UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, DECEMBER 2005

MIE343F - INDUSTRIAL ERGONOMICS

Exam Type B

Examiner - Paul White

MIE343 Final Examination
Ergonomics
December 7, 2005

This examination will last for 2.5 hours. You are not permitted any materials but may have a non-programmable calculator. There are 105 marks available. Budget your time carefully.

1. **Define the following terms:** (2 X 10= 20 marks)

   Lux

   Maximum voluntary contraction

   Jet lag

   Wotton test

   Decibel

   A-weighting scale

   Luminance

   Reflectance

   Direct and indirect lighting

   Calorie (scientific and food)

2. **Lighting issues**. (15 marks)

a. List both the human factors and the task/environmental related factors which influence the amount of illuminance required in the workplace? State how each changes. (8 marks)

b. Define glare and its consequences. (3 marks)

c. Provide an example of direct glare and an example of indirect glare in the workplace and recommend an engineering control strategy for each. (4 marks)

3. **Circadian Rhythm and Shift work** (15 marks)

   a. What is circadian rhythm? (3marks)

   b. Sketch a graph showing circadian rhythm. (4 marks)

c. Name three body functions that follow it (not body temperature). (3 marks)

d. It is recommended that shift rotation be "forward", i.e., day shift (8 am – 4 pm), then afternoon shift (4pm – midnight), then nights (midnight – 8 am). Why? (5 marks)

e. In the textbook, a study of gas meter readers was reported in which errors peaked at 3 pm and 3 am. Why? How would this inform your input into workplace scheduling issues? (5 marks)

4. **Ergonomics Programming** (15 Marks)

In class we discussed seven steps to build an ergonomics program. Outline the steps and give examples of the kinds of things you would do for each were you working in industry.

5. **Heat Stress** (25 marks)

Scooter Libby is in disgrace at the White House since he has been indicted for revealing the identity of a CIA agent in order to punish the agent's husband. He has been put in charge of "filing" all incriminating documents from the offices of George Bush and Dick Cheney; no small task!

The document disposal room at the White House contains a furnace where all papers, pictures and computer disks are incinerated using high-energy plasma, ensuring that the administration maintains "deniability". Scooter, has worked in this room in this room for 2 weeks now, throwing 25 kg file boxes into the furnace at a rate of 1 per minute. Being Republican, Scooter dresses appropriately in a black, three-piece Armani suit and an Egyptian cotton dress shirt with French cuffs. There is a reflective heat shield set back 1 meter from the front of the furnace opening. Because of this, Scooter is only exposed to the furnace's radiant heat for 15 seconds when actually throwing the boxes into the furnace.

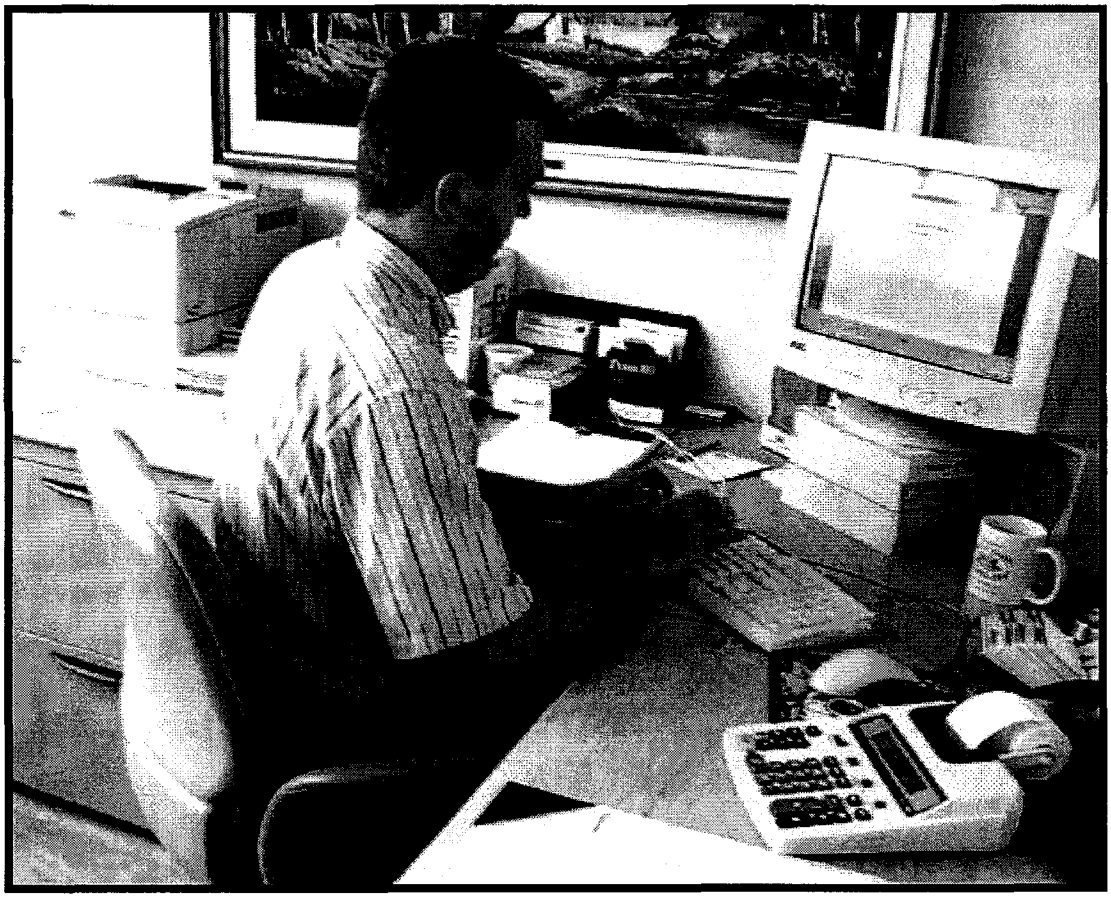
Since the starting his new job, Scooter has been complaining vociferously to anyone who will listen about the heat and the endless number of George's and Dick's nasty secrets that must be incinerated. Your firm, Heckfire Engineering, a subsidiary of Halliburton Inc., has been hired to resolve the situation and you have measured the environmental parameters to find:

	In front of furnace	**Rest of room**
Dry bulb temperature	29 C	29 C
Wet bulb temperature	23C	23 C
Globe Temperature	67 C	29 C

Your boss, Phil, the Prince of Insufficient Light, has asked you to determine whether Scooter is exposed to excessive heat stress. State any assumptions that you make. Suggest engineering and/or administrative controls that might be required either to bring the heat stress within acceptable limits and/or to make Scooter's life a bit easier.

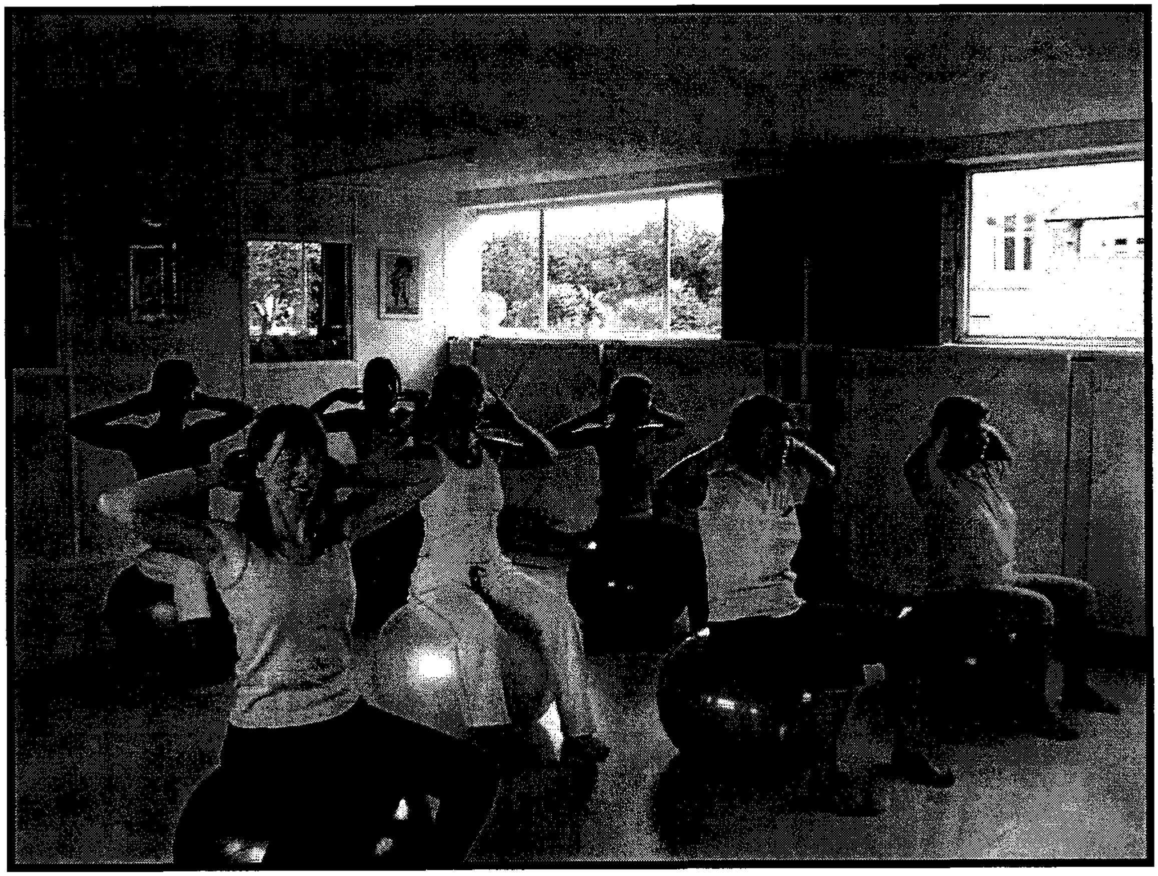
6. **Office Ergonomics** (15 marks)

a) Look at picture 1 below and determine the problems that are present. State the issue, the unpleasant consequence for the user, and a solution. (10 marks)



b) Some genius has come up with the idea of using a Pilates ball (see picture on next page) for an office chair. Some gullible schlemiels are following this advice. Why is this idea ***so*** wrong? (5 marks)

An excellent exercise tool!



‡HEAT STRESS

The heat stress TLVs specified in Table 1 and Figure 1 refer to heat stress conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects. These TLVs are based on the assumption that nearly all acclimatized, fully clothed (e.g., lightweight pants and shirt) workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body temperature of 38°C (100.4°F).

Where there is a requirement for protection against other harmful substances in the work environment and additional personal protective clothing and equipment must be worn, a correction to the Wet Bulb Globe Temperature (WBGT) TLV values, as presented in Table 2, must be applied.

Since measurement of deep body temperature is impractical for monitoring the workers' heat load, the measurement of environmental factors is required which most nearly correlate with deep body temperature and other physiological responses to heat. At the present time, the WBGT Index is the simplest and most suitable technique to measure the environmental factors. WBGT values are calculated by the following equations:

1. Outdoors with solar load:
   $WBGT = 0.7\ NWB + 0.2\ GT + 0.1\ DB$
2. Indoors or Outdoors with no solar load:
   $WBGT = 0.7\ NWB + 0.3\ GT$

where: WBGT = Wet Bulb Globe Temperature Index
NWB = Natural Wet-Bulb Temperature
DB = Dry-Bulb Temperature
GT = Globe Temperature

The determination of WBGT requires the use of a black globe thermometer, a natural (static) wet-bulb thermometer, and a dry-bulb thermometer.

Higher heat exposures than those shown in Table 1 and Figure 1 are permissible if the workers have been undergoing medical surveillance and it has been established that they are more tolerant to work in heat than the average worker. Workers should not be permitted to continue their work when their deep body temperature exceeds 38°C (100.4°F).

Evaluation and Control

I. *Measurement of the Environment*

The instruments required are a dry-bulb, a natural wet-bulb, a globe thermometer, and a stand. The measurement of the environmental factors should be performed as follows:

TABLE 1. Examples of Permissible Heat Exposure Threshold Limit Values [Values are given in °C and (°F) WBGT]*

	Work Load		
Work–Rest Regimen	**Light**	**Moderate**	**Heavy**
Continuous work	30.0 (86)	26.7 (80)	25.0 (77)
75% Work — 25% Rest, each hour	30.6 (87)	28.0 (82)	25.9 (78)
50% Work — 50% Rest, each hour	31.4 (89)	29.4 (85)	27.9 (82)
25% Work — 75% Rest, each hour	32.2 (90)	31.1 (88)	30.0 (86)

*As workload increases, the heat stress impact on an unacclimatized worker is exacerbated (see Figure 1). For unacclimatized workers performing a moderate level of work, the permissible heat exposure TLV should be reduced by approximately 2.5°C.

A. The range of the dry and the natural wet-bulb thermometer should be –5°C to +50°C (23°F to 122°F) with an accuracy of ± 0.5°C. The dry bulb thermometer must be shielded from the sun and the other radiant surfaces of the environment without restricting the airflow around the bulb. The wick of the natural wet-bulb thermometer should be kept wet with distilled water for at least 1/2 hour before the temperature reading is made. It is not enough to immerse the other end of the wick into a reservoir of distilled water and wait until the whole wick becomes wet by capillarity. The wick should be wetted by direct application of water from a syringe 1/2 hour before each reading. The wick should extend over the bulb of the thermometer, covering the stem about one additional bulb length. The wick should always be clean and new wicks should be washed before using.

B. A globe thermometer, consisting of a 15-cm (6-inch) diameter hollow copper sphere painted on the outside with a matte black finish or equivalent, should be used. The bulb or sensor of a thermometer (range –5°C to +100°C [23°F to 212°F] with an accuracy of ± 0.5°C)

TABLE 2. TLV WBGT Correction Factors in °C for Clothing

Clothing Type	**Clo Value***	**WBGT Correction**
Summer work uniform	0.6	0
Cotton coveralls	1.0	–2
Winter work uniform	1.4	–4
Water barrier, permeable	1.2	–6

*Clo: Insulation value of clothing. One clo unit = 5.55 kcal/m^2/hr of heat exchange by radiation and convection for each °C of temperature difference between the skin and adjusted dry-bulb temperature [the average of the ambient air dry bulb temperature and the mean radiant temperature, $t_{adb}=(t_a+\bar{t}_r)/2$].

must be fixed in the center of the sphere. The globe thermometer should be exposed at least 25 minutes before it is read.

C. A stand should be used to suspend the three thermometers so that they do not restrict free air flow around the bulbs, and the wet-bulb and globe thermometers are not shaded.

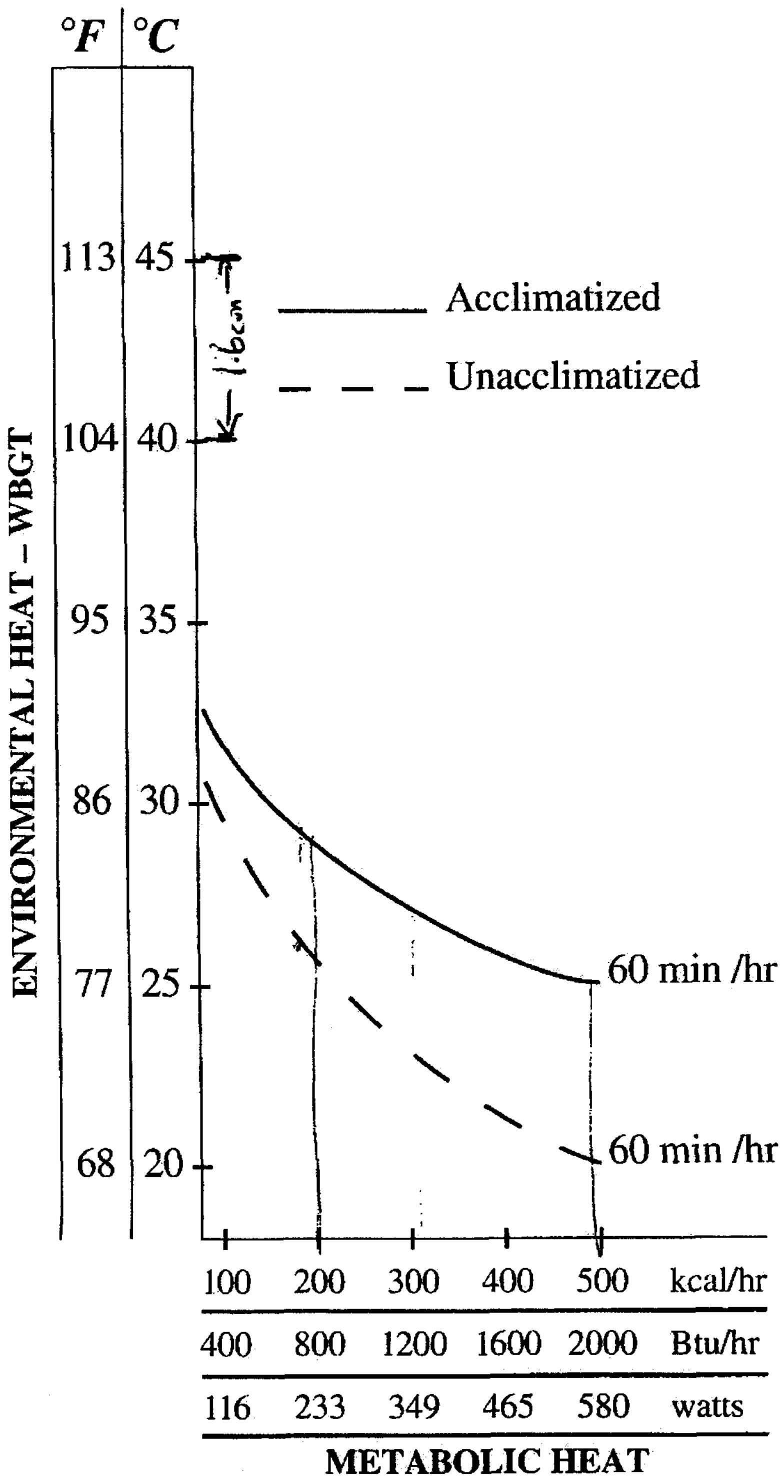


Figure 1—Permissible heat exposure TLVs for heat acclimatized and unacclimatized workers.

D. It is permissible to use any other type of temperature sensor that gives a reading identical to that of a mercury thermometer under the same conditions.

E. The thermometers must be placed so that the readings are representative of the conditions under which the employees work or rest, respectively.

II. *Work Load Categories*

Heat produced by the body and the environmental heat together determine the total heat load. Therefore, if work is to be performed under hot environmental conditions, the workload category of each job should be established and the heat exposure limit pertinent to the workload evaluated against the applicable standard in order to protect the worker exposure beyond the permissible limit.

A. The work load category may be established by ranking each job into light, medium, or heavy categories on the basis of type of operation:

1. light work (up to 200 kcal/hr or 800 Btu/hr): e.g., sitting or standing to control machines, performing light hand or arm work,
2. moderate work (200–350 kcal/hr or 800–1400 Btu/hr): e.g., walking about with moderate lifting and pushing, or
3. heavy work (350–500 kcal/hr or 1400– 2000 Btu/hr): e.g., pick and shovel work.

Where the work load is ranked into one of said three categories, the permissible heat exposure TLV for each workload can be estimated from Table 1 or calculated using Tables 3 and 4.

B. The ranking of the job may be performed either by measuring the worker's metabolic rate while performing a job or by estimating the worker's metabolic rate with the use of Tables 3 and 4. Additional tables available in the literature[1–4] may be utilized also. When this method is used, the permissible heat exposure TLV can be determined by Figure 1.

III. *Work–Rest Regimen*

The TLVs specified in Table 1 and Figure 1 are based on the assumption that the WBGT value of the resting place is the same or very close to that of the workplace . Where the WBGT of the work area is different from that of the rest area, a time-weighted average value should be used for both environmental and metabolic heat.

The time-weighted average metabolic rate (M) should be determined by the equation:

$$\text{Av. M} = \frac{M_1 \times t_1 + M_2 \times t_2 + \ldots + M_n \times t_n}{t_1 + t_2 + \ldots + t_n}$$

TABLE 3. Assessment of Work Load

Average values of metabolic rate during different activities.

A. Body position and movement	kcal/min
Sitting	0.3
Standing	0.6
Walking	2.0–3.0
Walking up hill	add 0.8 per meter (yard) rise

B. Type of Work		Average kcal/min	Range kcal/min
Hand work	*light*	0.4	0.2–1.2
	heavy	0.9	
Work with one arm	*light*	1.0	0.7–2.5
	heavy	1.7	
Work with both arms	*light*	1.5	1.0–3.5
	heavy	2.5	
Work with body	*light*	3.5	2.5–15.0
	moderate	5.0	
	heavy	7.0	
	very heavy	9.0	

where M_1, M_2...and M_n are estimated or measured metabolic rates for the various activities and rest periods of the worker during the time periods t_1, t_2...and t_n (in minutes) as determined by a time study.

The time-weighted average WBGT should be determined by the equation:

$$\text{Av. WGBT} = \frac{\text{WBGT}_1 \times t_1 + \text{WBGT}_2 \times t_2 + ... + \text{WBGT}_n \times t_n}{t_1 + t_2 + ... + t_n}$$

where WBGT_1, WBGT_2 ... and WBGT_n are calculated values of WBGT for the various work and rest areas occupied during total time periods and t_1, t_2 ... and t_n are the elapsed times in minutes spent in the corresponding areas which are determined by a time study. Where exposure to hot environmental conditions is continuous for several hours or the entire work day, the time-weighted averages should be calculated as an hourly time-weighted average, i.e., $t_1 + t_2 + ... t_n = 60$ minutes. Where the exposure is intermittent, the time-weighted averages should be calculated as two-hour time-weighted averages, i.e., $t_1 + t_2 + ... + t_n = 120$ minutes.

The TLVs for continuous work are applicable where there is a work–rest regimen of a 5-day work week and an 8-hour work day with a short morning and afternoon break (approximately 15 minutes) and a longer lunch break (approximately 30 minutes). Higher exposure values are permitted if additional resting time is allowed. All breaks, including unscheduled pauses and administrative or operational waiting periods during work, may be counted as rest time when additional rest allowance must be given because of high environmental temperatures.

IV. *Water and Salt Supplementation*

During the hot season or when the worker is exposed to artificially generated heat, drinking water should be made available to the workers in such a way that they are stimulated to frequently drink small amounts, i.e., one cup every 15–20 minutes (about 150 ml or 1/4 pint).

The water should be kept reasonably cool, 10°C to 15°C (50°F to 60°F) and should be placed close to the workplace so that the worker can reach it without abandoning the work area.

The workers should be encouraged to salt their food well during the hot season and particularly during hot spells. If the workers are unacclimatized, salted drinking water should be made available in a concentration of 0.1% (1 g salt to 1.0 liter or 1 level tablespoon of salt to 15 quarts of water). The added salt should be completely dissolved before the water is distributed, and the water should be kept reasonably cool.

TABLE 4. Activity Examples

- Light hand work: writing, hand knitting
- Heavy hand work: typewriting
- Heavy work with one arm: hammering in nails (shoemaker, upholsterer)
- Light work with two arms: filing metal, planing wood, raking of a garden
- Moderate work with the body: cleaning a floor, beating a carpet
- Heavy work with the body: railroad track laying, digging, barking trees

Sample Calculation

Assembly line work using a heavy hand tool.

A. Walking along		2.0 kcal/min
B. Intermediate value between heavy work with two arms and light work with the body		3.0 kcal/min
	Subtotal:	5.0 kcal/min
C. Add for basal metabolism		1.0 kcal/min
	Total:	6.0 kcal/min

V. *Other Considerations*

A. *Clothing*: The permissible heat exposure TLVs are valid for light summer clothing as customarily worn by workers when working under hot environmental conditions. If special clothing is required for performing a particular job and this clothing is heavier or it impedes sweat evaporation or has higher insulation value, the worker's heat tolerance is reduced, and the permissible heat exposure TLVs indicated in Table 1 and Figure 1 are not applicable. For each job category where special clothing is required, the permissible heat exposure TLV should be established by an expert.

Table 2 identifies TLV WBGT correction factors for representative types of clothing.

B. *Acclimatization and Fitness*: Acclimatization to heat involves a series of physiological and psychological adjustments that occur in an individual during the first week of exposure to hot environmental conditions. The recommended heat stress TLVs are valid for acclimated workers who are physically fit. Extra caution must be employed when unacclimated or physically unfit workers must be exposed to heat stress conditions.

C. *Adverse Health Effects*: The most serious of heat-induced illnesses is heat stroke because of its potential to be life threatening or result in irreversible damage. Other heat-induced illnesses include heat exhaustion which in its most serious form leads to prostration and can cause serious injuries as well. Heat cramps, while debilitating, are easily reversible if properly and promptly treated. Heat disorders due to excessive heat exposure include electrolyte imbalance, dehydration, skin rashes, heat edema, and loss of physical and mental work capacity.

If during the first trimester of pregnancy, a female worker's core temperature exceeds 39°C (102.2°F) for extended periods, there is an increased risk of malformation to the unborn fetus. Additionally, core temperatures above 38°C (100.4°F) may be associated with temporary infertility in both females and males.

References

1. Astrand, P-O.; Rodahl, K.: Textbook of Work Physiology. McGraw–Hill Book Co., New York, San Francisco (1970).
2. Ergonomics Guide to Assessment of Metabolic and Cardiac Costs of Physical Work. Am. Ind. Hyg. Assoc. J. 32:560 (1971).
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4. Durnin, J.V.G.A.; Passmore, R.: Energy, Work and Leisure. Heinemann Educational Books, Ltd., London (1967).