AN ACCURACY OF WORK HEAT LOAD EVALUATION BY EXPERT JUDGMENT

SUPAPORN MEKSAWI

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Supaporn Meksawi

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AN ACCURACY OF WORK HEAT LOAD EVALUATION BY EXPERT JUDGMENT

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ABSTRACT

The purpose of this quasi-experimental research was to test the accuracy of metabolic heat by comparing the oxygen consumption measurement method with an estimation conducted, based on the tables of energy expenditure. The sample was 119 occupational health experts who worked as safety officers in 25 types of factories where the heat level had to be measured as required by the regulation of the Ministry of Industry. Data were analyzed by means of Chi-square test, t-test, and One-Way ANOVA.

The results revealed that accuracy in estimating the metabolic rate using the energy expenditure tables of NIOSH were 43%. The accuracy in estimating the metabolic rates in eight sample situations was lower than 80% with statistical significance. Moreover, there were no statistically significant relationships between experiences in occupational health work, heat stress measurement, training, educational background, and type of safety officers and accuracy of work heat load estimation.

These findings led to the conclusion that the estimation of the metabolic rate conducted by occupational health experts using the energy expenditure table of NIOSH is highly erroneous, and that the estimation tends to be higher than it actually is.

KEY WORDS: ACCURACY/ WORK LOAD JUDGMENT/ METABOLIC RATE ESTIMATE/ OCCUPATIONA HEALTH EXPERT JUDGMENT

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ความถูกต้องของการประเมินภาระงานในที่ร้อนโดยวิธีลงความเห็นของผู้เชี่ยวชาญ
(AN ACCURACY OF WORK HEAT LOAD EVALUATION BY EXPERT JUDGMENT)

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บทคัดย่อ

การศึกษาครั้งนี้เป็นการวิจัยแบบกึ่งทดลองเพื่อศึกษาความถูกต้องของการประเมินภาระงานในที่ร้อนโดยการประมาณอัตราเมตาบอลิซึมจากตารางการใช้พลังงานของ NIOSH เปรียบเทียบกับอัตราเมตาบอลิซึมที่คำนวณจากอัตราการใช้ออกซิเจนของคนงาน กลุ่มตัวอย่างเป็นนักอาชีวอนามัยที่ทำงานในโรงงาน 25 ประเภทที่กระทรวงอุตสาหกรรมกำหนดให้มีการตรวจวัดความร้อน จำนวน 119 คน เก็บข้อมูลในระหว่างเดือนธันวาคม พ.ศ.2548 - มิถุนายน พ.ศ.2549 วิเคราะห์ข้อมูลโดยใช้สถิติ Chi-square test, t-test และ one-way ANOVA

ผลการศึกษาพบว่าผลการประเมินอัตราเมตาบอลิซึมโดยการประมาณค่าจากตารางการใช้พลังงานของ NIOSH มีความถูกต้องร้อยละ 43 ความถูกต้องของการประมาณอัตราเมตาบอลิซึมในสถานการณ์ตัวอย่างทั้ง 8 สถานการณ์น้อยกว่าร้อยละ 80 อย่างมีนัยสำคัญทางสถิติ (p-value < 0.05) ส่วนปัจจัยทางด้านประสบการณ์ในงานอาชีวอนามัย การตรวจวัดความร้อน การอบรม ระดับการศึกษา และประเภทของเจ้าหน้าที่ความปลอดภัยระดับวิชาชีพไม่มีความสัมพันธ์กับความถูกต้องของการประเมินภาระงาน

จากการวิจัยครั้งนี้สรุปว่า ผลการประเมินโดยการประมาณอัตราเมตาบอลิซึมจากตารางการใช้พลังงานของ NIOSH โดยนักอาชีวอนามัยมีความผิดพลาดสูงและมีค่าสูงกว่าความเป็นจริง

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LIST OF ABBREVIATIONS

NIOSH	=	National Institute for Occupational Safety and Health
ACGIH	=	American Conference of Governmental Industrial Hygienists
WBGT	=	Wet Bulb Globe Temperature
VO_2max	=	Maximum Oxygen Consumption
MAGC	=	Maximal Anaerobic Glycolytic Capacity
MVC	=	Maximum Voluntary Contraction
LT	=	Lactate Threshold
AT	=	Anaerobic Threshold
VE	=	Ventilation Exchange Rate
ADH	=	Antidiuretic Hormone
CNS	=	Central Nervous System
M	=	Metabolism
EE	=	Energetic Equivalent
RQ	=	Respiratory Quotient
VO_2	=	Oxygen Consumption
VCO_2	=	Carbon Dioxide Production
A_{DU}	=	The Body Surface, in square metres, according to Du Bois
W_b	=	The Body Weight, in kilograms
H_b	=	The Body Height, in metres
kPa	=	Saturated Water Vapour
kcal	=	Kilocalorie
t_{nwb}	=	Natural Wet Bulb Temperature
t_g	=	Globe Temperature
t_a	=	Dry Bulb Temperature

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CHAPTER I
INTRODUCTION

1.1 Background and Rationale

Heat stress monitor is the procedure in safety protection for the workers. The Ministry of Industry in Thailand recommends that worker exposure to heat stress in the workplace be controlled by complying with the regulations of safety protection in factories about working condition on November 6, 2002. (1) In this regulation, environmental heat measurement shall be made average for two hours during the hottest portion of each work shift, during the hottest months of the years.

In this Thai regulation, total heat storage in the body is considered to be the sum of heat gained in the body (metabolic heat) plus the heat gained from the environment (environment heat). The regulation establishes the threshold WBGT value for exposure at the three levels of physical work: light work ≤ 200 kcal/hr, 34 °C; moderate work = 200-350 kcal/hr, 32 °C; and heavy work ≥ 350 kcal/hr, 30 °C. The ranking of the job may be compared with the sample type job that is given or estimated by the use of the workload assessment procedure where both body position and movement and type of work are taken into consideration. However, many factors are included for consideration such as air velocity and clothing (2), but this regulation is not recommend.

The determination of metabolic heat shall be estimated from the energy expenditure table (2), and the metabolic heat production in kilocalories per minute shall be calculated using the upper value of rang given in the energy expenditure table (Table 2-2,2-3) for each body position and type of work for each specific task of each worker's job. (1,2) The metabolic rate shall be used for a worker who weighs 70 kilograms (kg.) and 1.8 m^2 body surface area. Therefore, for a worker that has other than a 70-kg weight and 1.8 m^2 body surface area, the best judgment would be used

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for appropriate estimate of metabolic heat for the duration of the task analysis. (2) However, the metabolic rate in each worker's job depends on many factors such as work speed, working skill, relaxing time during work, and others. (3) As a result, the determination of metabolic rate by using the upper value of rang given in the energy expenditure table would be used as the best judgment and the accuracy of estimating depends on the assessor's knowledge and experience. (2) Generally, errors in estimating metabolic rate from the energy expenditure table are reported to be as high as 30%. (4) However, an accuracy of the estimates made by a trained observer may vary by about ± 10-15%. (5)

If the estimated metabolic heat is incorrect, workers may be at risk because heat-induced occupational illnesses, injuries, and reduced productivity occur in situations in which the total heat load (environment plus metabolic) exceeds the capacities of the body to maintain normal body functions without excessive strain, at the same level of heat stress, when the worker's compensatory mechanism will no longer be capable of maintaining body temperature at the level required for normal body functions. As a consequence, the risk of heat-induced illnesses, disorders, and accidents substantially increases. (3) In heat stress, total blood supply must be divided between the working muscles and the skin where the heat exchange occurs. (6) Stroke volume rapidly reaches a constant value for a given intensity of the working muscles, as is essentially indicated by heart rate. (7) However, there have been reports that the basic physiological energy expenditure and cardiovascular load of Thai workers are different from those of the workers from industrialized Western countries. An upward shift for heart rate of about 30 to 35% for similar oxygen uptake is remarkable. (8) Thus, when working at the same level of total heat load, Thai workers may be at higher risks than workers from industrialized Western countries. For this reason, the accuracy of metabolic heat determination is deemed very important.

The aim of the present study was to test the determination of the accuracy of metabolic heat by comparing the oxygen consumption measurement method and occupational health experts' estimate of the metabolic rate in assessing muscular work load and human heat in the different activities by utilizing tabulated energy values from the energy expenditure table of NIOSH which specifies incremental metabolic heat resulting from the movement of different body parts, i.e., arm work, leg work,

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standing, and walking (2) in a rather large sample of 119 subjects. In this study, the relationship between different factors and accuracy of work heat load estimation were considered**.**

1.2 Objectives of the study

1.2.1. To examine an accuracy of the metabolic rate that is estimated by occupational health experts by using the energy expenditure table of NIOSH.

1.2.2. To study the relationship between different factors and accuracy of work heat load estimation

1.3 Research hypotheses

1.3.1. The average metabolic rates by occupational health experts estimated based on the energy expenditure table of NIOSH are different from the metabolic rates that were calculated from oxygen consumption measurement.

1.3.2. An accuracy of the estimating metabolic rate from the energy expenditure table of NIOSH by occupational health experts have value less than 80%.

1.3.3. Experience in occupational health work, heat stress measurement and estimation of metabolic rate of workers, training, actual field measurement, educational background, and type of safety officers are related to the accuracy of work heat load estimation

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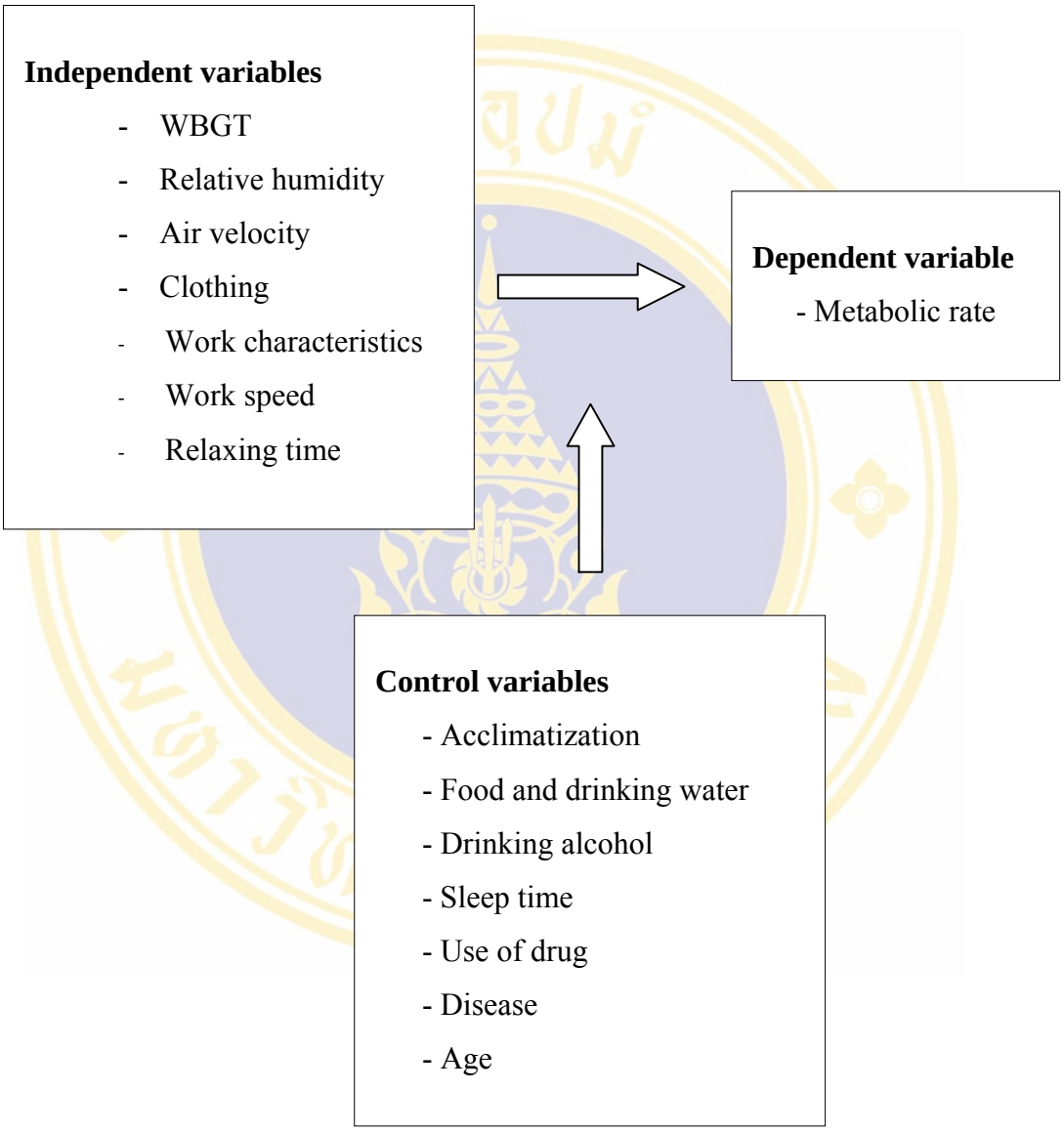
1.4 Study variables

1.4.1. Phase 1 (Measurement of O_2 Consumption)



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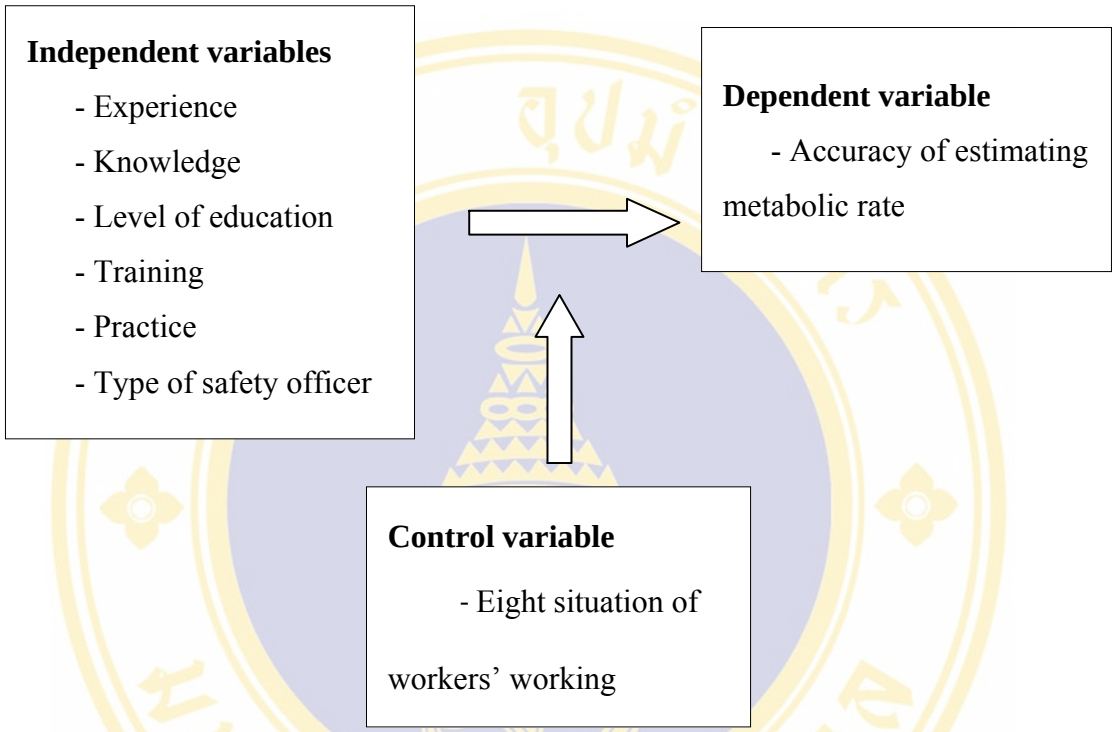
1.4.2. Phase 2 (occupational health experts' estimation of metabolic heat from the energy expenditure table of NIOSH)



1.5 Scope of the study

This study was aimed to investigate determination of metabolic rates by measurement of oxygen consumption in acclimated man workers who were exposed the heat in production process in the foundry factory. These workers were between 18 and 40 years old. Oxygen consumption measurement was conducted from December 2005 to January 2006. Occupational health experts determined the metabolic rates by estimating the metabolic rates from the upper value of range given in the energy expenditure table. Afterwards, the accuracy of metabolic rates estimated from the energy expenditure table were analyzed and subsequently compared with the metabolic rates that were calculated from oxygen consumption. Moreover, the relationship between experienced assessors and accuracy of assessment was analyzed, and the metabolic rates that were estimated by safety officers who were educated in occupational health and by trained safety officers were compared.

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1.6 Limitation of the study

The metabolic rates were estimated by means of videos which had been recorded during workers' work in the foundry factory. This was because there were a large number of observers, so they were not allowed to do field observations while the workers were actually working in the factory.

1.7 Definition of terms

Occupational health experts refer to persons who have been graduated with a bachelor's degree, a master's degree, or a doctorate in occupational health and safety or industrial hygiene and safety. They are teachers, safety officers, or technicians who work in the fields related to occupational health and safety work, or they can be those who have under gone a 180-hour training to become certified occupational health experts.

Safety officers refer to persons who work in a safety officer position in 25 types of factories where heat level had to be measured as required by the regulation who have been educated in occupational health and safety, industrial hygiene and safety, or those who have undergone a 180-hour training to become certified safety officers.

Workload refers to the metabolic rate that can be classified into three levels as follows:

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light work (metabolism < 200 Kcal/hr), moderate work (metabolism between 200 and 350 Kcal/hr), and heavy work (metabolism > 350Kcal/hr).

O_2 Consumption refers to the amount of oxygen that can be utilized by the body.

Metabolic rate refers to chemical energy that is transferred into free energy per unit time.

Metabolism refers to transformation of chemical energy in to the energy which is used for performing work and producing heat.

Experience refers to experience that is related to occupational health and safety work such as duration of work, measurement of heat stress practice, training, educational training, and actual field experience.

1.8 Expected outcomes and benefits

1.8.1. The findings of this study can be used to confirm the accuracy of the estimation of the metabolic rate by using the energy expenditure table of NIOSH which is allowed by the Thai regulations to be used in the assessment of workload.

1.8.2. The findings can also be used as a reference to reform the methods of metabolic rate assessment to ensure more accuracy.

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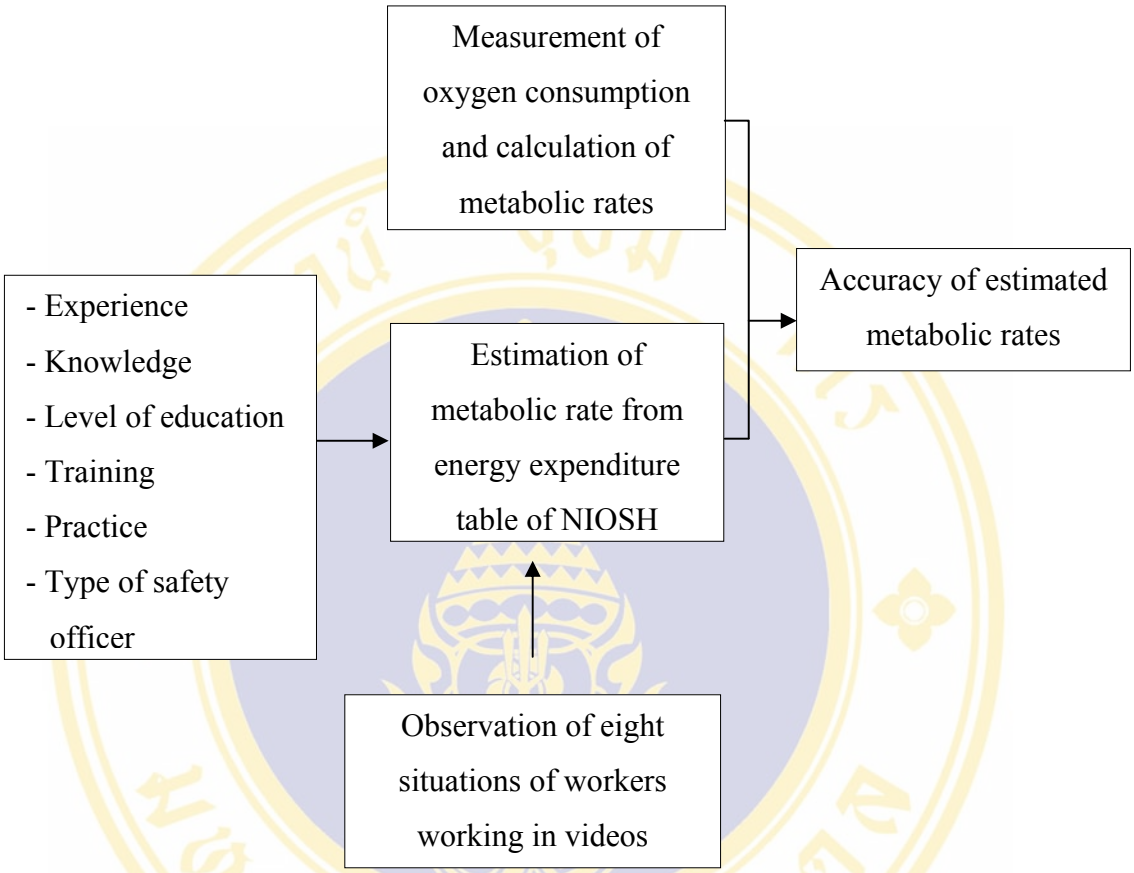
1.9 Conceptual framework of the study



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CHAPTER II
LITERATURE REVIEW

Operations involving high air temperatures, radiant heat source, high humidity, direct physical contact with hot objects, or strenuous physical activities have a high potential for inducing heat stress in workers engaged in such operations. Such places include iron and steel foundries, nonferrous foundries, brick-firing and ceramic plants, glass product facilities, rubber product factories, electrical utilities (particularly boiler rooms), bakeries, confectioneries, commercial kitchens, laundries, food canneries, chemical plants, mining sites, smelters, and steam tunnels. The level of heat stress at which excessive heat strain will result depends on the heat-tolerance capabilities of workers. (9) The workers engaged in job activities while in an uncomfortably hot or dangerously hot environment have two avenues leading to potential injury and illness. Firstly, the physiological responses can produce heat illness such as heat cramps, syncope, exhaustion, or stroke. Secondly, the effects of heat on the workers' perceptual motor and cognitive task performance can negatively affect the operations of controls, attention to warning signals, and reaction-response times. Reduced performance in this type of task can easily lead to mishaps and injuries to the workers. (10)

Heat exchange process

The major heat exchange modes between the body and the environment are convection, radiation, and evaporation. When the body is in contact with hot tools, equipment, floor, etc. which may cause burns, conduction plays a minor role in industrial heat stress. (2, 3)

Conduction is the transferring process of heat between materials that contact each other. Heat passes from the warmer material to the cooler material. For example, a worker's skin can transfer heat to a contacting surface if that surface is cooler, and

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vice versa. The heat conduction depends on surface area, time of transfer, and type of material. Steel has good conductivity. (9)

Convection is the transferring process of heat in a moving fluid. Air flowing past the body can cool the body if the air temperature is cool. On the other hand, air that exceeds 35 °C (95 °F) can increase the heat load on the body. (9)

Radiation is the transferring process of the heat energy through space. A worker whose body temperature is greater than the temperature of the surrounding surfaces radiates heat to these surfaces. Hot surfaces and infrared light sources radiate heat that can increase the body's heat load. (9)

Evaporation is the evaporation of water (sweat) from the skin surface which results in a heat loss from the body. The maximum evaporative capacity is a function of air motion and the water vapor pressure difference between the ambient air and the wetted skin at skin temperature. (9)

The total heat load imposed on the human body is the aggregation of environmental and physical work factors. The energy cost of an activity as measured by the metabolic heat (M) is a major element in the heat exchange balance between the human body and the environment. The metabolic heat value can be measured or estimated. The energy cost of an activity is made up of two parts: the energy expended in doing the work and the energy transformed into heat. On the average, muscles may reach 20% efficiency in performing heavy physical work. However, unless external physical work is produced, the body heat load is approximately equal to the total metabolic energy turnover. For practical purposes, M is equated with total energy turnover.

However, there are several factors which have direct and major contributory influences on the degree of heat storage within the human body. The fundamental thermodynamic process of heat exchange between the body and the environment may be described by the following equation:

$$S = M \pm R \pm C \pm K - E \qquad \text{---------- (1)}$$

Where M = energy metabolism or body heat production which is linearly related to aerobic metabolism

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R = radiative heat exchange

C = convective heat exchange

K = conductive heat exchange

E = evaporative heat loss

S = body heat storage

Thermal equilibrium occurs when heat storage (S) is zero, and indeed the thermoregulation process in human attempts to maintain this as a goal. The metabolic heat production (M) is always a positive factor, even under basal or resting conditions, since the body oxidizes fuel (food) and is generating heat in the metabolic rate process. The convective heat exchange (C) represents thermal exchange between the body and the fluid/air which surrounds it, and may be either positive or negative depending upon whether the temperature is above or below the temperature of the human skin. Radiative heat exchange (R) may also be either positive or negative depending upon whether the human body represents the hot or cold radiative body in the environment. Conductive heat exchange (K) is normally considered to be negligible in thermal balance considerations since human's sensory receptors do not transfer much heat conductively. Evaporative heat exchange (E), which is always a negative factor in this equation, represents the major mechanism for dissipation of stored body heat. (10)

The physiological responses to heat stress (2, 11)

Even at rest, the muscles produce about 20-25% of the total heat on the body. During exercises, the muscles produce a much larger amount of heat. The proportion of maximal aerobic capacity (VO_2max) is needed to do a specific job for several reasons. First, the cardiovascular system must respond with an increased cardiac output which at levels of work of up to about 40% VO_2max is brought about by an increase in both stroke volume and heart rate. (12) When maximum stroke volume is reached, additional increases in cardiac output can be achieved solely by increased heart rate. (11, 12) Further complexities arise when high work intensities are sustained for long periods, particularly when work is carried out in heat surroundings. Second, muscular activity is associated with an increase in muscle temperature, which then is

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associated with an increase in core temperature, with attendant influences on the thermoregulatory controls. (13) Third, at high levels of exercise, even in a temperate environment, the oxygen supply to the tissues may be insufficient to meet the oxygen needs of the working muscles completely. (2) In warmer conditions, an adequate supply of oxygen to the tissues may become a problem even at moderate work intensities because of competition for blood distribution between the working muscles and the skin. Because of the lack of oxygen, the working muscles must then begin to draw on their anaerobic reserves, deriving energy from the oxidation of glycogen in the muscles. (14) That event leads to the accumulation of lactic acid which may be associated with the development of muscular fatigue. As the proportion of VO_2max used increases further, anaerobic metabolism assumes a relatively greater proportion of the total muscular metabolism. An oxygen debt occurs when oxygen is required to metabolize the lactic acid that accumulates in the muscles. The oxygen debt may be repaid during the rest period. In hot environments, the recovery period is prolonged as the elimination of both the heat and the lactic acid stored in the body has to occur and water loss must be replenished. (15, 16) It is well established that, in a wide range of cool to warm environments, 5–29 °C, the deep body temperature rises during exercise to a similar equilibrium value in subjects working at the same proportion of VO_2max. (17, 18) However, two individuals doing the same job and working at the same absolute load level and who have widely different VO_2max values will have quite different core temperatures. Currently, recommendations for an acceptable proportion of VO_2max for daily industrial work vary from 30-40% of the VO_2max which, in comfortably cool surroundings, is associated with rectal temperatures of 37.4 °C and 37.7 °C, respectively, while working at 50% VO_2max yields a rectal temperature of 38 °C in the absence of heat stress. (11) If working at 60% VO_2max, the lactic acid accumulated in the body and heart rate, body temperature, body pressure, and oxygen consumption are all increased. (19)

Work capacity is reduced to a limited extent in hot surroundings if body temperature is elevated. That reduction becomes greater as the body temperature is increased. The VO_2max is not reduced by hypohydration itself so that its reduction in hot environments seems to be principally a function of body temperature. Core

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temperature must be above 38 °C before a reduction is noticeable; however, a rectal temperature of about 39 °C may result in some reduction of VO_2max. (11)

The circulatory system have role to transport mechanism responsible for delivering oxygen and foodstuffs to all tissues and for transporting by-product metabolites and heat from tissues. However, the heart cannot provide enough cardiac output to meet both the peak needs of all the body's organ systems and the need for dissipation of body heat. The autonomic nervous system and endocrine system control the allocation of blood flow among competing organ systems. When individuals are exposed to continuous work at high proportions of VO_2max or to continuous work at lower intensities in hot surrounding, the cardiac filling pressure remains relatively constant, but the central venous blood volume decreases as the cutaneous vessels dilate. The stroke volume falls gradually, and the heart rate must increases to maintain the cardiac output. The effective circulatory volume also decreases, partly due to hypohydration as water is lost in the sweat and partly as the thermoregulatory system tries to maintain an adequate circulation to the skin. (20)

Energy requirements at work

1. Basal metabolism (20)

The minimal amount of energy is needed to keep the body functioning even if no activities are done at all. This basal metabolism is measured after fasting for 12 hours, accompanied by protein intake restriction for at lest two days, with complete physical rest in a neutral ambient temperature. Under these conditions, the basal metabolic values depend on age, gender, height, and weight. Altogether there is relatively little inter-individual variation, hence a commonly accepted figure is 1 Kcal/hr or 4.9 kg/min for a person of 70 kg. The oxygen demand in rest period is 1/4 – 1/3 liters/min (0.25-0.33 l/min).

2. Work metabolism (20)

The increase in metabolism from resting to working is called "work metabolism." The increase above resting level represents the amount of energy needed to perform the work.

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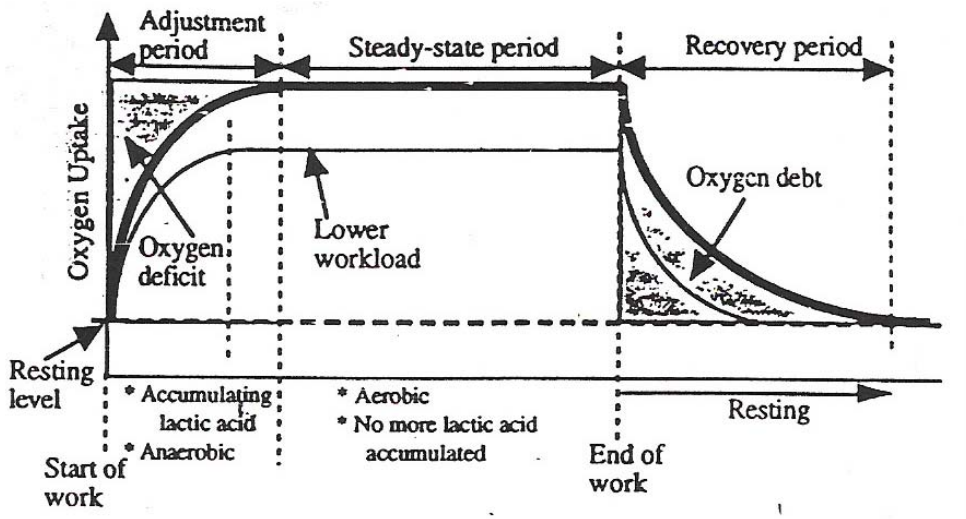

Figure 2-1: The oxygen demand of working time, start of work, during work, and after work

At the start of physical work, oxygen uptake initially follows the demand sluggishly. As Figure 2-1 shows, after a slow onset, oxygen intake rises rapidly and then slowly approaches the level at which the oxygen requirements of the body are met. During the first minutes of physical work, there is a discrepancy between oxygen demand and available oxygen. (During this time, the energy liberation in the body is largely anaerobic.) This oxygen deficit must be repaid at some time, usually during rest after work. The amount of this deficit depends on the kind of work performed and on the person, but the oxygen debt repaid is approximately twice as large as the oxygen deficit incurred. Certainly, given the close interaction between the circulatory and the metabolic systems, heart rate reacts similarly, but as it increases faster at the start of work than oxygen uptake, it also falls back more quickly to the resting level. One liter of oxygen can produce metabolic heat figure of 5 kcal. (20)

Anaerobic supply is the principal contributor during the initial stage of exercise, but that aerobic supply gradually takes over. The mechanical power output reaches its peak immediately after the beginning of exercise, then rapidly declines, becoming gradual after 60 s. The O_2 debt and O_2 deficit are highest immediately after the beginning of exercise, peak of lactic acid in 5 and 15 s, then rapidly decreases to nil in 60 s. The O_2 intake is small at the beginning, and then rapidly increases to attain a steady state in 30 s. (21) There are highly significant correlations between O_2 debt

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contracted and an increase in thermal stress. (22) A maximal anaerobic glycolytic capacity (MAGC) may be a limiting factor for muscle performance at 25% MVC and 40%MVC, but not at 10%MVC. (23) Values at 30% or 50% are based on estimated individual anaerobic threshold (AT) which can be observed from blood lactate level (lactate Threshold: LT). At this AT or LT, accumulation of lactic acid begins. When working at lower AT or LT level, lactic acid is not accumulated. (24) However, AT value shall reach 85% VO_2max for well-trained sportsmen. (25) Endurance training improves average VO_2 max by 15%. For the above AT tests, training reduces VO_2 drift substantially. The training-induced decrease in VO_2 drift is well correlated with a decrease in end exercise lactate and less well correlated with the drift in minute ventilation seen at the above AT work rates. (26) Training enables a superior body composition; aerobic work capacity and anaerobic work capacity are equal. (27)

Oxygen consumption (11)

Oxygen consumption is the volume of oxygen that the body can consume during intense, whole-body exercise, while breathing air at sea levels. This volume is expressed as a rate, either liters per min (L/min) or milliliters per kg body weight per minute (ml./kg/min). Because oxygen consumption is linearly related with energy expenditure, oxygen consumption can be measured by indirectly measuring an individual's maximal capacity to do work aerobically. At rest, the oxygen consumption is about 250 ml. or 25% oxygen arterial, while at normal condition, the body can consume oxygen more than body demand. However, when intensity increases, the oxygen consumption is also increased (Figure 2-2B) and the body respond by increasing cardiac output to enable oxygen transfer to cells, hence an increase in heart rates (Figure 2-2A).

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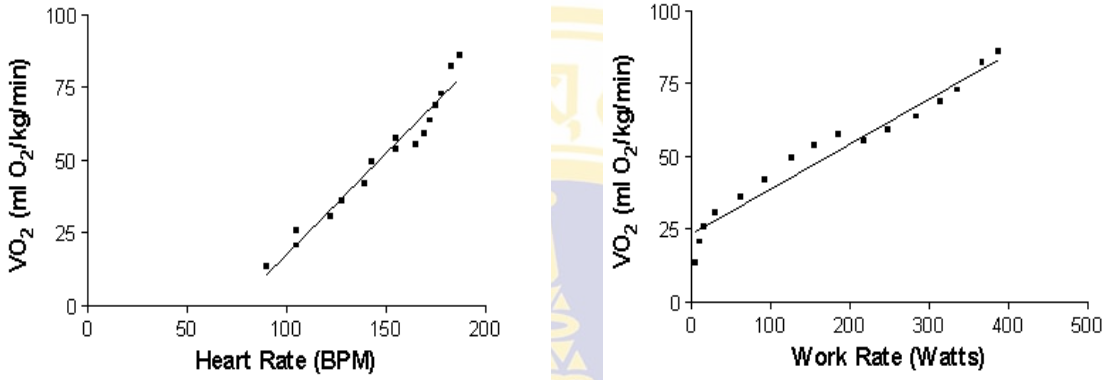
Relationship of heart rate to oxygen consumption (Elite Runner)

Relationship of work rate to oxygen consumption (Elite Runner)



A B

Figure 2-2: The relationship between Oxygen Consumption and Heart Rate and Work Rate

Oxygen consumption during constant-load exercise for 20 minutes at 65% and at 80% of VO_2max on the bicycle ergometer increases significantly from the 5th to 20th minutes of exercise at both levels of work intensity. Increased temperature could account for 30% of the rise; the estimated cost of increase VE could account for 30 and 81% of the rise at the two work loads. (28) In addition to sex- and age-related variability, the inter-individual variability of VO_2max is high; therefore, the range of VO_2max to include 95 of every 100 individuals will be ± 20% of the mean VO_2max value. Differences in body weight can account for about half of that variability when VO_2max is expressed as ml O_2/kg/min, but the source of the remaining variation has not been precisely identified. Age is associated with a reduction in healthy individuals by nearly 10% in each decade after the age of 30. (2) Level of maximum aerobic work capacity shall increase rapidly in childhood and reach the maximum value during the age of 20, and after the age of 50 the decrease in oxygen consumption occurs rapidly. (29) The decrease in VO_2max with age is less in individuals who have maintained a higher degree of physical fitness. Women have the level of VO_2max which averages

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about 70% of that for men in the same age group due to lower absolute muscle mass. (11)

Other related heat stress factors (17, 18)

1. Acclimatization to heat (30, 31)

Acclimatization is the adaptive process that results in a two-diminutional physiological responses produced by the application of a constant environment stress. On initial exposure to a hot environment, there is an impaired ability to work and evidence of physiological strain. If the exposure is repeated on several successive days, there is a gradual return of the ability to work and a decrease in physiological strain. Within four to seven days following initiation of the acclimatization process, a dramatic improvement in the ability to perform work is noticed; subjective discomfort practically disappears, body temperature and heart rate are lower, there is a more stable blood pressure, and the sweat is more profuse and dilute. Acclimatization to heat is well retained during periods of no exposure for about one week; thereafter, acclimatization is lost at a rate that varies among individuals. Within about three weeks to a month, acclimatization effects are lost and hardly any traces are to be found after a few months. Staying in a good physical condition helps retain acclimatization.

A few physiological parameters that are responsive during acclimatization are believed to be important in the process. Cardiac output increases during the first part of the acclimatization period, but returns to the “cool” environment level when acclimatization has been achieved. Blood volume is expanded during the first few days, but also returns to pre-exposure values. Venous tone increases but only temporarily. Peripheral blood flow may be extremely high during the first few days, but returns to steady state levels that may be only moderately increased. Peripheral blood flow appears to be higher in people who are living in temperate climates.

On repeated exposure there is a marked adaptation in which the principle physiologic benefit appears to result from an increased sweating efficiency (earlier onset, greater sweat production, and lower electrolyte concentration) and a concomitant stabilization of the circulation, so that after daily heat exposure for seven to ten days, the individuals perform the work with a much lower core temperature and heart rate and a higher sweat rate. The total sweat production increases with

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acclimatization, and sweating begins at a lower temperature. During exercise in heat, the production of aldosterone is increased to conserve salt from both the kidney and the sweat glands, while an increase in antidiuretic hormone conserves the amount of water lost through the kidneys.

2. Body fat

It is well established that obesity predisposes individuals to heat disorders. (32) The acquisition of fat means that additional weight must be carried, thereby calling for a greater expenditure of energy to perform a given task and use of a greater proportion of the VO_2max. In addition, the body surface to body weight ratio (m^2 to kg) becomes less favorable for heat dissipation. Probably more important is the lower physical fitness and decreased maximum work capacity and cardiovascular capacity frequently associated with obesity. The increased layer of subcutaneous fat provides an insulative barrier between the skin and the deep-lying tissues. The fat layer theoretically would reduce the direct transfer of heat from the muscles to the skin. (33)

3. Age

The aging process results in a more sluggish response of the sweat glands, which leads to a less effective control of body temperature. Aging also results in a curiously increased high level of skin blood flow associated with exposure to heat. The cause of this remains undetermined, but it implies an impaired thermoregulatory mechanism possibly related to a reduced efficiency of the sympathetic nervous system. (34, 35) For women, it has been found that the skin temperature increases with age in moderate and high heat loads, but not in low heat loads. (34, 36) When two groups of male coal miners of average age 47 and 27 years, respectively, worked in several comfortable or cool environments, they showed little difference in their responses to heat near the REL with light work, but in hotter environments the older men showed a substantially greater thermoregulatory strain than their younger counterparts. The older men also had lower aerobic work capacities. (37) In analyzing the distribution of five years' accumulation of data on heatstroke in South African gold mines, Strydom (38) found a marked increase in heat stroke with increasing age of the workers. Thus, men over 40 years of age represented less than 10% of the mining population, but they accounted for 50% of the fatal and 25% of the nonfatal cases of heat stroke. The

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incidence of cases per 100,000 workers was ten or more times greater for men over 40 years than for men under 25 years of age.

4. Gender

There are many factors to consider with respect to the deep body temperature when the same job is done by both men and women of varying body weights, ages, and work capacities. Other sources of variability when individuals work in hot environments are differences in circulatory system capacity, in sweat production, and in the ability to regulate electrolyte balance, each of which may be large. (2)

Purely on the basis of a lower aerobic capacity, the average woman, similar to a small man, is at disadvantage when she has to perform the same job as the average-sized man. While all aspects of heat tolerance in women have not been fully examined, their thermoregulatory capacities have. When they work at similar proportions of their VO_2max, the women perform either similarly or with little change in thermoregulatory capacities at different times during their menstrual cycles. (38)

4. Water, electrolyte, and salt balance and the influence of endocrines

It is imperative to replace the water lost in the sweat. It is not uncommon for workers to lose six to eight quarts of sweat during a working shift in hot industries. If the lost water is not replaced, there will be a progressive decrease of body water with shrinkage not only of the extracellular space and interstitial and plasma volumes but also of water in the cells. There is clear evidence that the amount of sweat production depends on the state of hydration (16, 32, 39) so that progressive hypohydration results in a lower sweat production and a corresponding increase in body temperature, which is a dangerous situation.

Sweat lost in such quantities is often difficult to replace completely as the day's work proceeds, and it is not uncommon for individuals to register a water deficit of 2-3% or greater of the body weight. During exercise in either cool or hot environments, a correlation has been reported between the elevation of rectal temperature and the percentage of water deficit in excess of 3% of body weight. (40) Because the normal thirst mechanism is not sensitive enough to ensure a sufficient water intake (16), every effort should be made to encourage individuals to drink water or low-sodium noncarbonated beverages. The fluid should be as palatable as possible

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at 10 -15 ˚C. Small quantities taken at frequent intervals, about 150 – 200 ml. every 15 - 20 minutes, is a more effective regimen for practical fluid replacement than the intake of 750 ml. or more once an hour. Also, 1 l/hour is not an uncommon rate of water loss. (2)

An important constituent of sweat is salt or sodium chloride. In most circumstances, a salt deficit does not readily occur, because our normal diet provides 8-14 g/d. However, the salt content of sweat in unacclimatized individuals may be as high as 4 g/l, while that for the acclimatized individual will be reduced to 1 g/l or less. It is possible for a heat-unacclimatized individual who consumes a restricted salt diet to develop a negative salt balance. In theory, a prolonged negative salt balance with a large fluid intake could result in a need for moderate supplementation of dietary salt. If there is a continuing negative salt balance, acclimatization to heat is diminished. However, salt supplementation of the normal diet is rarely required except possibly for heat-unacclimatized individuals during the first two to three days of heat exposure. (16) By the end of the third day of heat exposure, a significant amount of heat acclimatization will have occurred with a resulting decrease in salt loss in the sweat and urine and a decrease in salt requirement.

Two hormones are important in thermoregulation, the antidiuretic hormone (ADH) and aldosterone. A variety of stimuli encourages the synthesis and replacement of those hormones, such as change in plasma volume, plasma concentration of sodium chloride, etc. ADH is released by the pituitary gland, which has direct neural connections with the hypothalamus but may receive neural input from other sources. Its function is to reduce water loss by the kidneys, but it has no effect on the water loss through sweat glands. Aldosterone is released from the adrenal glands, and it reduces salt loss both in the kidney and in the sweat glands. (11)

5. Dietary factors

There is no reason to believe that a well-balanced diet for work in temperature environments should not suffice for hot climates. (2)

A very high protein diet might increase the obligatory urine output for nitrogen removal, and thus increases water intake requirements. (15, 16) The importance of water and salt balance has been emphasized above, and the possibility that it might be desirable to supplement the diet with potassium has also been

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considered. In some countries where the normal diet is low or deficient in vitamin C, supplementation may enhance heat acclimatization and thermoregulatory function. (41)

6. Drugs

Alcohol

Alcohol has been commonly associated with the occurrence of heatstroke. It is a drug which interferes with central and peripheral nervous functions and is associated with hypohydration by suppressing ADH production. The ingestion of alcohol prior to or during work in the heat should not be permitted because it reduces heat tolerance and increases the risk of heat illnesses. (32)

Therapeutic Drugs (2)

Many drugs prescribed for therapeutic purposes can interfere with thermoregulation. Some of these drugs are anti-cholinergic in nature or involve inhibition of monoamine oxidative reactions, but almost any drug that affects central nervous system (CNS) activity, cardiovascular reserve, or body hydration could potentially affect heat tolerance. Thus, a worker who requires therapeutic medications should be under the supervision of a physician who understands the potential ramifications of drugs on heat tolerance. In such instances, a worker taking therapeutic medications who is exposed only intermittently or occasionally to a hot environment should seek the guidance of a physician.

7. Non-heat Disorders (2)

It has been recognized that individuals suffering from degenerative diseases of the cardiovascular system and other diseases such as diabetes or simple malnutrition are in extra jeopardy when they are exposed to heat, as well as when stress is imposed on the cardiovascular system.

8. Individual Variation

In all experimental studies of the responses of humans to hot environmental conditions, a wide variation in responses has been observed. These variations are seen not only between different individuals but also to some extent in the same individual exposed to high stress on different occasions. Such variations are not totally understood. It has been shown (42) that the influence of body size and its relationship to aerobic capacity in tolerance to heat could account for about half of the variability,

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leaving the remainder to be unaccounted for. Possibly, changes in hydration and salt balance might be responsible for some of the remaining variability. (2) However, the degree of variability in tolerance to hot environments remains a vexing problem.

Direct measurement of metabolic rate (4)

The direct measurements of metabolic rate can be determined by two principal methods:

1. Partial Method shall be used for light and moderately heavy work because in the case of light and moderately heavy work the oxygen uptake reaches the oxygen requirement after a short period of work. The oxygen uptake reaches a steady state and equals the oxygen requirement. Thus, the procedure followed using the partial method should be measured in the steady state by the work that begins first without collecting any expired air. Since the steady state is normally reached after three to five minutes, the collection of expired air starts, without interrupting the work, after about five min (preliminary period) and the work continues for five to ten minutes (main period). Collect gas and stop when work ceases. When using the partial method, it is essential that the metabolic rate during work be less than the long-term stress limit. Thus, the metabolic rate can be determined from the following equation: 2

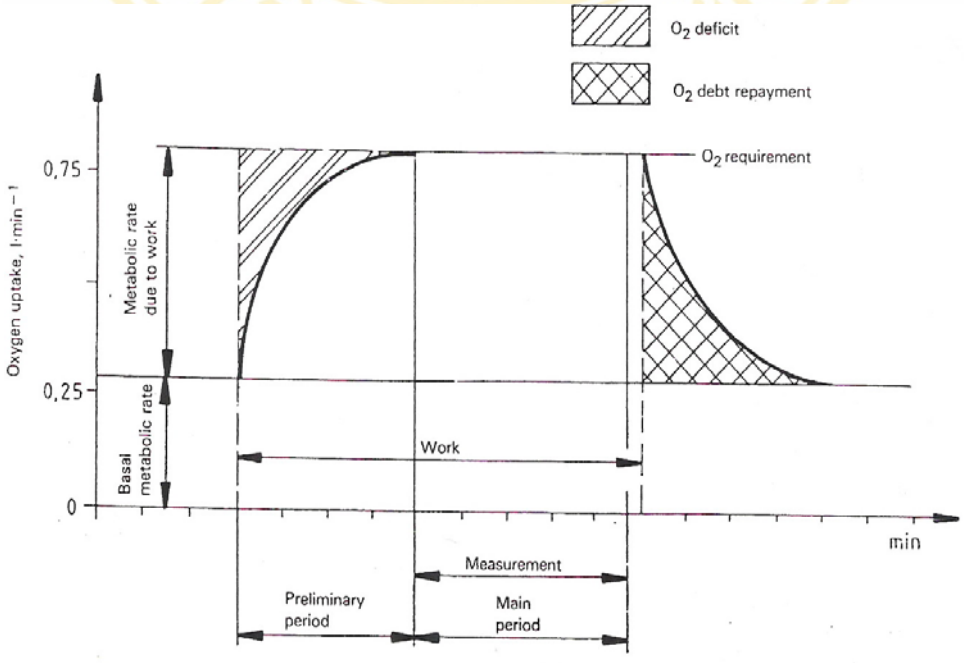

Figure 2-3: Measurement of metabolic rate using the partial method

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2. The integral method should be used in the case of heavy work and very heavy work. In the case of heavy work, oxygen requirement is above the long-term limit of aerobic power, and, in the case of very heavy work above the maximal aerobic power. During heavy work, oxygen uptake cannot reach oxygen requirement. The oxygen deficit is balanced after work ceases. Thus, the measurement includes the working and the subsequent resting period. The integral method should be used for an oxygen consumption of more than 60 liters of oxygen per hour (60 lO_2/h), equivalent to one liter of oxygen per minute. With the integral method, expired gas collection is started immediately at the beginning of the work, and the work continues for a certain time, usually for not more than two to three minutes (main period). At the end of work, the subject sits down, while the measurement continues until the resting value is attained. During this recovery period, the oxygen debt incurred during the work is repaid. Since the measurement includes the working (main period) and sitting (recovery period) activity, the metabolic rate needed for sitting has to be subtracted from the measured value in order to obtain the metabolic rate related to work alone. Thus, the metabolic rate can be determined from the following equations 18

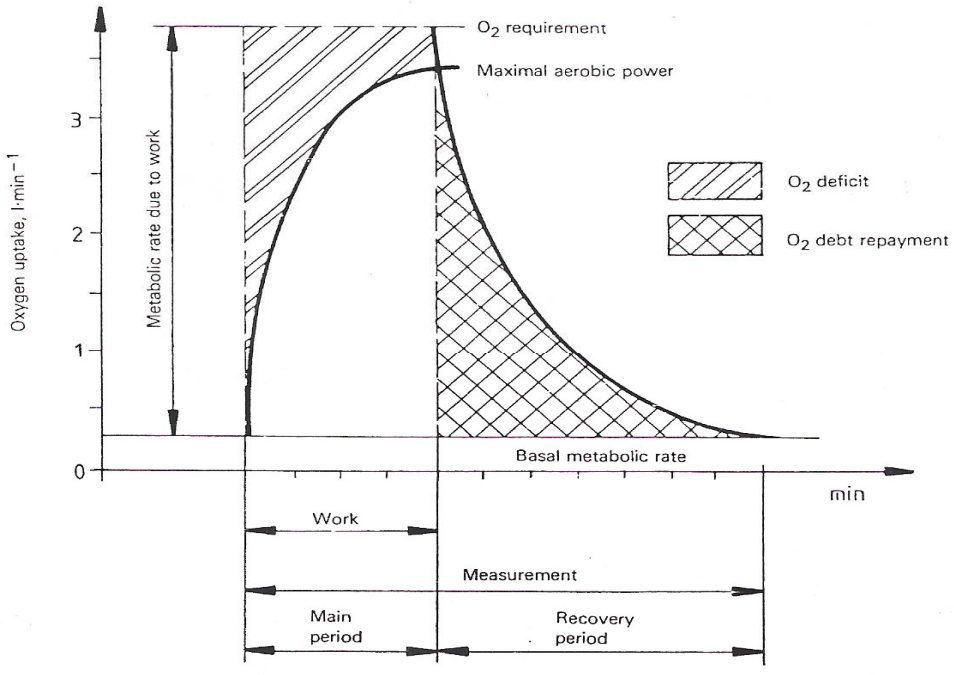

Figure 2- 4 Measurement of metabolic rate using the integral method

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Determination of Metabolic Rate from Oxygen Consumption

Partial Method

The metabolic rate can be determined, therefore, by measuring oxygen consumption. The energetic equivalent (EE) for oxygen is used to convert oxygen consumption into the metabolic rate from the following equations:

$$M = EE \times VO_2 \times \frac{1}{ADU} \quad \text{----------(2)}$$

$$EE = (0.23RQ+0.77) \times 5.88 \quad \text{----------(3)}$$

$$RQ = \frac{VCO2}{VO2} \quad \text{----------(4)}$$

Where

EE is the energetic equivalent in watts hours per liter of oxygen

RQ is the respiratory quotient

VO_2 is the oxygen consumption, in liters of oxygen per hour

VCO_2 is the carbon dioxide production, in liters of carbon dioxide per hour

M is the metabolic rate, in watts per square meter

A_{DU} is the body surface, in square meters, according to Du Bois

$$A_{DU} = 0.202 \times W_b^{0.425} \times H_b^{0.725} \quad \text{---------- (5)}$$

Where

W_b = is the body weight, in kilograms

H_b = is the body height, in meters

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Integral Method

The metabolic rate can be determined from the following equation:

$$M = (M_p \times T_m + T_r/T_m) - (M_s \times T_r/T_m) \quad \text{---------- (6)}$$

Where

M is the metabolic rate, in watts per square meter

M_p is the metabolic rate, in watts per square meter, for the partial method

M_s is the metabolic rate, in watts per square meter, seated

T_m is the duration of the main period, in minutes

T_r is the duration of the recovery period, in minutes

Determination of Oxygen Uptake

It is necessary to measure or to record the following data to determine oxygen uptake:

A) Personal data: sex, weight, height, and age

B) Method of measurement

C) Duration of the measurement

1) Partial method: main period

2) Integral method: main and subsequent periods

D) Atmospheric pressure

E) Volume of air expired

F) Temperature of the expired air

G) Fraction of oxygen in the expired air if determination of RQ is required

H) Fraction of carbon dioxide in the expired air

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Calculation of the STPD reduction factor

The reduction factor at standard condition (temperature = 0 ◦C, barometric Pressure 101.3 kPa,Dry) can be calculated from the following equations:

$$f = \frac{273(p - PH2O)}{(273 + t)101.3} \quad \text{---------- (7)}$$

Where

f is the STPD reduction factor

P is the measured atmospheric, in kilopascals

PH_2O is the partial pressure of the expired air, in degrees Celsius

If the collected expired air is heated up by the environment to a temperature in excess of 37 ◦C, the pressure of the saturated water vapors at a temperature of 37 ◦C shall be used:

$T \leq 37$ ◦C (see Table 2-1)

$T > 37$ ◦C $p_{H2O} = 6.27$ kPa

Table 2-1: Pressure of saturated water vapor (kPa) between 10 ◦C and 37 ◦C as shown in steps of 1 ◦C

Temperature (◦C)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
10	1.23	1.31	1.40	1.50	1.60	1.70	1.82	1.94	2.06	2.20
20	2.34	2.49	2.64	2.81	2.98	3.17	3.36	3.56	3.78	4.00
30	4.24	4.49	4.75	5.03	5.32	5.62	5.94	6.27	-	-

Source: ISO 8996: 1990

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Calculation of the expiration volume for STPD

$$V_{ex}\ STPD = V_{ex}\ ATPS \times f \quad \text{---------- (8)}$$

Where

V_{ex} STPD is the expiration volume, in liters, at STPD

V_{ex} ATPS is the expiration volume, in liters, at ATPS

f is as defined in the equation 7

Calculation of the volume flow

$$V_{ex} = V_{ex}\ STPD/T \quad \text{---------- (9)}$$

Where

V_{ex} is the volume flow, in liters per hour

T is the test duration in hours, i.e. the main period for the partial method and the main and recovery periods for the integral method.

Calculation of oxygen consumption

$$VO_2 = V_{ex} \times (0.209\text{-}FO_2) \quad \text{----------(10)}$$

Where

VO_2 is the oxygen consumption, in liters of oxygen per hour

FO_2 is the fraction of oxygen in the expired air

Calculation of carbon dioxide production

$$VCO_2 = V_{ex} \times (FCO_2 - 0.0003) \quad \text{----------(11)}$$

Where

VCO_2 is the carbon dioxide production, in liters of carbon dioxide per hour

FCO_2 is the fraction of carbon dioxide in the expired air

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The effect of contraction of the expired volume

The inspired and expired volumes are not equal if RQ ≠ 1. Contraction can be taken into account using the following equations:

$$VO_2 = V_{ex} [0.265(1-FO_2 - FCO_2) - FO_2] \quad \text{----------(12)}$$

$$VCO_2 = V_{ex} [FCO_2 – (1- FO_2 - FCO_2)0.380 \times 10^{-3} \quad \text{----------(13)}$$

Determination of metabolic rate for a work cycle

The metabolic rate for a work cycle can be determined from the metabolic rate of the respective activity and the respective duration from the following equation:

$$M = 1/T \sum_{i=1}^{n} M_i t_i \quad \text{----------(14)}$$

Where

M: the average metabolic rate of the work cycle, in watts per square meter

M_i: the metabolic rate of the respective activity, in watts per square meter

T: the duration in second, of the considered work cycle

t_i: the duration in second, of the respective activity

Estimation of Metabolic Heat

The procedures for direct measurement of metabolic heat are limited to relatively short duration activities and equipment for collecting and measuring the volume of the expired air and for measuring the oxygen and carbon dioxide concentrations. On the other hand, metabolic heat estimates, using tables of energy expenditure or task analysis, although less accurate and reproducible, can be applied for short and long duration activities and require no special equipment. However, the

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accuracy of the estimates made by a trained observer may vary by about ± 10-15%. A training program consisting of supervised practice in using the tables of energy expenditure in an industrial situation will usually result in an increased accuracy of the estimates of metabolic heat production. (5)

a. Tables of energy expenditures

Estimates of metabolic heat for use in assessing muscular work load and human heat regulation are commonly obtained from tabulated descriptions of energy cost for typical work tasks and activities. Errors in estimating metabolic rates from energy expenditure tables are reported to be as high as 30%. (4)

The International Organization for Standardization (ISO) (4) recommends that the metabolic rate be estimated by adding values of the following groups: 1) basal metabolic rate, 2) metabolic rate for body position or body motion, 3) metabolic rate for type of work, and 4) metabolic rate related to work speed. The basal metabolic rate averages 44 and 41 W/m^2 for the "standard" men and women, respectively. Metabolic rate values for body position and body motion, type of work, and those related to work speed are given.

b. Task analysis (2)

In order to evaluate the average requirements over an extended period of time for industrial tasks including both the work and rest activities, it is necessary to divide the task into its basic activities and sub-activities. The metabolic heat of each activity or sub-activity is then measured or estimated and a time-weighted average for the energy required for the task can be obtained.

It is common in such analyses to estimate the metabolic rate for the different activities by utilizing tabulated energy values from tables which specify incremental metabolic heat resulting from the movement of different body parts, i.e., arm work, leg work, standing, and walking. The metabolic heat of the activity can then be estimated by summing the component M values based on the actual body movements. The task analysis procedure recommended by NIOSH is summarized in Table 2-2 and Table 2-3.

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$$\text{Average metabolism} = \frac{(M1)(t1) + (M2)(t2) + ... + (Mn)(tn)}{t1 + t2 + ... + tn} \quad \text{---------- (15)}$$

Where

M = metabolism rate

t = time in minutes

Table 2-2: Activity Examples

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

Sample Calculation: Assembly line work using a heavy hand tool

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

Source: NIOSH 1986.

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Table 2-3: Estimating energy cost of work by task analysis

Body position and movement	***kcal/min****
Sitting	0.3
Standing	0.6
Walking	2.0-3.0
Walking uphill	add 0.8 for every meter (yard) rise

Type of work	***Average kcal/min***	***Range kcal/min***
Hand work		0.2-1.2
Light	0.4	
Heavy	0.9	
Work: One arm		0.7-2.5
Light	1.0	
Heavy	1.7	
Work: Both arms		1.0-3.5
Light	1.5	
Heavy	2.5	
Work: Whole body		2.5-15.0
Light	3.5	
Moderate	5.0	
Heavy	7.0	
Very heavy	9.0	

* For a "standard" worker of 70 kg body weight (154 lbs) and 1.8m^2 body surface

Source: NIOSH 1986.

Heat stress evaluation (2)

To have industrial application, an index must, at a minimum, meet the following criteria:

- Feasibility and accuracy must be proven with use.

- All important factors (environment, metabolic, clothing, physical condition, etc.) must be considered.

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- The measuring instruments and techniques applied should result in data which truly reflect the worker's exposure but do not interfere with the worker's performance.

- Index exposure limits must be supported by corresponding physiologic and/or psychological responses which reflect an increased risk to safety and health.

- It must be applicable for setting limits under a wide range of environmental and metabolic conditions.

Estimation of heat stress on working men, based on the WBGT- index (43)

The Wet Bulb Globe Temperature (WBGT) Index is one of the empirical indices representing the heat stress to which an individual is exposed. This index is easy to determine in an industrial environment. The method for evaluation the heat stress based on this index is a compromise between the desire to use a very precise index and the need to be able to carry out control measurements easily in an industrial environment. It should be regarded as an exploratory method.

Measurement of derived parameters supplied by the sensor for measuring the derived parameters is always dependent on the physical characteristics of the sensor used, all things being equal. These characteristic are specified as follows:

- The natural-dry-bulb thermometer is used for measuring air temperature. A basic parameter may be measured by any suitable method, whatever the shape of the sensor used. It is however necessary to comply with the measurement precautions relating to air temperature measurement. The air temperature sensor shall, in particular, be protected from radiation by a device which does not impede the circulation of air around the sensor. The measuring range for the air temperature is from 10 ℃ to 60 ℃ and the accuracy is ± 1 ℃.

- The natural wet bulb temperature is the value indicated by a temperature sensor covered with a wet wick which is ventilated naturally, i.e. placed in the environment under consideration without forced ventilation. The natural wet bulb temperature is thus different from the thermo-dynamic temperature determined with a psychrometer.

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The temperature sensor shall comply with the following characteristics:

a) Shape of the sensitive part of the sensor: cylindrical

b) External diameter of the sensitivity part of the sensor: 6 mm. ±1 mm.

c) Length of the sensor: 30 mm. ± 0.5 mm.

d) Measuring range: 5 °C to 40 °C

e) Accuracy of measurement: ± 0.5 °C

f) The whole sensitive part of the sensor shall be covered with a white wick of a highly water-absorbent material (such as cotton).

g) The support of the sensor shall have a diameter equal to 6 mm., and 20 mm. of it shall be covered by the wick to reduce conduction from the support to the sensor.

h) The wet wick shall be kept clean.

i) The lower part of the wick shall be immersed in a reservoir of distilled water. The free length of the wick in the air shall be 20 mm. to 30 mm.

j) The reservoir shall be designed in such a way that the temperature of the water inside cannot rise as a result of radiation from the environment.

- Globe thermometer sensor

The globe thermometer is the temperature indicated by a temperature sensor placed in the center of a globe having the following characteristics:

a) Diameter: 150 mm.

b) Mean emission coefficient: 0.95 (matt black globe)

c) Thickness: as thin as possible

d) Measuring range: 20 °C to 120 °C

e) Accuracy of measurement:

- Range 20 °C to 50 °C: ± 0.5 °C

- Range 50 °C to 120 °C ± 1 °C

The WBGT index combines the measurement of two derived parameters, natural wet-bulb temperature (t_{nwb}) and the globe temperature (t_g), and in some situations, the measurement of a basic parameter, air temperature (t_a) (dry bulb temperature). The following expressions show the relationship between these different parameters:

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The wet bulb temperature, globe temperature, and dry bulb air temperature can be used to calculate the WBGT in the following equation:

$WBGT_{in} = 0.7\ t_{nwb} + 0.3 t_g$ for indoor exposure ----------(16)

$WBGT_{out} = 0.7\ t_{nwb} + 0.2\ t_g + 0.1\ t_a$ for outdoor exposure ----------(17)

Where

WBGT is the Wet Bulb Globe Temperature Index

t_{nwb} is the Natural Wet Bulb Temperature

t_g is the Globe Temperature

t_a is the Dry Bulb Temperature

Calculation of the average WBGT (3)

For the work that involves intermittent exposure, it should be averaged over a 120-minute period. These averages should be calculated using the following formula:

$$\text{Average WBGT} = \frac{(WBGT1)(t1) + (WBGT2)(t2) + ... + (WBGTn)(tn)}{t1 + t2 + ... + tn} \quad \text{---------- (18)}$$

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Heat stress standard

1. NIOSH 1986 (2) recommended following figure below

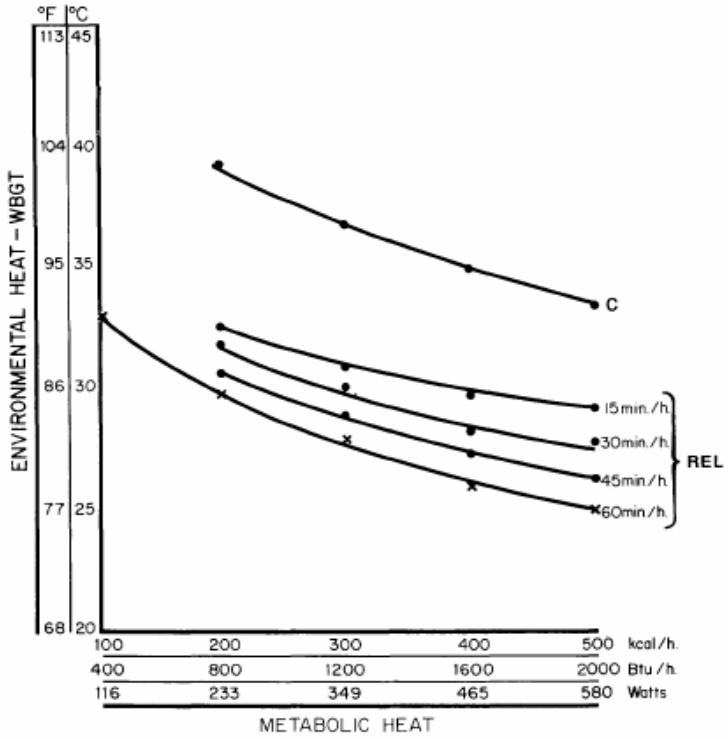

Figure 2-5: Recommended Heat-Stress Exposure Limit for Heat-Acclimatized Workers

C = Ceiling Limit, REL = Recommended Exposure Limit

*For "standard worker" of 70 kg (154 lbs) body weight and 1.8 m^2 (19.4ft^2) body surface

Source: National Institute for Occupational Safety and Health (NIOSH). Occupational exposure to hot environments (DHHS [NIOSH]#86-113),Washington DC: US, 1986.

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2. ISO Standard (43)

Table 2-4: Reference Values Corresponding to a Given Situation

Metabolic Rate Class	Metabolic rate M		Reference value of WBGT			
	Related to a unit skin surface area W/m^2	Total (for a mean skin surface area of 1.8 m^2) W	Person acclimatized to heat °C		Person not acclimatized to heat °C	
0 (resting)	M<65	M<117	33		32	
1	65<M<130	117<M<234	30		29	
2	130<M<200	234<M<360	28		26	
3	200<M<260	360<M<468	No sensible air movement 25	Sensible air movement 26	No sensible air movement 22	Sensible air movement 23
4	M>260	M>468	23	25	18	20

Note* The values given have been established allowing for a maximum rectal temperature of 38 °C for the persons concerned

Source: International Organization for Standardization (ISO 7243-1989)

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3. ACGIH 1992 (3) (American Conference of Governmental Industrial Hygiene) has set the following standard:

Table 2-5: Permissible Heat Exposure Threshold Limit

Base on 2001 Adopted ACGIH WBGT Screening Criteria (Wet Bulb Globe Temperature (C) F								
Work/ rest regimen (each hour)	Work Load							
	Light		Moderate		Heavy		Very Heavy	
	Un-acclimated	acclimated	Un-acclimated	acclimated	Un-acclimated	acclimated	Un-acclimated	acclimated
Continu-ous work	(27.5)81.5	(29.5)85.1	(25)77	(27.5)81.5	(22.5)72.5	(26)78.8	----------	----------
75% Work - 25% rest	(29)84.2	30.5(86.9)	(26.5)79.7	(28.5)83.3	(24.5)76.1	(27.5)81.5		
50% Work - 50% rest	(30)86	(31.5)88.7	(28)82.4	(29.5)85.1	(26.5)79.7	(28.5)83.3	(25)77	(27.5)81.5
25% Work - 75% rest	(31)87.8	(32.5)90.5	(29)84.2	31(87.8)	(28)82.4	(30)86	(26.5)79.7	(29.5)85.1

Source: ACGIH 2001

Table 2-6: WBGT Correction Factors in °C

Clothing type	WBGT Addition*
Summer work uniform	0
Cloth (woven material) overalls	+3.5
Double-cloth overalls	+5

* These value must not be used for encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement to fabrics.

Source: ACGIH 2004.

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4. Declaration of Ministry of Industry narrative method of safety protection in factories about working condition in 2003 (1)

Table 2-7: Thai regulation

Work load	WBGT (°C)
Light	34.0
moderate	32.0
heavy	30.0

Concepts related to judgment and opinion

Webster New World Dictionary defines opinion as decision, criticism, idea, or the pattern of assessment in mind regarding the information received. Further, it is individuals' beliefs about such information. Individuals' beliefs depend on their experiences and observation, as well as expression of ideas, interests, and feelings of experts concerning any particular object or event. (44) Opinion is commonly used in matters related to judgment and knowledge, while attitude is used in matters related to feelings and preferences. Mostly, the term 'opinion' is more frequently used that the term 'attitude,' but in fact opinion and attitude are closely intertwined. (45)

Opinion and attitude are interchangeable. Attitude refers to 'intention to act' which is closely related to habits and behaviors. On the other hand, opinion is more verbal and symbolic. Opinion is part of attitude, and they can be separated from each other as opinion is not as in-depth as attitude. (46)

Boontham Kampor has concluded that individuals' opinion is related to some personal characteristics such as background knowledge, work experience, and interpersonal interaction. It is a factor which shapes the direction of individuals' and groups' ways of thinking. This is because background knowledge is an observation process about which individuals have been trained for years until it has become the foundation of their opinion about particular issue or item. (47) Likewise, Ruangwate Rattana has pointed out that opinion is a spoken or written expression of feelings about something based on background knowledge, experience, and environment. Such an expression of opinion may be accepted or rejected by others. (46) Hernby, Gattenby, and Wakefield assert that opinion is belief or agreement which is not true knowledge

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in itself, though some opinions may be true. (48) Besides, Kolesnik states that opinion is an interpretation which results from fact which an individual thinks is accurate while others may not agree. (49) In addition, Uthai Hiranto contends that individuals' opinions can be divided into different levels. They can be either superficial or profound. Opinion which results from a true understanding of something is termed 'cognitive contents'. (50) Chatchai Tosinthiti also maintains that education has a great influence on expression of opinions. This is because it helps arrange individuals' experiences. (51) As such, it may be concluded that opinion is an expression of feelings and ideas about something through spoken or written means based on individuals' background knowledge, experiences, and social and environmental background, which can take place rather easily and disappear quickly. It cannot be said that an opinion is correct or not, and it may be accepted or rejected by others. It is accepted that individuals may have different opinions and opinions can change all the times. (52)

Related research and studies

In 1983, Bobo et.al. studied physiological responses of 65 mine workers. The determination of maximum aerobic capacity was conducted by estimating exhale air volume and heart rate during the subjects' exercise on the cycle ergometer. Furthermore, determination of oxygen consumption was carried out by measuring the ventilation rate during work, hence an evaluation of energy demand and oxygen consumption in each job characteristic. The results of this study revealed that the oxygen consumption capacities in mine workers were not different from those of other population groups. (53)

In Thailand, Panu studied the effects of heat stress on fatigue in acclimatized man worker in controlling blast furnaces, stamping a number on the mould, and pouring a cast iron division in a foundry factory. Physiological strains were measured by measurement of oxygen consumption, heart rate, energy expenditure, body temperature, and fatigue. The findings of this study regarding division workers who controlled the blast furnace showed that the increment of average heart rate was 25.3 beats/min, average VO_2max was 31.6%VO_2max, average energy expenditure was

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298.7 kcal/hr, increment of oral temperature was 0.1 ◦C on average, and skin temperature was 0.8 ◦C. It was concluded that this work was not heavy. The results regarding workers who worked to pour cast iron suggested that the increase in average heart rate was 18.8 beats/min, the average VO_2max was 24%VO_2max, average energy expenditure was 176.7 kcal/hr, and increment of oral temperature was averaged to 0.2 ◦ C and skin temperature was 1.7 ◦C, so it was concluded that this work was not heavy. The results regarding workers working to stamp numbers on moulds suggested that the increment of average heart rate was 11.8 beats/min, the average VO_2max was 19.5%VO_2max, average energy expenditure was 143.7 kcal/hr, and increment of oral temperature was averaged to -0.1 ◦C and skin temperature was 0.4 ◦C. It was then concluded that this work was not heavy. (54)

In 1993, Ghamjit studied the energy demand and maximum work capacity in. 60 male foundry workers. The results indicated that the average maximum work capacity was 1.58±0.28 l/min or 25.10±3.69 ml./kg-min, with rang VO_2 between 20 and 40%VO_2max. The analysis of variance showed that the effect of work activities has an influence on oxygen consumption, energy expenditure, and heart rate. Moreover, body movement in activities influences energy expenditure, while working at a hot workplace has an influence on increasing heart rate. (55)

An ergonomics study of strenuous tasks under tropical working conditions in 60 women and 60 men in three occupations, i.e. construction, steel industry, and transport material and supplies, was carried out. The laboratory test consisted of a standardized cyclo-ergometer test under controlled environment conditions. The field research concerned three workforce consuming activities for which they had been selected. Two were linked to the categorized jobs of construction and metallurgy, while the third was more general, namely manual material handling. For field research, the total ergonomics methodology was used, measuring and evaluating the external factor task, organization, and environment, both biomechanical and environmental. Simultaneously the internal or functional workload was assessed by using the wirker as a measurement instrument. The psycho-mental and physiological reactions were controlled with the emphasis placed on physiological measurements. The evaluation of the data was done by means of the existing legislation and existing

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adhoc international standards with the emphasis put on ISO 7243. According to the laboratory results, it was found that the basic physiological energy expenditure and cardiovascular load of Thai workers were different from those of the workers from industrialized Western countries. An upward shift for heart rate of about 30 to 35% for similar oxygen uptake was remarkable. Field results also revealed workload of which the intensity could be described as moderate and heavy. (8)

Busaba modified the heat stress index (WBGT index) that was recommended by ACGIH as suitable with Thai people. Data regarding air country climate in 1991 in 60 men who worked in iron, glass, paper mill, and textile factories were collected. The climate conditions of those factories were hot-humid. The subjects were divided into two groups. The first group performed light work which had average load between 81.81 and 116.73 kcal/hr, while the second performed moderate workload between 200.14 and 226.02 kcal/hr. The workers' heart rate was monitored, and their thermal sensation was interviewed. The study revealed that the WBGT index was significantly correlated with thermal sensation but did not correlate with incremental heart rate for light work. For moderate work, WBGT index did not correlate with both thermal sensation and incremental heart rate. This study showed that when workers performed light and moderate work, they felt hot at 34.11 °C WBGT and 32.4 °C WBGT, respectively. Extrapolating the curve showed that workers who performed heavy work felt hot at 30.6 °C WBGT. (56) After that, Busaba repeated the same study to confirm these WBGT values again in 1999. Data were collected from workers in a Thai glass manufacturing factory. This study showed that when workers performed light and moderate work, they felt hot at 33.32 °C WBGT and 31.58 °C WBGT, respectively. Extrapolating the curve indicated that workers who performed heavy work felt hot at 29.8 °C. Based on these findings, the author concludes that the result of this study and those of previous studies are not different. (57)

Bernard T. E. and Joseph B. S. developed two methods to estimate metabolic rate by using qualitative job descriptors that can be used easily and provide acceptable precision. These methods were developed from the oxygen consumption measurement on 80 typical jobs in automotive manufacturing. First, the Ready-Reference Method used three easily identified, dichotomous characteristics to classify the job into one of

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the four levels of metabolic rate. The characteristics were based on hand motion, weights or forces, and walking. The standard error of estimate for this method was 68 kcal/hr. Second, the Component Method had four terms that accounted for hand motion, walking/carrying, lifting, and pushing/pulling. Lifting factors and hand motions were characterized by three or four categories with a reference value to allow for easier determination by using more qualitative data. Walking/carrying and pushing/pulling data are noted as typical distances traveled in one minute. The standard error of estimate for this method was 62 kcal/hr. The advantage of the Component Method over the Ready-Reference Method is that it has a smaller standard error of estimate, and it has the ability to point toward the largest contributors to metabolic rate. (58)

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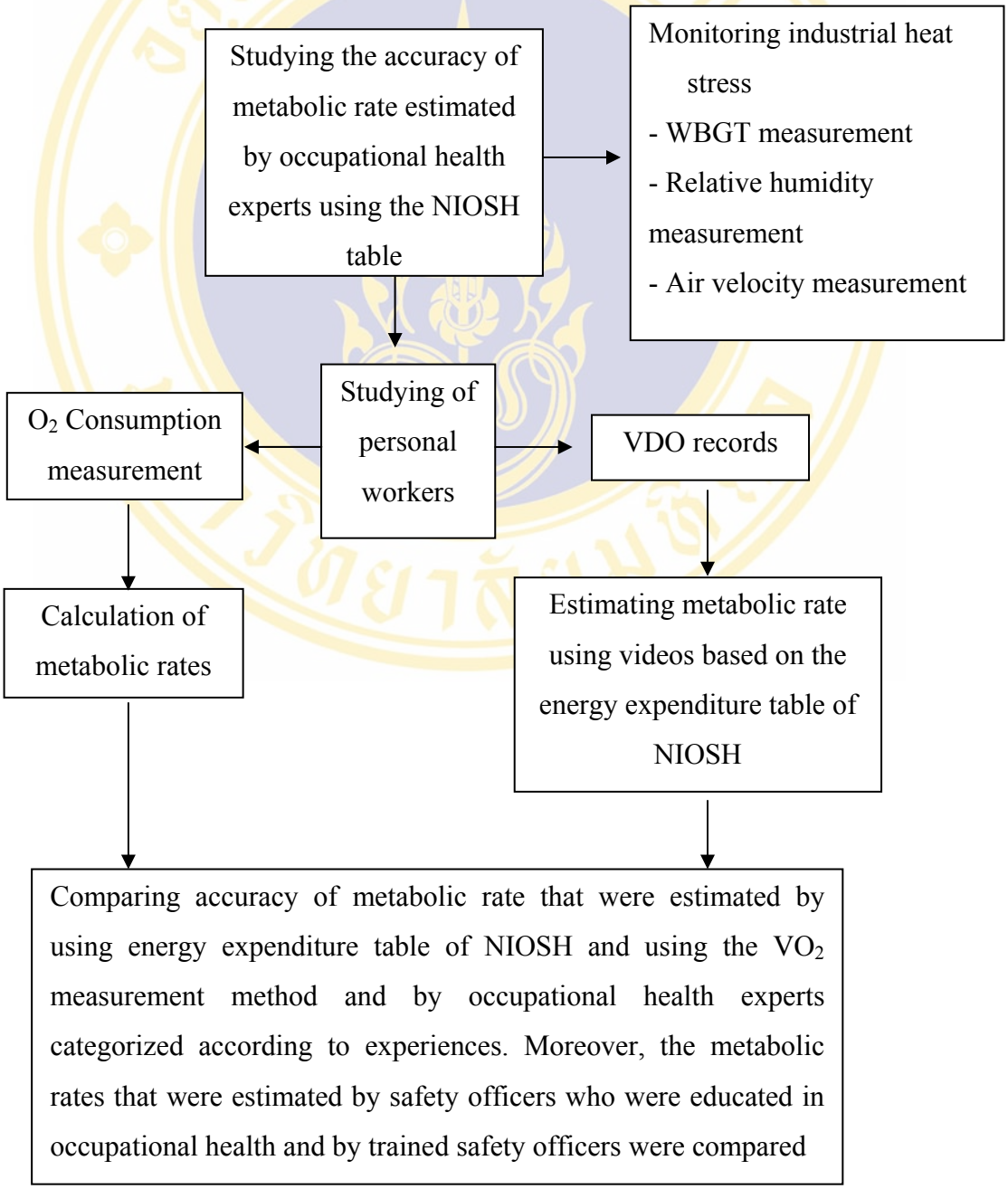
CHAPTER III
METHOD AND MATERIAL

3.1 Study design

The present study was quasi-experimental research.



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3.2 Research setting

The oxygen consumption was measured in workers who worked in two iron and steel foundry factories located in Bangkok Metropolis. The metabolic rate was estimated based on the energy expenditure table of NIOSH by occupational health experts at a meeting room of Samrong Hospital, Maung District, Samutprakarn Province and a conference room of Town in Town Hotel, Pattaya, Chonburi Province.

3.3 Population and sample

The population and sample in the determination of metabolic rate by oxygen consumption measurement consisted of eight male workers who working in two iron and steel foundry factories who were selected as the subjects met the inclusion criteria.

The population and sample in the determination of metabolic rate based on the energy expenditure table of NIOSH were 119 occupational health experts who worked as safety officers. Purposive sampling was used by sending the invitation letter to safety officers who were working in 25 types of factories where the heat level had to be measured as required by the regulation of the Ministry of Industry. These safety officers were asked to attend training on new laws regarding heat, heat measurement, and metabolism assessment techniques while working. They were divided into two groups: educationally trained safety officers and safety officers who had undergone 180-hour training and been certified.

3.4 Research instruments

- Oxygen consumption meter trademark; Cortex Biophysik model; Metamax X^R 3B serial number; MM3 31210306, Sensors accuracy: VO2 sensor = 0.1 Vol.%, VCO2 sensor = 0.1 Vol.%
- A notebook computer
- Wet Bulb Globe thermometer, Testo Brand, Model; 400 serial number; 01068325/ 503 and 016068307/503,

  The globe thermometer (D=150 mm.) is used to measure radiation temperature in accordance with ISO 7243, ISO 7726, DIN EN 27726, DIN 33403.

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Probe temperature: measuring range -200 to+800 ˚C, Resolution; -99.9 to 300˚C: 0.01 ˚C, Remaining rang: 0.1˚C, Accuracy: ±0.1˚C (-49.9 to+99.9˚C)

- An anemometer, TSI model; 8386A-M-GB serial number;03120366
- A tool to measure blood pressure and a stethoscope
- A balance
- A clock
- A video scope
- Questionnaire
- Metabolic rate assessment form

3.5 Data collection

Data collection was conducted in two parts:

Part I Collection of environmental and physiological data during the subjects' work performance

1. The researcher contacted the factories to ask for permission to collect data.

2. The researcher prepared the questionnaire and studied how to use the questionnaire until becoming truly proficient.

3. The researcher observed different steps in the line of work and selected the workers who were exposed to heat and had interesting work characteristics such as moving around when working, using different body organs while working, having inconsistent work, or working in more than one position, etc., for subsequent screening.

4. The researcher interviewed and screened the workers to ensure that those who were selected as the subjects met the inclusion criteria as follows: acclimatization to heat; healthiness; and lack of illness including cardiovascular disease, diarrhea or nausea, vomiting; absence of anti-cholinergic drug, etc. In addition, they were not alcoholic or addicted to drugs, did not go to bed late the night before, and had breakfast before starting to work. Their age had to be between 18 and 40 years, and the results of vital sings including blood pressure, respiratory rate, and heart rate were normal.

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5. The researcher conducted a walk-through survey to determine the points where the environmental aspect would be measured and prepared the instruments.

6. The researcher calibrated the oxygen consumption measuring instrument everyday during the data collection period.

7. The researcher assembled the oxygen consumption measuring instrument and attached it to the workers' body. After that, the workers could start work as they usually did. In general, the Metasoft^{R}2 software of the Matamax X^{2}R 3B brand measures the volume of oxygen and carbon dioxide using the Breath-by-Breath technology which directly calculates the parameter during the working period. Oxygen consumption was measured in two ways:

7.1. The Partial Method was used for light and moderately heavy work. In this method, the work began first without collecting any expired air. After the work had continued for five to ten minutes, collection of expired air started without interrupting the work and it stopped when the work was completed.

7.2 The Integral Method was used in the case of heavy work and very heavy work. Expired gas collection began immediately at the beginning of the work, and the work continued for a certain time. At the end of the work, the subject sat down, but the measurement continued until the resting value was attained.

8. The video of each worker working was recorded.

9. The heat stress was measure according to the WBGT standard of ISO 7243, and relative humidity and air velocity were also measured and recorded using an anemometer while each worker was working.

Part II Collection of data for the examination of metabolism rate by occupational health experts by estimating the metabolic rate based on the energy expenditure tables of NIOSH

1. The researcher prepared the workload assessment form and the videos for the assessors. The videos recorded the working situations of the workers whose oxygen consumption had already been measured. The working situations were divided as follows: two situations with heavy workload, three situations with moderate workload, and three situations with light workload, totaling eight working situations. The workload assessment form elicited information while each worker was working

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for subsequent assessment including WBGT values, RH, air velocity, weights of the objects the workers were moving, as well as age, body weight, and height of the workers.

2. The invitation letter was sent to occupational health experts who were working as safety officers in 25 types of factories where heat level had to be measured as required by the regulation. These safety officers were asked to attend training on new laws regarding heat, heat measurement, and metabolism assessment techniques while working.

3. The safety officers underwent training on new laws regarding heat, heat measurement, and metabolic rate assessment techniques while working. After that, they were asked to watch videos of the workers while working previously prepared and to assess the workload by estimating the metabolic rate based on the expenditure tables of NIOSH. The assessment was conducted every one minute starting from situation one and ending with situation eight, with the details as follows:

3.1 The assessors observed the steps in the work process and the characteristics and nature of each step before choosing the metabolic rate value from Table 2-2 and 2-3: (page30-31) before calculating the average metabolic rate by multiplying the selected metabolic rate selected from the table with the duration of the work in that particular step using the formula below:

$$\text{Average metabolism} = \frac{(M1)(t1) + (M2)(t2) + ... + (Mn)(tn)}{t1 + t2 + ... + tn}$$

M = metabolism rate

t = time in minutes

3.2 After the result of total metabolic rate was obtained, the basal metabolism value at one kilocalorie per minute was then added.

3.3 The total was then calculated for the average metabolic rate in kilocalorie per hour.

3.4 After that, the result was used to determine the workload (heavy, moderate, or light work) by comparing it to the standard of the Ministry of Industry:

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light work ≤ 200 kcal/hr, moderate work = 200 – 350 kcal/hr, and heavy work ≥ 350 kcal/hr.

3.5 After the assessment was completed, the assessment forms were then collected.

3.6 Data analysis

Data were analyzed by determining the accuracy of the metabolic rates estimated by the occupational health experts by comparing them with the metabolic rates calculated from the oxygen consumption of the workers as follows:

3.6.1 The differences in the mean metabolic rates estimated by the occupational health experts and those obtained from oxygen consumption of the workers were compared.

3.6.2 The accuracy of the metabolic rates of the occupational health experts was examined.

3.6.3 The results of the estimation of the occupational health experts were tested in accordance with related factors in the following six expects

- Testing the differences in the estimations of occupational health experts with experience in occupational health work according to length of work.
- Testing the differences in the estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate of workers
- Testing the differences in the estimations of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers.
- Testing the differences in the estimations of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves.
- Testing the differences in the estimations of occupational health experts with different educational background.

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- Testing the differences in the estimations of occupational health experts who had been educated in occupational health and those who underwent 180-hour training and became certified.

3.7 Statistics used in data analysis

Descriptive statistics were employed to explain the distribution of all variables in terms of percentage, mean, and standard deviation.

Analytical statistics were also used with the SPSS/FW Program Version 11.5.

3.7.1 One-Sample T-test was used to compare the differences in the mean metabolic rates estimated by the occupational health experts and those obtained from the measurement of oxygen consumption of the workers

3.7.2 The mean of accurate estimation in each situation was determined using One-Sample T-test.

3.7.3 The χ^2 – test was used to test the differences in the estimations of the five groups of occupational health experts with different lengths of work in each of the eight situations. One-Way ANOVA was also used to determine the accuracy of the overall estimations of the eight situations of the five groups of occupational health experts.

3.7.4 The χ^2 – test was used to test the differences in the estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate in each of the eight situations. Independent-Sample T-test was also used to determine the accuracy of the overall estimations of the eight situations of both groups of occupational health experts.

3.7.5 The χ^2 – test was used to test the differences in the estimations of the three groups of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers in each of the eight situations. One-Way ANOVA was also used to determine the accuracy of the overall estimations of the eight situations of the three groups of occupational health experts.

3.7.6 The χ^2 – test was used to test the differences in the estimations of occupational health experts who performed heat stress measurement and estimation of metabolic rate by themselves and those who did not perform the work themselves in

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each of the eight situations. Independent-Sample T-test was also used to determine the accuracy of the overall estimations of the eight situations of both groups of occupational health experts.

3.7.7 The χ^2 – test was used to test the differences in the estimations of the three groups of occupational health experts with different educational background in each of the eight situations. One-Way ANOVA was also used to determine the accuracy of the overall estimations of the eight situations of the three groups of occupational health experts.

3.7.8 The χ^2 – test was used to test the differences in the estimations of occupational health experts who had been educated in occupational health and those who underwent 180-hour training and became certified in each of the eight situations. Independent-Sample T-test was also finally used to determine the accuracy of the overall estimations of the eight situations of both groups of occupational health experts.

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CHAPTER IV
RESULTS

The investigation of the accuracy of estimation of workload in a working environment with heat stress based on the criteria of NIOSH by occupational health experts could be divided into two steps as follows:

Step 1: The level of workload was studied by measuring oxygen consumption of selected workers. The actual oxygen consumption values while working and the values of the volume of exhaled carbon dioxide were calculated using the international standard of metabolism rate (ISO 7933).

Step 2: The workload was estimated by asking occupational health experts to consider and analyze the characteristics of the work by watching videos of workers who were working and whose oxygen consumption was already recorded in Step 1. Occupational health experts were asked to calculate the metabolic rate based on the energy expenditure tables of NIOSH (1986). Then the metabolic rates estimated by occupational health experts were compared with the metabolic rate determined by means of oxygen consumption. In this chapter, the findings are presented in two parts:

Part I: Data regarding measurement of oxygen consumption

1. Demographic characteristics of the workers
2. Data regarding working environment
3. Results of oxygen consumption and calculation of metabolic rate

Part II: Data regarding assessment of workload by occupational health experts

1. Demographic characteristics of occupational health experts
2. Results of workload assessment with the details of metabolic rates
3. Results of hypothesis testing

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Part I: Data regarding measurement of oxygen consumption

1. Demographic characteristics of the workers

The eight workers had average age of 34.7 ± 5.8 years, average weight of 56 ± 6.93 kilograms, average height of 1.64 ± 0.05 meters, and average body surface area of 1.59 ± 0.11 m^2, with calculated from equation 5 (page 25) as shown in Table 4-1 below.

Table 4-1: Physical characteristics of the workers participating in oxygen consumption measurement

General info.	The order of working situations (1 worker per situation)								Mean	SD
	1	2	3	4	5	6	7	8		
Age (years)	36	40	35	30	40	23	35	39	34.75	5.8
Weight (kg.)	57	55	72	50	55	54	55	50	56	6.93
Height (m.)	1.59	1.59	1.70	1.60	1.73	1.65	1.60	1.62	1.64	0.05
Surface area (m^2)	1.58	1.55	1.83	1.5	1.65	1.58	1.56	1.51	1.59	.11

2. Data regarding working environment

The survey of the environmental condition in the areas where the workers were working showed that the WBGT value was between 28.53 °C– 47 ºC. The working area of the workers in Situation 7 had highest temperature of 47 ºC, followed by Situation 5 where the WBGT value was equal to 34 ºC. Also, the relative humidity was between 27.6 and 42.0%, with the air velocity between 0.2 and 0.55 meter per second, as depicted in Table 4-2.

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Table 4-2: Data regarding environmental conditions while working of the workers

General info.	The order of working situations (1 worker per situation)								Mean	SD
	1	2	3	4	5	6	7	8		
Age (years)	36	40	35	30	40	23	35	39	34.75	5.8
Weight (kg.)	57	55	72	50	55	54	55	50	56	6.93
Height (m.)	1.59	1.59	1.70	1.60	1.73	1.65	1.60	1.62	1.64	0.05
Surface area (m^2)	1.58	1.55	1.83	1.5	1.65	1.58	1.56	1.51	1.59	.11

3. Results of oxygen consumption and calculation of metabolic rate

The results of the measurement of oxygen consumption of eight workers indicated that oxygen consumption ranged from 42.21 to 110.3 liters per hour or 132.81 to 373.38 kilocalories per hour (see Table 4-3). The details of each worker were as follows:

1. Worker No. 1 was responsible for pouring liquid iron into clay molds

The details of the work

-Lifting a large crucible filled with liquid iron about 100–120 kilograms in weight with one hand to pour the content into smaller crucibles for nine times, with one worker standing on the opposite side to help lift the crucible.

-Lifting smaller crucibles which were now filled with liquid iron about 20 kilograms in weight to pour the content into clay molds for eight times.

- Carrying the large crucible with leftover liquid iron about 1/6 of its total capacity to pour the content into clay molds for two times, with three worker to help carry the crucible.

- Carrying the empty large crucible back to the furnace for a refill one time, with one assistant.

- Standing still for about 25 seconds.

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Amount of oxygen consumption

About 68.16 liters per hour

Estimated metabolism

Approximately 211.23 kilocalories per hour, hence a moderate workload

2. Worker No. 2 was responsible for collecting iron sheets from different points in the factory to be stored in a warehouse using a three-wheel cart

The details of the work

- Pushing the cart with three to four iron sheets in it, weighing about 120 kilograms, past the furnace to the warehouse, taking about 1.20 minutes. After that, lifting the iron sheets up and putting them in piles on the warehouse floor, taking about 30 seconds, before pushing the empty cart back to the locations where iron sheets were left, taking about 1.10 minutes. Then, lifting three or four more iron sheets, each weighing 30 – 40 kilograms, taking 30 seconds (to be repeated three times). Finally, pushing the cart carrying iron sheets 120 kilograms in weight past the furnace to the warehouse one more time.

Amount of oxygen consumption

About 87.65 liters per hour

Estimated metabolism

Approximately 279.81 kilocalories per hour, hence a moderate workload

3. Worker No. 3 was responsible for pouring liquid iron using a steering wheel to control the directions of the bucket and a pulley to ease the move

The details of the work

- Exerting energy to pull a large bucket filled with liquid iron, with the pulley system to help ease the movement, and with three workers to help pull the bucket and control the directions. After that, using two hands to turn the steering wheel to control the directions of the bucket when pouring the content into a large mold, taking about three minutes.

- Using two hands to pull the pulley and tie the rope around a large iron sheet. After that putting the sheet on top of the mold already filled with liquid iron before exerting energy to pull and push the iron platform, using the pulley to lift and place it

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on top of the mold filled with liquid iron, exerting energy four times in total and taking about 2.30 minutes.

-Lifting a small crucible filled with liquid iron to fill the crucible eight times, taking 2.25 minutes.

- Standing and doing nothing for about five seconds.

Amount of oxygen consumption

About 87.02 liters per hour

Estimated metabolism

Approximately 229.13 kilocalories per hour, hence a moderate workload

4. Worker No. 4 was responsible for pouring liquid iron into clay molds

The details of the work

-Lifting a large crucible filled with liquid iron about 100 – 120 kilograms in weight with one hand to pour the content into smaller crucibles for eight times, with one worker standing on the opposite side to help lift the crucible.

-Lifting smaller crucibles which were now filled with liquid iron about 20 kilograms in weight to pour the content into clay molds for eight times.

- Carrying iron platforms each about 15 – 20 kilograms in weight and placing them on a mold already filled with liquid iron for four times.

- Standing and doing nothing for about 10 seconds.

-Walking for 20 seconds.

Amount of oxygen consumption

About 108.36 liters per hour

Estimated metabolism

Approximately 351.2 kilocalories per hour, hence a heavy workload

5. Worker No. 5 was responsible for pushing and pouring liquid iron from a crucible on the cart into smaller crucibles using a joist to let the liquid pour into the crucibles by itself.

The details of the work

- Standing and moving the joist on the cart to pour liquid iron into small crucibles. After pouring the liquid once, other workers would pour the liquid into the

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mold until it ran out and came back for a refill, during which Worker No. 5 would stand and wait before starting to move the joist again for the refill. After the liquid iron on the cart ran out, he would push the cart back to the furnace for a refill, standing and waiting doing nothing until the cart was filled up. After that, he would push the cart up a 20-centimeter incline before standing and moving the joist to refill the liquid iron for other workers. This went on two times.

Amount of oxygen consumption

About 44.6 liters per hour

Estimated metabolism

Approximately 132.81 kilocalories per hour, hence a light workload

6. Worker No. 6 was responsible for making clay molds and pouring liquid iron

The details of the work

-Lifting a mold up and using hands to retouch it, using an air blower to blow dirt away.

-Rubbing the edge of the mold to make it smooth before putting it in a cast, using hands and an air blower to create pressure around the edge of the mold. After that, using a hammer to lightly pound on the edge a few times before pulling it off the cast.

-Laying the finished clay mold down on the ground.

-Walking back to the cast, putting the cast on the platform, and using a shovel to scoop up clay and put it in the cast. Then, using a sieve and shake it, before scooping up clay and putting it in the cast again until the cast is filled (about three times) and redoing the casting procedure one more time. After that, putting the finished clay mold on the ground and pouring liquid iron from a small crucible into clay molds on the ground four times.

Amount of oxygen consumption

About 53.3 liters per hour

Estimated metabolism

Approximately 167.74 kilocalories per hour, hence a light workload

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7. Worker No. 7 was responsible for scraping iron crumbs

The details of the work

-Standing in place and scraping iron crumbs by using both hands to hold the iron, moving the body slightly and taking a break intermittently. Scraping the iron crumb to be disposed of at the sides of the furnace, using both hands and exerting some energy. Moderately moving the body from side to side and taking a break intermittently.

Amount of oxygen consumption

About 42.21 liters per hour

Estimated metabolism

Approximately 137.43 kilocalories per hour, hence a light workload

8. Worker No. 8 was responsible for pouring liquid iron into clay molds

The details of the work

-Standing doing nothing for 25 seconds, then carrying a large crucible filled with liquid iron about 100 – 120 kilograms in weight to the pouring area with one worker, taking about 20 seconds. Then, using one hand to pour the content into smaller crucibles, with one worker standing on the opposite side to help lift the crucible. After that, lifting the small crucible filled with liquid iron about 20 kilograms in weight and emptying it before walking back to life the large crucible to refill the small crucible and lifting it back to the mold, repeatedly for five times.

-When the large crucible was empty, carrying it back to the furnace for a refill and carrying it back to the pouring area one more time. Then pouring the liquid iron from the large crucible into the small crucible and lifting the small crucible to pour the content into the mold, for five times.

Amount of oxygen consumption

About 110.3 liters per hour

Estimated metabolism

Approximately 373.38 kilocalories per hour, hence a heavy workload

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Table 4-3: Data regarding physiological conditions while working of the workers

General info.	The order of working situations (1 worker per situation)							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
VO_2 (l/hr)	68.16	87.65	87.02	108.36	44.60	53.3	42.21	110.3
VCO_2 (l/hr)	57.91	78.6	68.44	88.93	38.68	48.77	43.13	87.41
Metabolism (Kcal/hr)	211.23	279.81	229.13	351.2	132.8	167.74	137.43	373.38
Workload	Moderate	Moderate	Moderate	Heavy	Light	Light	Light	Heavy

The rate of oxygen and carbon dioxide exchange of each of the workers is shown in Figure 4-1 to Figure 4-8

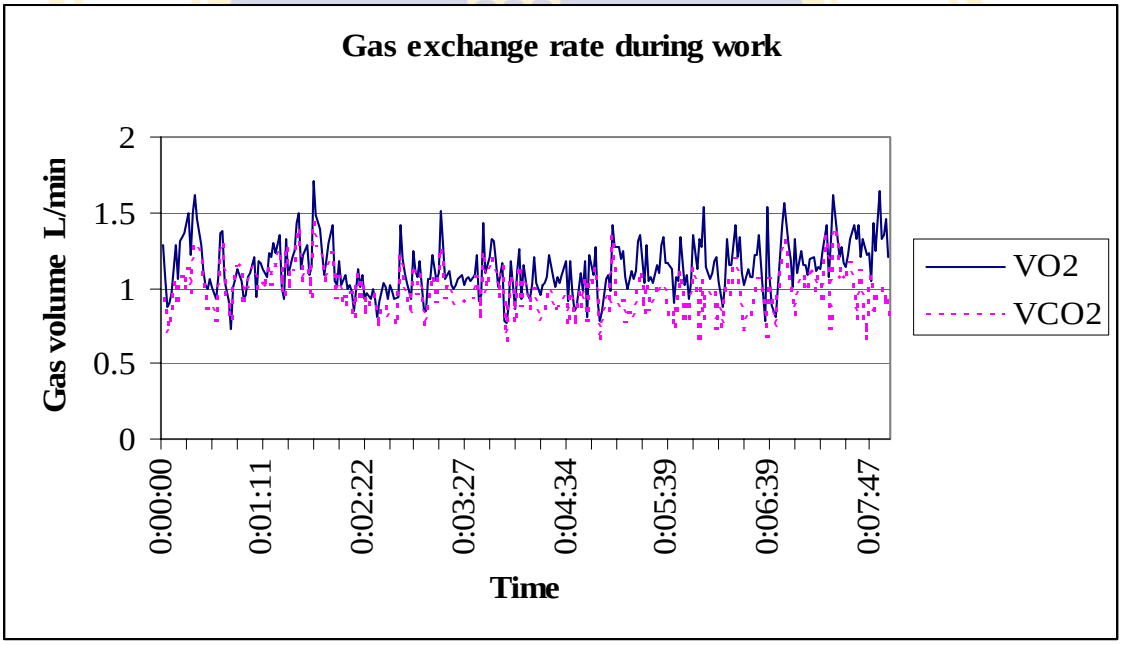

Figure 4-1: Oxygen consumption rate of Worker No. 1

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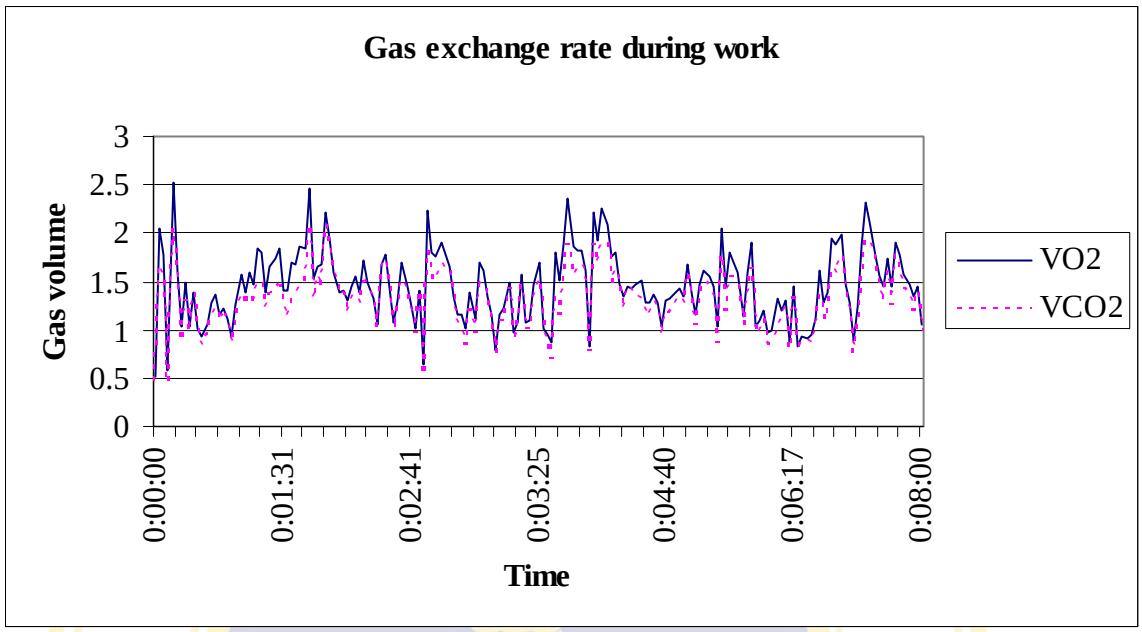

Figure 4-2: Oxygen consumption rate of Worker No. 2

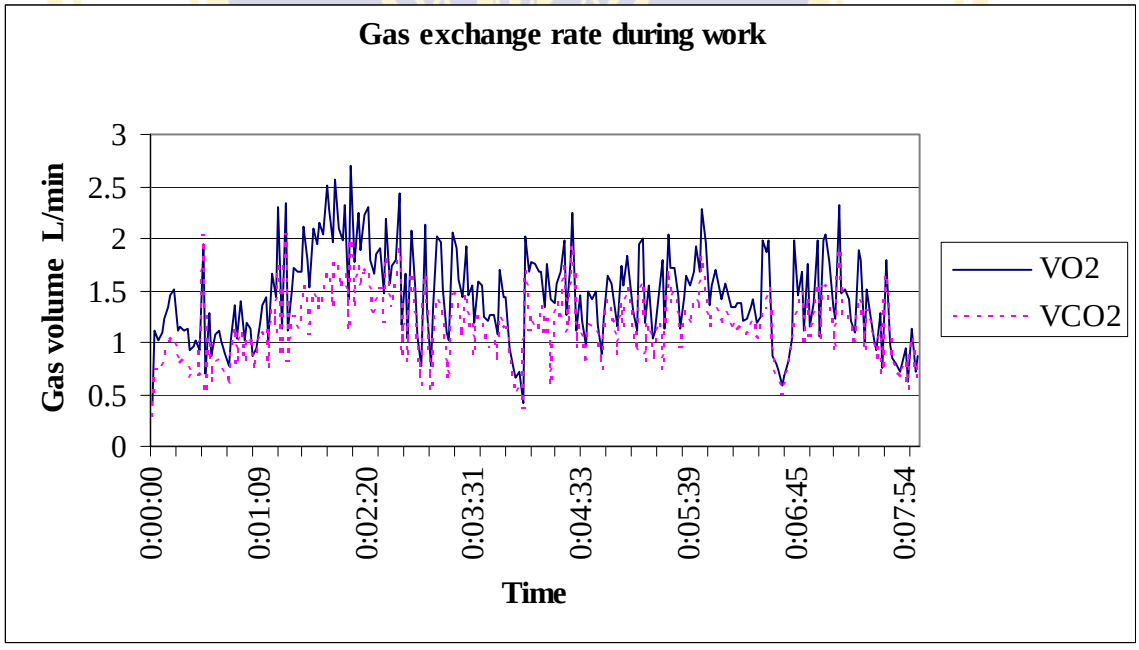

Figure 4-3: Oxygen consumption rate of Worker No. 3

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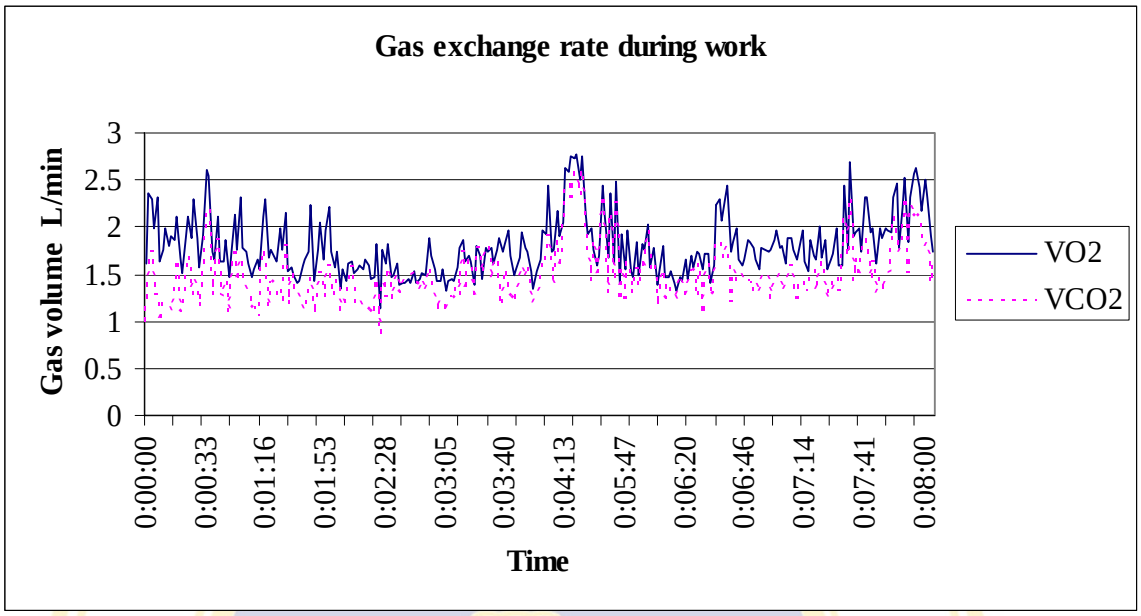

Figure 4-4: Oxygen consumption rate of Worker No. 4

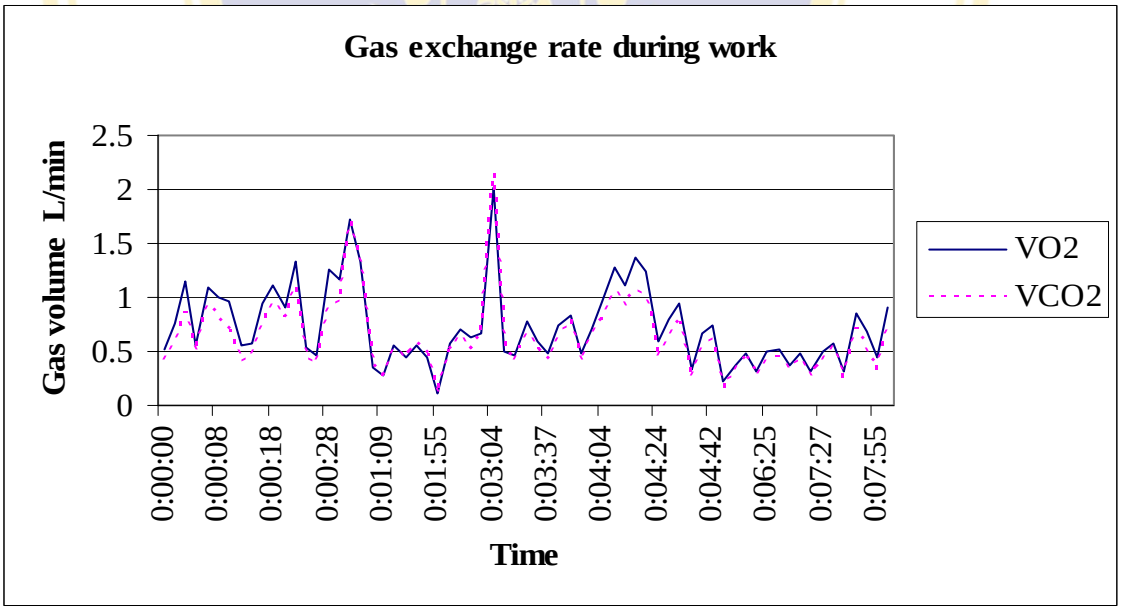

Figure 4-5: Oxygen consumption rate of Worker No. 5

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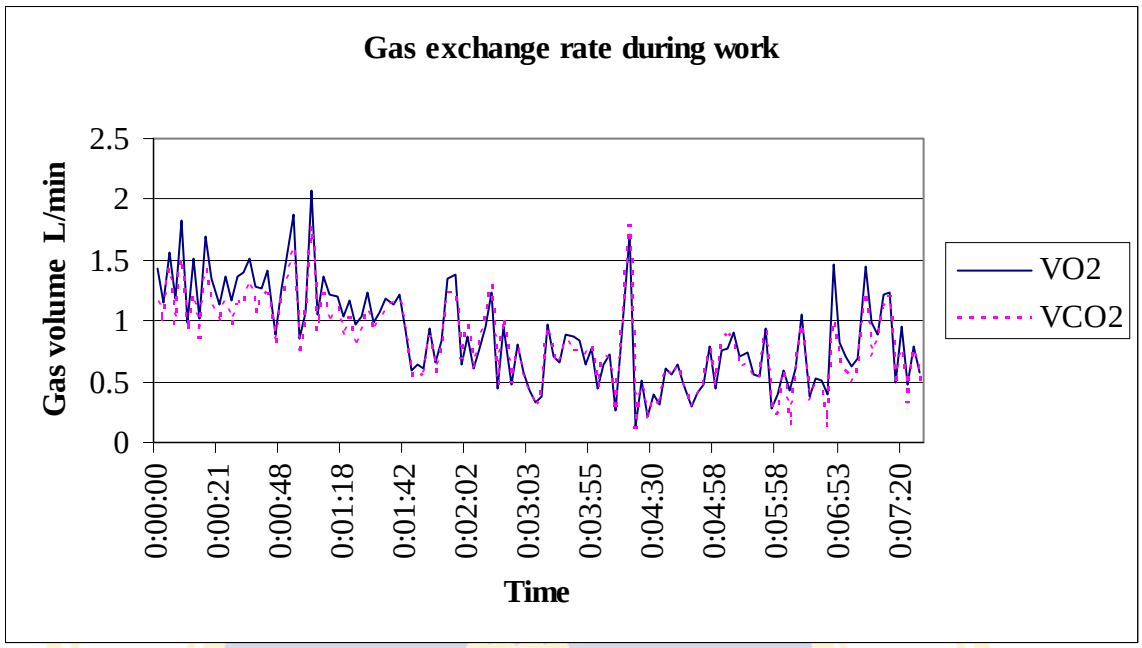

Figure 4-6: Oxygen consumption rate of Worker No. 6

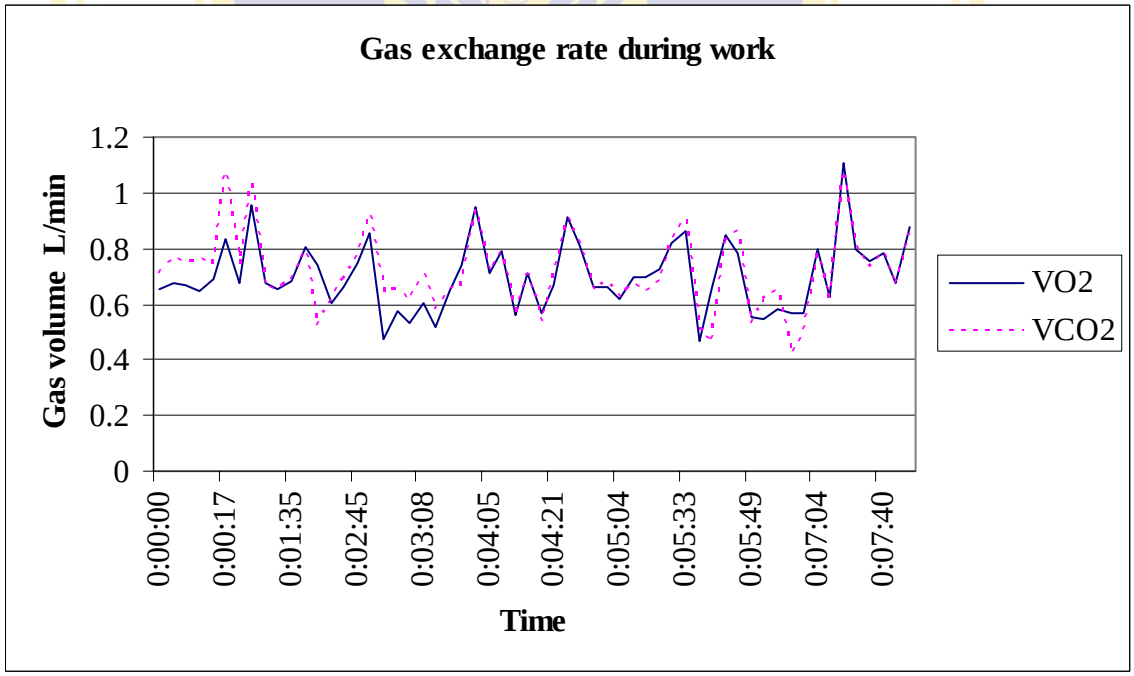

Figure 4-7: Oxygen consumption rate of Worker No. 7

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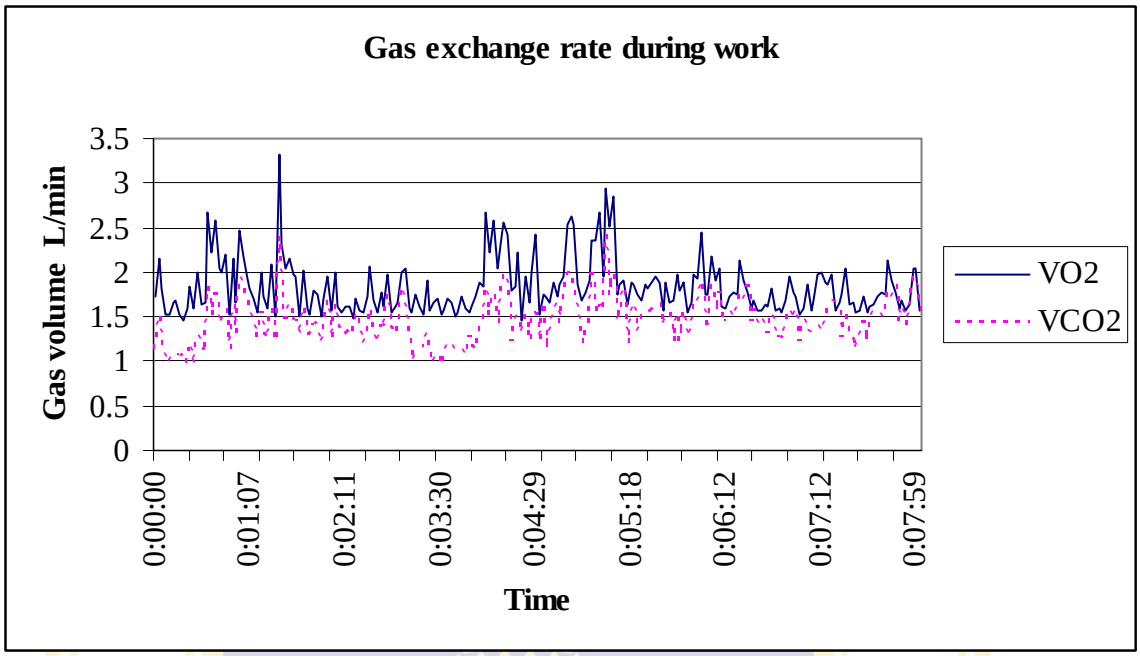

Figure 4-8: Oxygen consumption rate of Worker No. 8

Part II: Data regarding assessment of workload by occupational health experts

1. Demographic characteristics of occupational health experts

A total of 119 occupational health experts took part in the study. Of these, 20 did not graduate from a university, 88 held a bachelor's degree, and 11 of them graduated with a master's degree. In addition, 56 had been educated directly in the field of occupational health and safety, while 63 graduated in other fields but underwent 180-hour training and became certified. Of 119 occupational health experts, only 15 of them conducted heat stress measurement in the factory by themselves, while 104 did not do it themselves. The details are shown in Tables 4-4 and Table 4-5.

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Table 4-4: Demographic characteristics of occupational health experts who assessed the workload of the workers

Demographic characteristics	Number	Percentage
Educational background		
Lower than bachelor's degree	20	16.8
Bachelor's degree	88	73.9
Master's degree	11	9.2
Major areas of study		
Occupational health and related fields	56	47.1
Others	63	52.9
Current position		
Trained safety officers	63	52.9
Safety officers with degree in occupational health	56	47.1
Performance of measurement		
By self	15	12.6
By others	104	87.4
Confidence in accuracy of measurement		
Yes	27	22.7
No	92	77.3

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Table 4-5: Demographic characteristics of occupational health experts who assessed the workload of the workers as categorized according to work experience

Work experience	Number	Percentage
Experience in occupational health (years)		
None	7	5.9
1 – 3	54	45.4
3 – 6	27	22.7
6 – 10	14	11.8
> 10	17	14.3
Experience with measurement of heat stress		
Yes	21	17.6
No	98	82.4
Experience with length of work in measurement of heat stress (years)		
< 1	2	1.7
1	6	5
2	7	5.9
3	2	1.7
5	1	0.8
8	1	0.8
>10	2	1.7
None	98	82.4
Training experience		
Training and practice	31	26.1
Training but no practice	53	44.5
No training and no practice	35	29.4

2. Results of workload assessment with the details of metabolic rates

The assessment of the workload of eight workers revealed that occupational health experts were able to assess the workload correctly by 13.4 – 71.4%, as depicted in Table 4-6, which also reflects the distribution of the assessment from occupational health experts who performed the assessment in three workloads. For example, the light workload in Situation Five was assessed correctly by 36.1% of the occupational health experts, while 52.9% mistakenly assessed it as a moderate workload and 10.9% mistakenly assessed it as a heavy workload.

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Table 4-6: Assessment of metabolic rates while working.

Situation	Workload assessed by VO_2	Workload assessed by occupational health experts		
		Light (%)	Moderate (%)	Heavy (%)
1	Moderate	2.5	19.3	78.2
2	Moderate	2.5	40.3	57.1
3	Moderate	10.1	71.4	18.5
4	Heavy	4.2	41.2	54.6
5	Light	36.1	52.9	10.9
6	Light	13.4	68.1	18.5
7	Light	57.1	30.3	12.6
8	Heavy	8.4	40.3	51.3

Summary of the assessment of energy expenditure

When summarizing Table 4-6 to clearly illustrate the percentage of correct and incorrect estimation as shown in Table 4-7, it could be seen that Situation 3, which was a moderate workload, had the highest percentage of correct estimation at 71.4%. This was followed by Situation 7, a light workload, which was estimated correctly by 57.1%. In addition to this, when considering which situation was estimated incorrectly more than any other situation, it was found that Situation 6, which was a light situation, was estimated incorrectly at 86.6%, followed by Situation 1 at 80.7%.

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Table 4-7: Percentage of correct and incorrect assessments of metabolic rates of workers in each situation.

Situation	Workload assessed by VO_2 measurement	Workload assessed by occupational health experts		Number
		Correct (%)	Incorrect (%)	
1	Moderate	19.3	80.7	119
2	Moderate	40.3	59.7	119
3	Moderate	71.4	28.6	119
4	Heavy	54.6	45.4	119
5	Light	36.1	63.9	119
6	Light	13.4	86.6	119
7	Light	57.1	42.9	119
8	Heavy	51.3	48.7	119

As regards the correctness of the estimation of the eight situations on the overall, it was found that there were two occupational health experts who made the most correct estimations, getting seven situations correct, accounting for 1.7% of the total, followed by 0.8%. Most occupational health experts estimated four situations correctly, with the highest percentage of 29.4%, followed by three situations and two situations, accounting for 26.1% and 21.8%, respectively (see Table 4-8). The mean of correct estimations was 3.44 situations, totaling 43%, and the mean of incorrect estimations was 4.56 situations, or 57% (see Table 4-9).

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Table 4-8: Correct estimations in eight situations by occupational health experts

Number of correct situations	Percentage	Number
1	3.4	4
2	21.8	26
3	26.1	31
4	29.4	35
5	16.8	20
6	.8	1
7	1.7	2
8	0	0

Table 4-9: Mean of correct estimations in eight situations by occupational health experts

	Correct	Incorrect
Number of situations on average	3.44	4.56
Percentage	43	57

Then the means of correct estimations of the eight situations on the overall were considered according to the six categories of occupational health experts: 1) length of work, 2) experience with heat stress measurement and estimation of metabolic rate of workers, 3) training experience, 4) performance of heat stress measurement and estimation of metabolic rate of workers, 5) educational background, and 6) type of occupational health experts. It was found that the mean of correct estimations was between 3.19 and 3.86 situations (see Table 4-10), which was subsequently statistically analyzed to determine the differences among groups.

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Table 4-10: Correct estimations in eight situations by occupational health experts categorized according to experience

Occupational health experts		Number of correct estimation in each situation (%)								mean
		1	2	3	4	5	6	7	8	
Experience in occupa-tional health work	No experience	0	14.3	14.3	42.9	28.6	0	0	0	3.86
	1 – 3 years of experience	3.7	25.9	20.4	29.6	18.5	1.9	0	0	3.39
	3 – 6 years of experience	7.4	14.8	37.0	18.5	14.8	0	7.4	0	3.48
	6 – 10 years of experience	0	14.3	50.0	14.3	21.4	0	0	0	3.43
	More than 10 years of experience	0	29.4	11.8	52.9	5.9	0	0	0	3.35
Experience with heat stress measurement	Yes	0	28.6	28.6	33.3	9.5	0	0	0	3.24
	No	3.4	21.8	26.1	29.4	16.8	0.8	1.7	0	3.48
Experience with training	Training and practice	0	29.0	29.0	35.5	6.5	0	0	0	3.19
	Training but no practice	3.8	18.9	28.3	26.4	20.8	1.9	0	0	3.47
	No training and no practice	5.7	20.0	20.0	28.6	20.0	0	5.7	0	3.60
heat stress measurement by self	By self	0	20.0	40.0	33.3	6.7	0	0	0	3.27
	By others	3.8	22.1	24.0	28.8	18.3	1.0	1.9	0	3.46
Educational background	Lower than bachelors' Degree	5.0	20.0	25.0	25.0	20.0	0	5.0	0	3.55
	Bachelor's degree	3.4	25.0	23.9	28.4	17.0	1.1	1.1	0	3.39
	Master's degree	0	0	45.5	45.5	9.1	0	0	0	3.64
Type of occupational health experts	180-hour training	6.3	19.0	25.4	25.4	19.0	1.6	3.2	0	3.49
	Education in occupational health and safety	0	25.0	26.8	33.9	14.3	0	0	0	3.38

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The data regarding metabolic rates correctly estimated by occupational health experts were then selected and compared with the mean of metabolic rates obtained from measurement of oxygen consumption, as illustrated in Table 4-11. The estimations of some situations were rather similar, such as Situations 2 and 6. The other situations which yielded rather different estimations would be subsequently statistically tested.

Table 4-11: Metabolic rate during work as estimated by measurement of oxygen consumption compared with average metabolic rates correctly estimated by occupational health experts

Situation	Metabolic rate from VO2 measurement (Kcal/hr)	Average metabolic rate correctly estimated by occupational health experts (Kcal/hr)	SD	Min-Max metabolic rate estimated by occupational health experts (Kcal/hr)
1	211.23	290.79	43.5	200.17-345
2	279.81	288.81	40.9	206.16-348.70
3	229.13	276.56	36.84	206-342
4	351.2	464.85	96.58	356.25-842.25
5	132.81	162.82	24.55	107-199
6	167.74	164.71	31.04	87.75-198.75
7	137.43	168.81	21.0	120-199.5
8	373.38	461.49	110.09	352.5-1000

3. Results of hypothesis testing

The present study examined the differences in the metabolic rates of workers that were estimated by occupational health experts in the following aspects:

3.1 The testing of the differences in the average metabolic rates of workers that were estimated by occupational health experts and those obtained by means of measurement of oxygen consumption of the workers

3.2 The testing of the average of the correct estimations compared with the criterion set at 80%

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3.3 Testing the relationship between different factors and accuracy of work heat load estimation in the following six aspects:

3.3.1 Testing the differences in the estimations of occupational health experts with different lengths of work

3.3.2 Testing the differences in the estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate of workers

3.3.3 Testing the differences in the estimations of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers

3.3.4 Testing the differences in the estimations of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves

3.3.5 Testing the differences in the estimations of occupational health experts with different educational background

3.3.6 Testing the differences in the metabolic rates of workers that were estimated by occupational health experts who were educated in the field of occupational health and safety and those who underwent 180-hour training and became certified

Each of the topics was studied, and in this section the findings are presented in each of the situations as well as the average estimations of the eight situations on the overall.

3.1 The testing of the differences in the average metabolic rates of workers that were estimated by occupational health experts and those obtained by means of measurement of oxygen consumption of the workers

When comparing the means of correct estimations of metabolic rates in each situations (see Table 4-11) with the metabolic rates that were estimated by means of measurement of oxygen consumption of the workers, it was discovered that the means of correct estimations conducted by occupational health experts in each situation were different from those obtained through measurement of oxygen consumption with statistical significance (p-value < 0.001), except for Situations 2 and 6 in which the

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differences were not statistically significant (p-value = 0.134 and 0.710, respectively), as detailed in Table 4-12.

Table 4-12: A comparison of the means difference of metabolic rates estimated by those who correctly assessed the workload and the metabolic rates obtained from measurement of oxygen consumption

Situation	n	Mean difference	SD	t	df	p-value
1	23	-79.53	43.5	8.765	22	<0.001*
2	48	-9.0	40.9	1.525	47	0.134
3	85	-47.43	36.84	11.869	84	<0.001*
4	65	-113.65	96.58	9.5	64	<0.001*
5	43	-30.01	24.55	8.015	42	<0.001*
6	16	3.03	31.04	-0.391	15	0.710
7	68	-31.38	21.0	12.323	67	<0.001*
8	61	-88.11	110.09	6.251	60	<0.001*

* With statistical significance at the 0.05 level

3.2 The testing of the average of the correct estimations compared with the criterion set at 80%

From the studies that conducted by the American Industrial Hygiene Association Technical Committee on Ergonomics and Garg et al. have pointed out that the estimation conducted by well trained assessors using the NIOSH tables should yield the results with about 15 – 20% of errors. Thus, in this study, the criterion for accuracy of the estimation was set at 80%. A comparison among the means of correct estimations of the eight situations by 119 occupational health experts revealed that the correct estimations were lower than 80% with statistical significance in all eight situations (p-value < 0.05), as illustrated in Table 4-13.

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Table 4-13: A comparison of the means with the criterion (0.8 or 80%)

Situation	n	mean	SD	t	df	p-value
1	119	0.19	0.397	-16.691	118	<0.001*
2	119	0.40	0.493	-8.783	118	<0.001*
3	119	0.71	0.454	-2.061	118	0.041*
4	119	0.55	0.500	-5.537	118	<0.001*
5	119	0.36	0.482	-9.919	118	<0.001*
6	119	0.13	0.343	-21.193	118	<0.001*
7	119	0.57	0.497	-5.017	118	<0.001*
8	119	0.51	0.502	-6.246	118	<0.001*

* With statistical significance at the 0.05 level

When testing the differences in correct estimations of occupational health experts who were confident in the accuracy of their estimations and those who lacked confidence in the accuracy of their own estimations, it was discovered that the estimations of both groups were different with no statistical significance in all eight situations (p-value > 0.05), as shown in Table 4-14.

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Table 4-14: The differences in estimations of workload in eight situations of occupational health experts who were confident and who were not confidence in the accuracy of their estimations

Situation	Performance	Results		n	χ^2	Df	p-value
		Correct (%)	Incorrect (%)				
1	Confident	11.1	88.9	27	1.512	1	0.219
	Not confident	21.7	78.3	92			
2	Confident	51.9	48.1	27	1.924	1	0.165
	Not confident	37.0	63.0	92			
3	Confident	70.4	29.6	27	0.019	1	0.890
	Not confident	71.7	28.3	92			
4	Confident	40.7	59.3	27	2.715	1	0.099
	Not confident	58.7	41.3	92			
5	Confident	44.4	55.6	27	1.045	1	0.307
	Not confident	33.7	66.3	92			
6	Confident	11.1	88.9	27	0.164	1	0.763
	Not confident	14.1	85.9	92			
7	Confident	70.4	29.6	27	2.495	1	0.114
	Not confident	53.3	46.7	92			
8	Confident	40.7	59.3	27	1.547	1	0.214
	Not confident	54.3	45.7	92			

* With statistical significance at the 0.05 level

When considering the differences in the estimations of the two groups of occupational health experts—those who were confident in the accuracy of their estimations and those who lacked such confidence by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-15), it was found that the means of the correct estimations of these two groups of occupational health experts were 3.41 and 3.45 situations, respectively. Statistical analysis also pointed out that the means of correct estimations of both groups of occupational health experts were different with no statistical significance (p-value = 0.887).

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Table 4-15: Comparison of estimations in eight situations of occupational health experts who were confident and who were not confidence in the accuracy of their estimations

Estimators	n	mean	SD	t	df	p-value
Confident	27	3.41	1.010	-0.143	117	0.887
Not confident	92	3.45	1.278			

* With statistical significance at the 0.05 level

3.3 Testing the relationship between different factors and accuracy of work heat load estimation in the following six aspects:

3.3.1 Testing the differences in the estimations of occupational health experts with different lengths of work

When considering the estimations of Situation 1 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 11.8–25.9%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.617), as shown in Table 4-16

Table 4-16: Test of differences in estimation in situation 1 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	14.3	85.7	7	2.826	4	0.617
1 – 3 years	25.9	74.1	54			
3 – 6 years	14.8	85.2	27			
6 – 10 years	14.3	85.7	14			
> 10 years	11.8	88.2	17			

* With statistical significance at the 0.05 level

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When considering the estimations of Situation 2 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 33.3–57.1%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.806), as shown in Table 4-17.

Table 4-17: Test of differences in estimation in situation 2 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	57.1	42.9	7	1.615	4	0.806
1 – 3 years	42.6	57.4	54			
3 – 6 years	33.3	66.7	27			
6 – 10 years	35.7	64.3	14			
> 10 years	41.2	58.8	17			

* With statistical significance at the 0.05 level

When considering the estimations of Situation 3 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 68.5– 78.6%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.962), as shown in Table 4-18

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Table 4-18: Test of differences in estimation in situation 3 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	71.4	28.6	7	0.673	4	0.962
1 – 3 years	68.5	31.5	54			
3 – 6 years	74.1	25.9	27			
6 – 10 years	78.6	21.4	14			
> 10 years	70.6	29.4	17			

* With statistical significance at the 0.05 level

When considering the estimations of Situation 4 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 50–59.3%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.982), as shown in Table 4-19.

Table 4-19: Test of differences in estimation in situation 4 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	57.1	42.9	7	0.411	4	0.982
1 – 3 years	53.7	46.3	54			
3 – 6 years	59.3	40.7	27			
6 – 10 years	50.0	50.0	14			
> 10 years	52.9	47.1	17			

* With statistical significance at the 0.05 level

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When considering the estimations of Situation 5 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 14.3–48.1%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.476), as shown in Table 4-20.

Table 4-20: Test of differences in estimation in situation 5 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	14.3	85.7	7	3.510	4	0.476
1 – 3 years	35.2	64.8	54			
3 – 6 years	48.1	51.9	27			
6 – 10 years	28.6	71.4	14			
> 10 years	35.3	64.7	17			

* With statistical significance at the 0.05 level

When considering the estimations of Situation 6 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 9.3–21.4%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.791), as shown in Table 4-21.

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Table 4-21: Test of differences in estimation in situation 6 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	14.3	85.7	7	1.885	4	0.791
1 – 3 years	9.3	90.7	54			
3 – 6 years	14.8	85.2	27			
6 – 10 years	21.4	78.6	14			
> 10 years	17.6	82.4	17			

* With statistical significance at the 0.05 level

When considering the estimations of Situation 7 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 52.9–71.4%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.855), as shown in Table 4-22.

Table 4-22: Test of differences in estimation in situation 7 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	71.4	28.6	7	1.340	4	0.855
1 – 3 years	53.7	46.3	54			
3 – 6 years	63.0	37.0	27			
6 – 10 years	57.1	42.9	14			
> 10 years	52.9	47.1	17			

* With statistical significance at the 0.05 level

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When considering the estimations of Situation 8 of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, it was found that all groups could correctly estimate the metabolic rates by 40.7–85.7%. Statistical analysis also pointed out that the estimations of these five groups were different with no statistical significance (p-value = 0.312), as shown in Table 4-23.

Table 4-23: Test of differences in estimation in situation 8 of occupational health experts with different lengths of work experience

Experience	Results		n	χ^2	df	p-value
	Correct (%)	Incorrect (%)				
None	85.7	14.3	7	4.769	4	0.312
1 – 3 years	50.0	50.0	54			
3 – 6 years	40.7	59.3	27			
6 – 10 years	57.1	42.9	14			
> 10 years	52.9	47.1	17			

* With statistical significance at the 0.05 level

When considering the differences in the estimations of five groups of occupational health experts with different lengths of work—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience—further from the results obtained in Tables 4-16 to Table 4-23 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-24), it was found that the means of the correct estimations of five groups of occupational health experts were 3.86, 3.39, 3.48, 3.43, and 3.35 situations, respectively (see Table 4-10). Statistical analysis also pointed out that the estimations of these five groups of occupational health experts with different length of work experience were different with no statistical significance (p-value = 0.908), thus yielding further support to the findings of each situation depicted in Tables 4-16 to Table 4-23.

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Table 4-24: The differences in estimations of workload in eight situations of occupational health experts with different lengths of work experience

Source of variance	SS	df	MS	F	Sig
Between groups	1.535	4	0.384	0.252	0.908
Within groups	173.742	114	1.524		
Total	175.277	118			

* With statistical significance at the 0.05 level

3.3.2 Testing the differences in the estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate of workers.

When testing the differences in estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate of workers, it was found that the estimations of both groups of occupational health experts were different with no statistical significance in all eight situations (p-value > 0.05), as depicted in Table 4-25.

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Table 4-25: The differences in estimations of workload in eight situations of occupational health experts with and without experience in heat stress measurement and estimation of metabolic rate of workers

Situation	Experience	Results		n	χ^2	df	p-value
		Correct (%)	Incorrect (%)				
1	Yes	23.8	76.2	21	0.329	1	0.762
	No	18.4	81.6	98			
2	Yes	42.9	57.1	21	0.067	1	0.811
	No	39.8	60.2	98			
3	Yes	71.4	28.6	21	0.000	1	1.000
	No	71.4	28.6	98			
4	Yes	47.6	52.4	21	0.505	1	0.630
	No	56.1	43.9	98			
5	Yes	38.1	61.9	21	0.042	1	1.000
	No	35.7	64.3	98			
6	Yes	9.5	90.5	21	0.337	1	0.734
	No	13.5	86.5	98			
7	Yes	42.9	57.1	21	2.125	1	0.224
	No	60.2	39.8	98			
8	Yes	47.6	52.4	21	0.135	1	0.812
	No	52.0	48.7	98			

* With statistical significance at the 0.05 level

When considering the differences in the estimations of both groups of occupational health experts with and with no experience measuring heat stress and estimation of metabolic rate of workers further from the results obtained in Table 4-25 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-26), it was found that the means of the correct estimations of both groups of occupational health experts were 3.24 and 3.48 situations, respectively (see Table 10). Statistical analysis also pointed out that the estimations of these two groups of occupational health experts with and with no experience measuring heat stress were different with no statistical significance (p-value = .412), thus yielding further support to the findings of each situation depicted in Table 4-25.

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Table 4-26: Comparison of estimations in eight situations of occupational health experts with and with no experience measuring heat stress and estimation of metabolic rate of workers

Estimators	n	mean	Std. Deviation	t	df	p-value
With experience	21	3.24	0.995	-0.823	117	0.412
With no experience	98	3.48	1.262			

* With statistical significance at the 0.05 level

3.3.3 Testing the differences in the estimations of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers

When testing the differences in estimations of three groups of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers, those who had undergone training but had no actual practice, and those with no training and no practice (see Table 4-27), it was found that the estimations of these three groups of occupational health experts were different with no statistical significance in situations 1, 2, 3, 5, 6, and 7 (p-value > 0.05). However, there were statistically significant differences in situations 4 and 8 (p-value = 0.012 and 0.05, respectively). The differences in the numbers of correct estimations were then examined in the following step.

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Table 4-27: The differences in estimations of workload in eight situations of occupational health experts with different training experience and practice of heat stress measurement and estimation of metabolic rate of workers

Situation	Experience	Results		n	χ^2	df	p-value
		Correct (%)	Incorrect (%)				
1	Training & Practice	19.4	80.6	31	1.525	2	0.467
	Training w/ no Practice	15.1	84.9	53			
	No training & No practice	25.7	74.3	35			
2	Training & Practice	35.5	64.5	31	1.864	2	0.394
	Training w/ no Practice	47.2	52.8	53			
	No training & No practice	34.3	65.7	35			
3	Training & Practice	77.4	22.6	31	0.864	2	0.649
	Training w/ no Practice	67.9	32.1	53			
	No training & No practice	71.4	28.6	35			
4	Training & Practice	38.7	61.3	31	8.916	2	0.012*
	Training w/ no Practice	50.9	49.1	53			
	No training & No practice	74.3	25.7	35			
5	Training & Practice	41.9	58.1	31	1.378	2	0.502
	Training w/ no Practice	37.7	62.3	53			
	No training & No practice	28.6	71.4	35			
6	Training & Practice	6.5	93.5	31	4.451	2	0.107
	Training w/ no Practice	20.8	79.2	53			
	No training & No practice	8.6	91.4	35			
7	Training & Practice	61.3	38.7	31	4.197	2	0.123
	Training w/ no Practice	64.2	35.8	53			
	No training & No practice	42.9	57.1	35			
8	Training & Practice	38.7	61.3	31	10.693	2	0.005*
	Training w/ no Practice	43.4	56.6	53			
	No training & No practice	74.3	25.7	35			

* With statistical significance at the 0.05 level

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When considering the differences in the estimations of the three groups of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers, those who had undergone training but had no actual practice, and those with no training and no practice further from the results obtained in Table 4-27 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-28), it was found that the means of the correct estimations of the three groups of occupational health experts were 3.19, 3.47, and 3.60 situations, respectively (see Table 4-10). Statistical analysis also pointed out that the estimations of these three groups of occupational health experts were different with no statistical significance (p-value = 0.389).

Table 4-28: The differences in estimations in eight situations of occupational health experts with different training experience and practice of heat stress measurement and estimation of metabolic rate of workers

Source of variance	SS	df	MS	F	Sig
Between groups	2.831	2	1.416	0.952	0.389
Within groups	172.466	116	1.487		
Total	175.277	118			

* With statistical significance at the 0.05 level

3.3.4 Testing the differences in the estimations of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves

When testing the differences in estimations of the occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves, it was found that the estimations of these two groups of occupational health experts were different with no statistical significance in all eight situations (p-value > 0.05), as shown in Table 4-29.

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Table 4-29: The differences in estimations of workload in eight situations of occupational health experts who performed the estimation by themselves and who did not.

Situation	Performance	Results		n	χ^2	df	p-value
		Correct (%)	Incorrect (%)				
1	By self	20.0	80.0	15	0.005	1	1.000
	By others	19.2	80.8	104			
2	By self	40.0	60.0	15	0.001	1	0.977
	By others	40.4	59.6	104			
3	By self	60.0	40.0	15	1.098	1	0.360
	By others	73.1	26.9	104			
4	By self	46.7	53.3	15	0.438	1	0.508
	By others	55.8	44.2	104			
5	By self	33.3	66.7	15	0.058	1	0.809
	By others	36.5	63.5	104			
6	By self	13.3	86.7	15	0.000	1	1.000
	By others	13.5	86.5	104			
7	By self	80.0	20.0	15	3.662	1	0.056
	By others	53.8	46.2	104			
8	By self	33.3	66.7	15	2.208	1	0.137
	By others	51.3	48.7	104			

* With statistical significance at the 0.05 level

When considering the differences in the estimations of the two groups of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves further from the results obtained in Table 4-29 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-30), it was found that the means of the correct estimations of both groups of occupational health experts were 3.27 and 3.46 situations, respectively (see Table 4-10). Statistical analysis also pointed out that the estimations of these two groups of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves were different with no statistical significance (p-value = 0.565).

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Table 4-30: Comparison of estimations in eight situations of occupational health experts who performed the estimation by themselves and who did not

Estimators	n	mean	SD	t	df	p-value
By self	15	3.27	0.884	-0.577	117	0.565
By others	104	3.46	1.261			

* With statistical significance at the 0.05 level

3.3.5 Testing the differences in the estimations of occupational health experts with different educational background

When testing the differences in estimations of three groups of occupational health experts with different educational backgrounds—those whose education was lower than an undergraduate level, those with a bachelor's degree, and those with a master's degree, it was found that the estimations of these three groups of occupational health experts were different with statistical significance in situations 2, 4, and 8 (p-value = 0.016, 0.010, and 0.019, respectively). However, there were no statistically significant differences in situations 1, 3, 5, 6, and 7 (see Table 4-31). The differences in the numbers of correct estimations were then examined in the following step.

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Table 4-31: The differences in estimations of workload in eight situations of occupational health experts with different educational background

Situation	Educational background	Results		n	χ^2	df	p-value
		Correct (%)	Incorrect (%)				
1	Lower than bachelor's degree	30.0	70.0	20	2.274	2	0.321
	Bachelor's degree	18.2	81.8	88			
	Master's degree	90.1	90.9	11			
2	Lower than bachelor's degree	20.0	80.0	20	8.244	2	0.016*
	Bachelor's degree	40.9	59.1	88			
	Master's degree	72.7	27.3	11			
3	Lower than bachelor's degree	60.0	40.0	20	3.327	2	0.190
	Bachelor's degree	71.6	28.4	88			
	Master's degree	90.9	901	11			
4	Lower than bachelor's degree	85.0	15.0	20	9.134	2	0.010*
	Bachelor's degree	47.7	52.3	88			
	Master's degree& No practice	54.5	45.5	11			
5	Lower than bachelor's degree	35.0	65.0	20	0.457	2	0.796
	Bachelor's degree	37.5	62.5	88			
	Master's degree	27.3	72.7	11			
6	Lower than bachelor's degree	5.0	95.0	20	1.864	2	0.499
	Bachelor's degree	15.9	84.1	88			
	Master's degree	9.1	90.9	11			
7	Lower than bachelor's degree	40.0	60.0	20	3.070	2	0.215
	Bachelor's degree	61.4	38.6	88			
	Master's degree	54.5	45.5	11			
8	Lower than bachelor's degree	80.0	20.0	20	7.948	2	0.019*
	Bachelor's degree	45.5	54.5	88			
	Master's degree	45.5	54.5	11			

* With statistical significance at the 0.05 level

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When considering the differences in the estimations of the three groups of occupational health experts with different educational backgrounds—those whose education was lower than an undergraduate level, those with a bachelor's degree, and those with a master's degree further from the results obtained in Table 4-31 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-32), it was found that the means of the correct estimations of the three groups of occupational health experts with different educational backgrounds were 3.55, 3.39, and 3.64 situations, respectively (see Table 4-10). Statistical analysis also pointed out that the estimations of these three groups of occupational health experts with different educational backgrounds were different with no statistical significance (p-value = 0.737).

Table 4-32: The differences in estimations in eight situations of occupational health experts with different educational background

Source of variance	SS	df	MS	F	Sig
Between groups	0.918	2	0.459	0.305	0.737
Within groups	174.359	116	1.503		
Total	175.277	118			

* With statistical significance at the 0.05 level

3.3.6 Testing the differences in the metabolic rates of workers that were estimated by occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified.

When testing the differences in estimations of occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified (see Table 4-33), it was discovered that the estimations of both groups in situations 1, 2, 3, and 6 were different with no statistical significance (p-value > 0.05). However, there were statistically significant differences in situations 4, 5, 7, and 8 (p-value = 0.005, 0.028, 0.025, and < 0.001, respectively). Further statistical analyses were then carried out in the following step.

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Table 4-33: The differences in estimations of workload in eight situations of occupational health experts who were educated in occupational health and safety and those who underwent 180-hour training and became certified

Situation	Performance	Results		n	χ^2	df	p-value
		Correct (%)	Incorrect (%)				
1	180-hour training	19.0	81.0	63	0.007	1	0.935
	Occupational health education	19.6	80.4	56			
2	180-hour training	33.3	66.7	63	2.728	1	0.099
	Occupational health education	48.2	51.8	56			
3	180-hour training	73.0	27.0	63	0.165	1	0.684
	Occupational health education	69.6	30.4	56			
4	180-hour training	66.7	33.3	63	7.836	1	0.005*
	Occupational health education	41.1	58.9	56			
5	180-hour training	27.0	73.0	63	4.857	1	0.028*
	Occupational health education	46.4	53.6	56			
6	180-hour training	14.3	85.7	63	0.081	1	0.776
	Occupational health education	12.5	87.5	56			
7	180-hour training	47.6	52.4	63	4.958	1	0.025*
	Occupational health education	67.9	32.1	56			
8	180-hour training	68.3	31.7	63	15.474	1	<0.001*
	Occupational health education	32.1	67.9	56			

* With statistical significance at the 0.05 level

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When considering the differences in the estimations of the three groups of occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified further from the results obtained in Table 4-33 by testing the accuracy of the estimations of the eight situations on the overall (see Table 4-34), it was found that the means of the correct estimations of these two groups of occupational health experts were 3.38 and 3.49 situations, respectively (see Table 4-10). Statistical analysis also pointed out that the estimations of both groups of occupational health experts were different with no statistical significance (p-value = 0.597).

Table 4-34: Comparison of estimations in eight situations of occupational health experts who were educated in occupational health and safety and those who underwent 180-hour training and became certified

Estimators	n	mean	SD	t	df	p-value
180-hour training	63	3.49	1.378	0.531	113.380	0.597
Occupational health education	56	3.38	1.019			

* With statistical significance at the 0.05 level

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CHAPTER V
DISCUSSION

The present study aimed at investigating the accuracy of the workload in a working environment with heat stress and determining the relationship between the selected factors and the accuracy of work heat load estimations by 119 occupational health experts who could be divided into two groups: those who had a degree in occupational health and safety and those who underwent 180-trainign and became certified. These occupational health experts were also different in terms of working experiences. The assessment of workload was conducted by means of videos recording eight working situations in which the workers' oxygen consumption had already been measured. Each situation lasted eight minutes, and the situations varied in terms of intensity of work, continuation of work, speed of work, and intermittent breaks. The occupational health experts had to consider the work and estimate the metabolic rate every minute. Also, they had to calculate the overall metabolic rate of the work in each situation, and then use the outcomes to categorize the works based on the standard of the Ministry of Industry: light work ≤ 200 kcal/hr, moderate work = 200–350 kcal/hr, and heavy work ≥ 350 kcal/hr. After that, the researcher tested the estimation outcomes using statistical formulas so as to test the research hypotheses previously formulated.

When recording the videos of the working situations of the workers, the researcher selected actual situations in a foundry factory as follows: three light workloads, three moderate workloads, and two heavy workloads. The working situations in the foundry factory were of interest because the level of heat stress was rather high, and the nature of most of the works was mobile. In addition, the workers were constantly required to move different parts of the body and to exert a rather great amount of energy. The characteristics of the works were not specific, and the speeds of work and breaks of the workers varied. For these reasons, the researcher found that the working situations in the foundry factory were suitable for the estimation as the

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occupational health experts had to consider a number of factors very carefully and thoroughly when making decisions about the workloads.

However, it is worth noting that the estimation conducted with videos may have been different from the estimation conducted in an actual setting. This is because when the occupational health experts were not in the actual situation, the clarity of the situation may be affected, hence a different estimation of the workload. This is considered one of the limitations of the present study.

The results of the estimation of metabolic rates in all eight working situations would be considered according to the criterion requiring 80% of accuracy. Studies conducted by the American Industrial Hygiene Association Technical Committee on Ergonomics and Garg et al. have pointed out that the estimation conducted by well trained assessors using the energy expenditure table of NIOSH should yield the results with about 15 – 20% of errors. Thus, in this study, the criterion for accuracy of the estimation was set at 80%. The findings showed that the accuracy of the estimations in all eight situations by occupational health experts was lower than 80% with statistical significance (p-value < 0.05) (see Table 4-13). Furthermore, the situations which had the highest percentage of incorrect estimation, which was higher than 80%, were Situation 6 (light workload) and Situation 1 (moderate workload) (see Table 4-7). When considering the situations with higher incorrect estimations than correct estimations, it was discovered that Situation 1 (moderate workload), Situation 2 (moderate workload), Situation 5 (light workload), and Situation 6 (light workload) were estimated inaccurately by more than 50% (see Table 4-7). It was also found that the inaccurate estimations resulted from judging that the workload was heavier than it actually was (see Tables 4-6 and 4-11). Likewise, according to the International Organization Standardization (ISO, 1983), the assessment of workload based on the estimation of metabolic rates using the energy expenditure table of NIOSH is likely to be more erroneous than 30% (4). And even though the estimators have been well trained, know how to use the tables, and use their best judgment in the estimation, the errors are still ±10–15% (5). In this study, the situation which was estimated with the highest accuracy was Situation 3 (moderate workload), at 71.4% (see Table 4-7). As for Situations 4 and 8, both of which were heavy workloads, even though they more estimated more correctly than incorrectly, the rate of accuracy was only a little bit

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higher than 50% (see Table 4-7). When considering the details of each of the eight situations, it could be seen that Situations 1, 4, and 8 were rather similar. In other words, all these three situations required the worker to use one hand to lift a large crucible filled with liquid iron about 100–120 kilograms in weight with one assistant to help pour the content into small crucibles. Then they had to exert energy to lift the small crucibles filled with liquid iron about 20–25 kilograms in weight and walk to pour the content into clay molds on the ground. However, these three situations were different in terms of details. For example, in Situations 4 and 8, the workers had to carry the large crucible to the furnace to refill it with liquid iron and carry it back to the working point. Moreover, the speed of work, number of lifts, and the duration of break were different in these situations, all of which had an effect on the oxygen consumption rate of the body. Therefore, even though these three situations were generally similar, but the speed of the work in Situation 1 was slower than that in Situations 4 and 8. The number of time the workers had to lift and carry something was largest in Situation 8, with the fastest speed of work and hence the smallest number of breaks as well. Thus, the metabolic rate was higher than that in Situations 4 and 1, respectively despite the fact that Situation 1 was considered a moderate workload due to slower speed of work and more short breaks. This made the rate of oxygen consumption of the body decreased rapidly when the break first began before slowing down (11). As a result, even though the worker took a very short break, when the breaks occurred frequently, the workload would be reduced.

In Situation 2, the worker was required to lift heavy objects, which were iron sheets weighing 30 and 40 kilograms. If they were 30-kilogram iron sheets, the worker had to lift four sheets at a time, but if they were 40-kilogram sheets, the worker had to lift them three sheets at a time. They had to lift these sheets onto a cart and then out of a cart onto the floor. This had to be done altogether six rounds (18 times). Other works included walking while pushing the cart with the iron sheets, about 120 kilograms in total, to the warehouse to store them and then pushing the empty cart back. In this study, most of the occupational health experts estimated this as a heavy workload, when in fact it was a moderate workload. This is because the lifting was done briefly, with not much speed, and the empty cart was not heavy either. Thus, the body needed

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to consume a large amount of oxygen for a short period of time, hence a moderate workload.

As regards Situation 3, three types of work were combined—dragging, pushing, and pouring. Dragging and pushing were done with a pulley. The worker dragged a large bucket weighing about 500 kilograms and attached to a pulley with the help of three assistants to pour the liquid iron inside into a large cast. The pouring was done with a steering wheel to control the directions of the bucket. The worker needed to exert a lot of energy only when he was dragging the bucket. After that the second part of the work began. The worker pulled the rope of the pulley and tied it around a large iron platform. Then he pushed the platform and placed it on top of the cast already filled with liquid iron. This was done alone with no assistant. After that, the work resembled that in Situations 1, 4, and 8 when the worker poured the liquid iron from small crucibles into the cast. The findings indicated that most of the occupational health experts estimated the workload in this situation correctly that it was a moderate workload. As the worker only controlled the steering wheel in the first part, so it could be considered light to moderate work. For the second and third part, even though the worker had to push and lift something, the workload was still clearly moderate. Thus, most of the occupational health experts could estimate the workload in Situation 2 correctly.

In Situation 5, the worker pushed the cart with liquid iron to refill the small crucibles for other workers. The worker worked with a cart equipped with a joist that could be moved to lift the bucket up when pouring. Thus, he did not have to exert much energy, except for when he had to push the cart filled with liquid iron up a 15-centimeter incline for two times, which took about 15 seconds in one round of work. He could stand doing nothing except when refilling the small crucibles for other workers. Thus, the workload was light. However, most of the occupational health experts mistakenly thought the work in this situation was a moderate workload as they may not have taken the time when the worker stood doing nothing, during which the oxygen consumption of the body dramatically decreased, into account (20).

In Situation 6, the worker made clay molds used in the pouring of liquid iron. He had to lift the cast which was two pieces of iron and put them together on a table. After that, he used a shovel to scoop clay up and put it in the cast, using his hands to

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press the clay in the cast and smooth the edge. He then removed the cast and lift the finished clay mold, about five kilograms in weight, and put them it down on the floor. Then he switched to pouring liquid iron, lifting a small crucible to pour the content inside into the clay molds, just like in Situations 1, 4, and 8. However, the pouring could be done slowly without haste. Most of the occupational health experts estimated this situation as a moderate workload, making the decision on the metabolic rate when the worker scooped the clay up and pouring the liquid iron, which required a rather large amount of energy, hence a moderate light work on average. However, the work in this situation was a light workload, as scooping up clay and pouring liquid iron were done for only a brief period of time. After that, the worker just stood and did light work such as using hands to smooth the surface of the clay mold and or poured liquid iron which was done rather slowly, thus the overall workload was light.

In Situation 7, the worker used both hands to hold a long-handled but light-weighted iron scraper to scrape iron crumbs out of the furnace and leave them on the sides. They had to move their body rather considerably. However, only 57% of the occupational health experts estimated the work in this situation as a light workload (see Table 4-7), which was correct, because they mistakenly estimated the metabolic rate during the scraping process.

It could be seen that the estimation of workload based on the energy expenditure table of NIOSH requires the clear and thorough analysis of the nature of the work. In other words, the estimators need to use their best judgment (2). This is because the actual work of a person has details which may be different from those specified in the energy expenditure table of NIOSH. Occupational health experts have to take different related factors into thorough consideration to make the estimation as accurate as possible. In the present study, it could be seen that the occupational health experts' estimations based on the metabolic rate in the energy expenditure table of NIOSH were remarkably different from the workloads assessed by scientific means, especially the work which did not have specific pattern and the work which required movements from one point to another, hence an even more difficult estimation. In addition, in this study none of the workloads could be considered very heavy workload because in real-situations, the workers are likely to take a short break of approximately 30 – 60 seconds when they feel exhausted, making the oxygen level reach the level

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required by the body. Put another way, when working hard, the body needs more oxygen, hence an increase in the breathing rate. When reaching this point, the workers would feel exhausted and they would then take a short break, after which the oxygen level will meet the needed level of the body and the breathing returns to normal (11). The workers would then resume their work, and the cycle goes on. For this reason, a very heavy workload is hardly found in real-life working situations where quantity of work or speed of work is not enforced and where workers can briefly take a break when they feel like it. On the other hand, in the laboratories the workloads can be enforced at different levels and those performing the works may not be able to take a break as they like.

The findings of this study also revealed that the metabolic rates estimated by occupational health experts were much higher than what they actually were (see Table 4-11), and they were statistically significantly different from the metabolic rates obtained through the measurement of oxygen consumption, except for Situations 2 and 6 for which the estimations of the occupational health experts and the estimation obtained through the measurement of oxygen consumption were different with no statistical significance (see Table 4-12).

The average of the correct estimations compared with the criterion set at 80%

A comparison among the means of correct estimations of the eight situations by occupational health experts revealed that the correct estimations were lower than 80% with statistical significance in all eight situations (see Table 4-13). The finding showed that the correct estimations of occupational health experts were higher than 50% in some of the situations such as situation 3 (moderate workload), situation 7 (light workload), and situations 4 and 8 (heavy workloads), accounting for 71.4%, 57.1%, 54.6%, and 51.3%, respectively (see Table 4-7). However, these percentages were still lower than 80%. In addition, the analysis of the accuracy of the estimations on the overall showed that the mean number of situations for which correct estimations were made was 3.44 situations, or only 43% of the total. This means that the rate of inaccurate estimations was as high as 57%. These findings were in agreement with the International Organization Standardization 1983 (4) which found that the rate of inaccurate estimation using the metabolic rates in the NIOSH tables

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could be higher than 30%. This clearly suggests that the estimations made by occupational health experts in different situations with different types of work was not yet totally reliable as individual occupational health experts may have different opinions toward the same workloads. Moreover, the fact that the occupational health experts have confidence in their estimations does not mean that such estimations are accurate. In this study, when testing the differences in correct estimations of occupational health experts who were confident in the accuracy of their estimations and those who lacked confidence in the accuracy of their own estimations, it was discovered that the estimations of both groups were different with no statistical significance in all eight situations (p-value > 0.05) (see Table 4-14). Besides the means of the correct estimations of these two groups of occupational health experts were 3.41 and 3.45 situations, respectively. Statistical analysis also pointed out that the means of correct estimations of both groups of occupational health experts were different with no statistical significance (p-value = 0.887) (see Table 4-15).

Based on the findings of this study, it could be concluded that the use of the metabolic rates specified in the energy expenditure table of NIOSH to estimate the workloads in the foundry factory is rather erroneous. Consequently, the legal estimations lack reliability and credibility, and this may affect the enforcement of the laws. The findings of the present study revealed that the estimations of different groups of occupational health experts categorized according to different educational, practical, and professional experience were different with no statistical significance, and most of the estimations were incorrect rather than correct. Also, the estimation of the same individual occupational health experts may vary even in the same situations because of their decision to select the metabolism rates specified in the energy expenditure table of NIOSH. This supports the theory stating that the decision individuals make depends on their background knowledge and experience (46). The individuals who have similar background knowledge and experience may have similar ideas and opinions, but it is not always the case (47). It is also unable to judge if any particular individual's or group's ideas or decisions are correct or not, some ideas may be true but others may be not (48). This is all because individuals may have different opinions and decisions (52).

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The testing of the relationship between selected factors and accuracy of work heat load estimation in six aspects

In this study, the relationship between selected factors and accuracy of work heat load estimations was determined in six aspects: 1) length of work in occupational health and safety, 2) experience with heat stress measurement and estimation of metabolic rate of workers, 3) training experience, 4) actual performance of heat stress measurement and estimation of metabolic rate of workers, 5) educational background and 6) type of safety officer. The occupational health experts were asked to estimate the workload in eight situations, which can be concluded and discussed as follows:

1. The length of work in occupational health and safety was used to categorize occupational health experts into five groups—no experience, 1–3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience. The findings indicated that when considering the estimations of the workloads in eight situations of the occupational health experts with different lengths of work in the field were different with no statistical significance (p-value > 0.05) (see Tables 4-16 to 4-23). When further analyzing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of five groups of occupational health experts were 3.86, 3.39, 3.48, 3.43, and 3.35 situations, respectively. Statistical analysis also pointed out that the estimations of these five groups of occupational health experts with different length of work experience were different with no statistical significance (p-value = 0.908) (Table 4-24).

2. Experience in heat stress measurement and estimation of metabolic rate of workers was used to categorize the occupational health experts into two groups: those with the experience and those without the experience. According to the study findings, the estimations of both groups of occupational health experts were different with no statistical significance in all eight situations (p-value > 0.05) (see Table 4-25). It is worth noting that the number of occupational health experts who had experience in heat stress measurement and estimation of metabolic rate of workers was only 21, while the number of those who lacked such experience was 98. The interviews of occupational health experts revealed that the industrial factories where most of them

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worked did not require them to perform heat stress measurement and estimation of metabolic rate. Instead, they hired outsiders to do the job. When considering the differences in the estimations of both groups of occupational health experts with and with no experience measuring heat stress and estimation of metabolic rate of workers further by testing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of both groups of occupational health experts were 3.30 and 3.47 situations, respectively. Further statistical analysis also pointed out that the estimations of these two groups of occupational health experts with and with no experience measuring heat stress were different with no statistical significance (p-value = 0.563) (see Table 4-26).

However, in this study, it could be seen that even though occupational health experts may have both knowledge of and experience with heat stress measurement, the accuracy of this particular group of occupational health experts was not different from that conducted by other groups of occupational health experts, with a rather high level of errors. This may be because regardless of their previous experiences with heat stress measurement, these occupational health experts did not know the actual work heat load because they had never used a standardized method such as the VO_2 by themselves and no learning had taken place as a result. Undeniably, this could affect their subsequent estimations which could still be highly erroneous.

3. As regards experience with heat stress measurement and estimation of metabolic rate of workers, the occupational health experts were divided into three groups: occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers, those who had undergone training but had no actual practice, and those with no training and no practice. The findings suggested that the estimations of these three groups of occupational health experts were different with no statistical significance in situations 1, 2, 3, 5, 6, and 7 (p-value > 0.05). However, there were statistically significant differences in situations 4 and 8 (p-value = 0.012 and 0.05, respectively), both of which were situations with a heavy workload. It is noteworthy that the subjects who did not have previous training or practice in heat stress measurement and estimation of metabolic rate of workers somehow performed the tasks with more accuracy than the other two groups (see Table 4-27). When further considering the findings, it was found

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that those who accurately estimated the workloads and metabolic rates in situations 4 and 8 were those who underwent 180-hour training to become certified. According to Table 4-11, the workloads estimated by the occupational health experts were much higher than what they actually were. It may be explained that the occupational health experts who underwent 180-hour training and became certified and who never had experience with actual training and practice had more accurate predictions than the others because they were likely to estimate the workload higher than what it actually was. Thus, when the workloads in situations 4 and 8 were already heavy, this group of occupational health experts then had more likelihood to get the correct estimation. When considering the differences in the estimations of these three groups of occupational health experts further by testing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of the three groups of occupational health experts were 3.19, 3.47, and 3.60 situations, respectively. Statistical analysis also pointed out that the estimations of these three groups of occupational health experts with and with no experience measuring heat stress were different with no statistical significance (p-value = 0.389).(Table 4-28)

4. Experience with actual performance of measuring heat stress and estimation of metabolic rate of workers was used to divide the occupational health experts into two groups: those who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves. It was found that the estimations of these two groups of occupational health experts were different with no statistical significance in all eight situations (p-value > 0.05) (see Table 4-29). Further analysis of the differences in the estimations of the two groups of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves by testing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of both groups of occupational health experts were 3.27 and 3.46 situations, respectively (Table 4-30). Statistical analysis also pointed out that the estimations of these two groups of occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves were different with no statistical significance (p-value = 0.565).

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5. Educational background was used to classify the occupational health experts into three groups: those whose education was lower than an undergraduate level, those with a bachelor's degree, and those with a master's degree. The findings revealed that the estimations of these three groups of occupational health experts were different with statistical significance in situations 2, 4, and 8 (p-value > 0.05). However, there were no statistically significant differences in situations 1, 3, 5, 6, and 7 (see Table 4-31). In situation 2, a moderate workload, the occupational health expert with a master's degree got the highest percentage of accurate estimation, followed by those with a bachelor's degree and those whose education was lower than a bachelor's degree. On the other hand, the workloads in situations 4 and 8 were heavy workloads, and those whose education was lower than a bachelor's degree got the highest percentage of correct estimation, whereas the percentages of correct estimations of those with a bachelor's degree and those with a master's degree were rather similar. Besides, the occupational health workers whose education was lower than a bachelor's degree had higher percentages of correct estimations when the workloads were heavy, but the means were still much different from those obtained through measurement of oxygen consumption, as previously discussed. Furthermore, the estimations of those with a bachelor's degree and those with a master's degree were rather similar, but the occupational health experts who held a master's degree made more correct estimations of moderate workloads, while those with a bachelor's degree made more correct estimations of light workloads (see Table 4-31). When considering the differences in the estimations of the three groups of occupational health experts further by testing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of the three groups of occupational health experts with different educational backgrounds were 3.55, 3.39, and 3.64 situations, respectively. Statistical analysis also pointed out that the estimations of these three groups of occupational health experts with different educational backgrounds were different with no statistical significance (p-value = 0.737) (see Table 4-32).

6. Type of safety officer was used to divide the occupational health experts into two groups: occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified. The findings revealed that when testing the differences in

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estimations of occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified, it was discovered that the estimations of both groups in situations 1, 2, 3, and 6 were different with no statistical significance (see Table 4-33). However, there were statistically significant differences in situations 4, 5, 7, and 8 (p-value < 0.05). For situations 4 and 8 which were heavy workload, the occupational health experts who underwent 180-hour training and became certified were able to make more correct estimations. On the other hand, for situations 5 and 7 which were light workload, the occupational health experts who were educated directly in the field of occupational health and safety were able to make more correct estimations. These findings yielded support to the findings shown in Tables 4-31 and 4-27 that the occupational health officials whose education was lower than a bachelor's degree and who lacked experience in measuring heat stress and metabolic rate were able to make more accurate estimations of heavy workloads. When considering the differences in the estimations of the three groups of occupational health experts who were educated directly in the field of occupational health and safety and those who underwent 180-hour training and became certified by testing the accuracy of the estimations of the eight situations on the overall, it was found that the means of the correct estimations of these two groups of occupational health experts were 3.38 and 3.49 situations, respectively (see Table 4-34). Statistical analysis also pointed out that the estimations of both groups of occupational health experts were different with no statistical significance (p-value = 0.597).

Based on the findings of this study, it could be concluded that the length of work in occupational health and safety, experience with heat stress measurement and estimation of metabolic rate of workers, training experience, actual performance of heat stress measurement and estimation of metabolic rate of workers, educational background, and type of safety officer were not related to accuracy of work heat load estimations.

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The errors that had taken place in this study may have resulted from the following factors:

1. The mask used in the measurement of the gas volume worn by the workers may not perfectly fit the size of their face, hence a leak of air.

2. The estimations conducted by watching a video of working situations may be more difficult that those conducted in the actual field.

3. The occupational health experts who conducted the estimations may not have carefully observed each and every step of the works or may not have fully paid attention to the videos shown to them.

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CHAPTER VI
CONCLUSION AND RECOMMENDATIONS

Summary

The present study aimed at determining the accuracy of estimation of workload while working with heat stress as conducted by experts. The findings of this study can be summarized as follows:

1. A comparison of the means of metabolic rates as estimated by occupational health experts and those obtained from the measurement of oxygen consumptions of workers showed that there were statistically significant differences in situations 1, 3, 4, 5, 7, and 8. In situations 2 and 6, the differences found were not statistically significant.

2. An examination of the means of correct estimations in each of the eight situations revealed that the correct estimations were lower than 80% with statistical significance in all eight situations.

3. When testing the differences in estimations of five groups of occupational health experts with different lengths of occupational health work—with no experience, 1-3 years of experience, 3–6 years of experience, 6–10 years of experience, and more than 10 years of experience, with each of the eight situations considered one by one, it was found that the estimations of these five groups of occupational health experts were different with no statistical significance in all eight situations. The test of the accuracy of the estimations of the five groups also suggested that the differences were not statistically significant.

4. When testing the differences in estimations of occupational health experts with experience and with no experience in heat stress measurement and estimation of metabolic rate of workers, with each of the eight situations considered one by one, it was found that the estimations of both groups of occupational health experts were different with no statistical significance in all eight situations. The test of the accuracy

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of the estimations of both groups also indicated that the differences were not statistically significant.

5. When testing the differences in estimations of three groups of occupational health experts with experience in training and practice of heat stress measurement and estimation of metabolic rate of workers, those who had undergone training but had no actual practice, and those with no training and no practice, with each of the eight situations considered one by one, it was found that the estimations of these three groups of occupational health experts were different with no statistical significance in situations 1, 2, 3, 5, 6, and 7. However, there were statistically significant differences in situations 4 and 8. The test of the accuracy of the estimations of the three groups also suggested that the differences were not statistically significant.

6. When testing the differences in estimations of the occupational health experts who performed heat stress measurement and estimation of metabolic rate of workers by themselves and those who did not perform the work themselves, with each of the eight situations considered one by one, it was found that the estimations of these two groups of occupational health experts were different with no statistical significance in all eight situations. The test of the accuracy of the estimations of the three groups also indicated that the differences were not statistically significant.

7. When testing the differences in estimations of three groups of occupational health experts with different educational backgrounds—those whose education was lower than an undergraduate level, those with a bachelor's degree, and those with a master's degree, with each of the eight situations considered one by one, it was found that the estimations of these three groups of occupational health experts were different with statistical significance in situations 2, 4, and 8. However, there were no statistically significant differences in situations 1, 3, 5, 6, and 7. The test of the accuracy of the estimations of the three groups also suggested that the differences were not statistically significant.

8. When testing the differences in estimations of occupational health experts who were educated in the field of occupational health and those who underwent 180-hour training and became certified, with each of the eight situations considered one by one, it was discovered that the estimations of both groups in situations 1, 2, 3, and 6 were different with no statistical significance. However, there were statistically

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significant differences in situations 4, 5, 7, and 8. The test of the accuracy of the estimations of both groups also indicated that the differences were not statistically significant.

The findings of this study could answer the research hypotheses previously formulated as follows:

1. Hypothesis One stated that the average metabolic rates by occupational health experts estimated based on the energy expenditure table of NIOSH were different from the metabolic rates that were calculated from oxygen consumption measurement. The findings showed that in situations 1, 3, 4, 5, 7, and 8, the means of metabolic rates estimated by occupational health experts were statistically significantly different from those obtained by means of oxygen measurement. Thus, the findings supported Hypothesis One. However, the differences in situations 2 and 6 were not statistically significant, so they did not support Hypothesis One.

2. Hypothesis Two stated that an accuracy of the estimating metabolic rate from the energy expenditure table of NIOSH by occupational health experts had value less than 80%. This hypothesis was supported by the findings of the study.

3. Hypothesis Three stated that experience in occupational health work, heat stress measurement and estimation of metabolic rate of workers, training, actual field measurement, educational background, and type of safety officers are related to the accuracy of work heat load estimation. However, the findings showed that when considering the estimations of the occupational health experts in all eight situations with all factors taken into account in six aspects it was discovered that there were no statistically significant differences regardless of differences in experience of occupational health experts. Therefore, Hypothesis Three was not supported.

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Recommendations from finding in this study

1. More accurate methods of heat stress measurement and work heat load estimation should be devised and subsequently imposed as a law to ensure accuracy and fairness among both employers and employees. Also, the oxygen consumption foundation should be used in work heat load estimation, which can be done either directly or indirectly.

2. The relationship between heat stress and physiological strains such as heart rate and muscular fatigue should be taken into consideration together with the WBGT standard.

3. The standardization of work with a high level of heat should take into account the appropriate level of work load which does not lead to physiological strain or muscular fatigue during eight-hour work shift. For example, the work load should not exceed 30-40% VO_2max.

4. If the energy expenditure table is to be used in work heat load estimation, the details included in the table should be further developed to cover more details of activities or work postures as well as to differentiate types of works and factors that need to be taken into consideration.

Recommendations for future research

1. The assessment of workload should be conducted in actual settings, and the findings should be compared to those obtained from the observation with videos.

2. Further studies should be carried out with more varied working situations to cover all types of industrial work currently available in Thailand.

3. The relationship between the WBGT values and the appropriate work load should be explored with the factors regarding physiological strains including oxygen consumption, heart rate, and accumulation of lactic acid in each work load level taken into account.

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APPENDIX

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APPENDIX A

CALCULATIONS OF METABOLIC RATE

Worker No. 1: Weight 57 kg., Height 1.59 m., VO_2 = 68.16 l/hr, VCO_2 = 57.91 l/hr

From equation RQ = VCO_2/VO_2
= 57.91/68.16
= 0.85

From equation EE = (0.23RQ+0.77) × 5.88
= [0.23(0.85)+0.77] × 5.88
= 5.68

From equation A_{DU} = $0.202W_b^{0.425} \times H_b^{0.725}$
= $0.202 \times 57^{0.425} \times 1.59^{0.725}$
= 1.58

From equation M = EE × VO_2 × $1/A_{DU}$
M = 5.68 × 68.16 × 1/1.58
= 245.03 W/ m^2
= 245.03 W/ m^2 × 0.862 kcal/hr
= 211.23 kcal/hr

Worker No. 2: Weight 55 kg., Height 1.59 m., VO_2 = 87.65 l/hr, VCO_2 = 78.6 l/hr

From equation RQ = VCO_2/VO_2
= 78.6/87.65
= 0.9

From equation EE = (0.23RQ+0.77) × 5.88
= [0.23(0.9)+0.77] × 5.88
= 5.74

From equation A_{DU} = $0.202 \times W_b^{0.425} \times H_b^{0.725}$
= $0.202 \times 55^{0.425} \times 1.59^{0.725}$
= 1.55

From equation M = EE × VO_2 × $1/A_{DU}$

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M = 5.74 × 87.65 × 1/1.55

= 324.59 W/ m^2

= 324.59 W/ m^2 × 0.862 kcal/hr

= 279.81 kcal/hr

Worker No. 3: Weight 72 kg., Height 1.70 m., VO_2 = 87.02 l/hr,VCO_2 = 68.44 l/hr

From equation RQ = VCO_2/VO_2

= 68.44/87.02

= 0.79

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(0.79)+0.77] × 5.88

= 5.59

From equation A_{DU} = $0.202W_b^{0.425} \times H_b^{0.725}$

= $0.202 \times 72^{0.425} \times 1.7^{0.725}$

= 1.83

From equation M = EE × VO_2 × $1/A_{DU}$

M = 5.59 × 87.02 × 1/1.83

= 265.82 W/ m^2

= 265.82 W/ m^2 × 0.862 kcal/hr

= 229.13 kcal/hr

Worker No. 4: Weight 50 kg., Height 1.6 m., VO_2 = 108.36 l/hr, VCO_2 = 88.93 l/hr

From equation RQ = VCO_2/VO_2

= 88.93/108.36

= 0.82

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(0.82)+0.77] × 5.88

= 5.64

From equation A_{DU} = $0.202 \times W_b^{0.425} \times H_b^{0.725}$

= $0.202 \times 50^{0.425} \times 1.60^{0.725}$

= 1.50

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From equation M = EE × VO_2 × $1/A_{DU}$

M = 5.64 × 108.36 × 1/1.50

= 407.43 W/ m^2

= 407.43 W/ m^2 × 0.862 kcal/hr

= 351.2 kcal/hr

Worker No. 5: Weight 55 kg., Height 1.73 m., VO_2 = 44.6 l/hr, VCO_2 = 38.68 l/hr

From equation RQ = VCO_2/VO_2

= 38.68/44.6

= 0.87

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(0.87)+0.77] × 5.88

= 5.7

From equation A_{DU} = $0.202W_b^{0.425} \times H_b^{0.725}$

= $0.202 \times 55^{0.425} \times 1.73^{0.725}$

= 1.65

From equation M = EE × VO_2 × $1/A_{DU}$

M = 5.7 × 44.6 × 1/1.65

= 154.07 W/ m^2

= 154.07 W/ m^2 × 0.862 kcal/hr

= 132.8 kcal/hr

Worker No. 6: Weight 54 kg., Height 1.65 m., VO_2 = 53.3 l/hr, VCO_2 = 48.77 l/hr

From equation RQ = VCO_2/VO_2

= 48.77/53.3

= 0.92

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(0.92)+0.77] × 5.88

= 5.77

From equation A_{DU} = $0.202W_b^{0.425} \times H_b^{0.725}$

= $0.202 \times 54^{0.425} \times 1.65^{0.725}$

= 1.58

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From equation M = EE × VO_2 × $1/A_{DU}$

M = 5.77 × 53.3 × 1/1.58

= 194.6 W/ m^2

= 194.6 W/ m^2 × 0.862 kcal/hr

= 167.74 kcal/hr

Worker No. 7: Weight 55 kg., Height 1.60 m., VO_2 = 42.21 l/hr, VCO_2 = 43.13 l/hr

From equation RQ = VCO_2/VO_2

= 43.13/42.21

= 1.02

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(1.02)+0.77] × 5.88

= 5.9

From equation A_{DU} = $0.202W_b^{0.425} \times H_b^{0.725}$

= $0.202 \times 55^{0.425} \times 1.60^{0.725}$

= 1.56

From equation M = EE × VO_2 × $1/A_{DU}$

M = 5.9 × 42.21 × 1/1.56

= 159.43 W/ m^2

= 159.43 W/ m^2 × 0.862 kcal/hr

= 137.43 kcal

Worker No. 8: Weight 50 kg., Height 1.62 m., VO_2 = 110.3 l/hr, VCO_2 = 87.41 l/hr

From equation RQ = VCO_2/VO_2

= 87.41/110.3

= 0.79

From equation EE = (0.23RQ+0.77) × 5.88

= [0.23(0.79)+0.77] × 5.88

= 5.93

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From equation $A_{DU} = 0.202W_b^{0.425} \times H_b^{0.725}$

$= 0.202 \times 50^{0.425} \times 1.62^{0.725}$

$= 1.51$

From equation $M = EE \times VO_2 \times 1/A_{DU}$

$M = 5.93 \times 110.3 \times 1/1.51$

$= 433.16 \text{ W/ m}^2$

$= 433.16 \text{ W/ m}^2 \times 0.862 \text{ kcal/hr}$

$= 373.38 \text{ kcal/hr}$

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APPENDIX B

Figures show during worker number 1 was working

Figure B-1: Activity characteristic

Figure B-2: Activity characteristic

Figure B-3: Activity characteristic

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Figures show during worker number 2 was working

Figure B-4: Activity characteristic

Figure B-5: Activity characteristic

Figure B-6: Activity characteristic

Copyright by Mahidol University

Figures show during worker number 3 was working

Figure B-7: Activity characteristic

Figure B-8: Activity characteristic

Figure B-9: Activity characteristic

Copyright by Mahidol University

Figure B-10: Activity characteristic

Figures show during worker number 4 was working

Figure B-11: Activity characteristic

Figure B-12: Activity characteristic

Copyright by Mahidol University

Figures show during worker number 5 was working

Figure B-13: Activity characteristic

Figure B-14: Activity characteristic

Figure B-15: Activity characteristic

Copyright by Mahidol University

Figures show during worker number 6 was working

Figure B-16: Activity characteristic

Figure B-17: Activity characteristic

Figure B-18: Activity characteristic

Copyright by Mahidol University

Figures show during worker number 7 was working

Figure B-19: Activity characteristic

Figure B-20: Activity characteristic

Figures show during worker number 8 was working

Figure B-21: Activity characteristic

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Figure B-22: Activity characteristic

Figure B-23: Activity characteristic

Figure B-24: Activity characteristic

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APPENDIX C

แบบประเมินอัตราการใช้ออกซิเจนของคนงาน

ชื่อโรงงาน .....

ประเภทโรงงาน/ประเภทของการผลิต .....

วัน/เดือน/ปีที่เก็บข้อมูล.....

ตอนที่ 1 ข้อมูลทั่วไป

1. ชื่อ (นาย,นาง,นางสาว).....นามสกุล.....อายุ.....ปี.....เดือน
2. ส่วนสูง.....เซนติเมตร น้ำหนัก .....กิโลกรัม

รายละเอียดงานที่ทำประจำในปัจจุบัน.....

.....

3. เริ่มงานเวลา .....น. เลิกงานเวลา.....น.
4. ช่วงเวลาหยุดพัก.....น.ถึง.....น.
5. ขณะนี้ทำงานในกะ..... กะนี้ทำติดต่อมาแล้วเป็นเวลา.....วัน
6. บรรจุเข้าทำงานที่นี่มาเป็นเวลานาน.....ปี.....เดือน
7. หน้าที่หรืออาชีพเดิมก่อนมาทำงานในหน้าที่นี้ คือ .....

.....ทำมาเป็นเวลานาน.....ปี.....เดือน

8. งานอื่น ๆ ที่ทำนอกเหนือจากงานประจำในปัจจุบันคือ.....

.....

9. จำนวนชั่วโมงที่นอนหลับในช่วงกลางคืนก่อนมาทำงาน.....ชั่วโมง
10. โรคประจำตัว/โรคที่เจ็บป่วยบ่อย ๆหรือโรคที่เคยเป็น คือ.....

.....ยาที่กินเป็นประจำคือ.....

11. การดื่มสุรา ☐ ไม่เคยดื่ม ☐ ดื่มเป็นประจำ จำนวน.....แก้ว/วัน

☐ เคยดื่มแต่เลิกแล้ว เลิกมาเป็นเวลานาน.....ปี.....เดือน

12. การออกกำลังกาย ☐ สม่ำเสมอ ☐ ไม่สม่ำเสมอ จำนวน.....ครั้ง/สัปดาห์

☐ ไม่ออกกำลังกาย

13. ลักษณะ/ประเภทของการออกกำลังกาย.....
14. รับประทานอาหารวันละ.....มื้อ ปริมาณน้ำที่ดื่มในแต่ละวันประมาณ.....แก้ว

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15. จำนวนครั้งที่ขาดงานเนื่องจากความเจ็บป่วยในรอบ 2 ปีที่ผ่านมา.....ครั้ง
ลักษณะของการเจ็บป่วย.....

16. ในขณะนี้หรือ 24 ชั่วโมงที่ผ่านมาท่านมีอาการเหล่านี้หรือไม่

☐ รู้สึกร้อน ☐ หายใจหอบเหนื่อย
☐ มีอาการเป็นไข้ ☐ หัวใจเต้นแรงผิดปกติ
☐ ปวด/เวียนศีรษะ มึนงง ☐ ท้องเสีย
☐ คลื่นไส้ อาเจียน ☐ เป็นตะคริวที่แขน ขา
☐ อ่อนเพลีย/กล้ามเนื้ออ่อนแรง ☐ อื่น ๆ (ระบุ).....

17. ใน 24 ชั่วโมงที่ผ่านมาท่านได้รับประทานสิ่งเหล่านี้หรือไม่

☐ เหล้า ยี่ห้อ.....จำนวน.....แก้ว
☐ ยาตามแพทย์สั่ง
☐ ยาซื้อกินเอง
ชนิดของยาที่กิน ☐ ยาระงับปวด ☐ ยาลดกรด
☐ ยาระบายท้อง ☐ ยาระงับประสาท
☐ ยากระตุ้น ☐ ยาแก้หวัด แก้ไอ
☐ ยาขับปัสสาวะ ☐ อื่น ๆ (ระบุ).....

18. การสวมใส่ชุดทำงาน เสื้อ ☐ แขนยาว ☐ แขนสั้น
กางเกง ☐ ขายาว ☐ ขาสั้น

เนื้อผ้า ☐ ผ้ายีนส์ ☐ ผ้าไนลอน
☐ ผ้าฝ้าย ☐ ผ้าใยสังเคราะห์
☐ ผ้าลินิน ☐ อื่น ๆ (ระบุ).....

19. การสวมใส่อุปกรณ์ป้องกันอันตรายส่วนบุคคล

☐ ชุดกันความร้อน ☐ แว่นตา
☐ ถุงมือ ☐ หมวกนิรภัย
☐ รองเท้า ☐ อื่น ๆ (ระบุ).....

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ตอนที่ 2. ข้อมูลการตรวจวัดสิ่งแวดล้อม

ชื่อโรงงาน .....

ประเภทโรงงาน/ลักษณะการทำงาน.....

วัน/เดือน/ปี ที่เก็บข้อมูล.....

ยี่ห้อ/หมายเลขเครื่องวัดความร้อน.....

จุด/บริเวณที่ทำงานหรือบริเวณที่เก็บตัวอย่าง.....

เวลาที่เก็บข้อมูล.....น ถึง.....น. รวม.....ชั่วโมง.....นาที

ชื่อ.....นามสกุล.....แผนก.....

อายุ.....ปี น้ำหนัก.....กิโลกรัม ส่วนสูง.....เซนติเมตร

เสื้อผ้า.....

ตารางที่ 1. ข้อมูลการตรวจวัดความร้อนที่ตัวคนงานและสิ่งแวดล้อม

คนงาน	สิ่งแวดล้อม
1. อัตราการเต้นของหัวใจก่อนทำงาน ..... beat/min หลังทำงาน..... beat/min 2. ความดันโลหิตก่อนทำงาน.....mmHg หลังทำงาน..... mmHg 3. อัตราการหายใจ.....beat/min 4. อัตราการใช้ออกซิเจน.....l/min	1. ค่า WBGT……°C 2. ความชื้นสัมพัทธ์.....%. 3. ความเร็วลม.....ft/min 4. อุณหภูมิการแผ่รังสีความร้อน .....°C

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แบบประเมินภาระงานโดยใช้ตารางการใช้พลังงานของ NIOSH

ตอนที่ 1 ข้อมูลส่วนตัว

1. ผู้ประเมิน (นาย) (นาง) (นางสาว).....
ตำแหน่ง.....
2. ที่ทำงานปัจจุบัน บริษัท.....เลขที่ .....
ตำบล/เขต.....อำเภอ.....จังหวัด.....
รหัสไปรษณีย์.....โทรศัพท์.....Fax…….....
ลักษณะธุรกิจ…….....
3. ระดับการศึกษา (ระบุทุกระดับการศึกษาที่ท่านได้จบการศึกษามา)
   - ☐ ต่ำกว่า ป. ตรี สาขา.....
   - ☐ ป. ตรี สาขา .....
   - ☐ ป. โท สาขา.....
   - ☐ ป. เอก สาขา.....
4. ท่านเป็น จ.ป. วิชาชีพ โดยวิธีใด
   - ☐ จ.ป.อบรม 180 ชั่วโมง ☐ จบการศึกษาด้านอาชีวอนามัยและความปลอดภัยโดยตรง
   - ☐ ไม่ได้เป็น จ.ป. วิชาชีพ
5. ท่านมีประสบการณ์ในการทำงานด้านอาชีวอนามัยและความปลอดภัยมาเป็นเวลา.....ปี.....เดือน
6. ท่านมีประสบการณ์ในการตรวจวัดความร้อนและประเมินการใช้พลังงานในการทำงานของร่างกายคนงานหรือไม่
   - ☐ มี และเคยตรวจวัดมาแล้ว.....ปี…….เดือน
   - ☐ ไม่มีประสบการณ์
7. ท่านเคยได้รับการอบรมเรื่องความร้อนและฝึกปฏิบัติการตรวจวัดความร้อนและประเมินภาระงานหรือไม่ (อบรมในที่นี้รวมถึงการเรียนตามหลักสูตรด้วย)
   - ☐ เคยได้รับการอบรมและเคยฝึกปฏิบัติการตรวจวัดและประเมินภาระงาน
   - ☐ เคยได้รับการอบรมแต่ไม่เคยฝึกปฏิบัติการตรวจวัดและประเมินภาระงาน
   - ☐ ไม่เคยได้รับการอบรมและไม่เคยฝึกปฏิบัติการตรวจวัดและประเมินภาระงาน

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8. หน้าที่งานของท่านในปัจจุบันท่านต้องทำการตรวจวัดความร้อนและประเมินภาระงานด้วยตนเองหรือไม่

☐ ดำเนินการด้วยตนเอง ☐ ไม่ได้ดำเนินการเอง

9. ท่านแน่ใจหรือไม่ว่าท่านสามารถประเมินภาระงานด้วยวิธีการเทียบเคียงกับตัวอย่างงานที่กระทรวงอุตสาหกรรม และกระทรวงแรงงานกำหนดเอาไว้ใน เรื่องความร้อนได้อย่างถูกต้อง

☐ แน่ใจ ☐ ไม่แน่ใจ

ตอนที่ 2. การประเมินจากการดู VCD การทำงาน

นิยาม

“งานเบา” หมายความว่า ลักษณะงานที่ใช้แรงน้อยหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายไม่เกิน 200 กิโลแคลอรี่/ชั่วโมง เช่น งานเขียนหนังสือ งานพิมพ์ดีด งานบันทึกข้อมูล งานเย็บจักร งานนั่งตรวจสอบผลิตภัณฑ์ งานประกอบชิ้นงานขนาดเล็ก งานบังคับเครื่องจักรด้วยเท้า การยืนคุมงาน เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

“งานปานกลาง” หมายความว่า ลักษณะงานที่ใช้แรงปานกลาง หรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายเกินกว่า 200 กิโลแคลอรี/ชั่วโมง ถึง 350 กิโลแคลอรี/ชั่วโมง เช่น งานยก ลาก หรือเคลื่อนย้ายสิ่งของด้วยแรงปานกลาง งานตอกตะปู งานตะไบ งานขับรถบรรทุก งานขับรถแทรกเตอร์ เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

“งานหนัก” หมายความว่า ลักษณะงานที่ใช้แรงมากหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายมากกว่า 350 กิโลแคลอรี/ชั่วโมง เช่น งานที่ใช้พลั่วหรือเสียม ขุดตัก งานเลื่อยไม้ งานเจาะไม้เนื้อแข็ง งานทุบโดยใช้ฆ้อนขนาดใหญ่ งานยกหรือเคลื่อนย้ายของหนักขึ้นที่สูงหรือที่ลาดชัน เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

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<u>สถานการณ์ที่ 1</u>

คนงานชาย อายุ 36 ปี น้ำหนัก 57 ก.ก. สูง 159ซ.ม. WBGT เฉลี่ย = 27.6 °C, ความชื้นสัมพัทธ์ = 34%, ความเร็วลม = 0.24 เมตรต่อวินาที, น้ำหนักเบ้าเล็ก = 20-25 กิโลกรัม, น้ำหนักเบ้าใหญ่ = 100-110 กิโลกรัม

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 2</u>

คนงานชาย อายุ 40 ปี น้ำหนัก 55 ก.ก. สูง 159 ซ.ม. WBGT เฉลี่ย = 31.4°C, ความชื้นสัมพัทธ์ = 37.4%, ความเร็วลม = 0.2 m/s, น้ำหนักแผ่นเหล็กแผ่นใหญ่ที่ยก = 40 ก.ก. ,น้ำหนักแผ่นเหล็กแผ่นเล็กที่ยก = 30 ก.ก.,น้ำหนักที่ต้องเข็นกับรถเข็น คือ (40*3) = 120 ก.ก. หรือ (30*4) = 120 ก.ก.

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... ..... กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 3</u>

คนงานชาย อายุ 35 ปี น้ำหนัก 72 ก.ก. สูง 170 ซ.ม. WBGT เฉลี่ย = 28.9 °C, ความชื้นสัมพัทธ์ = 32.2%, ความเร็วลม = 0.33 เมตรต่อวินาที, น้ำหนักเบ้าที่ลากด้วยรอกประมาณ 500 ก.ก., น้ำหนักแผ่นเหล็กที่ยกด้วยรอกประมาณ 50 -70 ก.ก., น้ำหนักเบ้าเล็กประมาณ 20-25 ก.ก.

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 4</u>

คนงานชาย อายุ 30 ปี น้ำหนัก 50 ก.ก. สูง 160 ซ.ม. WBGT เฉลี่ย = 27.8 °C, RH = 28%,
ความเร็วลม = 0.3 เมตรต่อวินาที, น้ำหนักเบ้าเล็กประมาณ 20-25 ก.ก., น้ำหนักเบ้าใหญ่ประมาณ 100-110 ก.ก,
น้ำหนักแผ่นเหล็กที่ยกทับแบบ ประมาณ 15-20 ก.ก.

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... ..... กิโลแคลอรี่

คิดเป็น $\text{.....} \times \frac{60}{8} = \text{.....}$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 5</u>

คนงานชาย อายุ 40 ปี น้ำหนัก 55 ก.ก. สูง 173 ซ.ม. WBGT เฉลี่ย = 36 ˚C, ความชื้นสัมพัทธ์ = 30.3%, ความเร็วลม = 0.55 เมตรต่อวินาที น้ำหนักที่ต้องเข็นประมาณ 100-110 ก.ก., ทางที่เข็นรถเข็นขึ้นลาดชันประมาณ 25 ซ.ม.

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 6</u>

คนงานชาย อายุ 23 ปี น้ำหนัก 54 ก.ก. สูง 165 ซ.ม., WBGT เฉลี่ย = 30 °C, ความชื้นสัมพัทธ์ = 27.6%, ความเร็วลม
= 0.2 เมตรต่อวินาที, แม่แบบหนักประมาณ 5-6 ก.ก., แบบดินที่ยกไปวางหนักประมาณ 5 ก.ก., เบ้าเล็กหนักประมาณ 20-25 ก.ก.

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
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4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 7</u>

คนงานชาย อายุ 35 ปี น้ำหนัก 55 ก.ก. สูง 160ซ.ม., WBGT เฉลี่ย = 47 ˚C, ความชื้นสัมพัทธ์ = 42%, ความเร็วลม = 0.24 เมตรต่อวินาที

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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<u>สถานการณ์ที่ 8</u>

คนงานชาย อายุ 39 ปี น้ำหนัก 50 ก.ก. สูง 162 ซ.ม. WBGT เฉลี่ย = 32.1 °C, ความชื้นสัมพัทธ์ = 34.4%, ความเร็วลม = 0.27 เมตรต่อวินาที, น้ำหนักเบ้าเล็กประมาณ 20-25 ก.ก., น้ำหนักเบ้าใหญ่ประมาณ 100-110 ก.ก,

การประเมินโดยวิธีดูกิจกรรมที่คนงานทำในแต่ละช่วงเวลา

นาทีที่	กิจกรรม	พลังงาน (กิโลแคลอรี/นาที)	รวมพลังงานในกิจกรรมนี้ (กิโลแคลอรี)
1			
2			
3			
4			
5			
6			
7			
8			
Basal metabolism		1	8
รวมใช้พลังงานทั้งหมด			รวม..... .....กิโลแคลอรี่

คิดเป็น $\ldots\ldots\ldots\ldots\ldots \times \frac{60}{8} = \ldots\ldots\ldots\ldots\ldots$ กิโลแคลอรี่/ชั่วโมง

สรุป เป็นลักษณะงาน ☐ **งาน เบา** ☐ **งานปานกลาง** ☐ **งานหนัก**

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10. ท่านคิดว่าวิธีการประเมินภาระงานโดยการใช้วิจารณญาณและการเทียบเคียงกับตัวอย่างงานที่กระทรวงอุตสาหกรรมกำหนดไว้ให้เป็นวิธีการประเมินที่เหมาะสมหรือไม่

☐ เหมาะสม

เพราะว่า……
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☐ ไม่เหมาะสม เพราะว่า……
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BIOGRAPHY

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