9) was significant for rest temperature (101 beats/min for warm-humid, 103 beats/min for cool, and 107 beats/min for hot-dry), time (100 beats/min, 100 beats/min, 101 beats/min, 109 beats/min, 107 beats/min, and 106 beats/min in order of work period), and subject (94 beats/min, 98 beats/min, 109 beats/min, and 114 beats/min). Figures 38-45 show the mean heart rate of the four subjects for the eight conditions. Due to the moderate metabolic work rate, heart rate tended to increase slightly by the end of the time. Means of heart rate of the eight conditions were not significantly different (Table 10) except one condition, the most severe one. Figure 8 shows heart rate for the two rest ratios. Rest ratio was significant for heart rate in the condition of hot-dry work and rest. There was an unexpected increase of three pairs at 25% rest in Figure 8, though the differences were not significant.

Evaporative weight loss

Evaporative weight loss (Table 9) was significant for work temperature (184.3 $g/m^2 - h$ for warm-humid and 256.9 $g/m^2 - h$ for hot-dry). Figures 46-53 show mean evaporative weight loss of four subjects for the eight conditions. Means of evaporative weight loss of the eight conditions were significantly different (Table 11). Figure 9 shows evaporative weight loss for the two rest ratios. Rest ratio was not significant for evaporative weight loss so far as work and rest temperatures were concerned.

Systolic blood pressure

Systolic blood pressure (Table 12) was significant for ratio (129 mmHg for 8% rest and 124 mmHg for 25% rest), time (126 mmHg, 124 mmHg, 125 mmHg, 131 mmHg, 131 mmHg, and 129 mmHg in order or work period), and subject (115 mmHg, 125 mmHg, 135 mmHg, and 136 mmHg). Figures 54-61 show the

Table 9. Analysis of Variance of heart rate and evaporative weight loss

		Heart rate		Evaporative weight loss	
Source	d.f.	Mean square	F	Mean Square	F
Ratio (R)	1	2.61	0.10	30221	2.58
Work-Temp. (WT)	1	36.90	1.36	115496	9.86 **
Rest-Temp. (RT)	2	231.22	8.50 **	30149	2.57
Time (T)	5	454.11	16.70 **	24028	2.05
Subject	3	4098.06	150.34 **	5311	0.45
R * WT	1	91.88	3.38	13136	1.12
R * RT	2	178.74	6.57 **	5988	0.51
R * T	5	28.47	1.05	12533	1.07
WT * T	5	48.58	1.79	21023	1.80
RT * T	10	26.10	0.96	24486	2.09 *
Error	150	27.20		11713	
Total	185				

* $\alpha < 0.05$

** $\alpha < 0.01$

Table 10. Multiple range test for heart rate.

Condition	Mean (beats/min)		
HD-work, 8% HD-rest (2)	109.83	A	
WH-work, 25% C-rest (1)	104.72	A	B
HD-work, 25% C-rest (4)	103.46		B
WH-work, 25% WH-rest (7)	103.25		B
HD-work, 25% HD-rest (8)	103.08		B
HD-work, 8% C-rest (5)	102.25		B
WH-work, 8% C-rest (6)	101.50		B
WH-work, 8% WH-rest (3)	100.08		B

WH; warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

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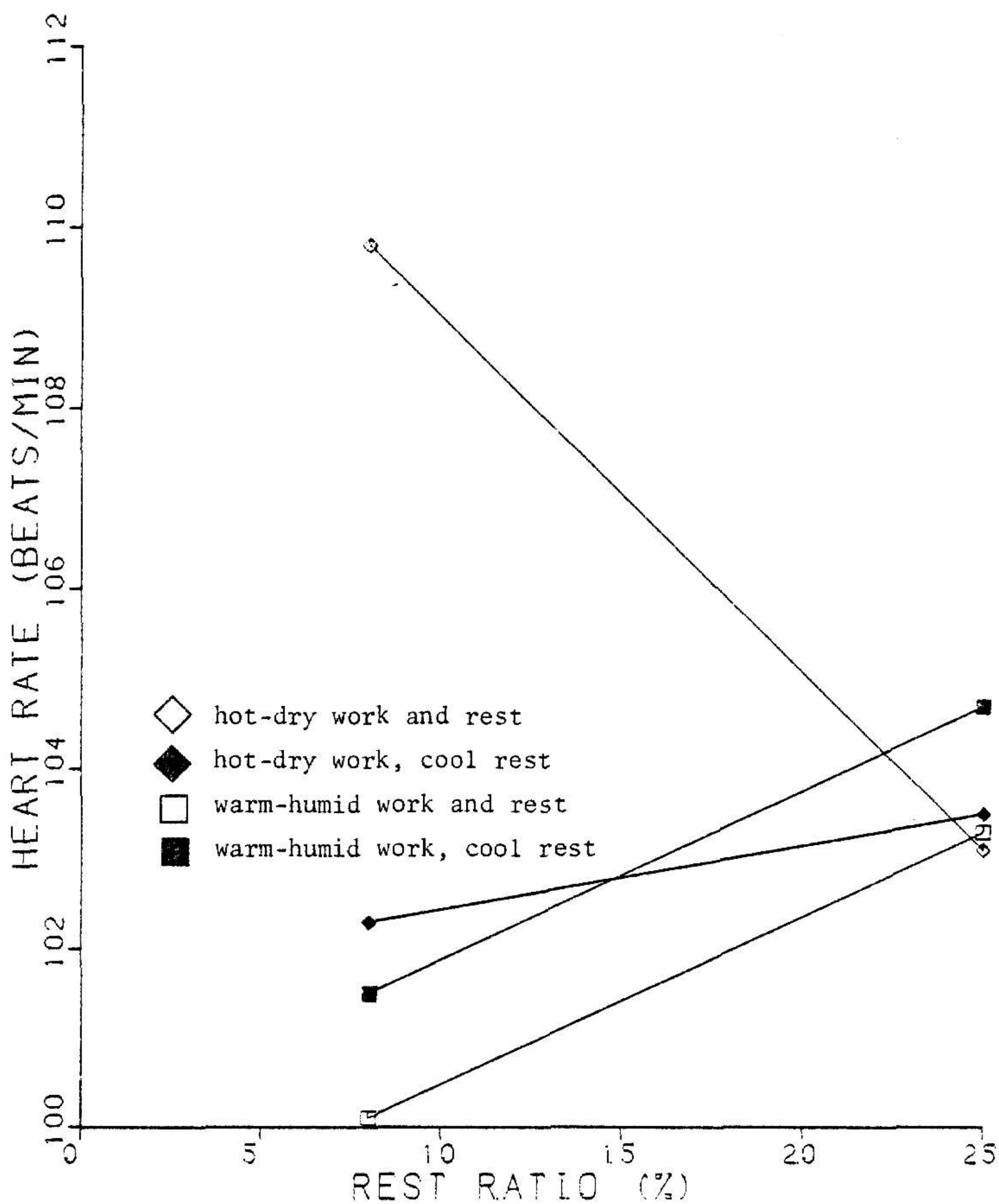

Figure 8. Heart rate vs Rest ratio

Table 11. Multiple range test for evaporative weight loss

Condition	Mean $(g/m^2 - h)$		
HD-work, 8% C-rest (5)	300.0	A	
HD-work, 25% C-rest (4)	257.9	A	B
HD-work, 8% HD-rest (2)	245.4	A	B
HD-work, 25% HD-rest (8)	219.6	C	B
WH-work, 25% C-rest (1)	207.2	C	B
WH-work, 8% WH-rest (3)	205.0	C	B
WH-work, 8% C-rest (6)	202.9	C	B
WH-work, 25% WH-rest (7)	168.3	C	

WH: warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh17%)

C : cool (23°Cdb, rh 50%)

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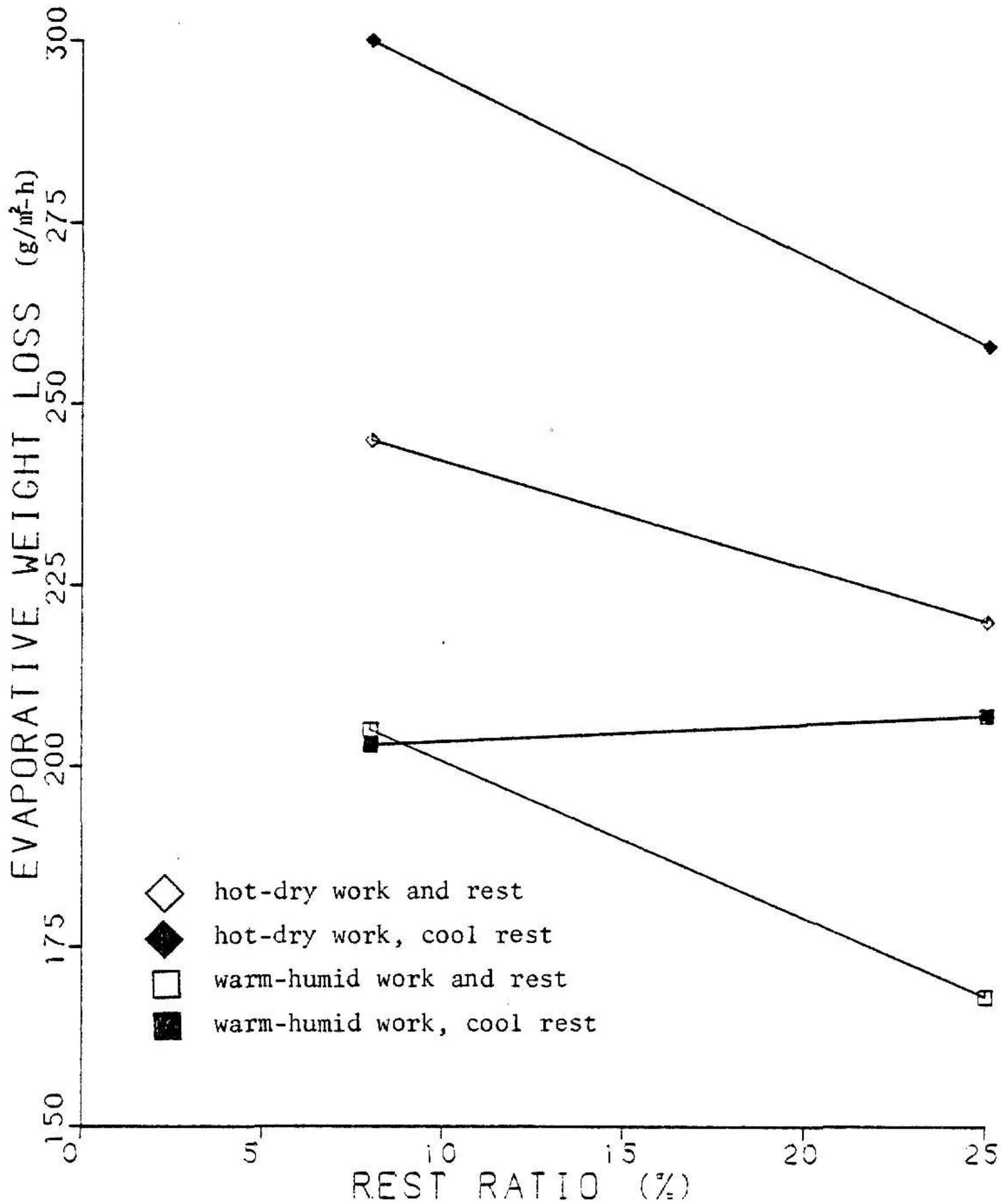

Figure 9. Evaporative weight loss vs Rest ratio

Table 12. Analysis of Variance of blood pressure

	Systolic blood pressure			Diastolic blood pressure	
Source	d.f.	Mean square	F	Mean square	F
Ratio (R)	1	410.30	5.19 *	175.85	2.11
Work-Temp. (WT)	1	66.58	0.84	581.59	6.99 **
Rest-Temp. (RT)	2	200.53	2.54	290.37	3.49 *
Time (T)	5	219.50	2.78 *	118.56	1.42
Subject	3	4614.25	58.39 **	2490.70	29.92 **
R * WT	1	1008.71	12.76 **	16.21	0.19
R * RT	2	358.44	4.54 *	62.99	0.76
R * T	5	147.86	1.87	53.33	0.64
WT * T	5	42.03	0.53	160.60	1.93
RT * T	10	57.98	0.73	112.59	1.35
Error	150	79.03		83.25	
Total	185				

* $\alpha < 0.05$

** $\alpha < 0.01$

trend of mean systolic and diastolic blood pressure of the four subjects. Means of systolic blood pressure (Table 13) of the eight conditions were significantly different. Figure 10 shows systolic blood pressure for the two rest ratios. Rest ratio was significant for systolic blood pressure in the condition of hot-dry work and cool rest.

Diastolic blood pressure

Diastolic blood pressure (Table 12) was significant for work temperature (80 mmHg for warm-humid and 75 mmHg for hot-dry), rest temperature (76 mmHg for cool, 76 mmHg for warm-humid and 81 mmHg for hot-dry), and subject (68 mmHg, 76 mmHg, 82 mmHg, and 84 mmHg). Means of diastolic blood pressure (Table 14) were not significantly different for condition. Figure 11 shows diastolic blood pressure for the two rest ratios. Rest ratio was not significant for diastolic blood pressure so far as work and rest temperatures were concerned.

Thermal sensation vote

Thermal sensation vote (Table 15) was significant for work temperature (6.14 for warm-humid and 6.56 for hot-dry), rest temperature (6.11 for warm-humid, 6.42 for cool and 6.54 for hot-dry), time (6.03, 6.32, 6.37, 6.47, 6.44, and 6.48 in order of work period), and subject (6.13, 6.27, 6.50, and 6.51). Means of the thermal sensation vote of the eight conditions were significantly different (Table 16). Figure 12 shows thermal sensation vote for the two rest ratios. Rest ratio was not significant for thermal sensation vote so far as work and rest temperatures were concerned. Due to performing work, the actual thermal sensation vote was about 7% higher than the predicted one for sedentary sitting (Appendix II).

Table 13. Multiple range test for systolic blood pressure

Condition	Mean (mmHg)			
HD-work, 8% C-rest (5)	131.17	A		
WH-work, 8% WH-rest (3)	130.67	A	B	
HD-work, 8% HD-rest (2)	128.42	A	B	C
WH-work, 25% WH-rest (7)	128.33	A	B	C
WH-work, 8% C-rest (6)	127.83	A	B	C
HD-work, 25% HD-rest (8)	126.21	A	B	C
HD-work, 25% C-rest (4)	122.79		B	C
WH-work, 25% C-rest (1)	120.06			C

WH: warm-humid (30°Cdb, rh67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh50%)

(): sequence

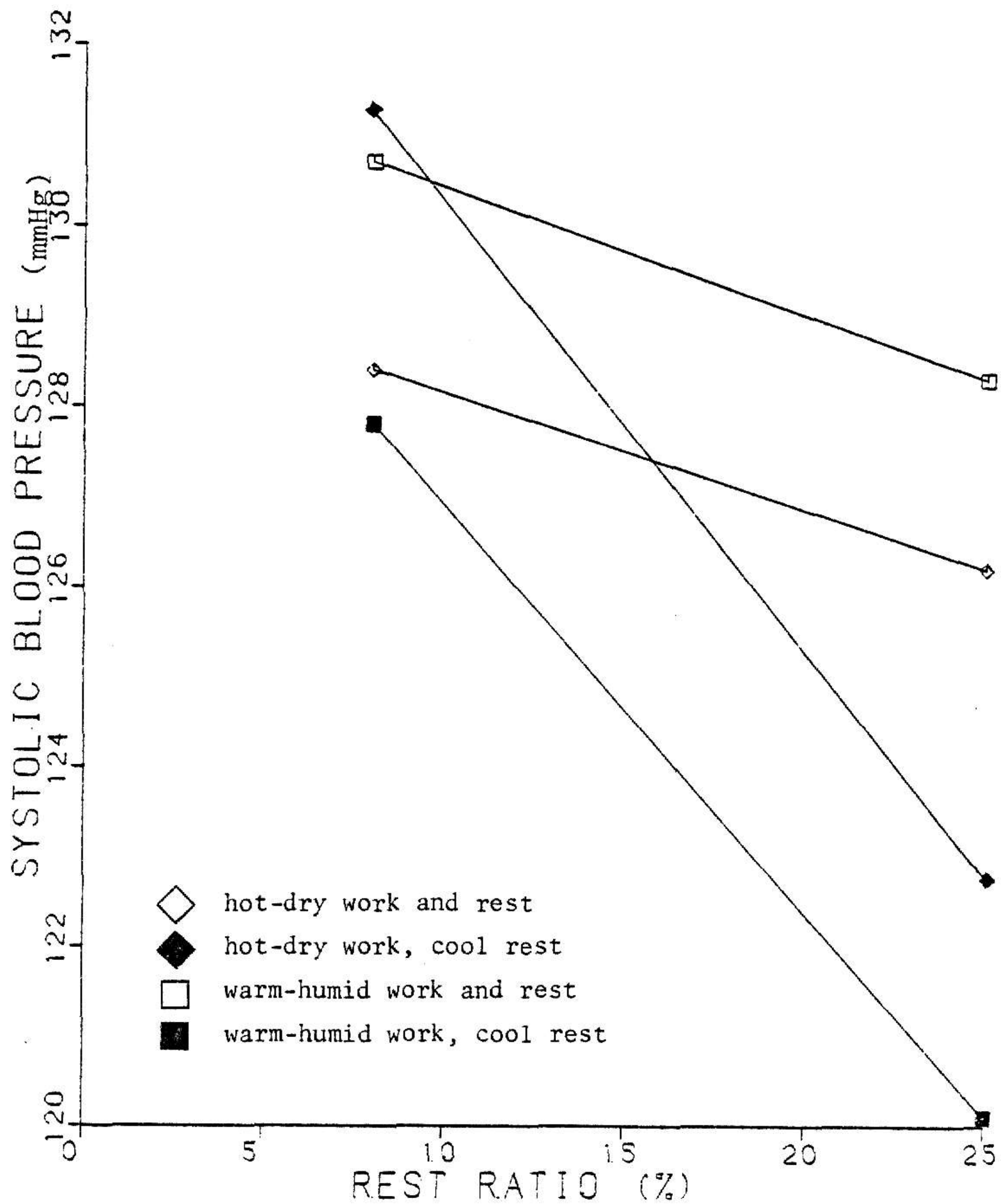

Figure 10. Systolic blood pressure vs Rest ratio

Table 14. Multiple range test for diastolic blood pressure

Condition	Mean (mmHg)	
HD-work, 25% HD-rest (8)	79.96	A
WH-work, 25% WH-rest (7)	79.42	A
WH-work, 25% C-rest (1)	79.33	A
WH-work, 8% C-rest (6)	77.71	A
WH-work, 8% WH-rest (3)	77.42	A
HD-work, 8% HD-rest (2)	76.08	A
HD-work, 8% C-rest (5)	73.42	A
HD-work, 25% C-rest (4)	72.79	A

WH: warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

(): sequence

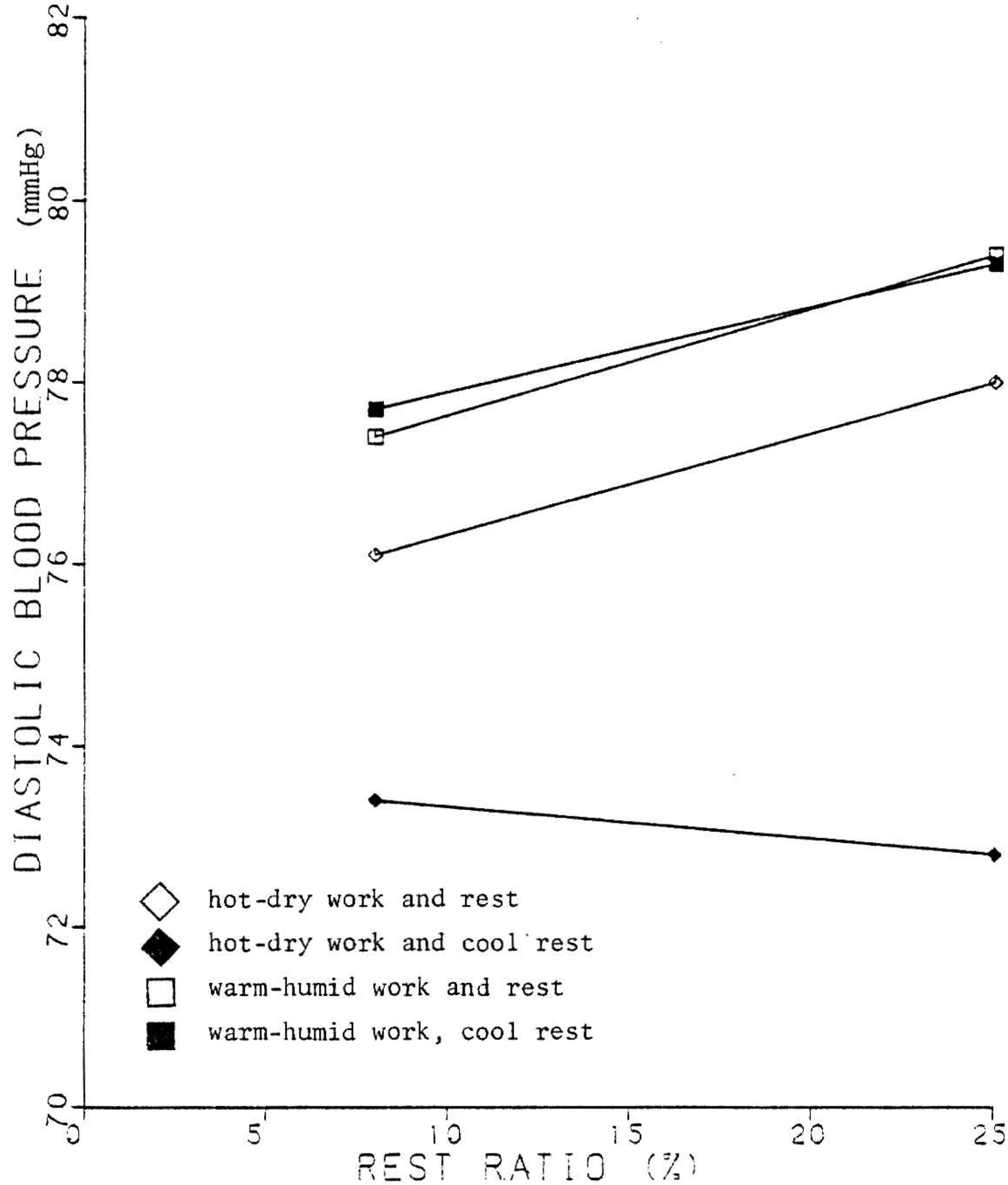

Figure 11. Diastolic blood pressure vs Rest ratio

Table 15. Analysis of Variance of thermal sensation and comfort vote

		Thermal sensation vote		Seven-pair comfort vote	
Source	d.f.	Mean square	F	Mean square	F
Ratio (R)	1	0.14	0.76	16.7	0.39
Work-Temp. (WT)	1	3.86	21.57 **	680.9	15.99 **
Rest-Temp. (RT)	2	1.24	6.92 **	124.5	2.92
Time (T)	5	0.85	4.73 **	533.8	12.54 **
Subject	3	1.56	8.70 **	591.4	13.89 **
R * WT	1	0.92	5.17 **	2.9	0.07
R * RT	2	0.13	0.74	201.5	4.73 *
R * T	5	0.15	0.82	27.9	0.66
WT * T	5	0.25	1.37	37.5	0.88
RT * T	10	0.09	0.52	57.3	1.35
Error	150	0.18			
Total	185				

* $\alpha < 0.05$

** $\alpha < 0.01$

Table 16. Multiple range test for thermal sensation vote

Condition	Mean		
HD-work, 8% HD-rest (2)	6.88	A	
HD-work, 8% C-rest (5)	6.71	A	B
HD-work, 25% HD-rest (8)	6.63	A	B
HD-work, 25% C-rest (4)	6.54	C	B
WH-work, 25% C-rest (1)	6.28	C	D
WH-work, 8% C-rest (6)	6.08	E	D
WH-work, 25% WH-rest (7)	5.92	E	
WH-work, 8% WH-rest (3)	5.88	E	

WH: warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

(): sequence

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

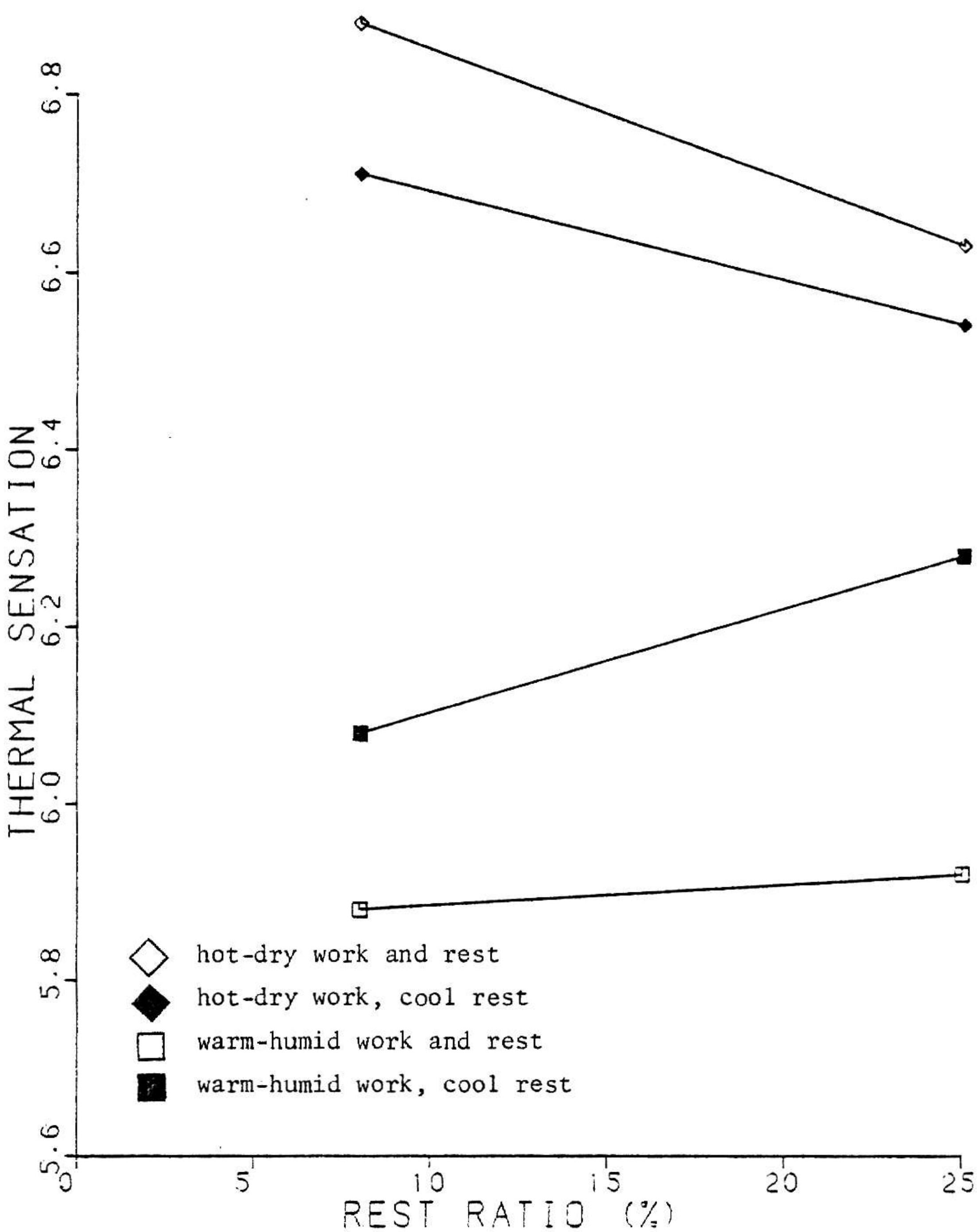

Figure 12. Thermal sensation vote vs Rest ratio

Seven-pair comfort vote

The seven-pair comfort vote (Table 15) was significant for work temperature (25.7% for hot-dry, and 31.2% for warm-humid), time (35.4%, 31.5%, 28.6%, 25.9%, 25.9%, and 23.5% in order of work period), and subject (24.1%, 27.2%, 30.7%, 31.8%). Means of the vote (Table 17) of the eight conditions were significantly different. Figure 13 shows comfort for the two rest ratios. Rest ratio was not significant for comfort so far as work and rest temperatures were concerned. Unlike the thermal sensation vote, the subjects felt more comfort with 8% rest, though there was no significant difference between the two rest ratios, when rest temperature was the same as work temperature. Rest temperature was not significant for comfort while it was significant for the thermal sensation vote in Table 15.

Table 17. Multiple range test for seven-pair comfort vote.*

Condition	Mean (%)			
WH-work, 8% WH-rest (3)	35.2	A		
WH-work, 25% C-rest (1)	33.9	A	B	
WH-work, 25% WH-rest (7)	31.1	A	B	C
WH-work, 8% C-rest (6)	30.0		B	C
HD-work, 25% C-rest (4)	27.6	D		C
HD-work, 8% C-rest (5)	24.8	D		
HD-work, 8% HD-rest (2)	23.7	D		
HD-work, 25% HD-rest (8)	23.2	D		

WH: warm-humid (30°Cdb, rh 67%)

HD: hot-dry (39°Cdb, rh 17%)

C : cool (23°Cdb, rh 50%)

(): sequence

* See Appendix II(c) for thermal comfort ballot.

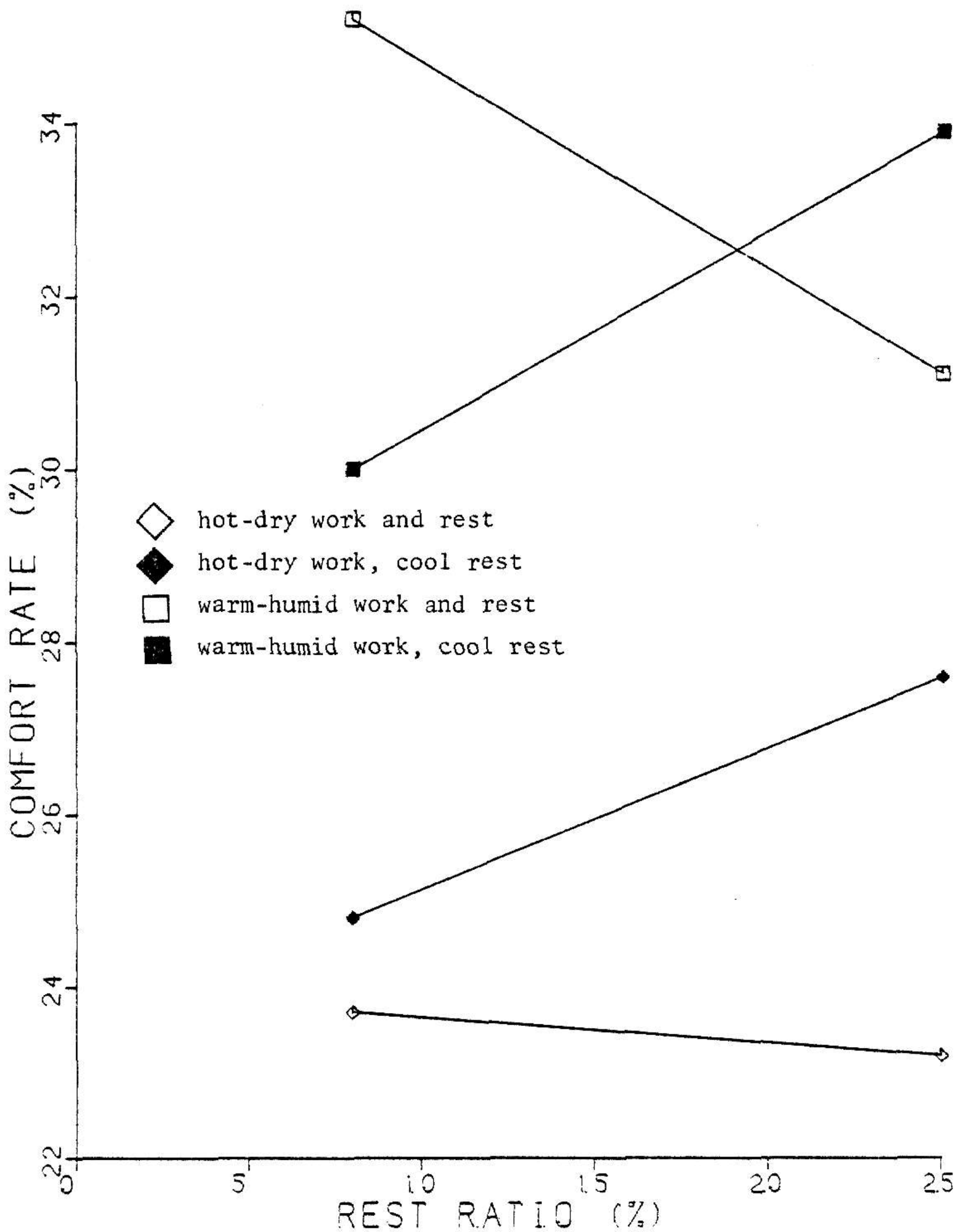

Figure 13. Comfort vs Rest ratio. 100% is maximum comfort.

CONCLUSION

The work-rest ratio, work environment, rest environment, and work time were adequate enough for the subjects to perform the given work (300 Watts) safely.

Skin temperature was affected by ratio, work temperature and time. Rectal temperature was affected by ratio, work temperature, and rest temperature. Oral temperature, which was not comparable with rectal temperature due to the subjects' cold water intake during work performance, was affected by ratio. Heart rate was affected by rest temperature and time. Evaporative weight loss, the amount of which was proportional to each subject's weight, was affected by work temperature only. Systolic blood pressure was affected by ratio and time. Distolic blood pressure was affected by work temperature and rest temperature. Thermal sensation vote was affected by work temperature, rest temperature, and time, while comfort vote was affected by work temperature and time. All the above is summarized in Table 18.

Though none of the eight conditions were repeated, acclimatization was noticeable from two conditions, warm-humid work and 25% cool rest (first day) and warm-humid work and 8% cool rest (sixth day). Men are acclimatized most rapidly during the first seven days (Robinson 1943). In spite of the smaller rest ratio of the sixth day, the means of sixth day were lower than those of first day: 0.38°C less for skin temperature, 3.2 beats/min less for heart rate, 1.6 mmHg less for diastolic blood pressure, and 0.2 less for thermal sensation vote.

Table 18. Summary of conclusions

Variable	Criteria								
	Skin temp.	Rectal temp.	Oral temp.	Heart rate	Weight loss	Systolic blood pressure	Diastolic blood pressure	Thermal sensation	Comfort
Ratio	*	*	*			*			
Work Temp.	*	*			*		*	*	*
Rest Temp.		*		*			*	*	
Time	*			*		*		*	*

* significant ($\alpha < 0.05$)

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APPENDIX I

Calculation of metabolic rate

Ford et al (1957) example:

Weight (W): 77.2 kg + 2.5 kg (apparatus) = 79.7 kg

No. of trips (N) : 22 trips/1.5 min for age 20-24 group

Vertical Distance (D): 0.46 m/trip

Work = W x N x D

= 79.7 kg x 22 trip/1.5 min x 0.46 m/trip

= 537.71 kg - m/min

= 87.856 watt

Energy cost (by experiment) = 8.5 kcal/min

= 593.13 watt

$$\text{Efficiency} = \frac{87.856 \text{ watt}}{593.13 \text{ watt}} = 0.148$$

$$\text{Energy cost} = \frac{1}{0.148}\ W \cdot N \cdot D \text{ kg - m/min for step task.}$$

My experiment:

W = 78.5 kg + 3.85 kg (apparatus) = 82.35 kg

N = 12 trip/min

D = 0.46 m/trip

$$\text{Energy cost (activity)} = \frac{1}{0.148}\ W \cdot N \cdot D$$

$$= \frac{1}{0.148} \times 82.35 \text{ kg} \times 12 \text{ trip/min} \times 0.46 \text{ m/trip}$$

= 3071 kg - m/min

= 502 watt

= 7.2 kcal/min

Total metabolic rate for stepping

= Basal + Activity

= 1.0 kcal/min + 7.2 kcal/min

= 8.2 kcal/min

= 572 watt

Energy cost for standing (Goelzer, 1977)

= 0.6 kcal/min

Total metabolic rate for standing

= Basal + Activity

= 1.0 kcal/min + 0.6 kcal/min

= 1.6 kcal/min

= 110 watt

Total metabolic rate for 40% stepping and 60% standing

= 0.4 x 572 watt + 0.6 x 110 watt = 300 watt

APPENDIX II

a. Thermal sensation vote

Vote No. ______________________ Test No. ______________________

Name: ______________________________________

Circle the number beside the adjective that describes how you feel

7 Hot

6 Warm

5 Slightly warm

4 Neutral

3 Slightly cool

2 Cool

1 Cold

b. Thermal sensation vote (Rohles, Hayter, and Milliken, 1975)

$TS = -1.047 + 0.158\ ET^* \qquad ET^* < 20.7$

$TS = -4.444 + 0.326\ ET^* \qquad 20.7 < ET^* < 31.7$

$TS = 2.547 + 0.106\ ET^* \qquad ET^* > 31.7$

TS = Thermal sensation vote

ET* = new effective temperature, °C

For example:

IF $ET^* = 31°C$

$TS = -4.444 + 0.326\ (31) = 5.662$

IF $ET^* = 34°C$

$TS = 2.547 + 0.106(34) = 6.151$

c. Seven-pair comfort vote

Name: ______________________ Test No. __________

Vote No. __________

comfortable	9	8	7	6	5	4	3	2	1	uncomfortable
bad temperature	1	2	3	4	5	6	7	8	9	good temperature
pleasant	9	8	7	6	5	4	3	2	1	unpleasant
good ventilation	9	8	7	6	5	4	3	2	1	poor ventilation
unacceptable	1	2	3	4	5	6	7	8	9	acceptable
uncomfortable temperature	1	2	3	4	5	6	7	8	9	comfortable temperature
satisfied	9	8	7	6	5	4	3	2	1	dissatisfied

% comfort = (Σ ratings - 7) 1.79

$$\frac{100}{\text{rating of } 9 \times 7 \text{ pairs} - \text{rating of } 1 \times 7 \text{ pairs}}$$

$$= \frac{100}{63-7}$$

= 1.79

Appendix III

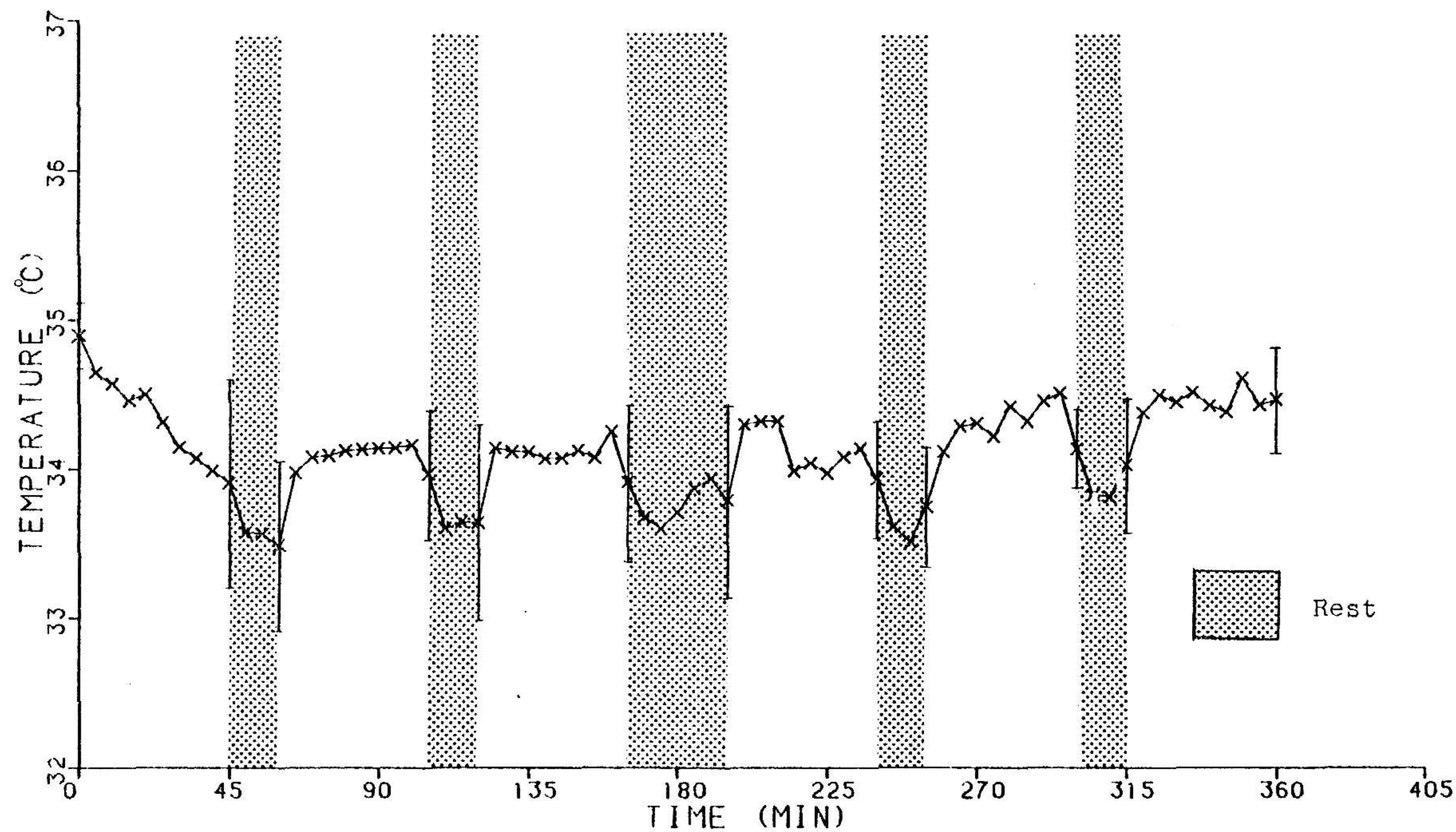

Figure 14. Mean skin temperature(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

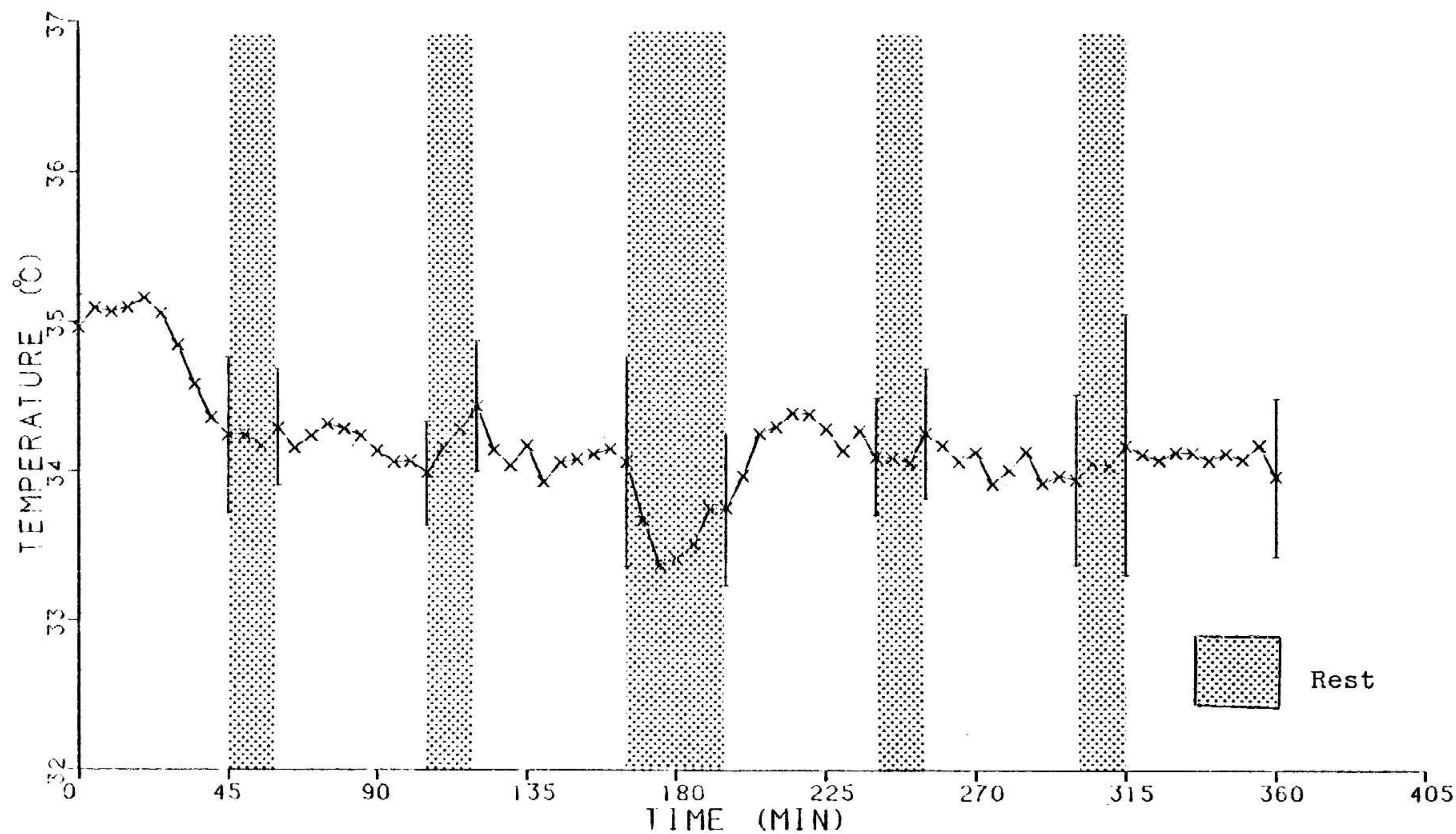

Figure 15. Mean skin temperature(25% rest, warm-humid work and rest)

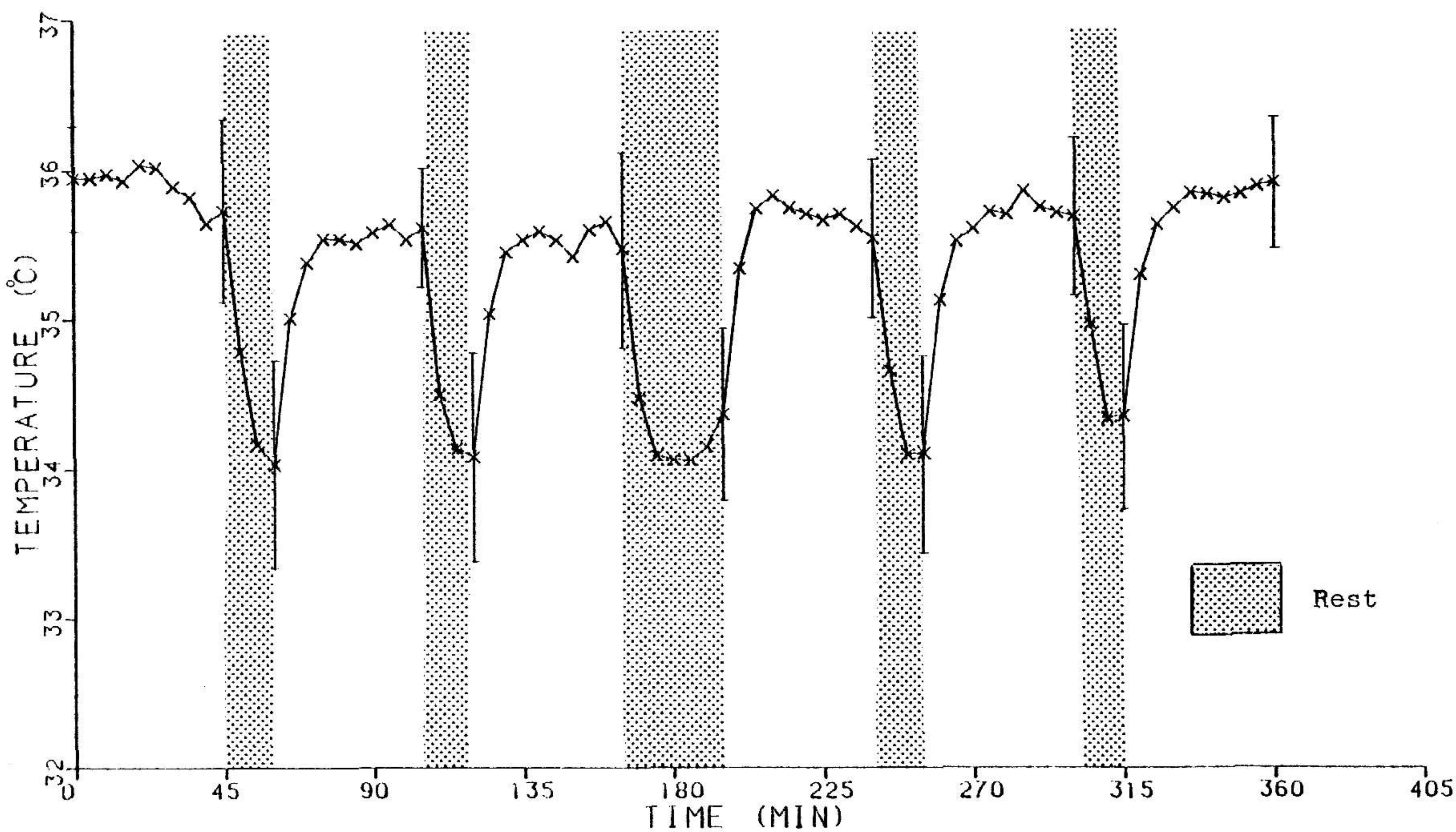

Figure 16. Mean skin temperature(25% rest, hot-dry work, cool rest)

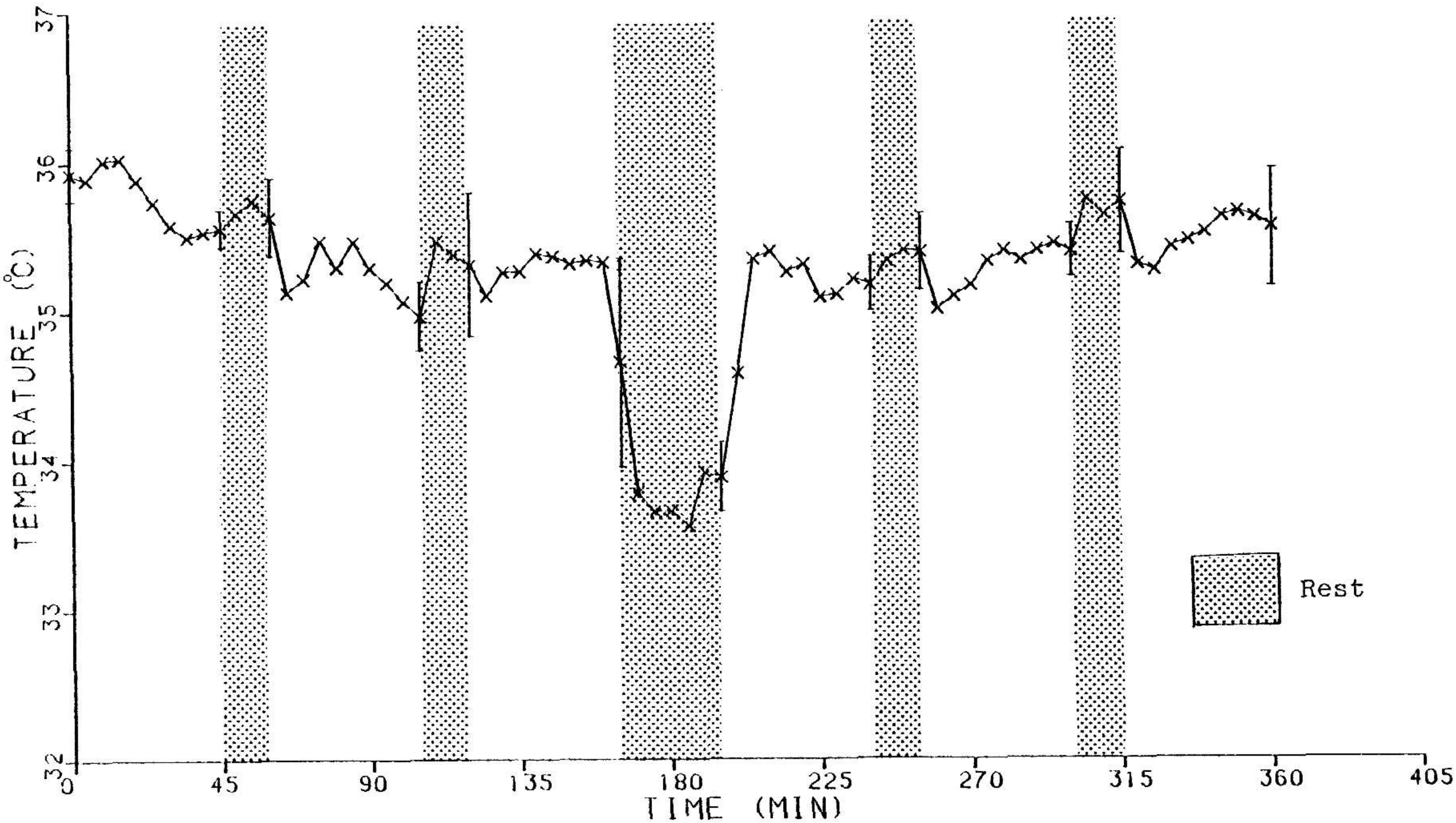

Figure 17. Mean skin temperature(25% rest, hot-dry work and rest)

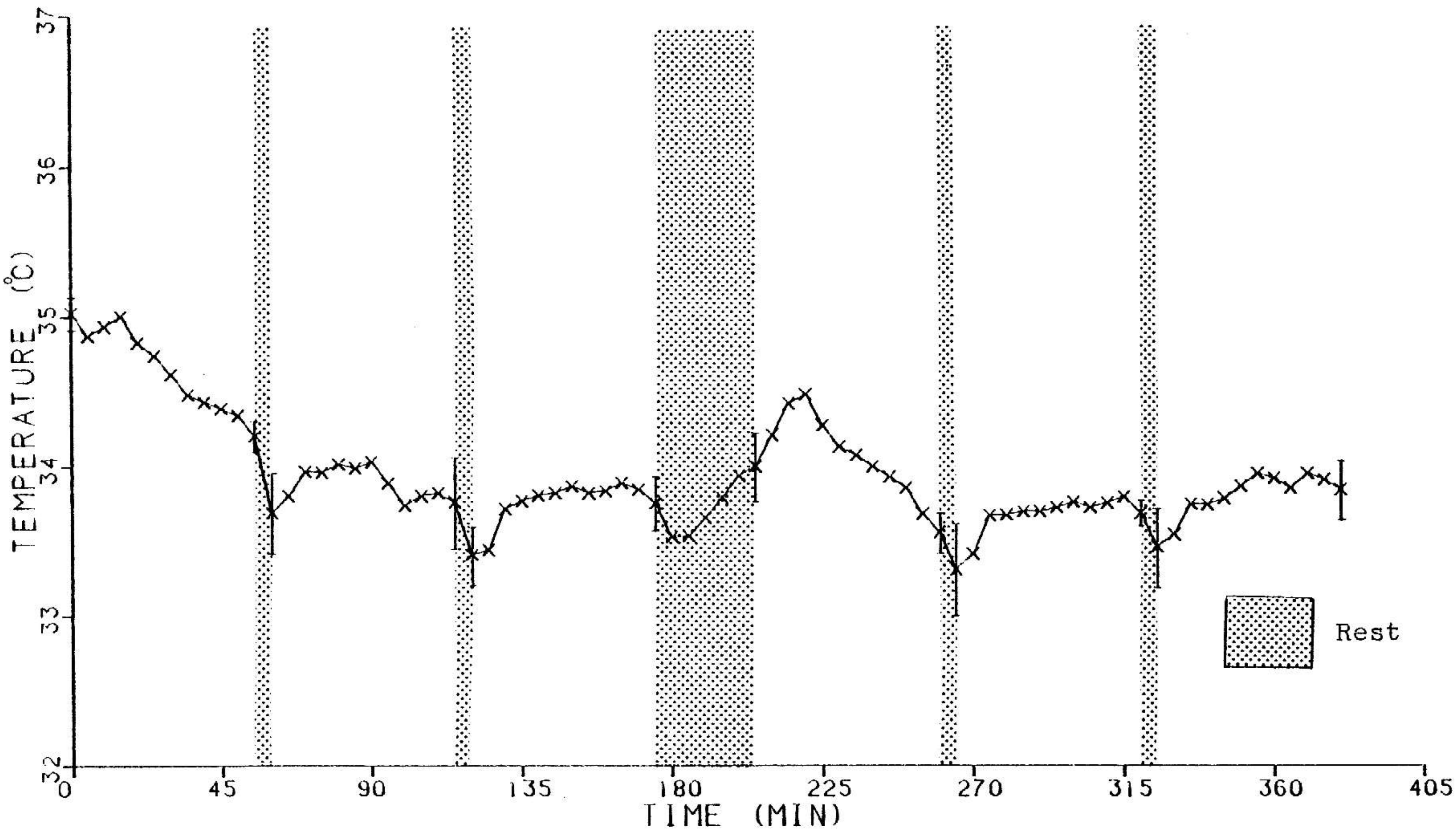

Figure 18. Mean skin temperature(8% rest, warm-humid work, cool rest)

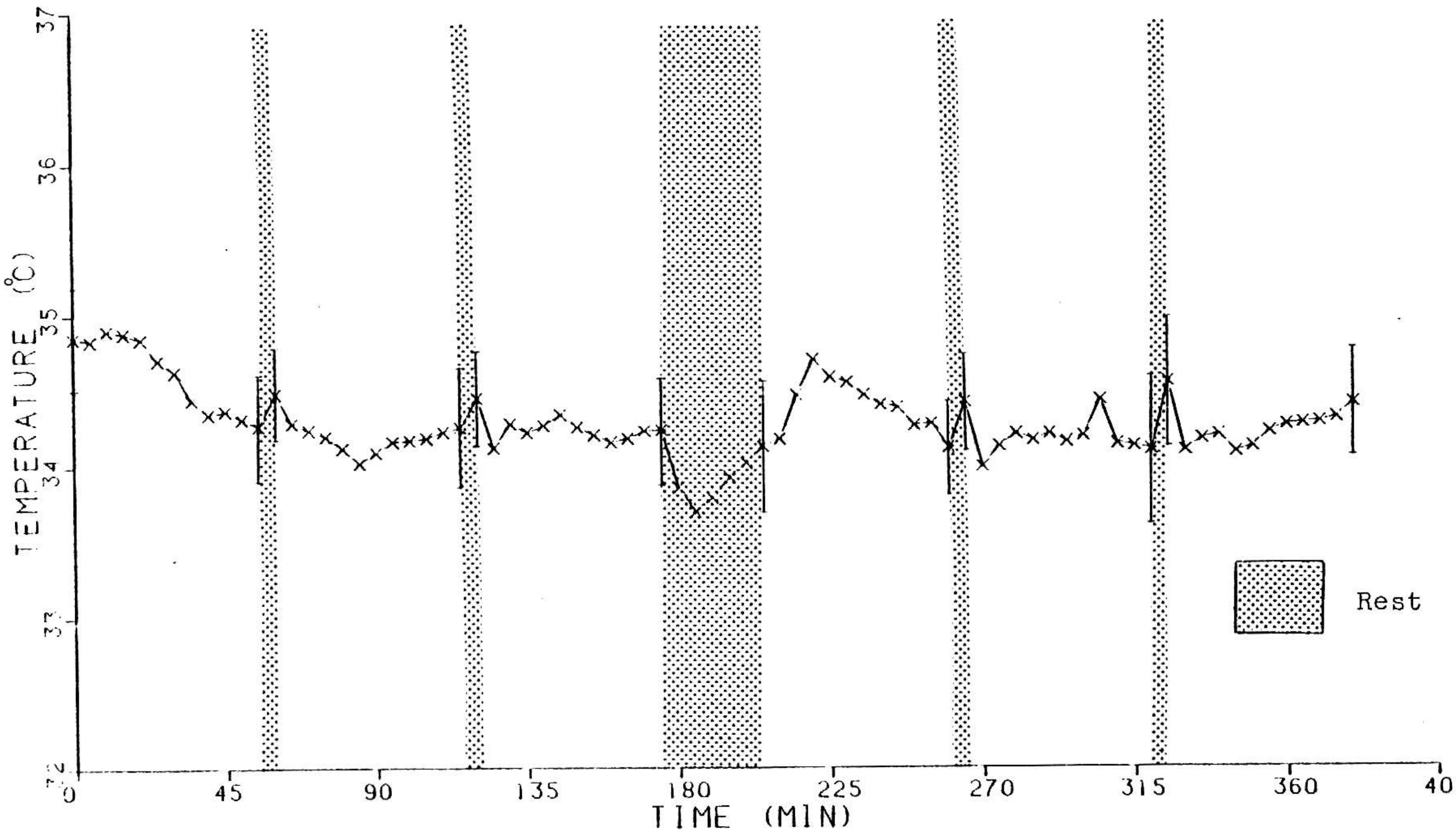

Figure 19. Mean skin temperature(8% rest, warm-humid work and rest)

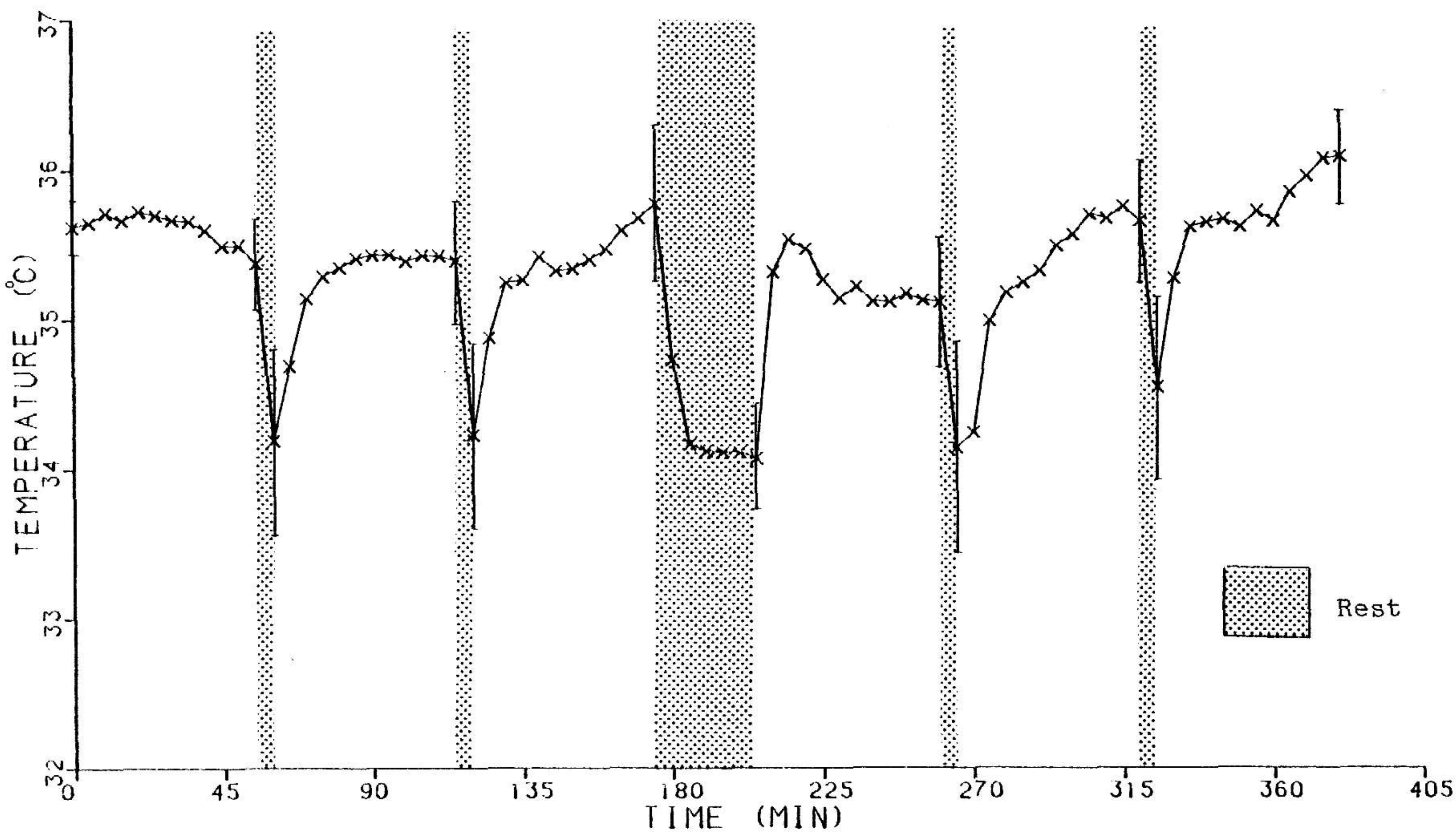

Figure 20. Mean skin temperature(8% rest, hot-dry work, cool rest)

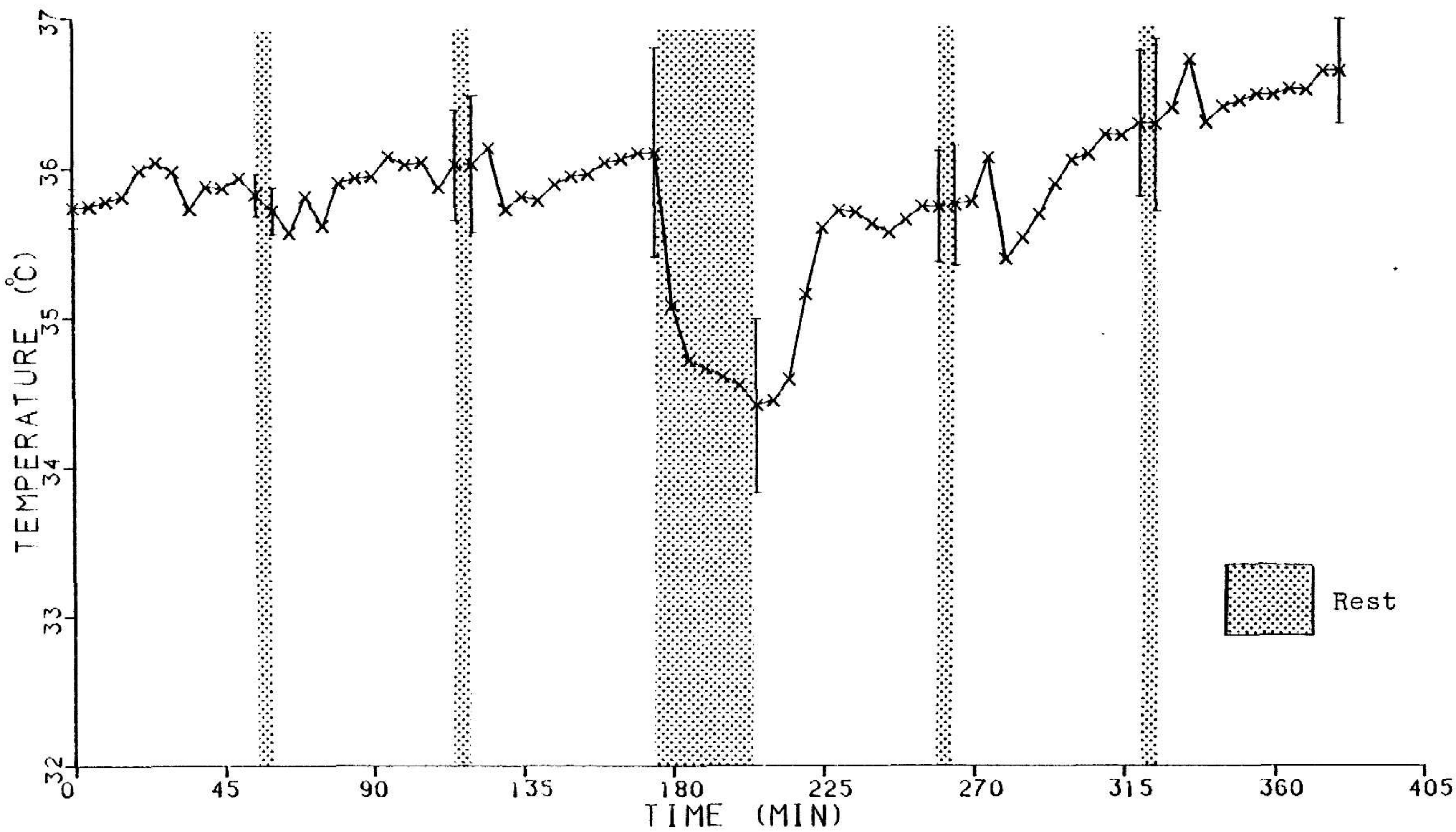

Figure 21. Mean skin temperature(8% rest, hot-dry work and rest)

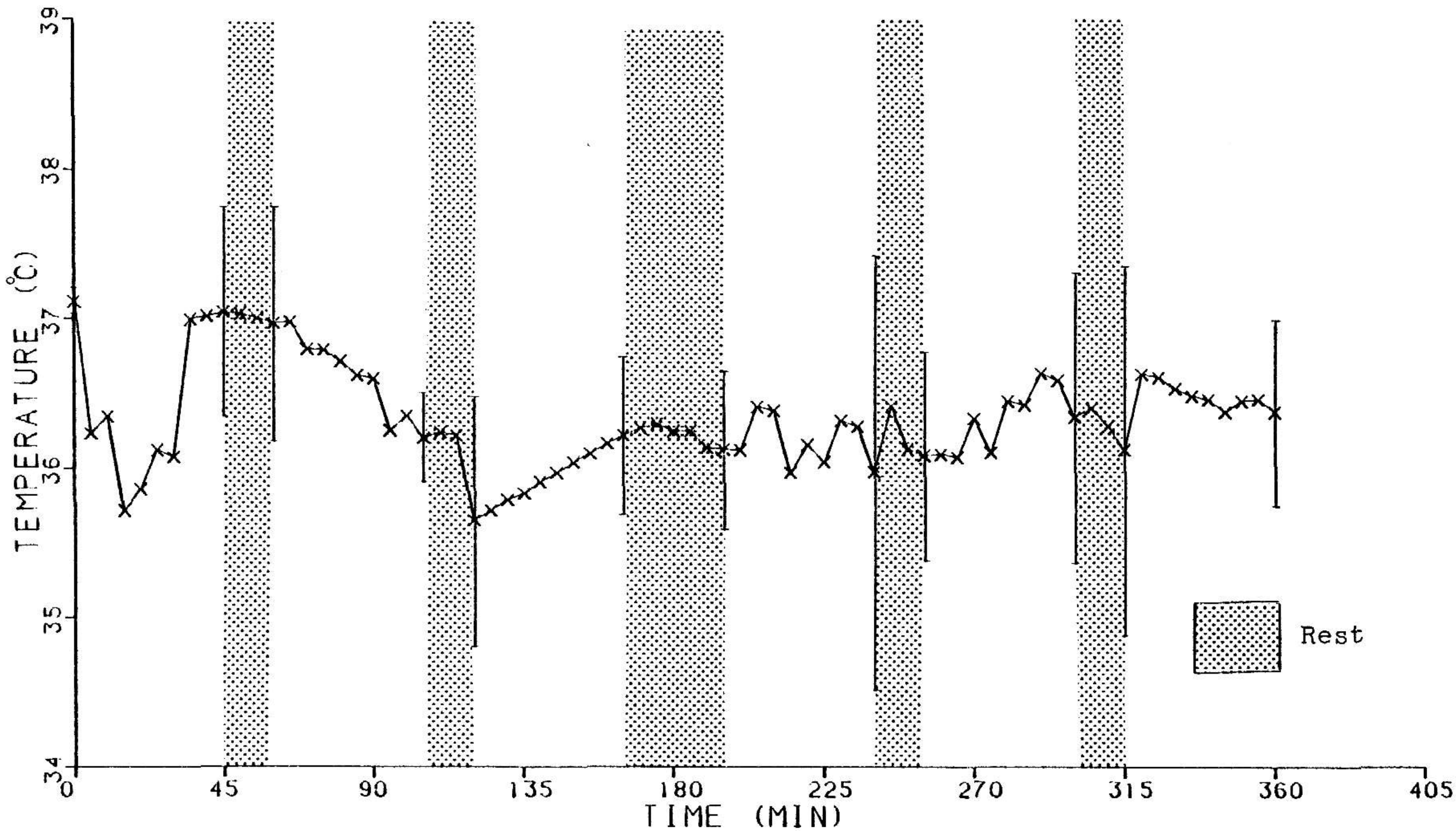

Figure 22. Rectal temperature(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

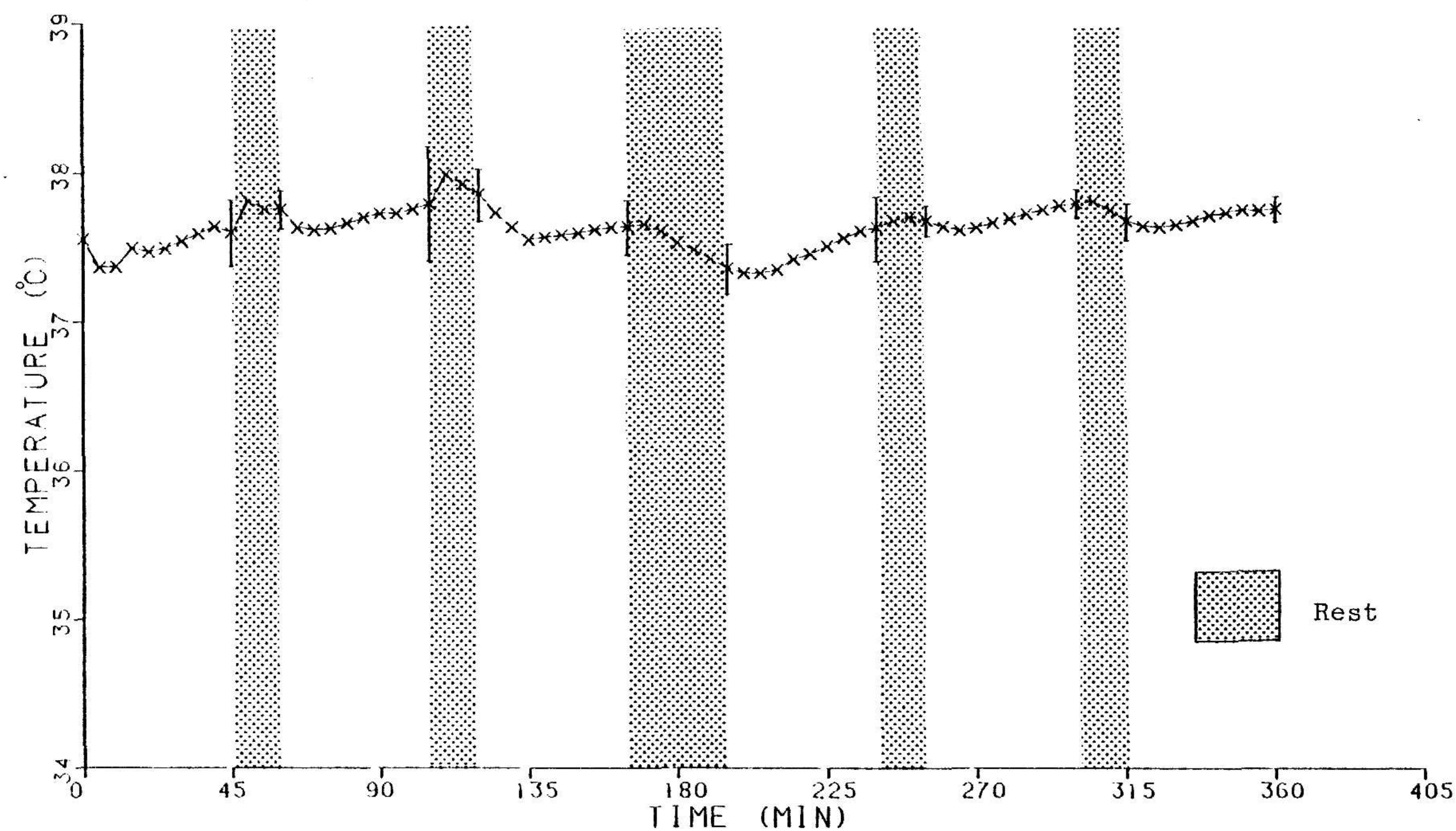

Figure 23. Rectal temperature(25% rest, warm-humid work and rest)

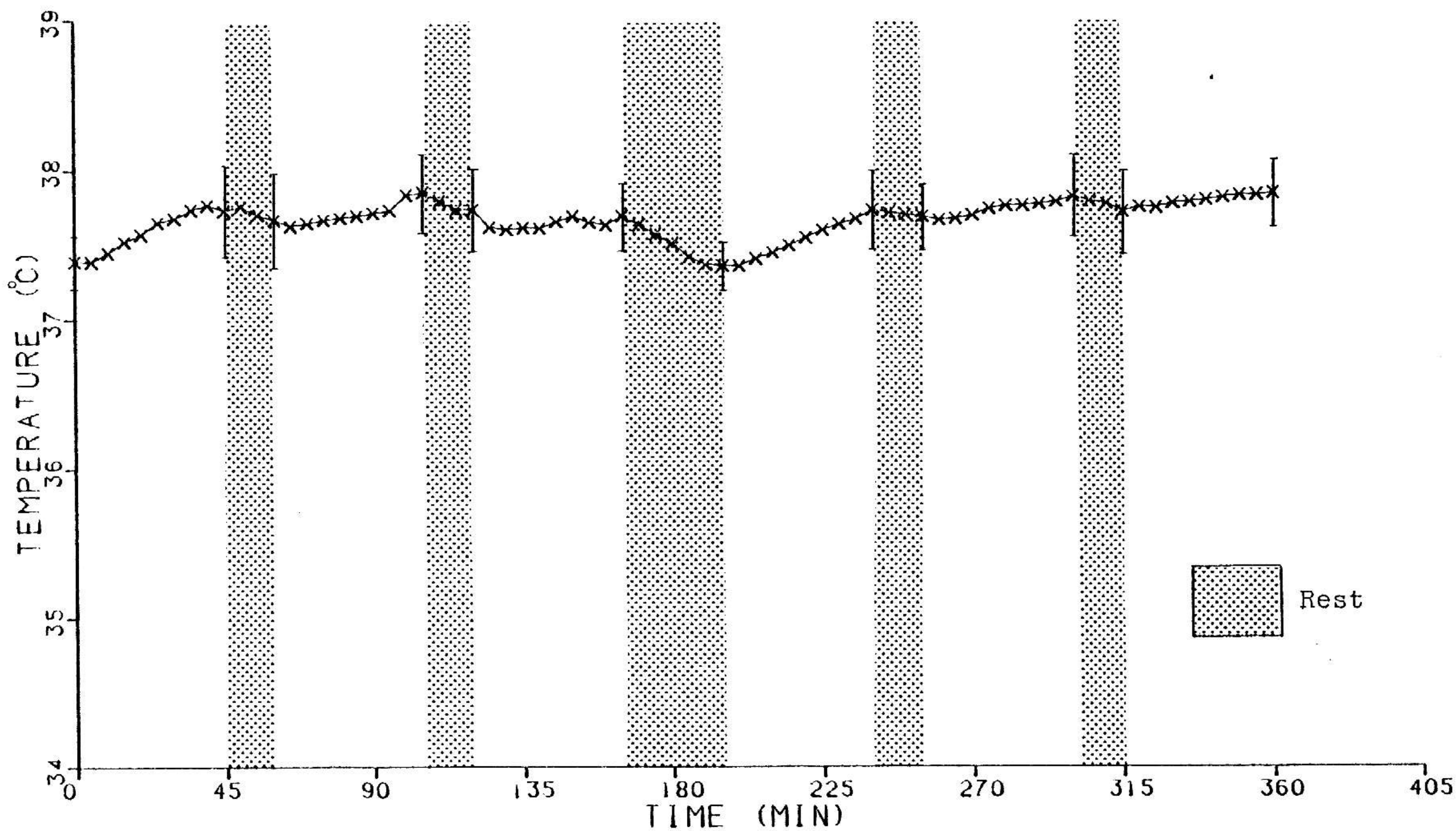

Figure 24. Rectal temperature(25% rest, hot-dry work, cool rest)

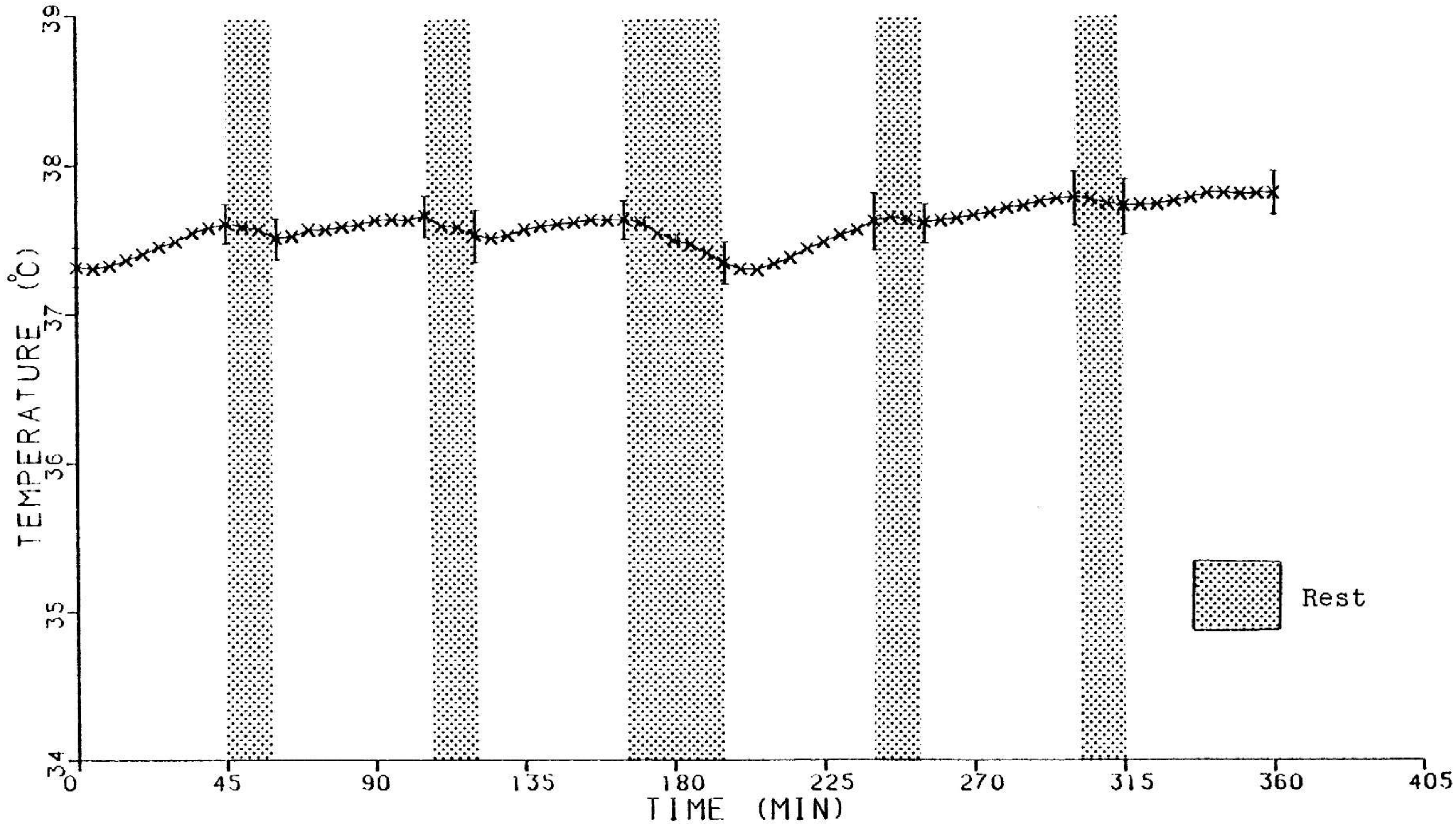

Figure 25. Rectal temperature(25% rest, hot-dry work and rest)

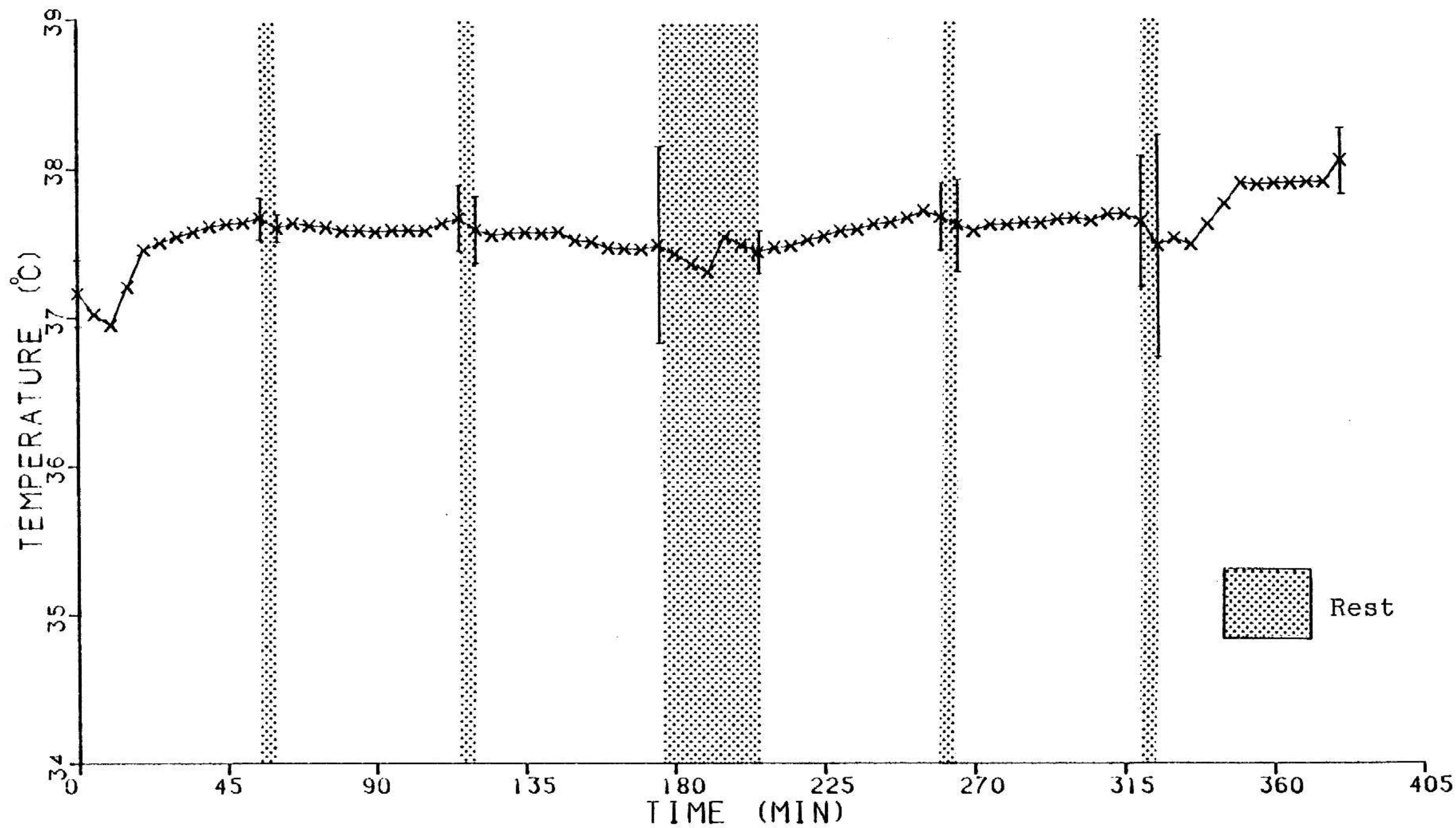

Figure 26. Rectal temperature(8% rest, warm-humid work, cool rest)

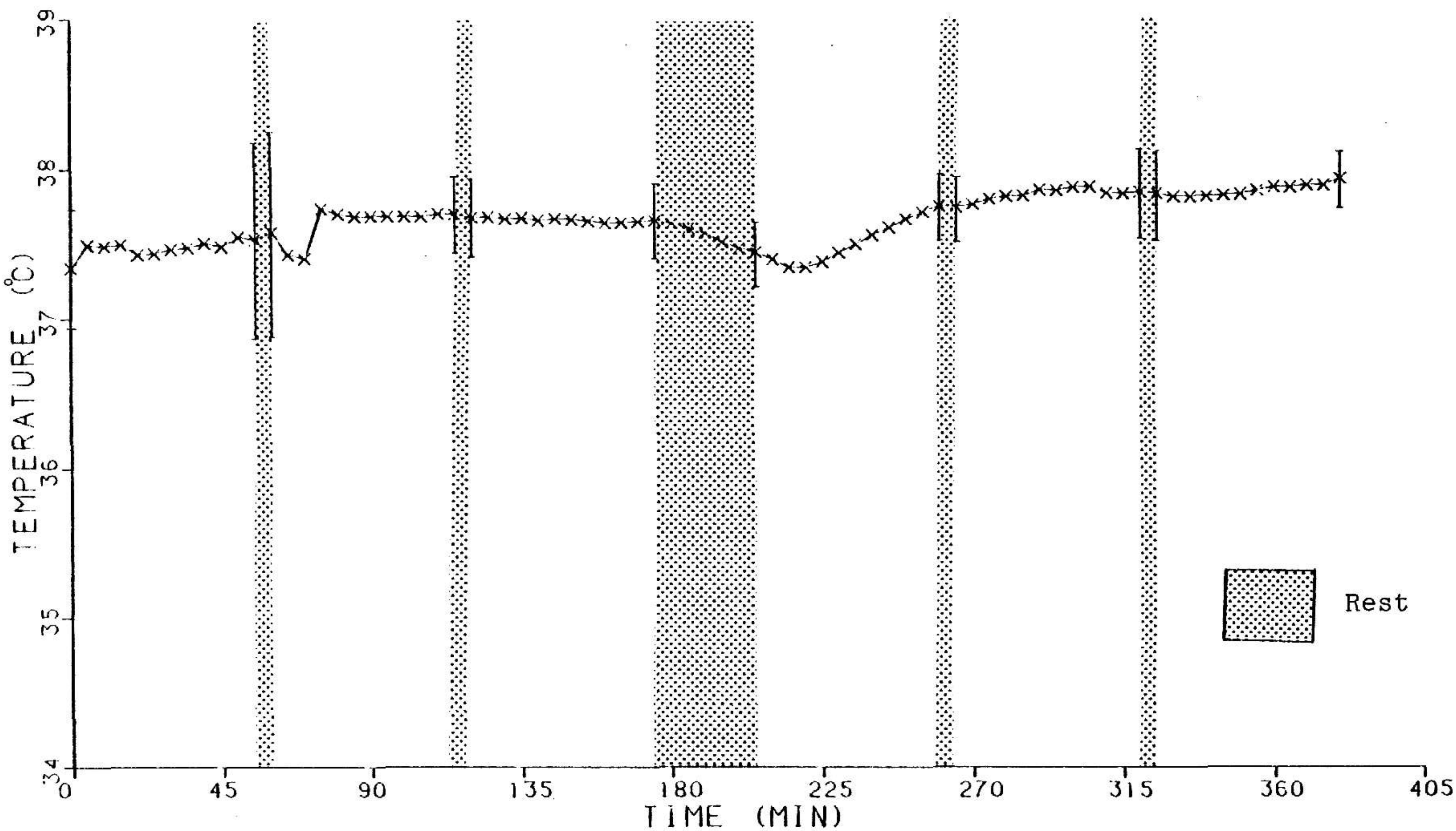

Figure 27. Rectal temperature(8% rest, warm-humid work and rest)

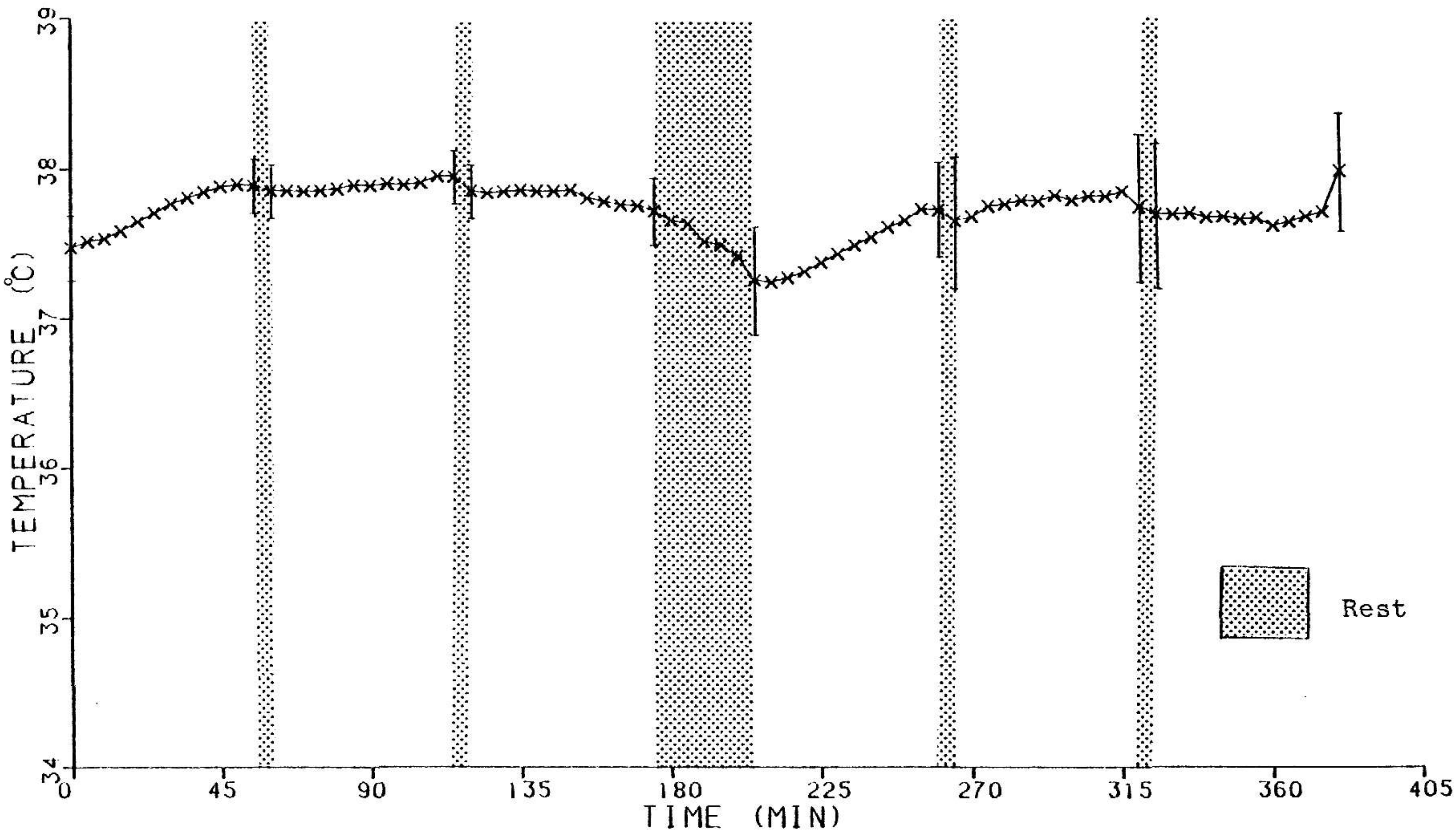

Figure 28. Rectal temperature(8% rest, hot-dry work, cool rest)

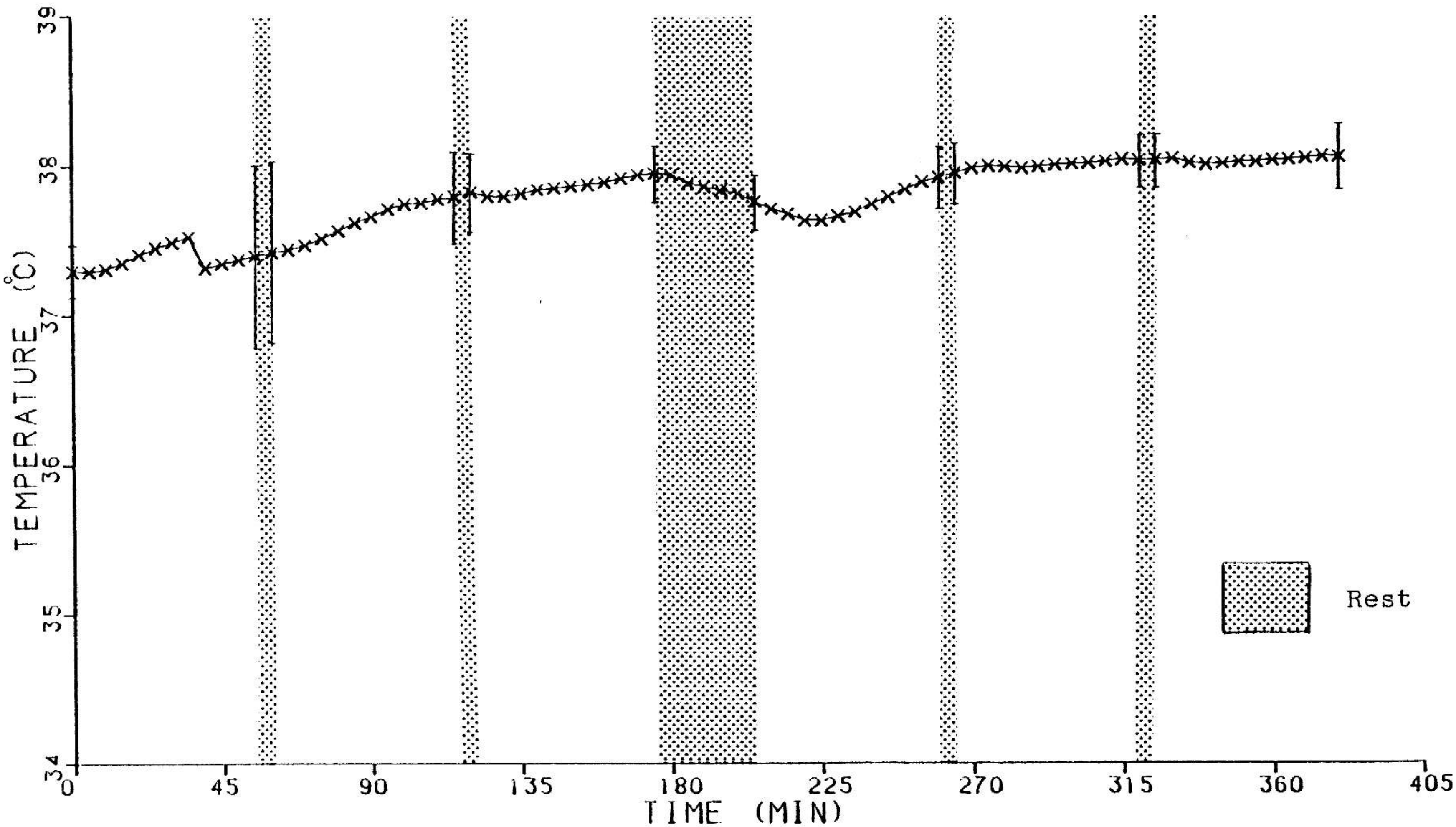

Figure 29. Rectal temperature(8% rest, hot-dry work and rest)

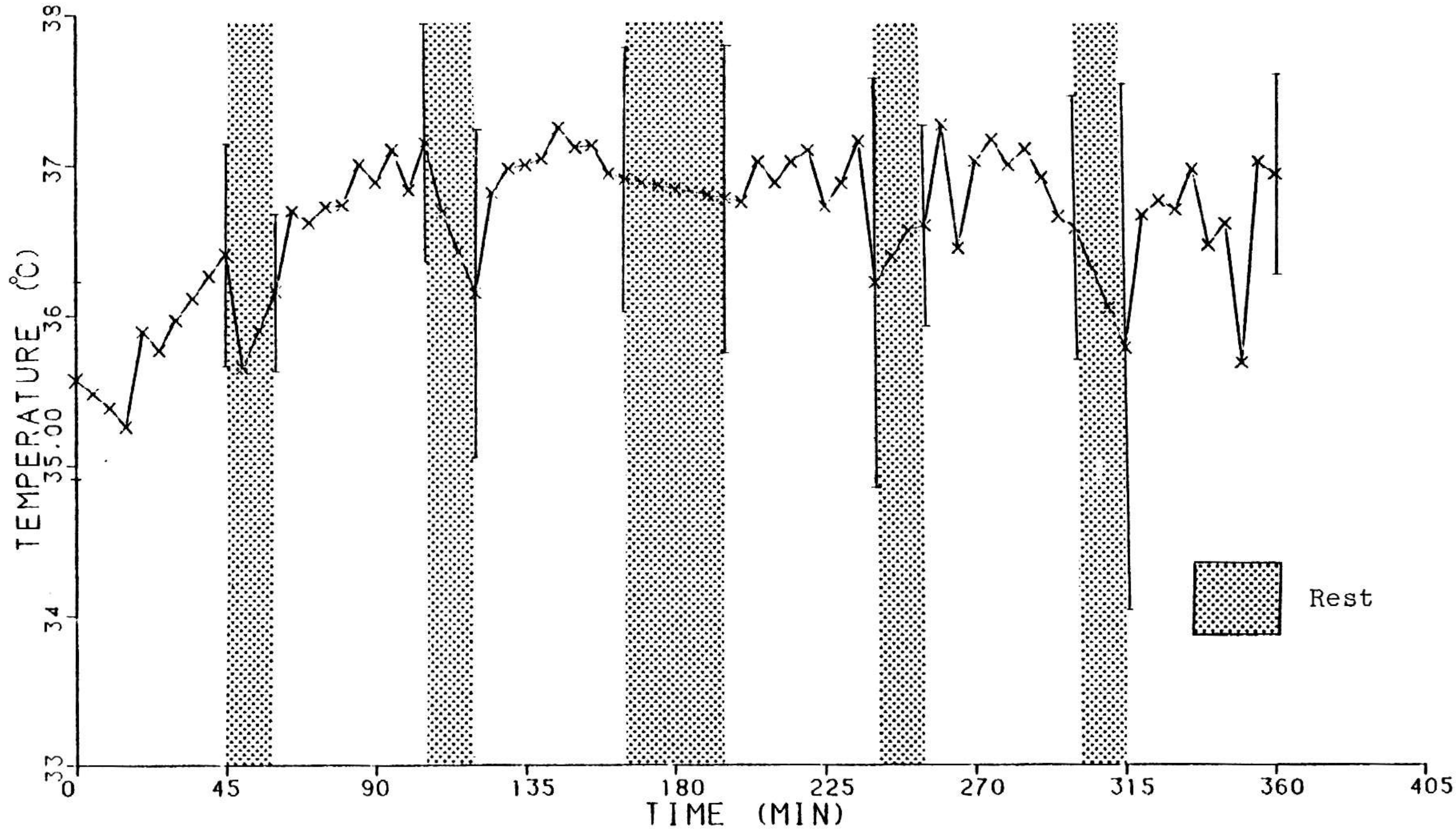

Figure 30. Oral temperature(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

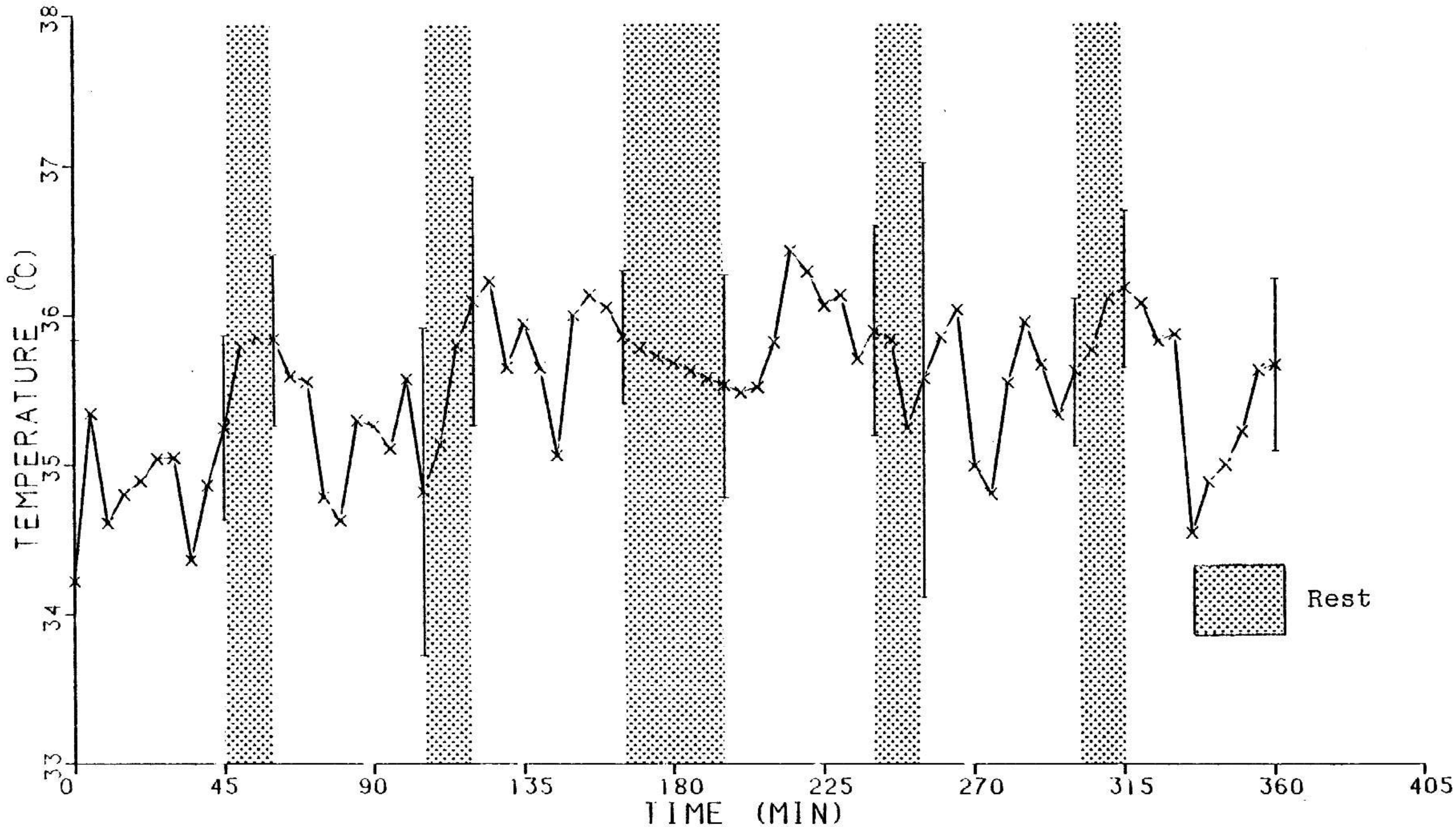

Figure 31. Oral temperature(25% rest, warm-humid work and rest)

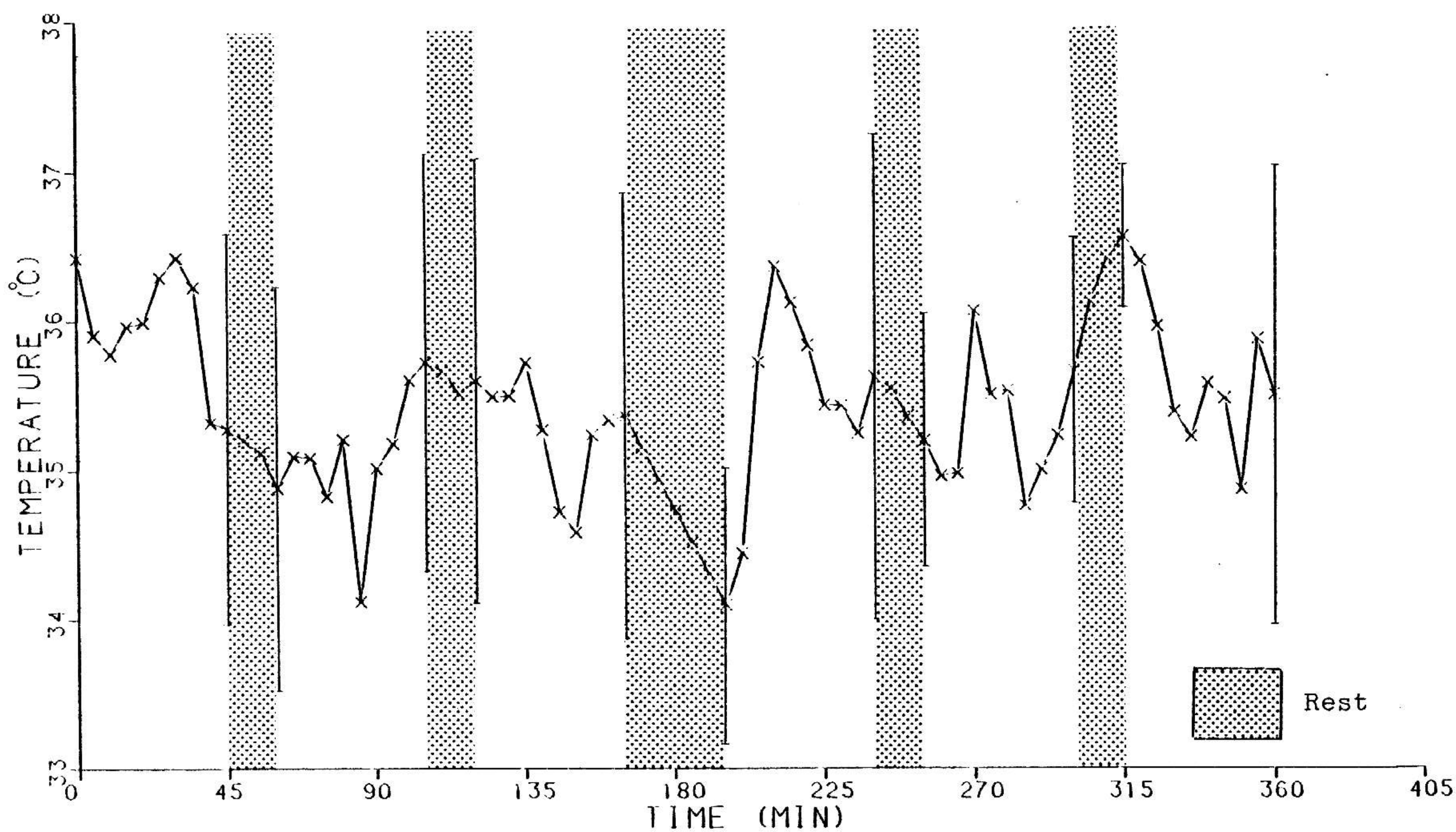

Figure 32. Oral temperature(25% rest, hot-dry work, cool rest)

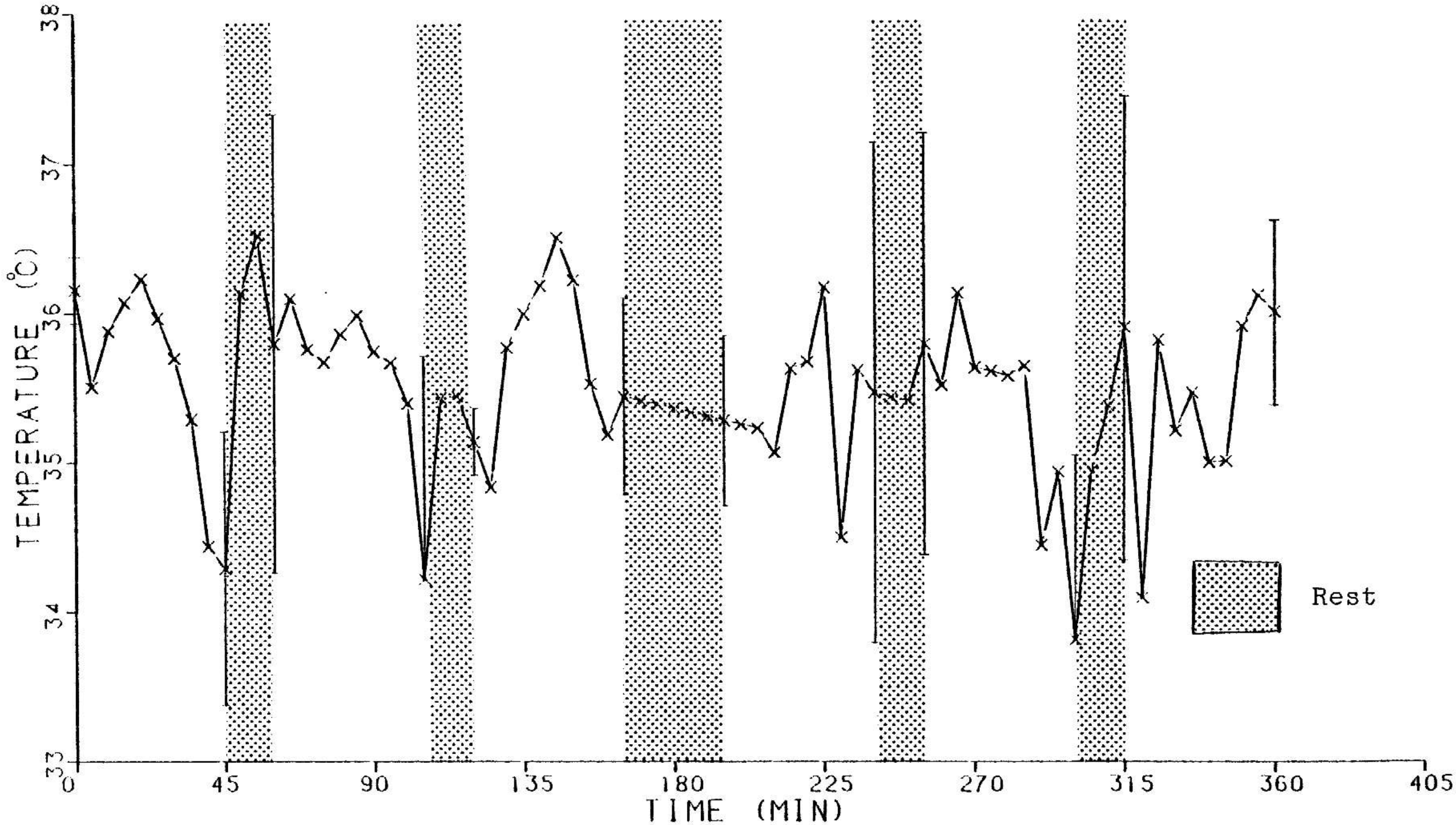

Figure 33. Oral temperature(25% rest, hot-dry work and rest)

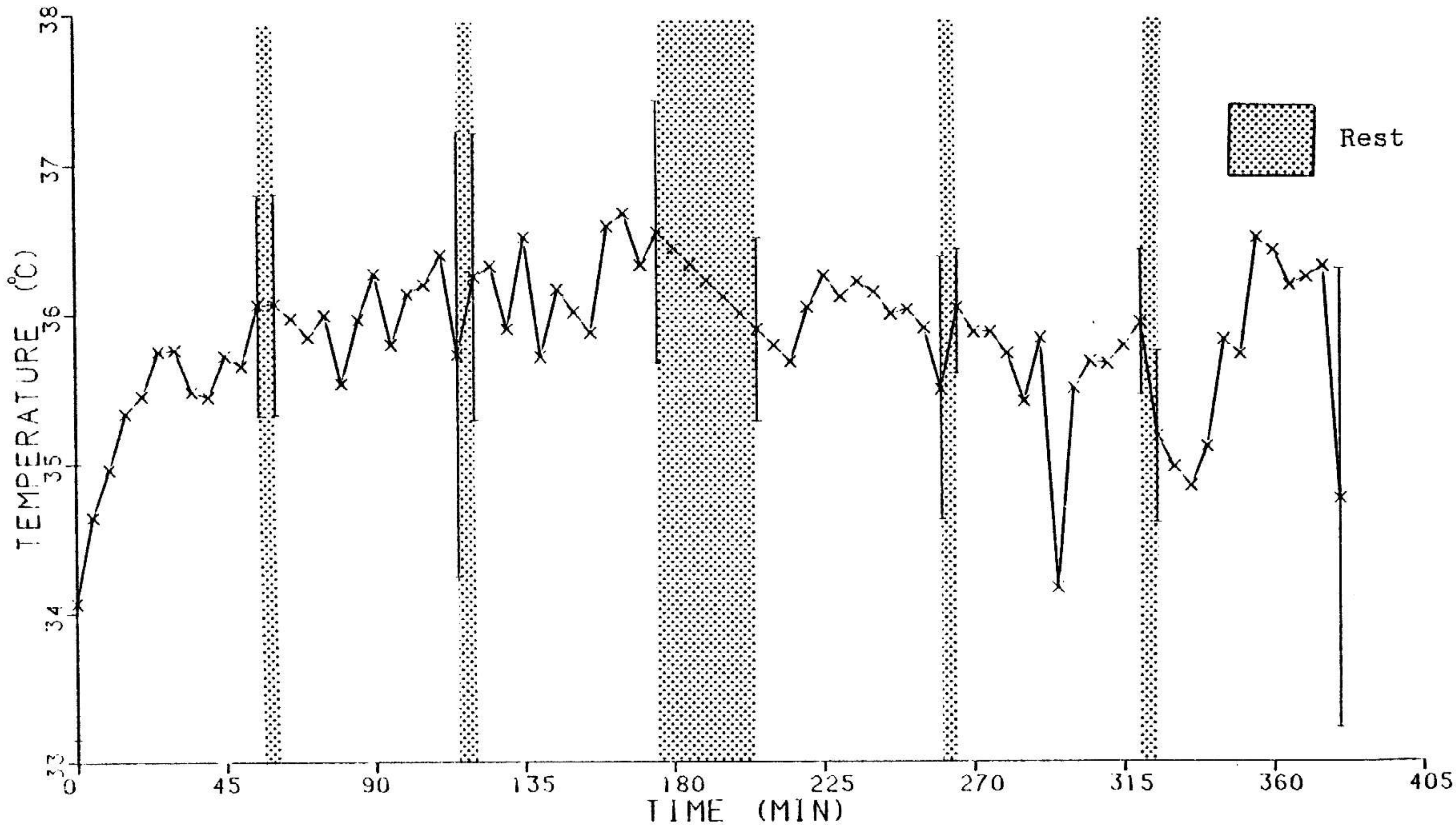

Figure 34. Oral temperature(8% rest, warm-humid work, cool rest)

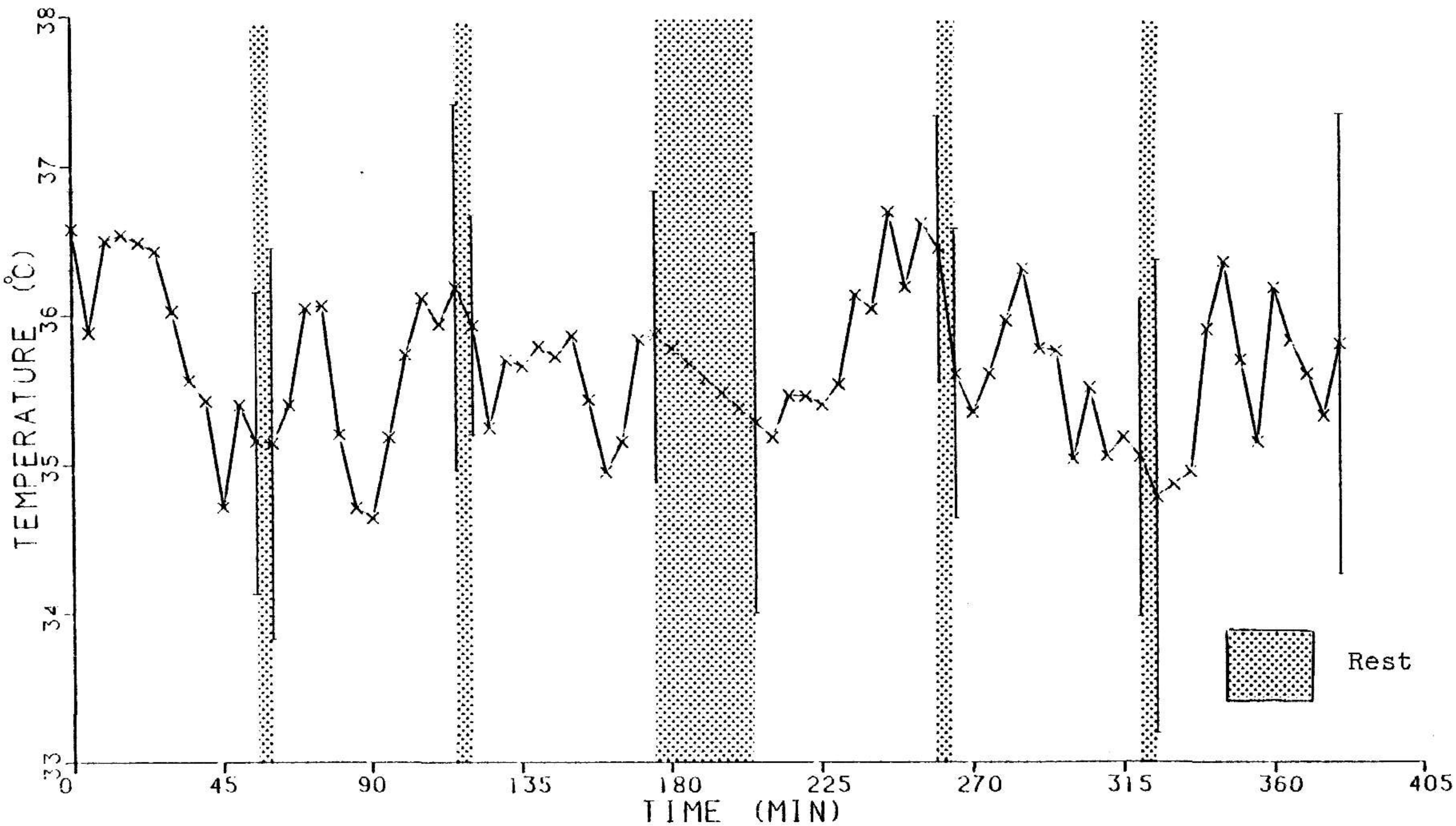

Figure 35. Oral temperature(8% rest, warm-humid work and rest)

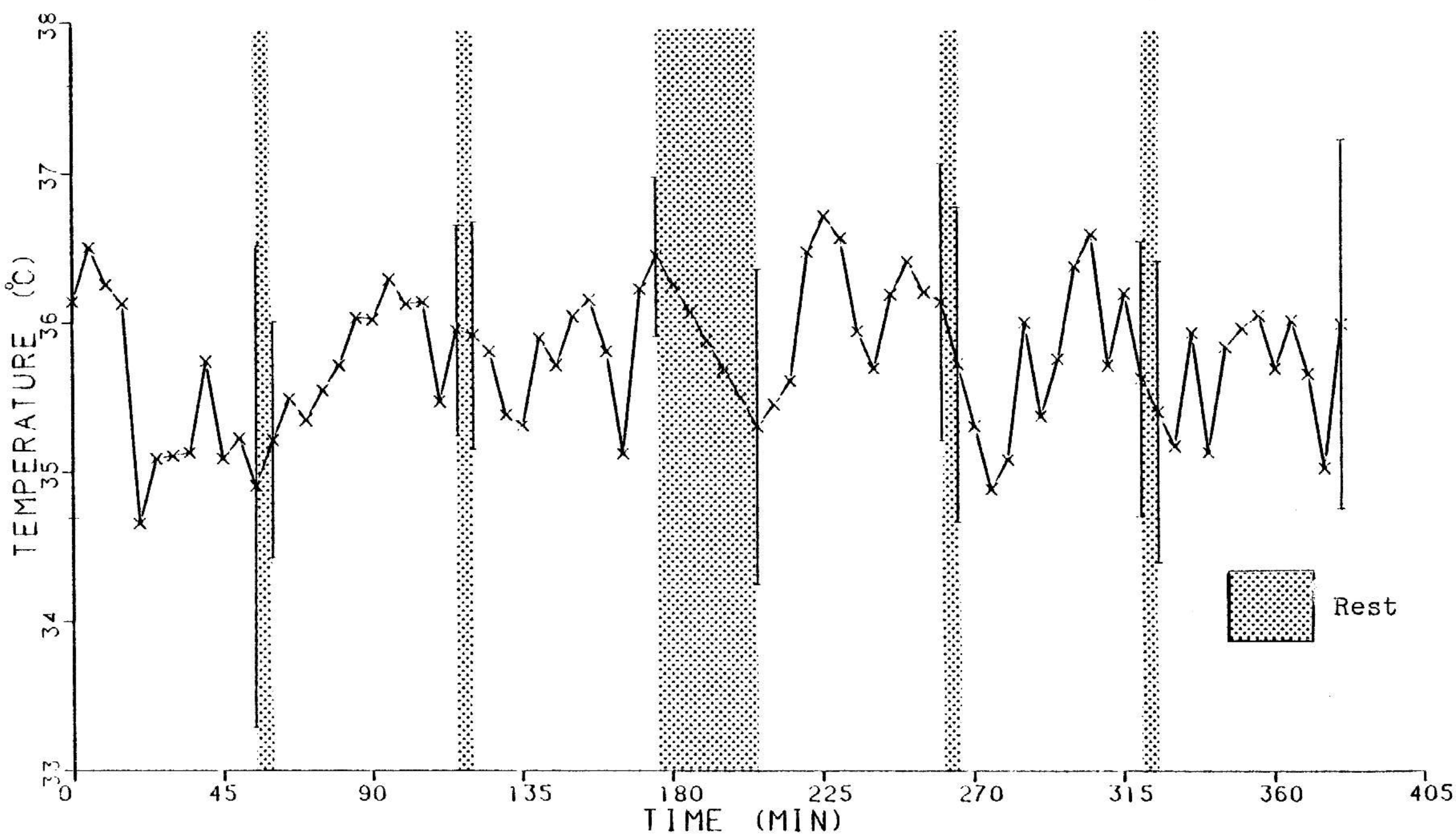

Figure 36. Oral temperature(8% rest, hot-dry work, cool rest)

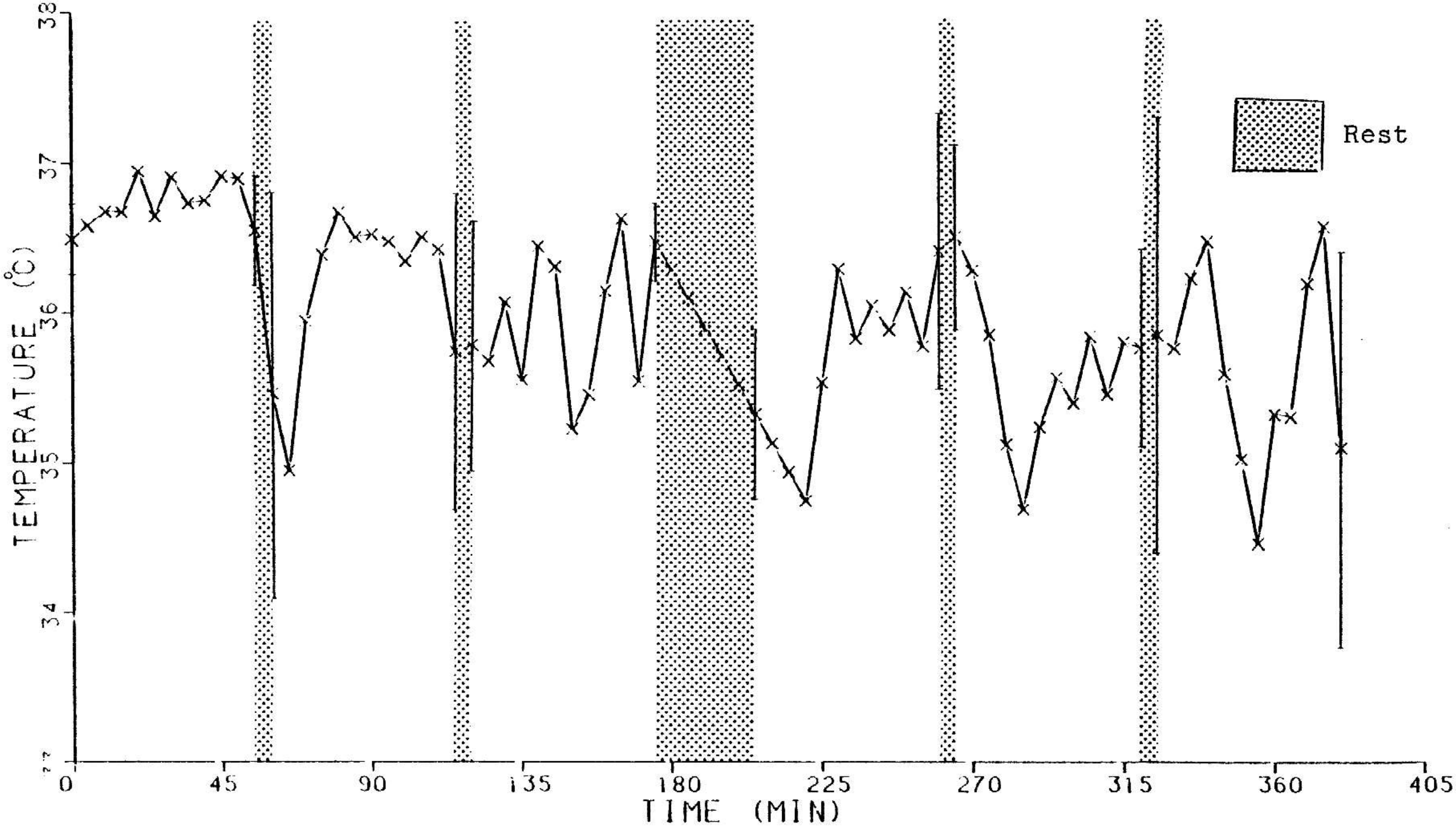

Figure 37. Oral temperature(8% rest, hot-dry work and rest)

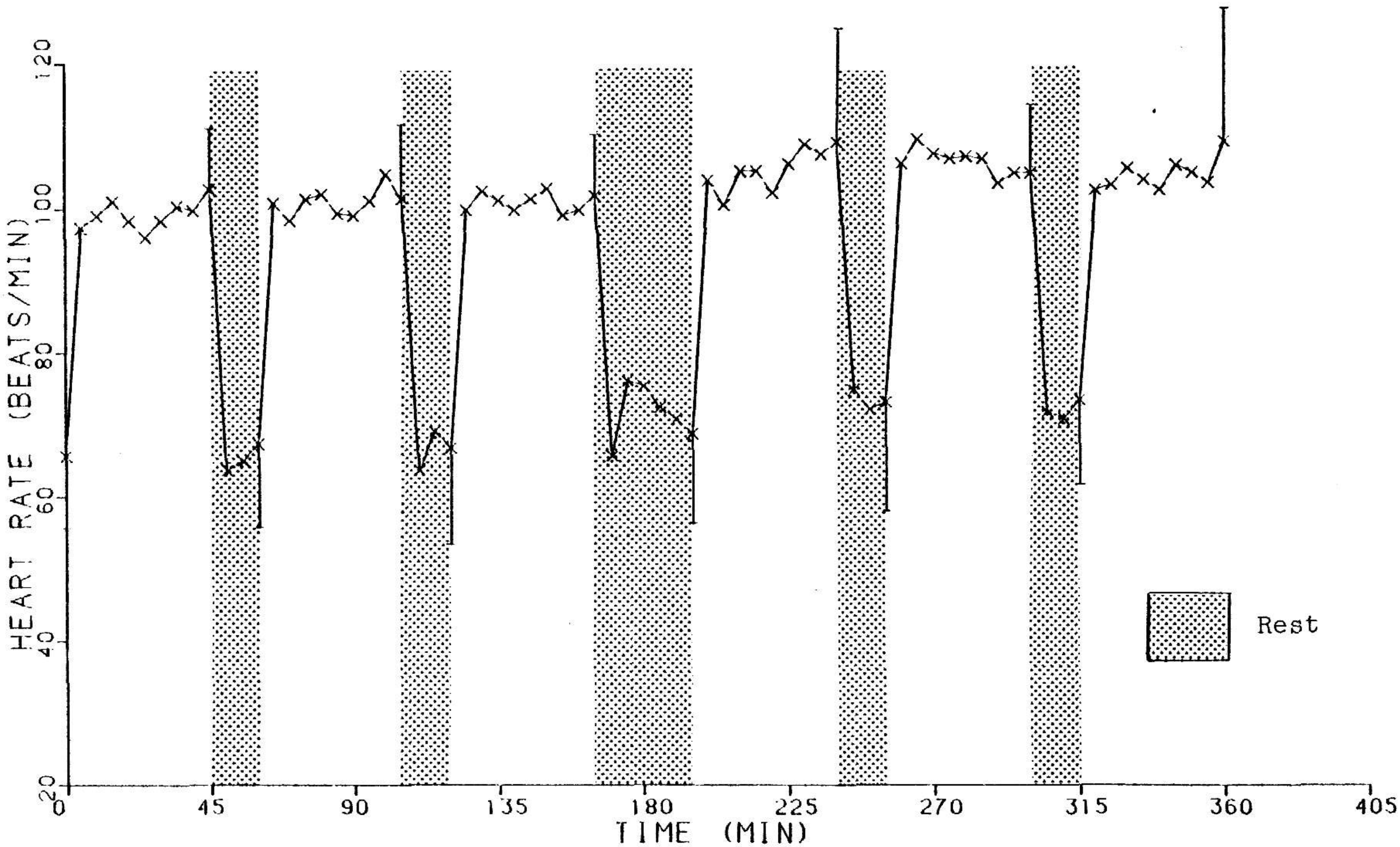

Figure 38. Heart rate(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

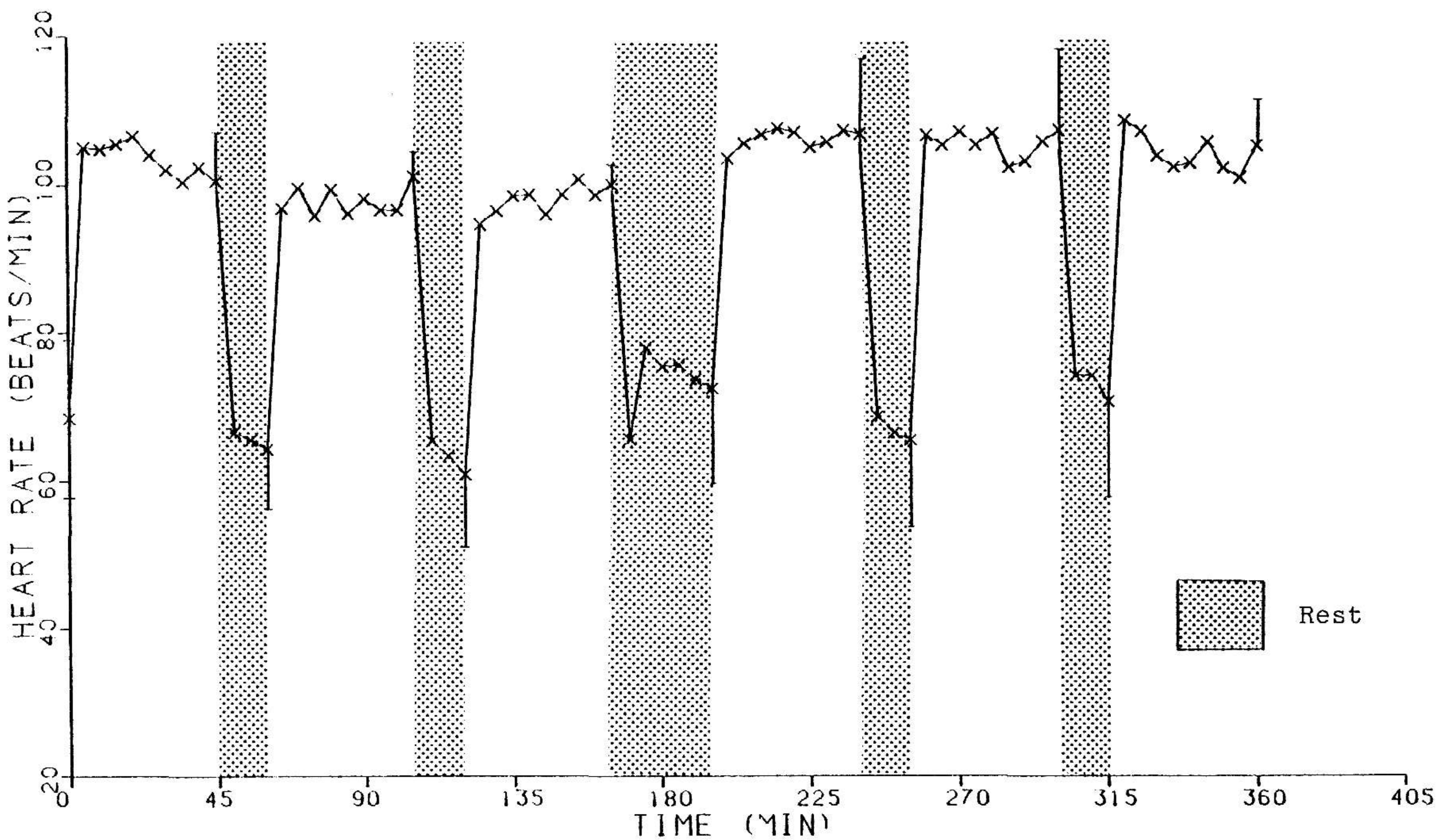

Figure 39. Heart rate(25% rest, warm-humid work and rest)

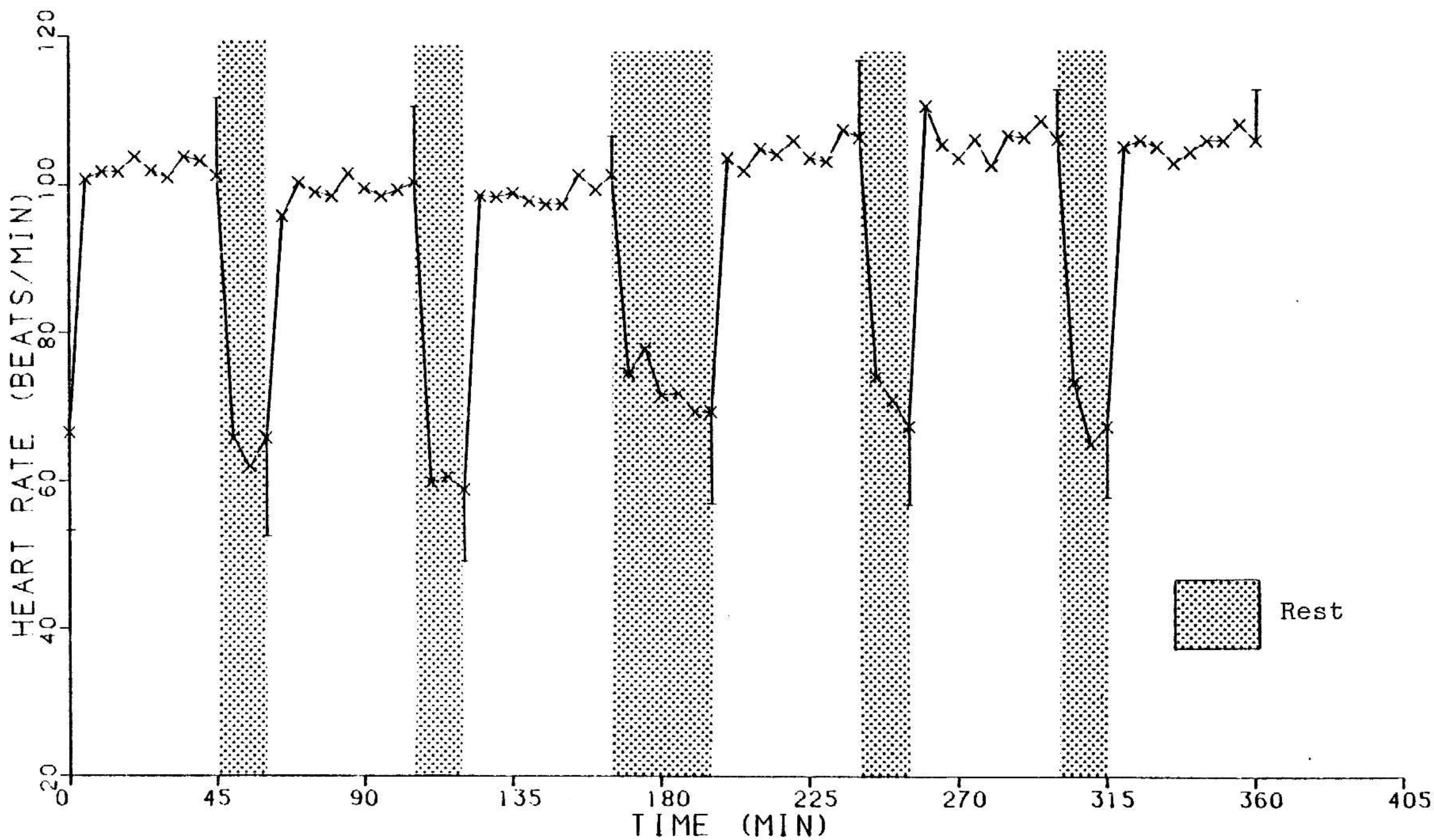

Figure 40. Heart rate(25% rest, hot-dry work, cool rest)

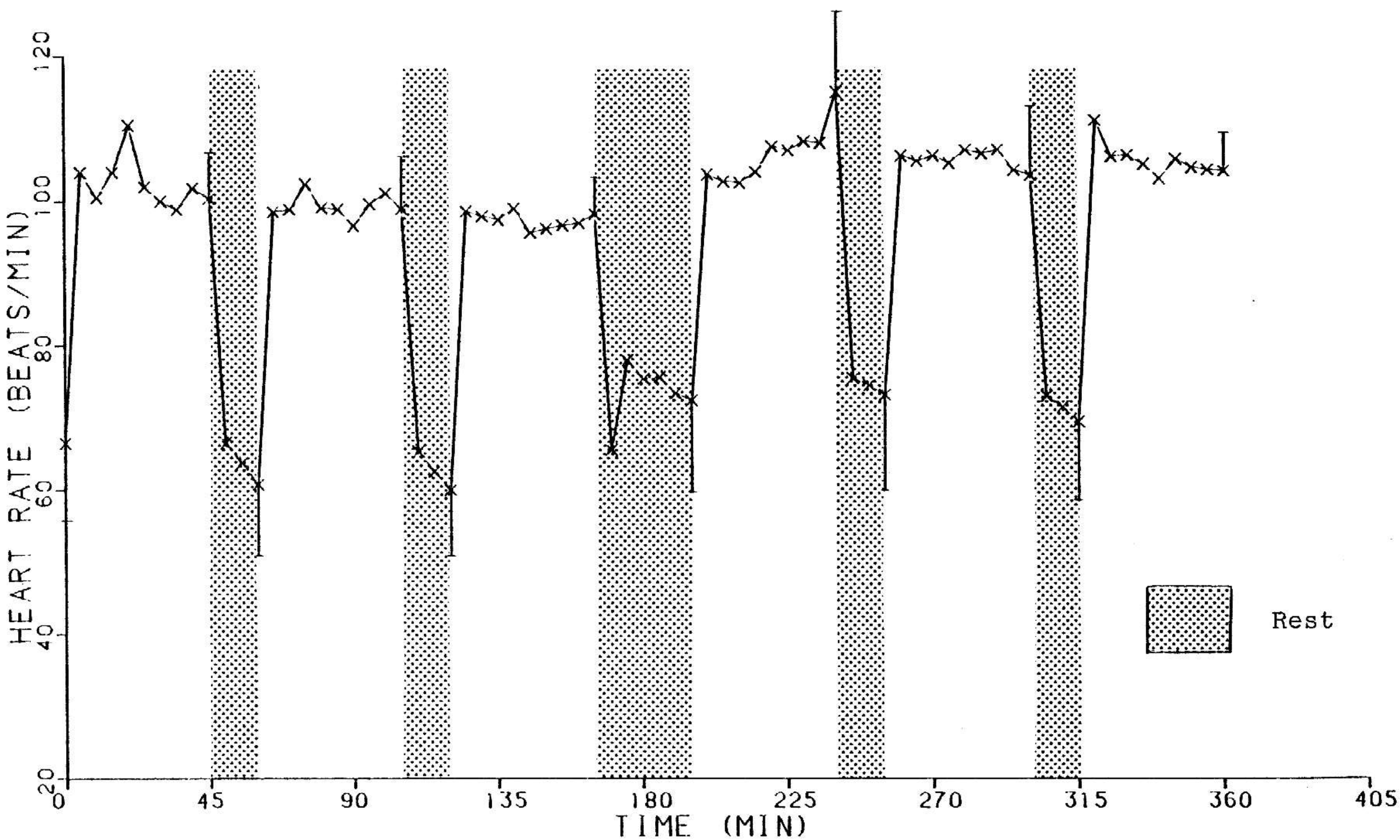

Figure 41. Heart rate(25% rest, hot-dry work and rest)

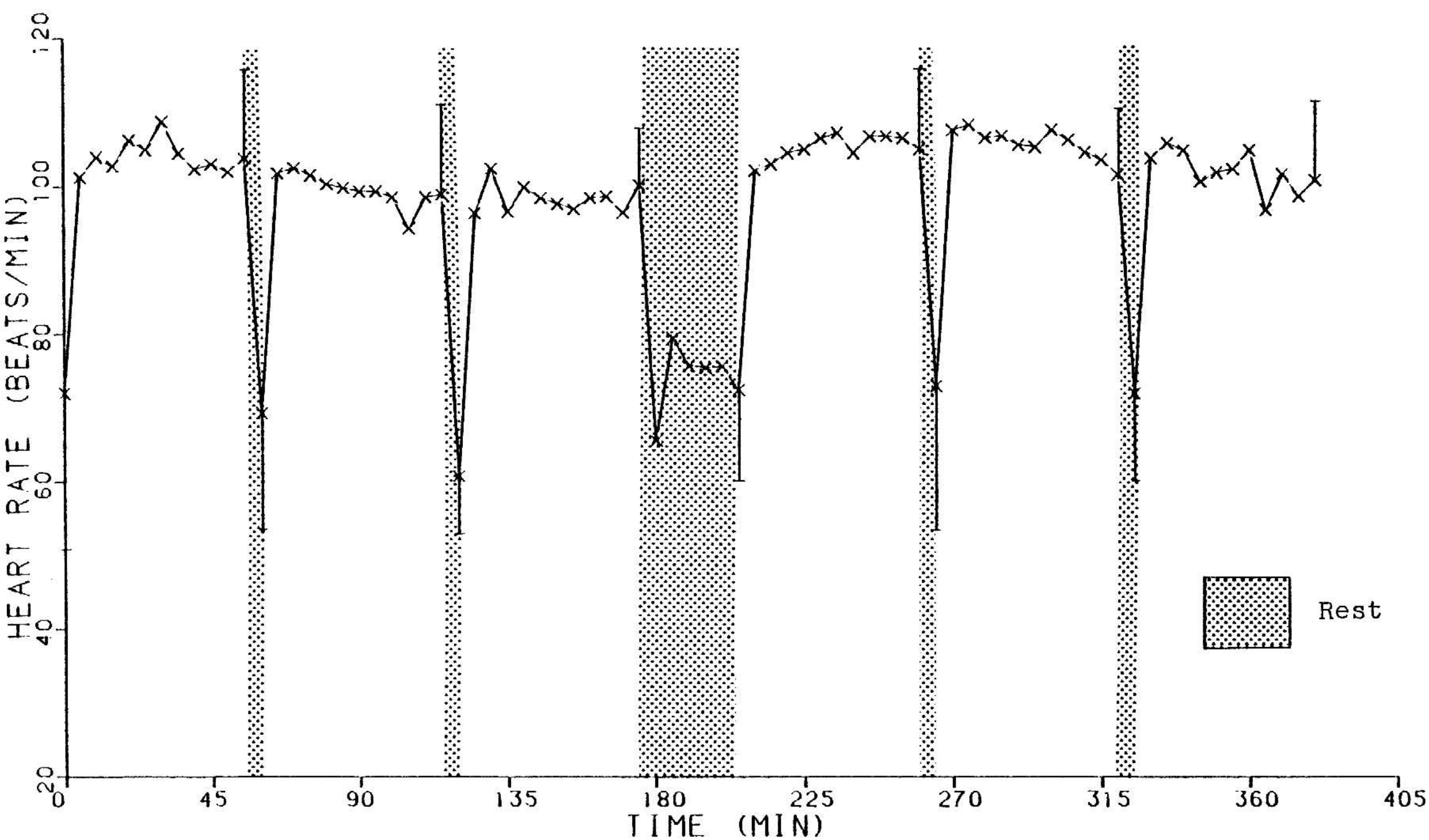

Figure 42. Heart rate(8% rest, warm-humid work, cool rest)

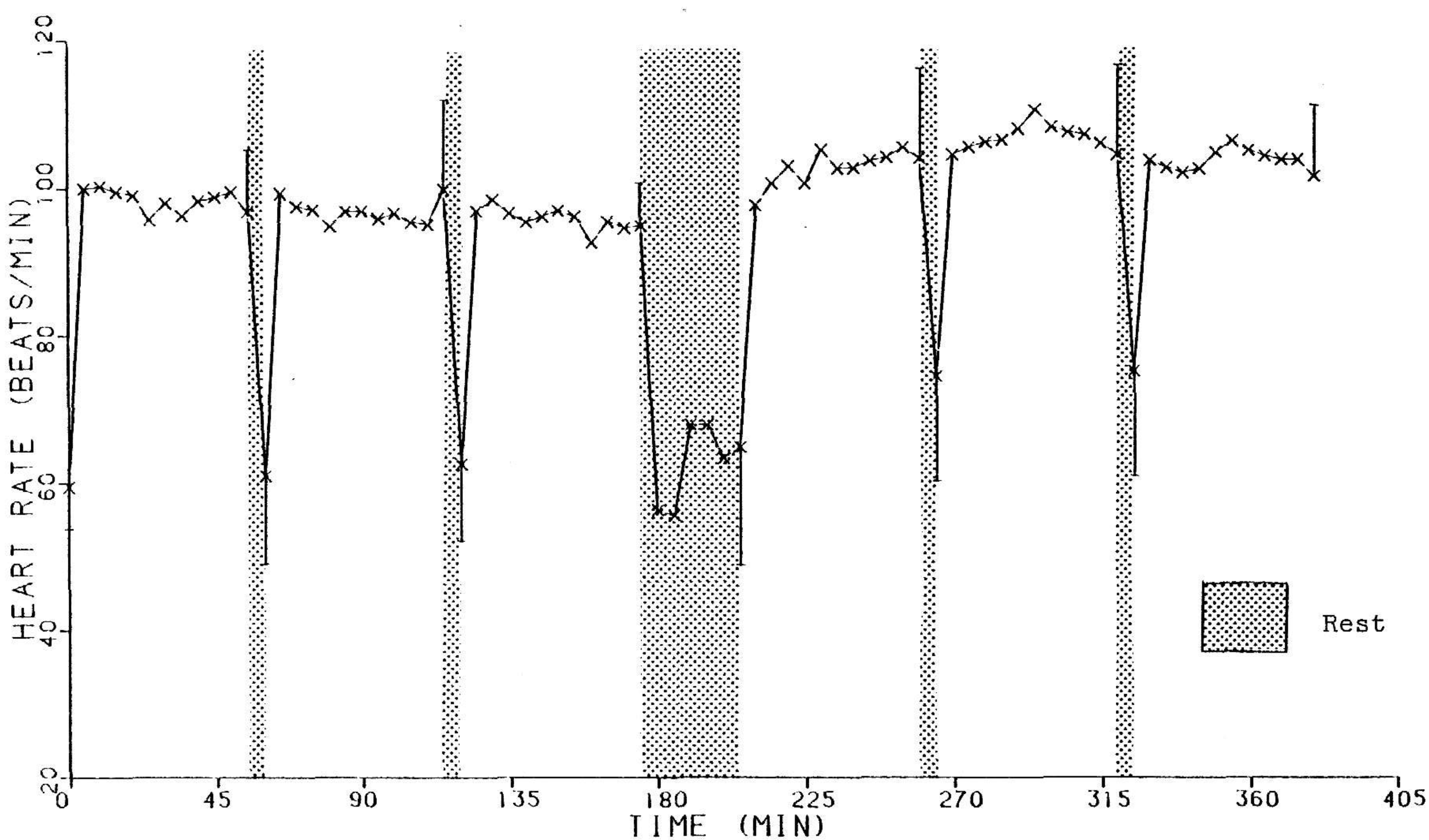

Figure 43. Heart rate(8% rest, warm-humid work and rest)

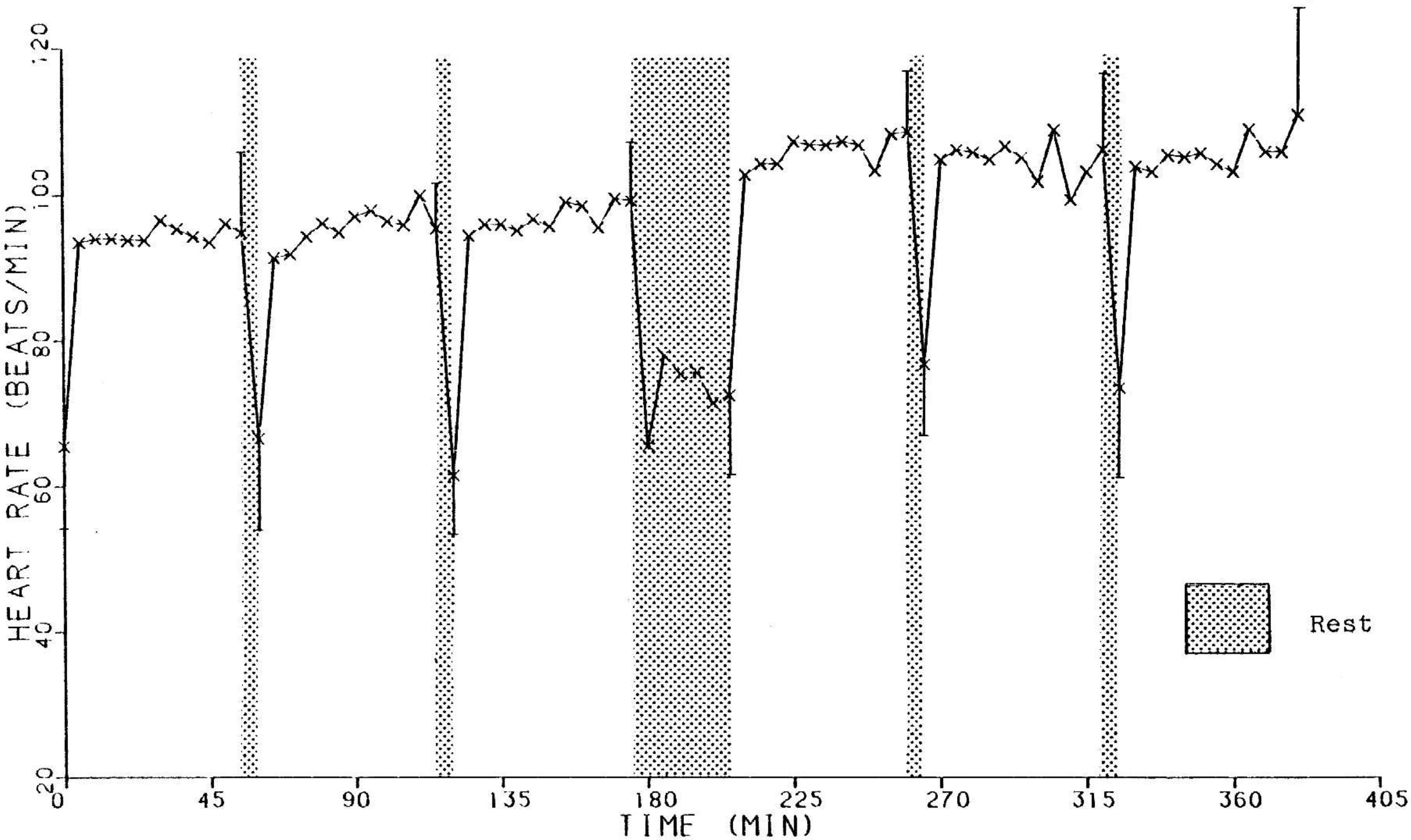

Figure 44. Heart rate (8% rest, hot-dry work, cool rest)

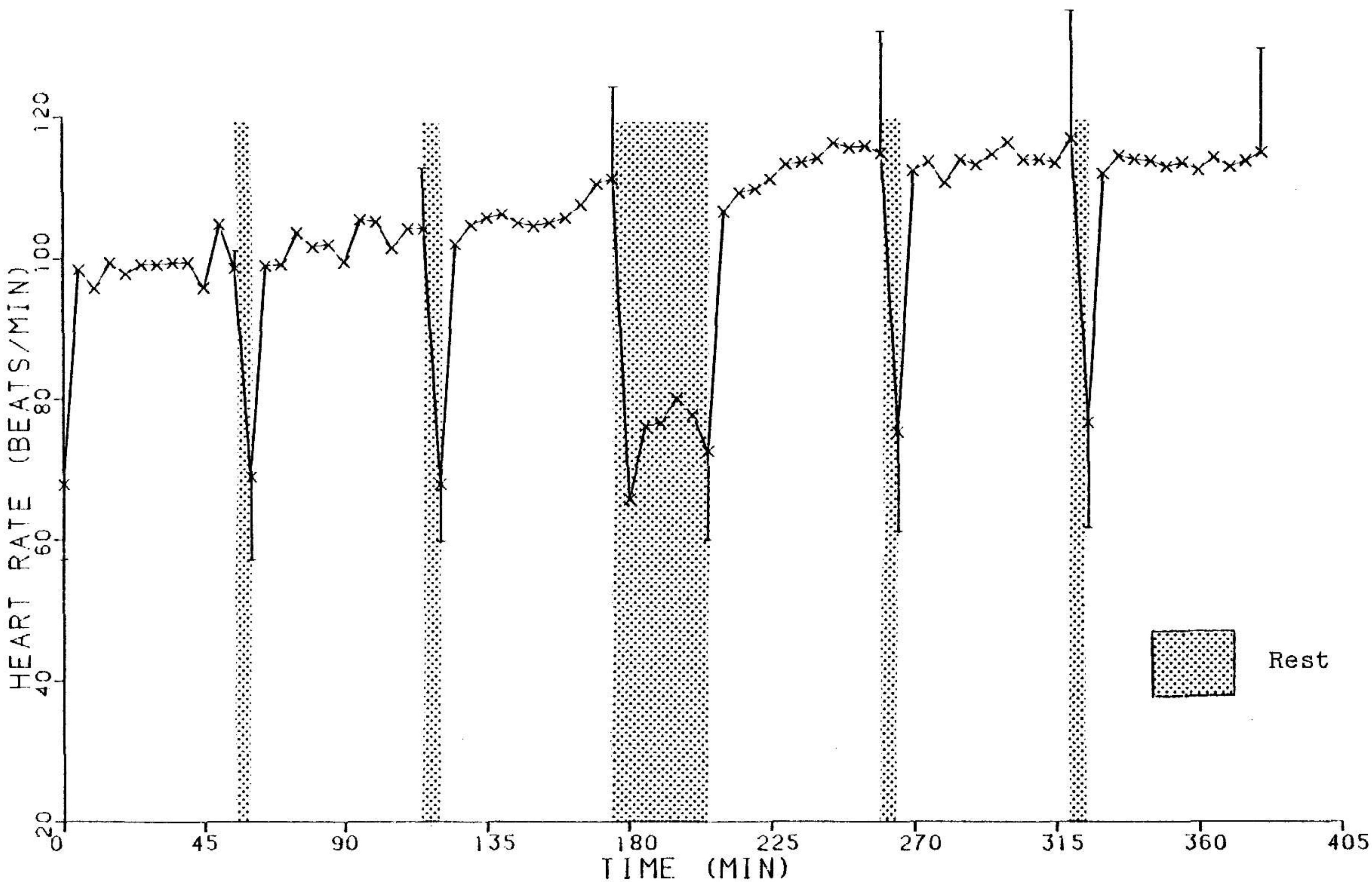

Figure 45. Heart rate(8% rest, hot-dry work and rest)

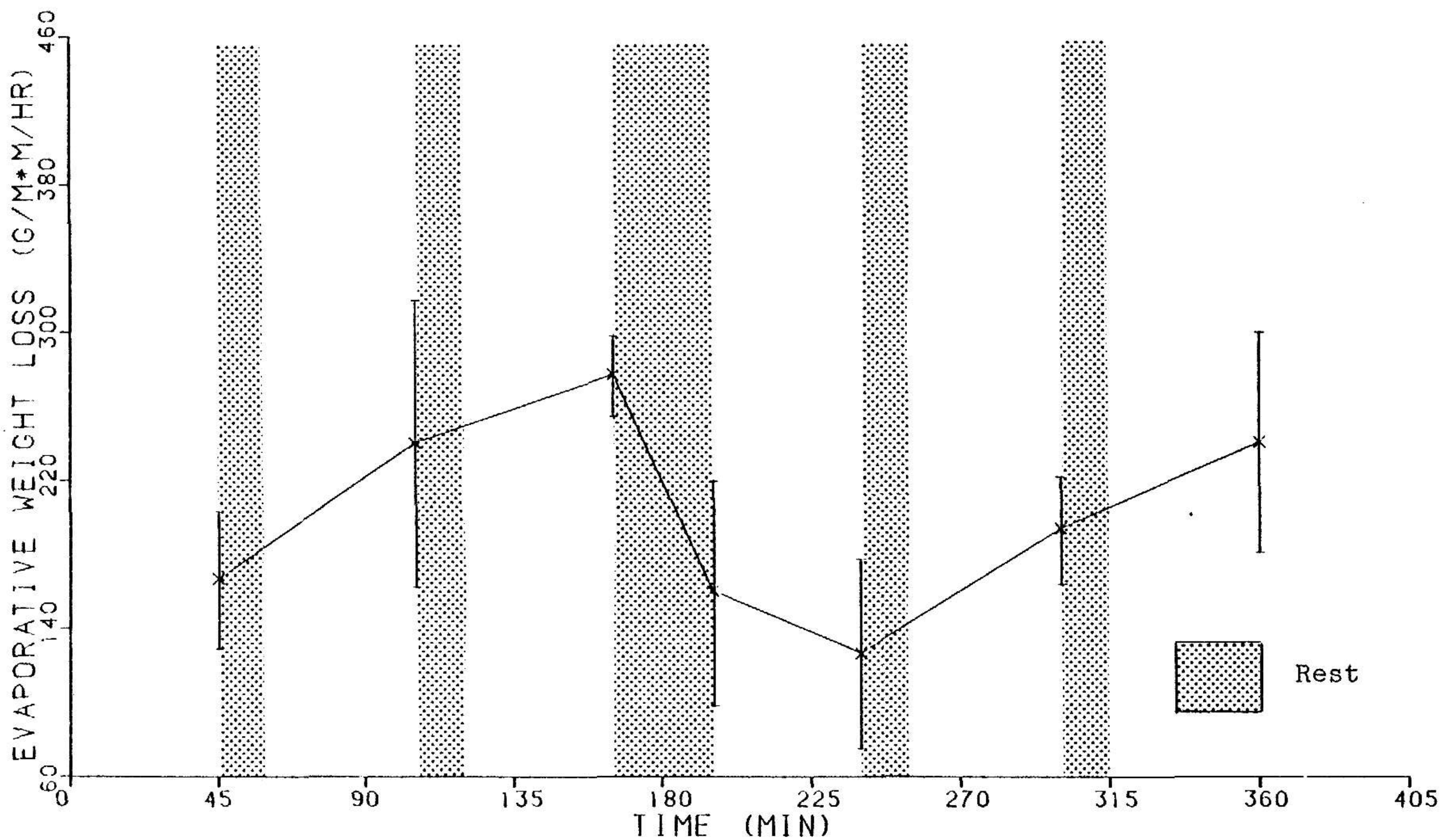

Figure 46. Evaporative weight loss(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

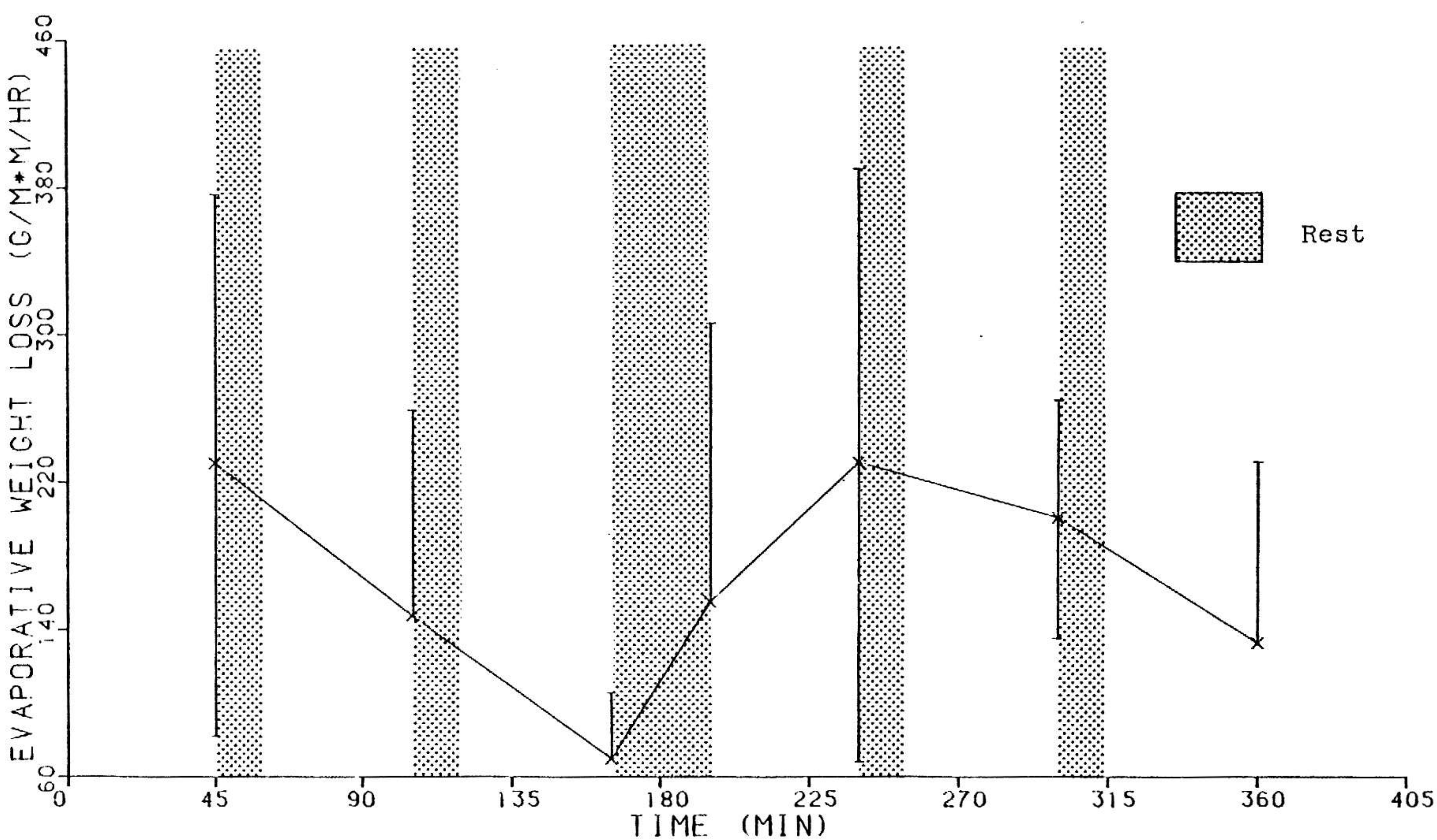

Figure 47. Evaporative weight loss(25% rest, warm-humid work and rest)

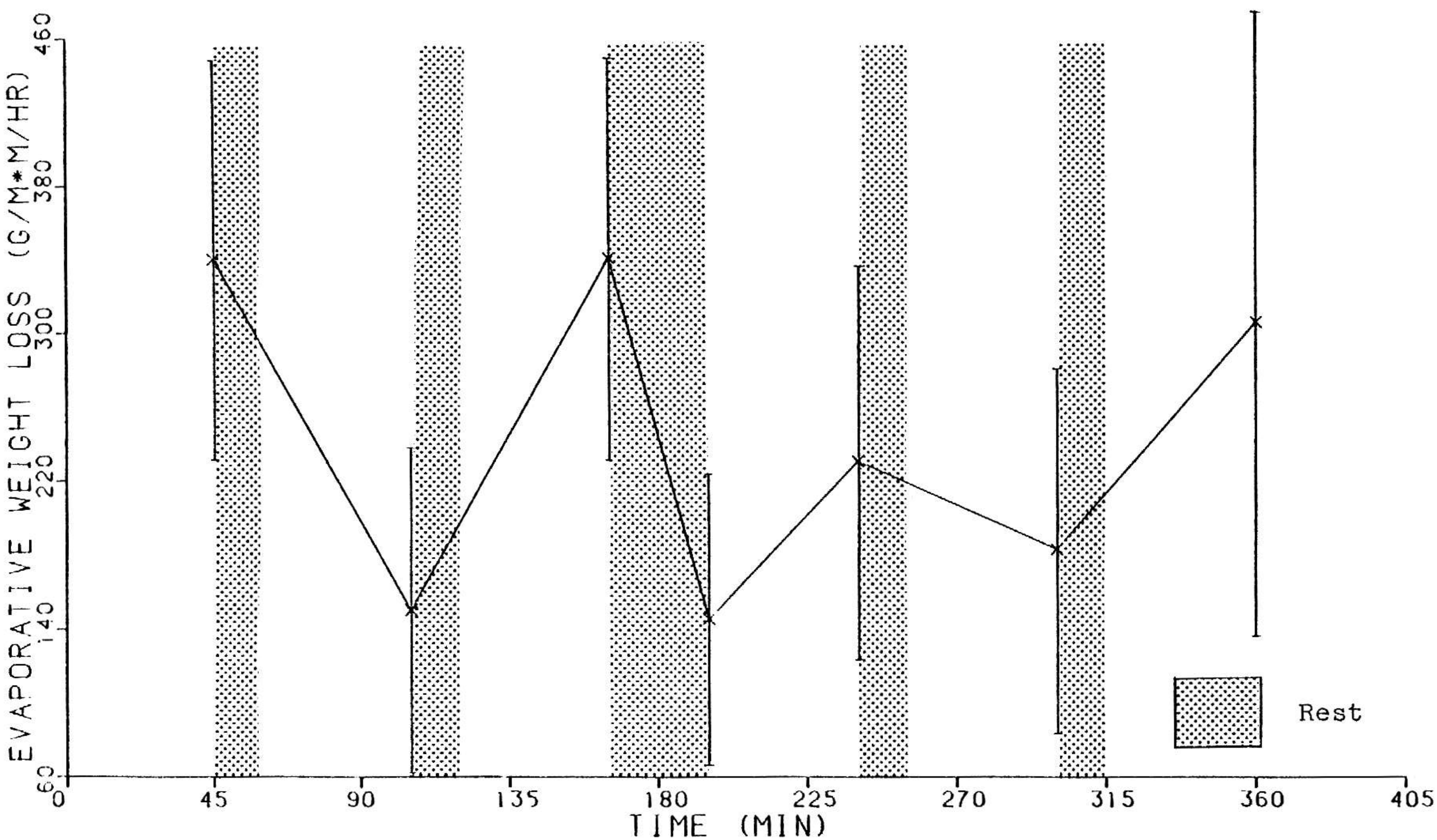

Figure 48. Evaporative weight loss(25% rest, hot-dry work, cool rest)

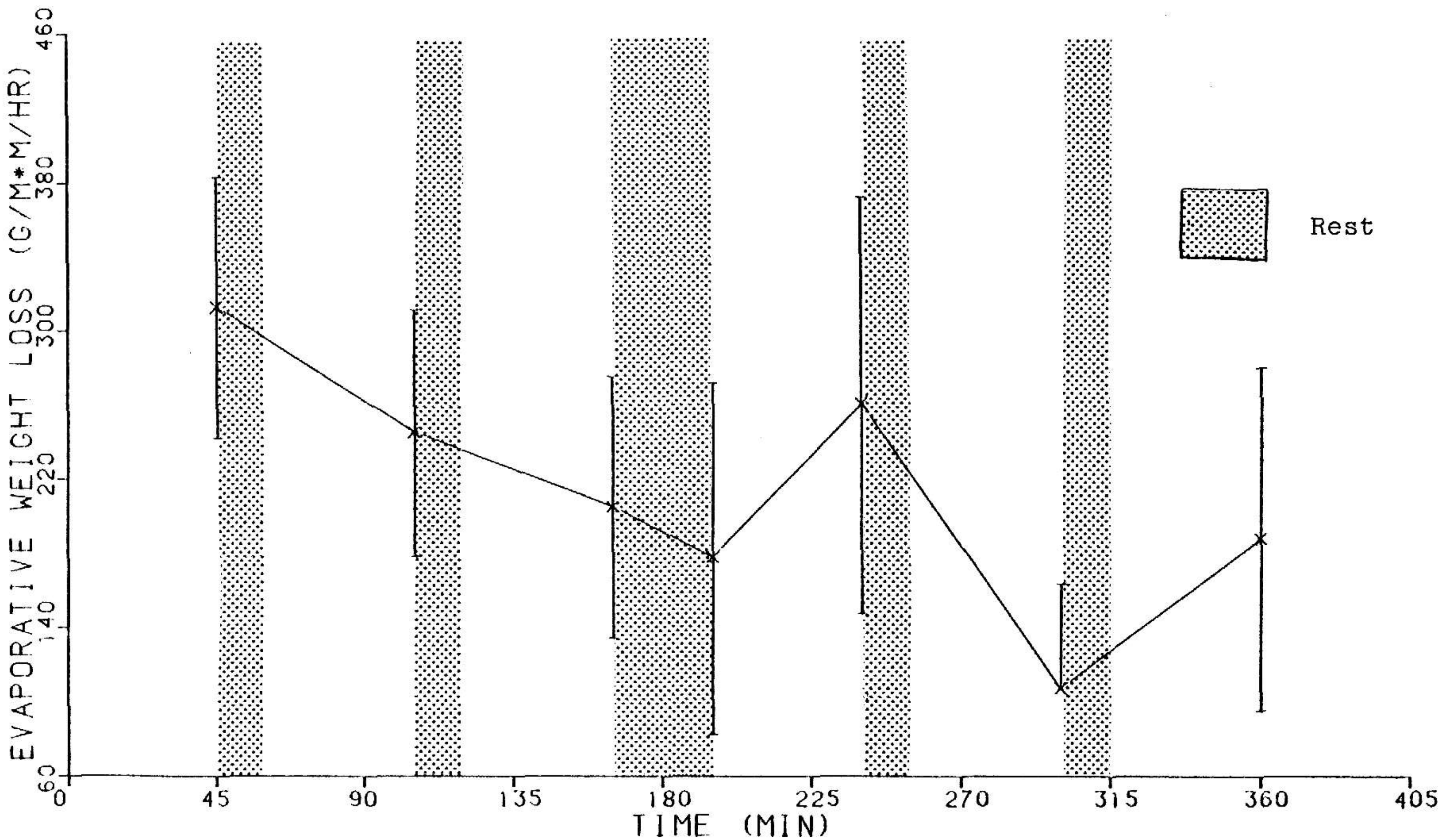

Figure 49. Evaporative weight loss(25% rest, hot-dry work and rest)

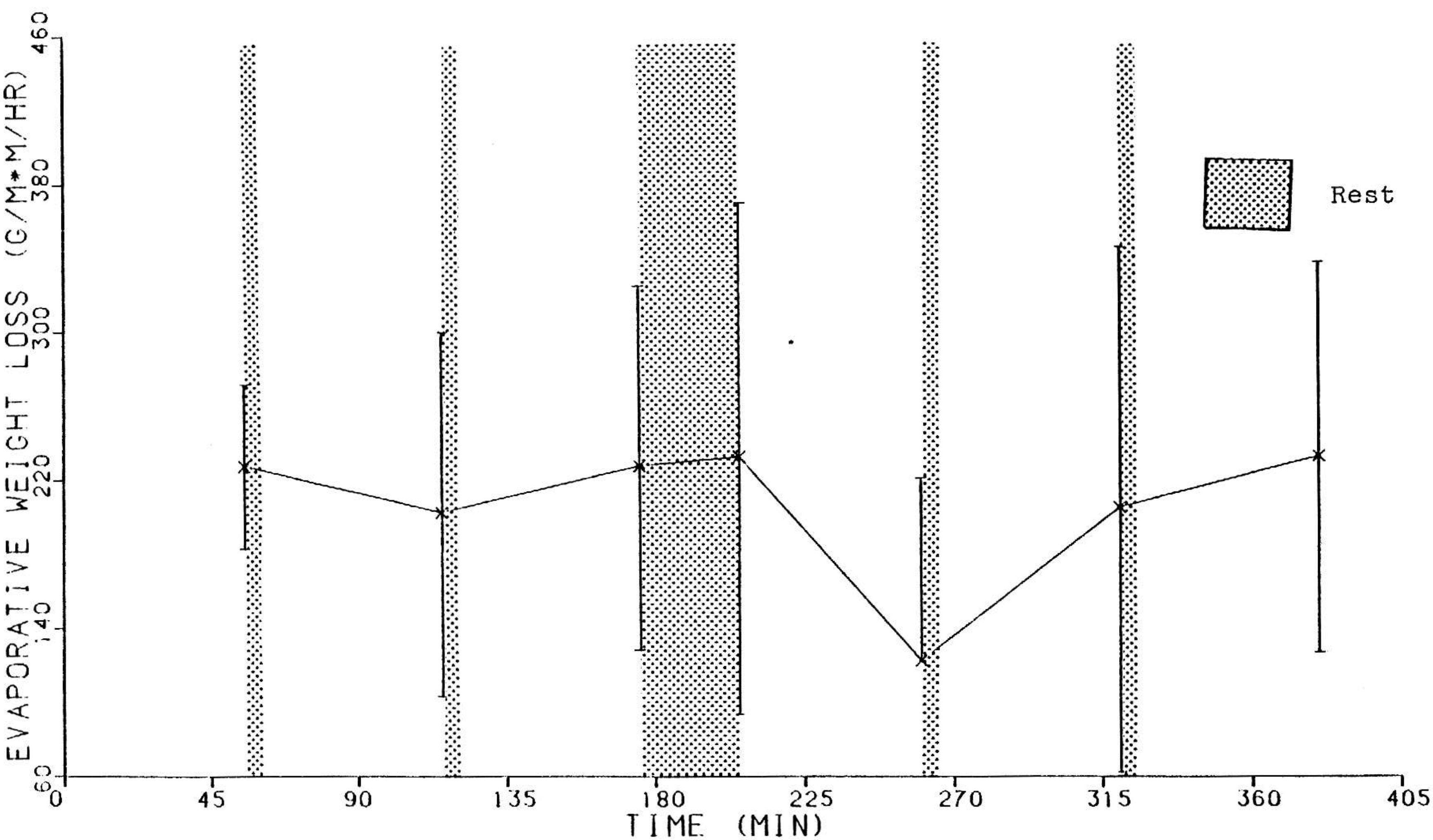

Figure 50. Evaporative weight loss(8% rest,warm-humid work, cool rest)

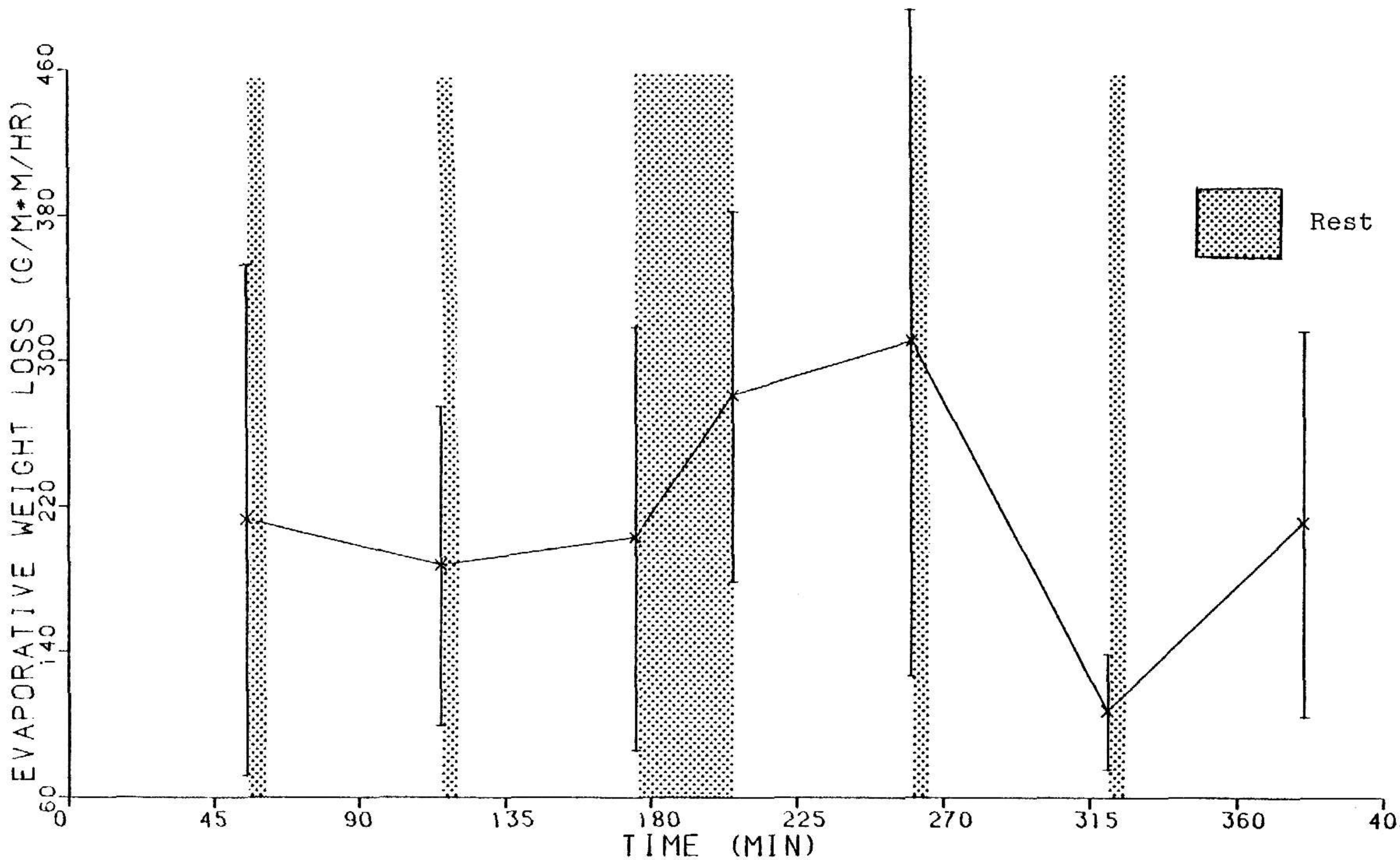

Figure 51. Evaporative weight loss(8% rest, warm-humid work and rest)

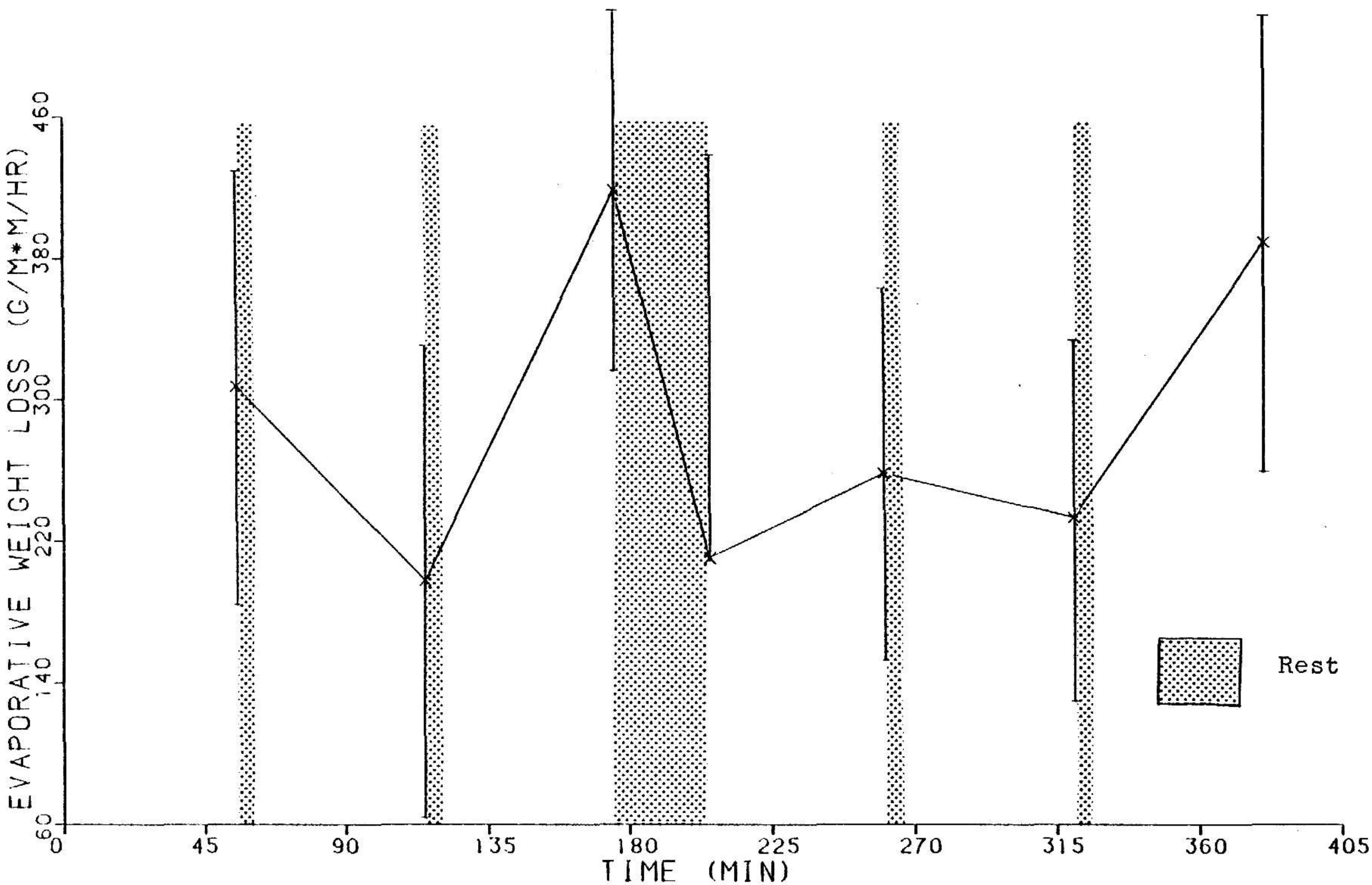

Figure 52. Evaporative weight loss(8% rest, hot-dry work, cool rest)

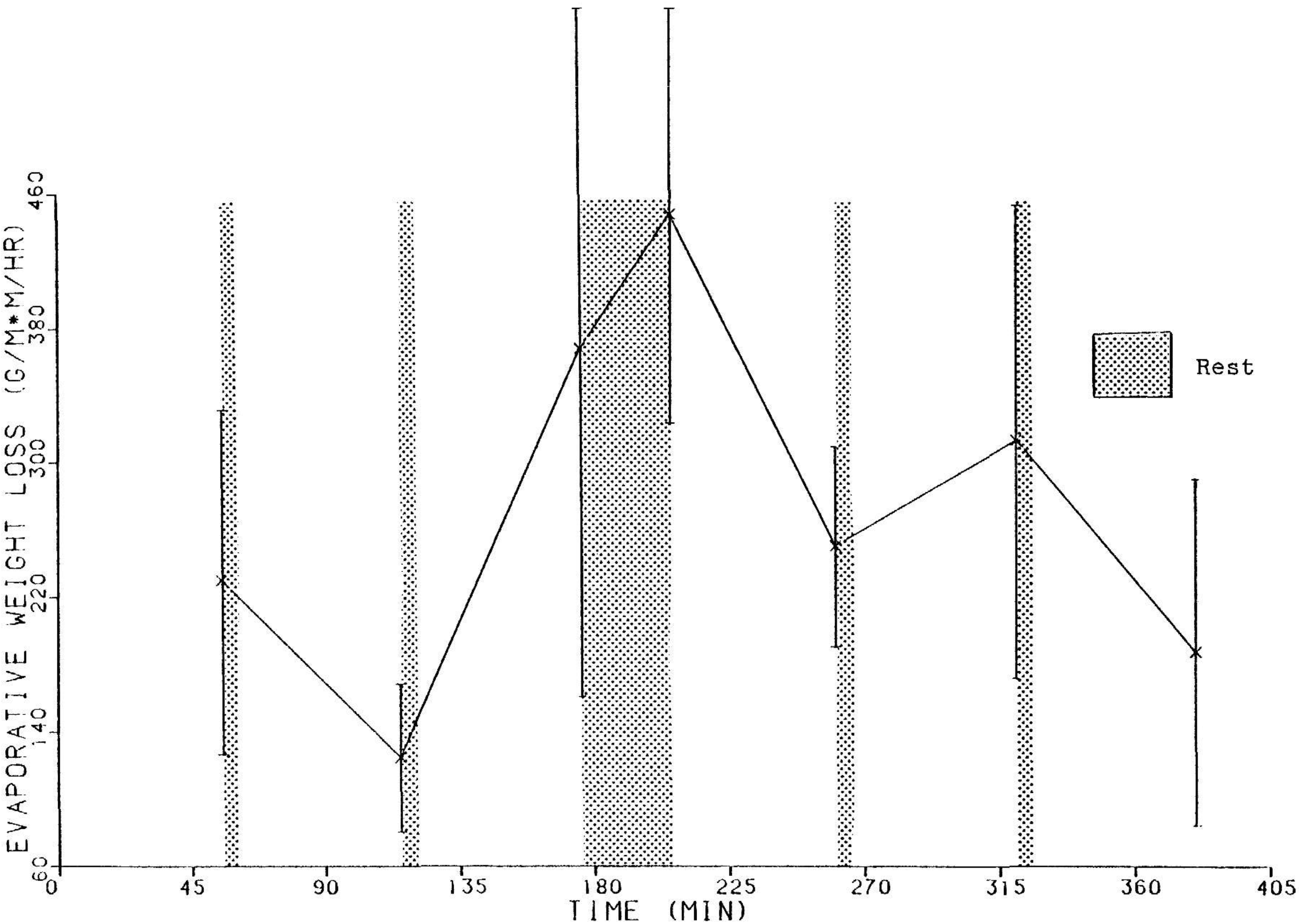

Figure 53. Evaporative weight loss(8% rest, hot-dry work and rest)

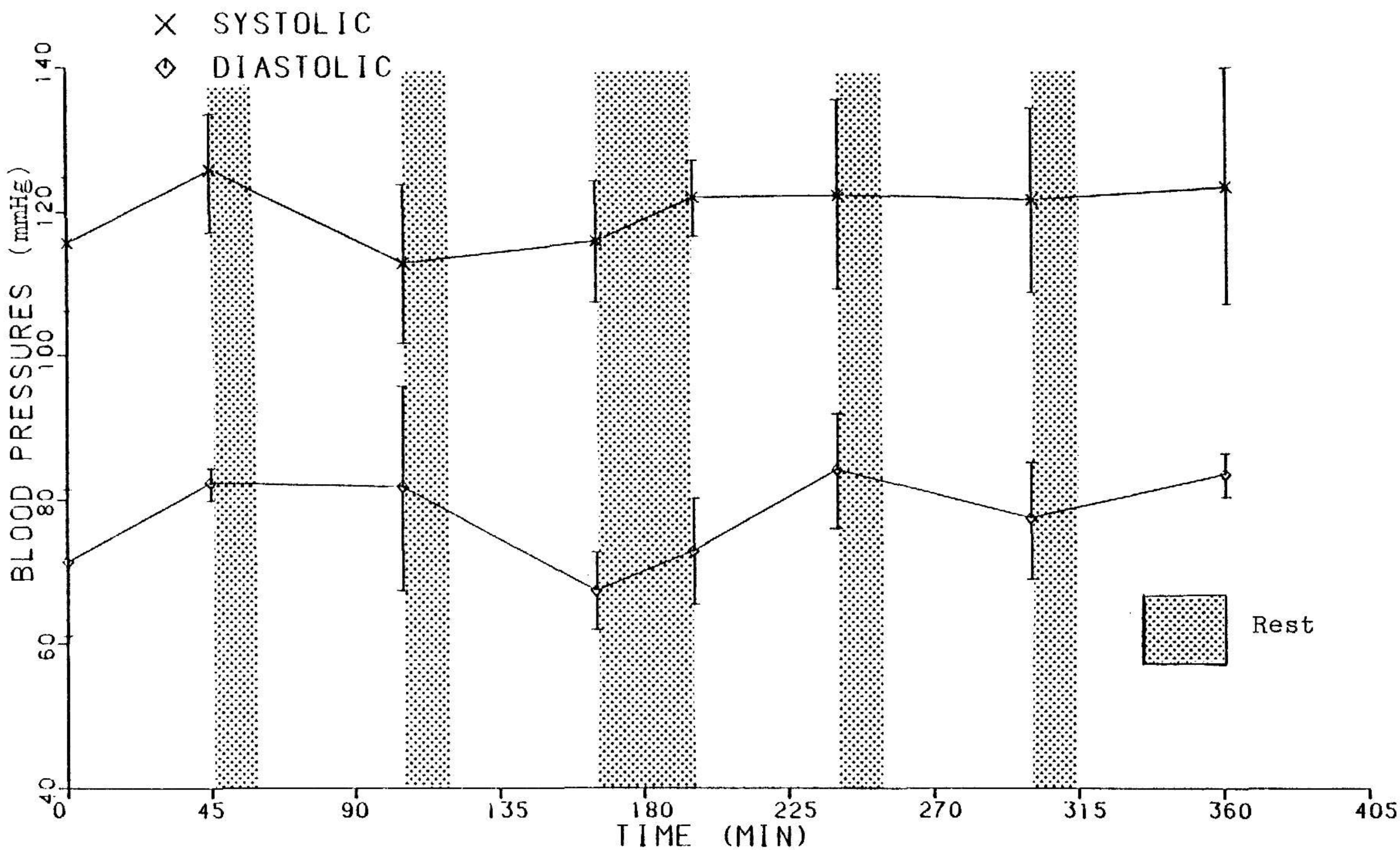

Figure 54. Blood pressure(25% rest, warm-humid work, cool rest). Vertical bars represent one standard deviation.

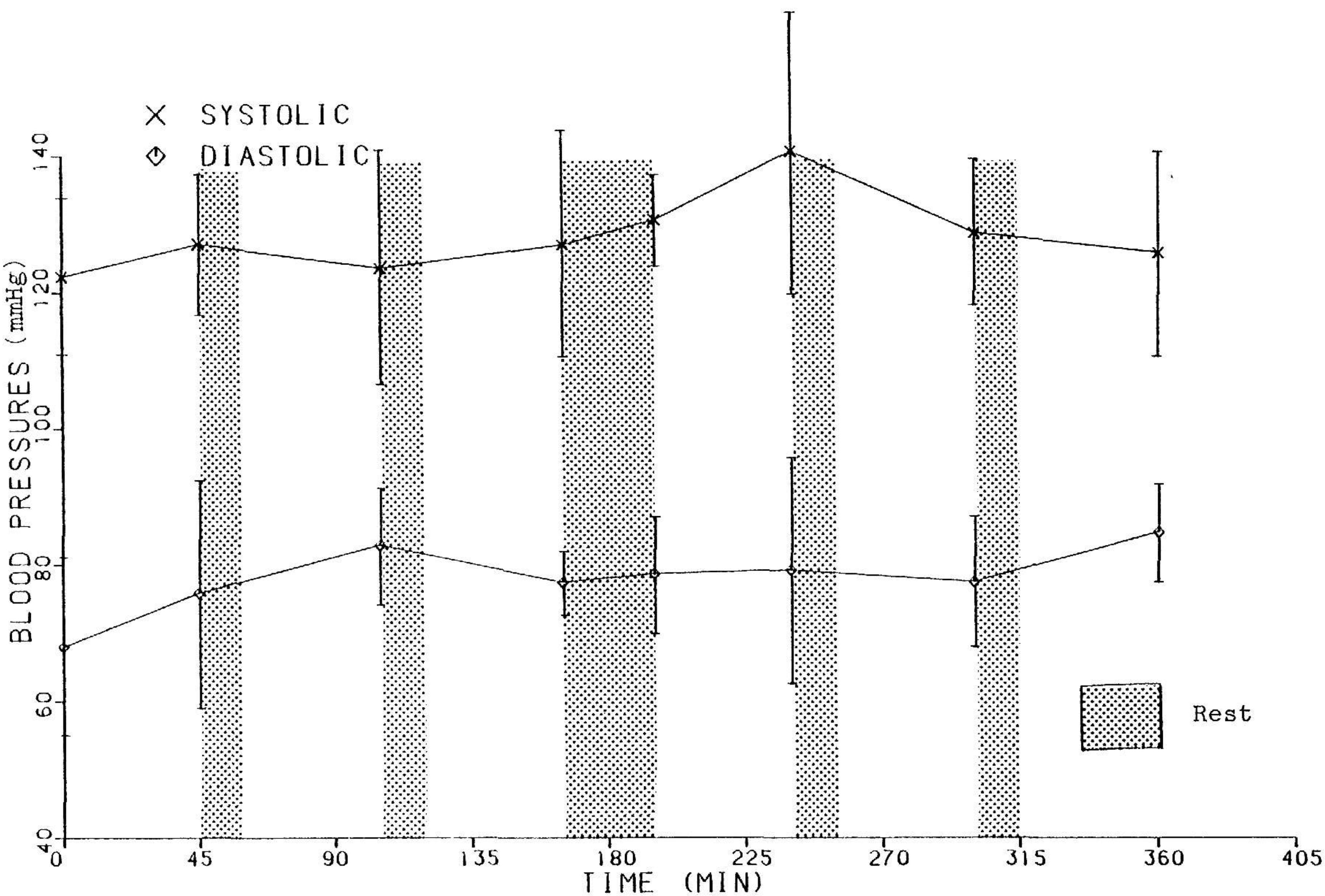

Figure 55. Blood pressure(25% rest, warm-humid work and rest)

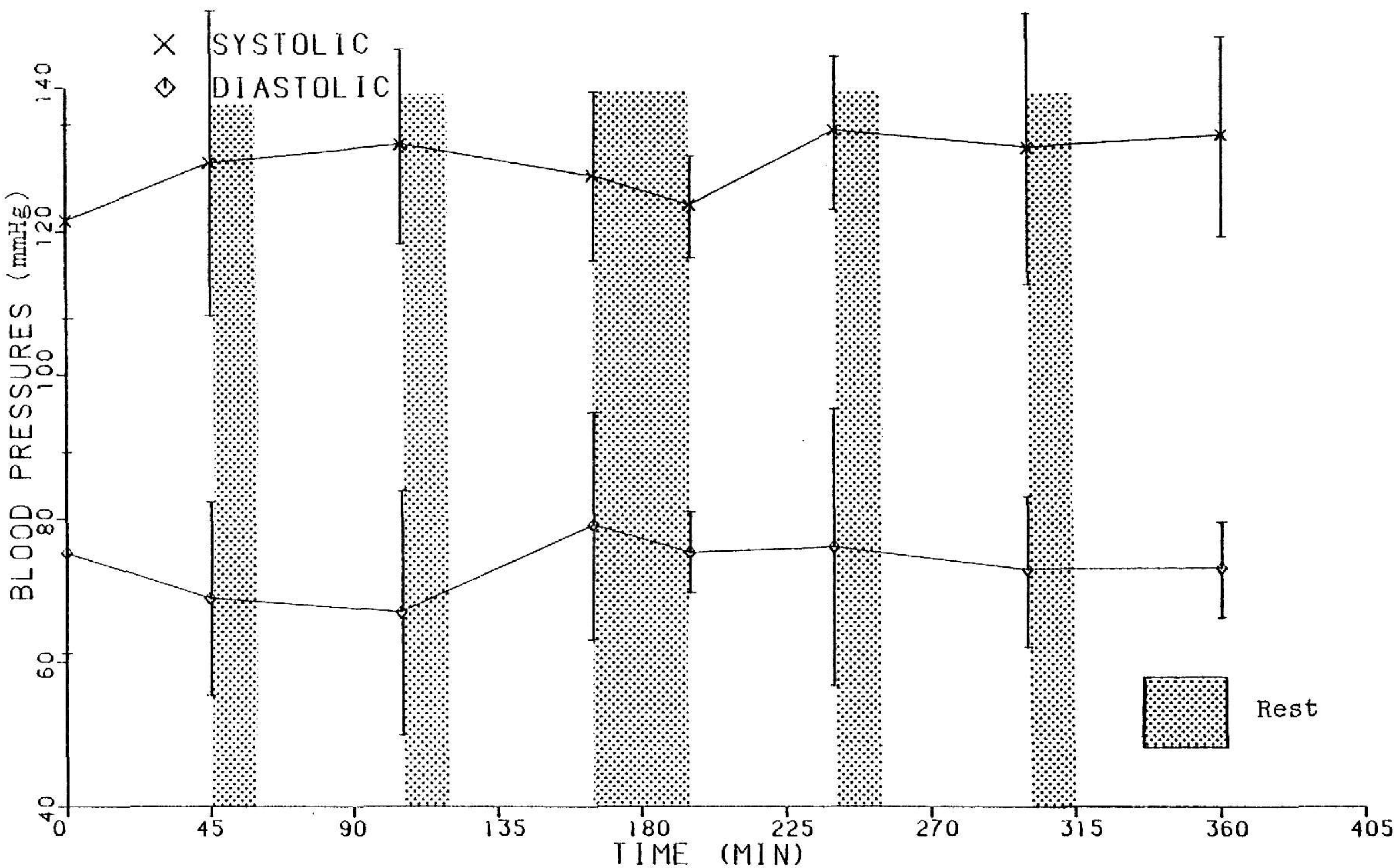

Figure 56. Blood pressure(25% rest, hot-dry work, cool rest)

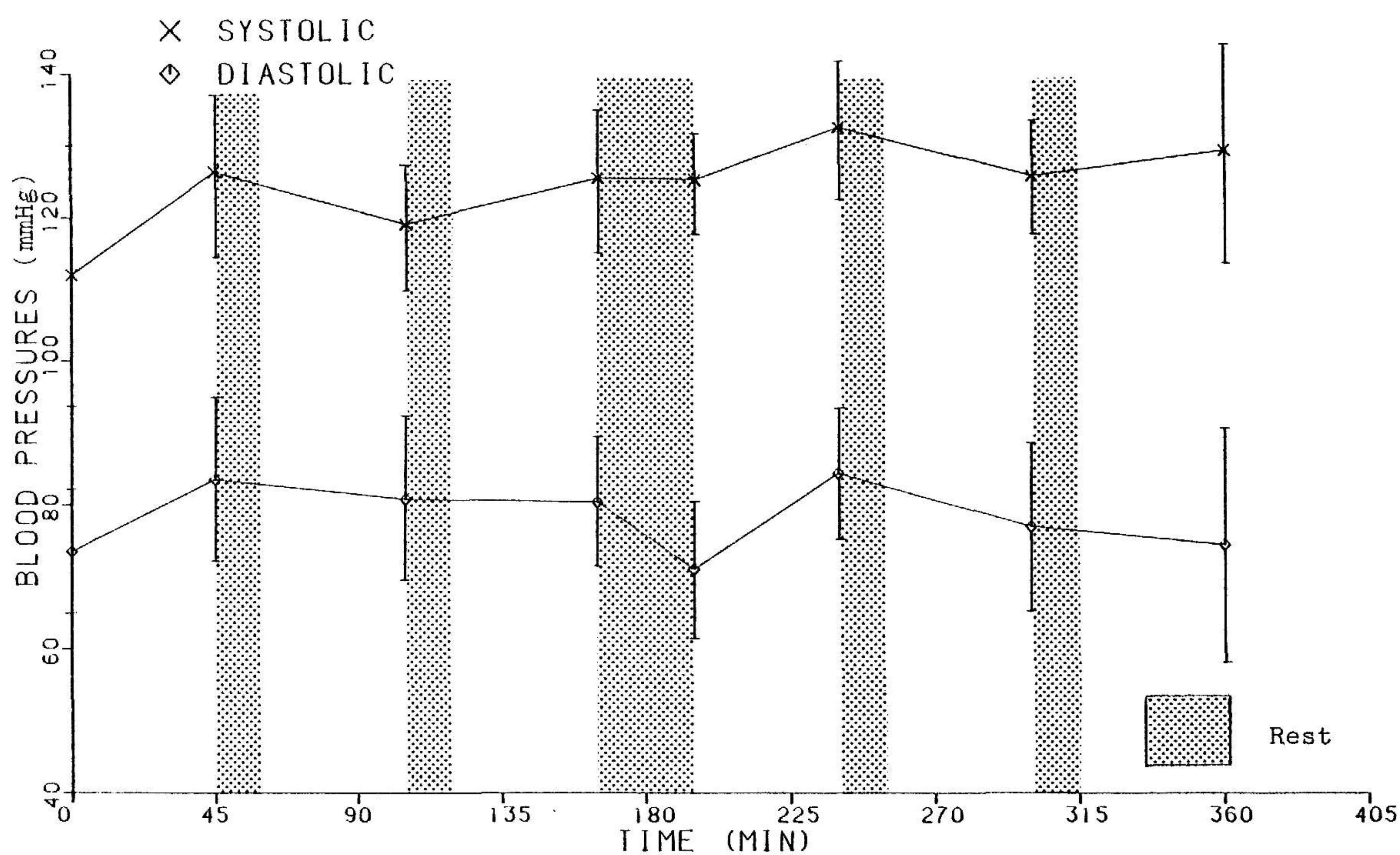

Figure 57. Blood pressure(25% rest, hot-dry work and rest)

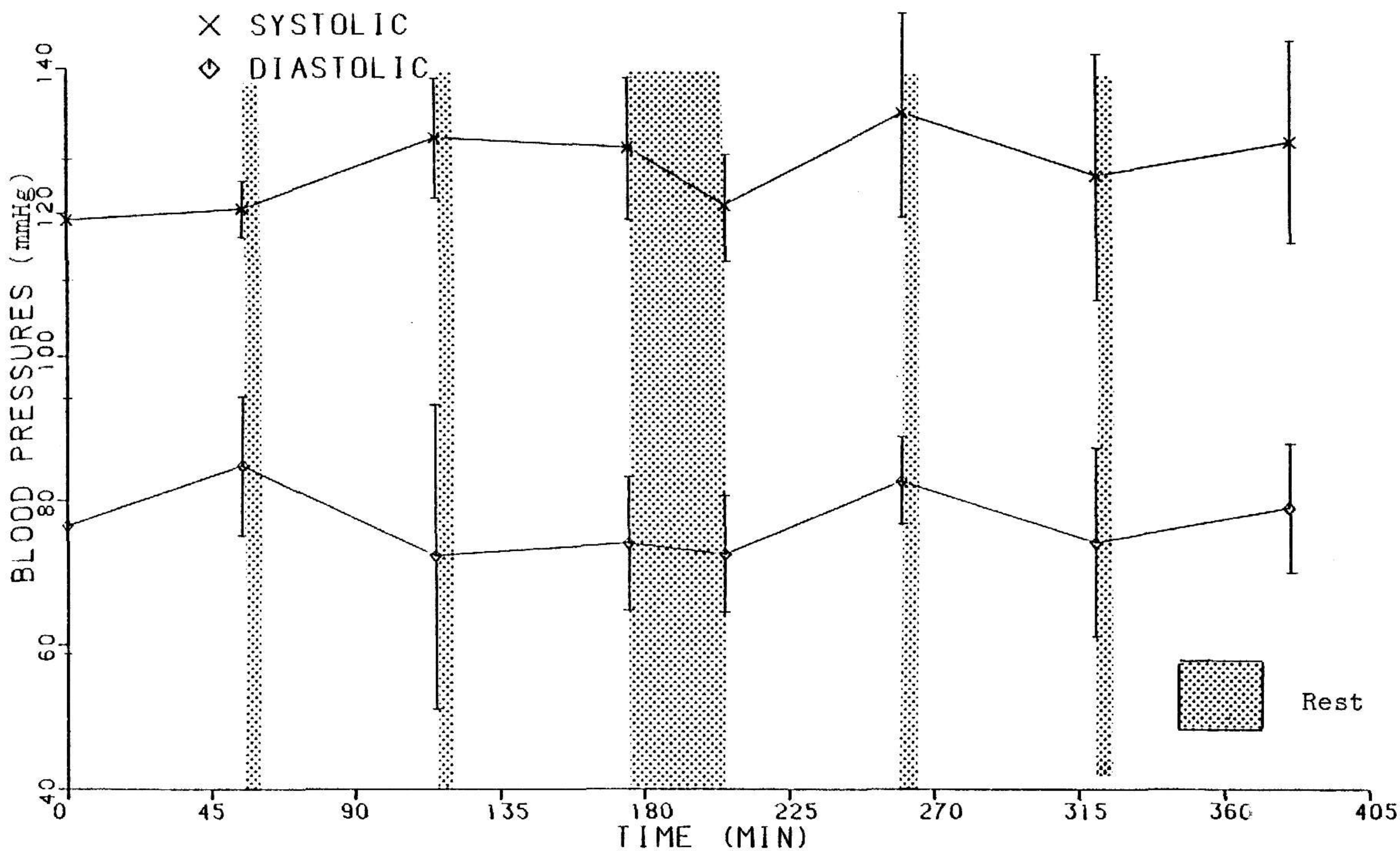

Figure 58. Blood pressure(8% rest, warm-humid work, cool rest)

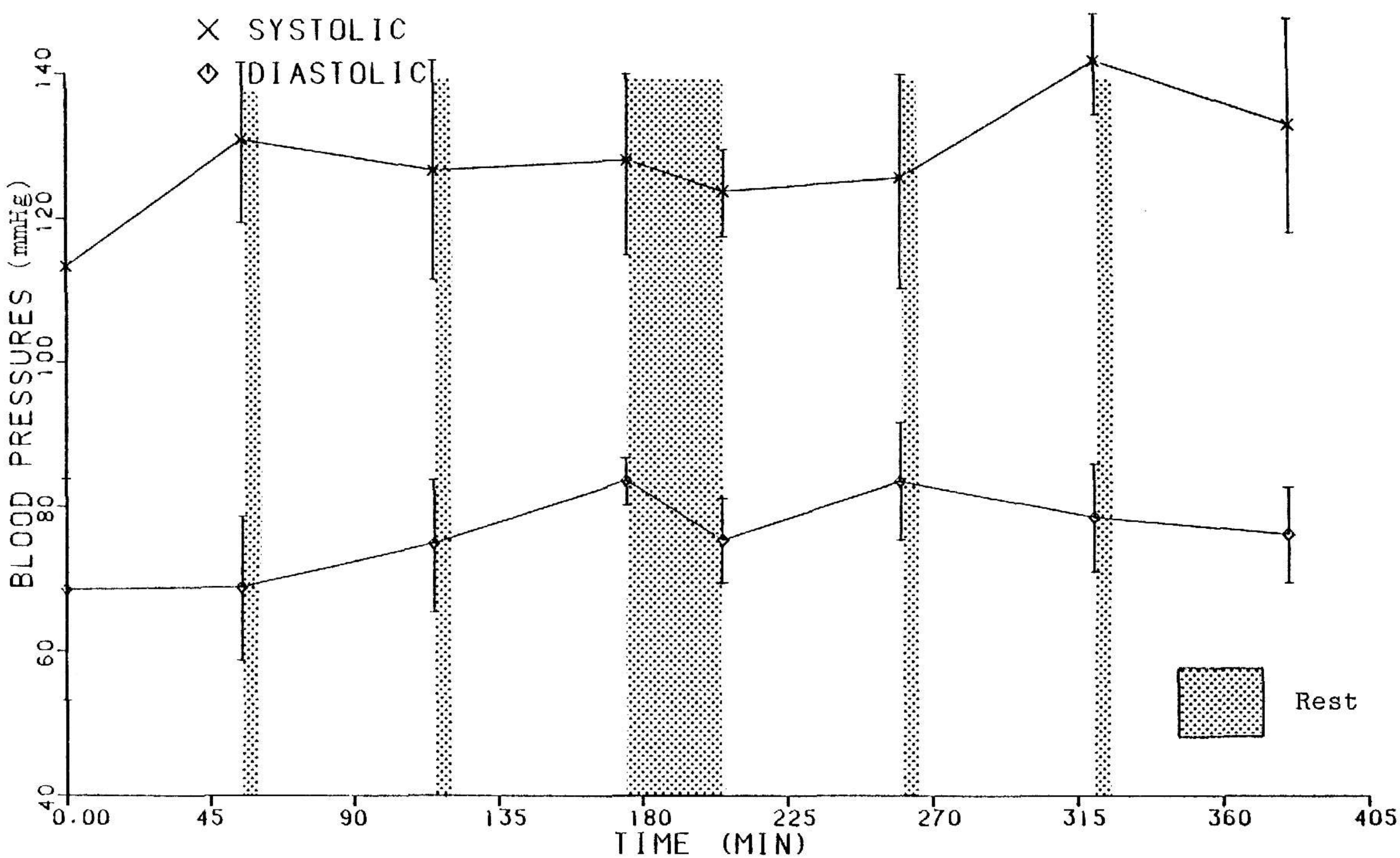

Figure 59. Blood pressure(8% rest, warm-humid work and rest)

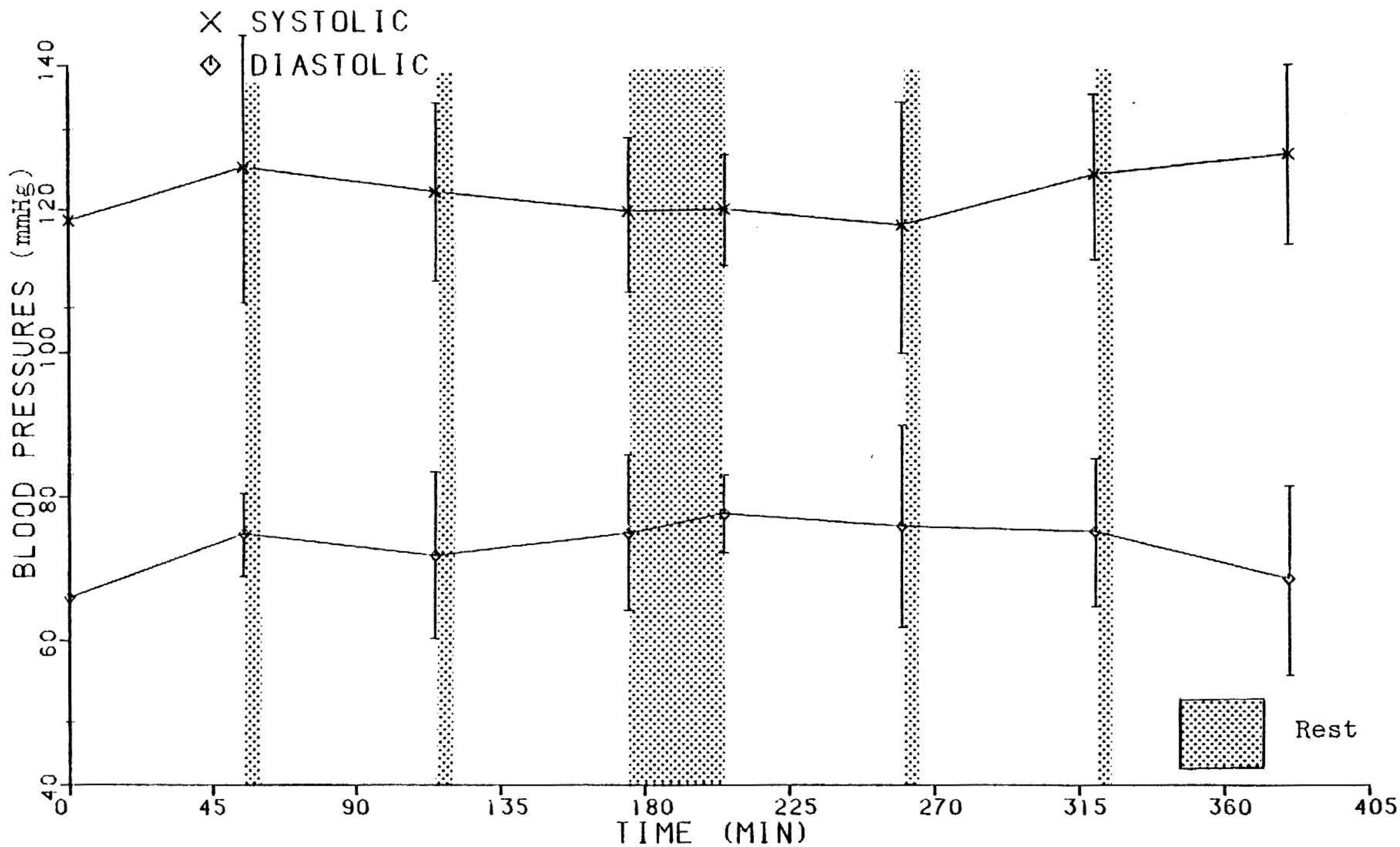

Figure 60. Blood pressure(8% rest, hot-dry work, cool rest)

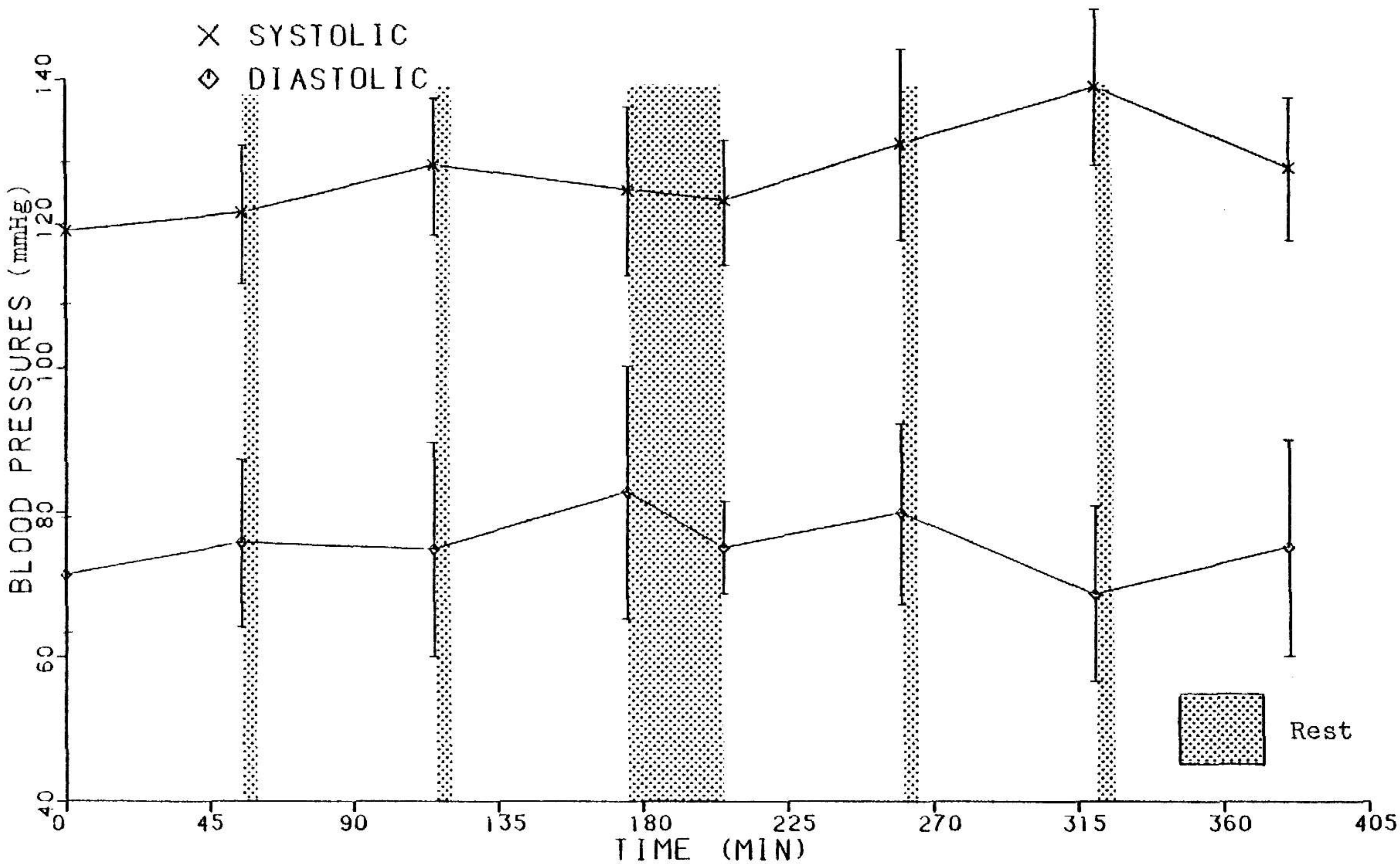

Figure 61. Blood pressure(8% rest, hot-dry work and cool rest)

PHYSIOLOGICAL RESPONSES TO

INTERMITTENT HEAT STRESS

BY

KOON H. CHUNG

B. S., Kansas State University, 1978

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

Four male subjects participated in an experiment of eight conditions: two work environments (warm-humid of Tdb 30°C, rh 67% and hot dry of Tdb 39°C, rh 17%), three rest environments (Tdb 23°C, rh 50%, and the work environments) for each work environment, and two work-rest ratios (75% work and 25% rest, 92% work and 8% rest). Metabolic rate was maintained at 300 Watts by alternating standing and stepping. Skin temperature was significant for work-rest ratio, work temperature, time, and subject. Rectal temperature was significant for work-rest ratio, work temperature, and rest temperature. Oral temperature was significant for work-rest ratio. Heart rate was significant for rest temperature and time. Evaporative weight loss was significant work work temperature. Systolic blood pressure was significant for time, while diastolic blood pressure was significant for work temperature and rest temperature.