THE COMPARISON STUDY OF THE USE OF STEEL AND CARBON FIBER SELF-CONTAINED BREATHING APPARATUS (SCBA) AMONG FIREFIGHTERS : THE EVALUATION OF EFFECTS

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ABSTRACT

SCBA (Self-Contained Breathing Apparatus) is an air containing unit which is used in a limited amount of air area, in toxic gas contaminated atmospheres or for rescue operations. In the past, SCBA air cylinders were made from steel which was heavy and inconvenient for use. Later on, due to the development of material technology the lighter material came to replace them for weight reduction and the most modernized SCBA's air cylinders were made from carbon fiber.

The purpose of this study was to compare the use of steel and carbon fiber SCBA among firefighters. Firefighters performed the practice training under the simulated rescue operation in test stations. The results from this study show that the heart rate before and after using steel SCBA was statistically significantly different at 95 % confidence interval level ($p < 0.001$) where the heart rate after using SCBA was increased from before using SCBA. The heart rate before and after using carbon fiber SCBA was statistically significantly different at 95 % confidence interval level ($p < 0.001$) where the heart rate after using SCBA was increased from before using SCBA. The difference (Delta) of heart rate between steel and carbon fiber SCBA was not statistically significantly different at 95 % confidence interval level ($p = 0.237$). The sweat loss before and after using steel SCBA was statistically significantly different at 95 % confidence interval level ($p < 0.001$) where the body weight (nude) after using SCBA was decreased from before using SCBA. The sweat loss before and after using carbon fiber SCBA was statistically significantly different at 95 % confidence interval level ($p < 0.001$) where the body weight (nude) after using SCBA was decreased from before using SCBA. The difference (Delta) of sweat loss between steel and carbon fiber SCBA was not statistically significantly different at 95 % confidence interval level ($p = 0.580$). The fatigue in all body parts between using steel and carbon fiber SCBA was statistically significantly different at 95 % confidence interval level ($p = 0.006$) where the using steel SCBA caused more fatigue.

The results from this study show that the use of steel and carbon fiber SCBA had no different effects on heart rate and sweat loss, but found the differences on fatigue when using different types of SCBA, because in this study the rescue operation was done within only 10 minutes which is a shorter duration than the duration in actual rescue or firefighting operation.

KEY WORDS: SELF-CONTAINED BREATHING APPARATUS (SCBA) / FIREFIGHTERS / HEART RATE / SWEAT LOSS / FATIGUE

121 pages

การศึกษาเปรียบเทียบการใช้ SCBA (Self-Contained Breathing Apparatus) แบบชนิดถังเหล็กกับชนิดถังคาร์บอนไฟเบอร์ในพนักงานดับเพลิง : ประเมินผลกระทบ

THE COMPARISON STUDY OF THE USE OF STEEL AND CARBON FIBER SELF-CONTAINED BREATHING APPARATUS (SCBA) AMONG FIREFIGHTERS: THE EVALUATION OF EFFECTS

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บทคัดย่อ

SCBA (Self-Contained Breathing Apparatus) เป็นถังอากาศที่ใช้สำหรับงานในบริเวณที่มีอากาศไม่เพียงพอ มีก๊าซพิษอยู่ในระดับที่เป็นอันตรายหรือใช้ในงานกู้ภัยต่างๆ ซึ่งถังบรรจุอากาศ SCBA แต่เดิมผลิตมาจากเหล็ก มีน้ำหนักมาก ใช้งานไม่สะดวก ต่อมามีการลดน้ำหนักของถังบรรจุลง จึงได้มีการใช้วัสดุต่างๆที่เบามาผลิต ซึ่งแบบล่าสุดและเบาที่สุดของถังบรรจุอากาศ SCBA เป็นแบบชนิดถังคาร์บอนไฟเบอร์

การศึกษาวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบการใช้ SCBA แบบชนิดถังเหล็กกับชนิดถังคาร์บอนไฟเบอร์ในพนักงานดับเพลิง โดยให้พนักงานดับเพลิงทำการทดลองปฏิบัติการกู้ภัยภายในห้องฝึก ซึ่งได้จำลองสถานการณ์การกู้ภัยขึ้นมา ผลการวิจัยพบว่า อัตราการเต้นหัวใจก่อนและหลังจากการใช้ SCBA แบบชนิดถังเหล็กมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p < 0.001$) โดยหลังทดลองเพิ่มสูงขึ้นกว่าก่อนทดลอง อัตราการเต้นหัวใจก่อนและหลังจากการใช้ SCBA แบบชนิดถังคาร์บอนไฟเบอร์มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p < 0.001$) โดยหลังทดลองเพิ่มสูงขึ้นกว่าก่อนทดลอง และความแตกต่าง (Delta) ของอัตราการเต้นหัวใจจากการใช้ SCBA แบบชนิดถังเหล็กกับชนิดถังคาร์บอนไฟเบอร์ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p = 0.237$) ส่วนการสูญเสียเหงื่อก่อนและหลังจากการใช้ SCBA แบบชนิดถังเหล็กมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p < 0.001$) โดยหลังทดลองมีน้ำหนักตัวลดลงจากก่อนทดลอง การสูญเสียเหงื่อก่อนและหลังจากการใช้ SCBA แบบชนิดถังคาร์บอนไฟเบอร์มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p < 0.001$) โดยหลังทดลองมีน้ำหนักตัวลดลงจากก่อนทดลอง และความแตกต่าง (Delta) ของการสูญเสียเหงื่อจากการใช้ SCBA แบบชนิดถังเหล็กกับชนิดถังคาร์บอนไฟเบอร์ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p = 0.580$) ส่วนความเมื่อยล้าของร่างกายมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 95% ($p = 0.006$) โดยเมื่อใช้ SCBA แบบชนิดถังเหล็กรู้สึกเมื่อยล้ามากกว่า

จากผลการศึกษาครั้งนี้ พบว่า SCBA แบบชนิดถังเหล็กกับชนิดถังคาร์บอนไฟเบอร์เมื่อใช้ปฏิบัติงานแล้วไม่พบความแตกต่างกันของอัตราการเต้นหัวใจและการสูญเสียเหงื่อ แต่พบความแตกต่างกันของความเมื่อยล้า เนื่องจากการศึกษาครั้งนี้ปฏิบัติการกู้ภัยภายในห้องฝึกใช้ระยะเวลาสั้นเพียง 10 นาที แต่การปฏิบัติงานจริงของพนักงานดับเพลิงจะใช้ระยะเวลาที่นานกว่านี้

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CHAPTER I
INTRODCTION

1.1 Background and rationale

In Thailand, the occurrences of public hazards in Thailand included flood, storm, fire, chemical hazard, transportation hazard, drought, coldness and wildfire but the most frequently occurrence hazard which cause a lot of life and property damages is fire. Fire can be both occurred by natural effect or human. Fire is a heat energy that without any control and monitor this heat energy can propagate to fuel and continuously combustion that can cause damages in both life and property if enough time and fuel had been fulfilled. The possibility of fire hazards and it effects are continuously increasing year by year. From the statistical database of fire hazards in Thailand, the most frequent causes of fire is the forgetfulness and careless of fire. The Hong Kong's fire report shown that the most frequent fire occurrences types of building is residential building and this information also same to America database. From fire occurrence database of Thailand between B.E. 2532 to 2554 collected and analyzed by Office of Public Hazard Mitigation, Department of Public Hazard Prevention and Mitigation shown that fire is highest B.E. 2539 by 3,622 times, the second B.E. 2540 by 3,314 times and the lowest B.E. 2545 by 1,135 times. However, every occurrences of fire cause lot of damaged cost (1).

In case of fire, to minimize the consequential damage and increase the rescue chance of fire victims, firefighting need to be correctly operation with timely manner especially the fire in the metropolitan or overcrowded area such as Bangkok Metropolitan where is the capitol of the country and center of economic with a lot of peoples inside this city for both living and working and also lot of residential building, office building and traffic jams, all of the above statement is the obstruction which obstacle of firefighting operation. From the Bangkok's fire statistic recorded by planning division, planning and academic sections, Bangkok Fire and Rescue Department between B.E. 2535 to 2553 indicated that the fire hazards are most occurs

B.E. 2550 for 3,598 times and the second frequency B.E. 2552 for 1,078, the third places B.E. 2551 for 962 times and the lowest B.E. 2546 for 367 times (2).

The occurrences of fire can cause severe damages on both life and property of fire victims. Moreover, firefighters are also received the direct effect during firefighting operation due to their duties in prevention and mitigation of the effect from emergency situations, always in firefighting operation which results in risk of life on duties. The sources of dangerous that firefighters face during operation depended on severity level of the fire scenes and other factors such as duration of operation. As the hazards firefighters will face during operation in very severe, the firefighters need to conduct the training, practices, improve physical and mental condition and use of protective equipment to ensure ready to react in any emergency situations with safe operation. The frequent hazards that firefighters face are accident hazard, physical hazard, chemical hazard, biological hazard, ergonomic and psychosocial hazard.

Ergonomic and psychosocial hazards are very important because firefighters always face these hazards every time of work. Firefighting operation is a very serious work with high tension and responsibility together with extensive need of physical condition and heavy workload to the body which cause fatigue such as heavy object relocation during rescue operation and heavy weight of protective equipment (fire suits, boots, helmets, and SCBA).

SCBA (Self-Contained Breathing Apparatus) is an air containing unit used for breathing in a limited air content or toxic gas contaminated atmospheres and other rescue operation for example in firefighting, chemical leakage and work inside the confined space that can cause high severity life and health hazard. During firefighting operation, firefighters might contact with heat, flame, toxic gases, smoke and other chemical agents that lower the concentration of fresh air. Therefore, the use of SCBA is important for firefighters to protect breathing system during firefighting operation (3).

In the past, air containers of the SCBA were made from steel which was heavy and inconvenient for use. Later on, the weight of air containers was continuously reduced by using of light weight material. Presently, the carbon fiber was applied as the material. From the study of Hooper et al. (2001) (4) indicated that the heart rate of steel SCBA users is more than carbon fiber SCBA users in all cases and carbon fiber SCBA has more statistically significant level on comfortable more than the steel SCBA. The study of Griefahn et al. (2003) (5) indicated that duration, heart rate and evaluation of SCBA users had statistically significant level depend on different in SCBA types (steel SCBA / carbon fiber SCBA / Rucksack SCBA). The study of Punakallio et al. (2003) (6) indicated that the effect of using the fire protective equipment on reduction of postural balance and functional balance and also indicated the reduction of functional balance due to using of SCBA.

From the literature reviews, the summary is as follow the steel SCBA has heavy weight which cause more energy required for using of it during firefighting operation and it consequential activities is the body required more oxygen cause increasing in heart rate, more fatigue, movement limitation that result in reduction of work capability and illness due to high heat. However, the steel SCBA had advantages on long useful operation duration without any replacement performed until the defect was found. The steel tank can be inspected for maximum allowable pressure limit by hydrostatic test. For carbon fiber SCBA, the weight of this SCBA is lighter for more convenient and comfortable of using. The energy required for carbon fiber SCBA usage is also reduced which increasing works capability and efficiency as results from many factors such as weight, design and SCBA components (4). The disadvantages of carbon fiber SCBA is their shorter operation lifetime (approximately 10 years of operation lifetime) and the periodic hydrostatic test need to perform in yearly basis. The SCBA play very important roles as protective equipment of firefighters but in the other hand the using of SCBA can cause negative effect in performance and capability of firefighter as well (6).

Therefore, at present Thailand's firefighters using of SCBA international standard which the size of tank fit for foreign firefighters and still using steel SCBA has heavy weight which can cause negative effect such as more energy required for firefighting operation, higher heart rate and increasing of uncomfortable feeling and fatigue. These effects reduce too much working efficiency and capability of the firefighters. From the above effects in addition with high temperature atmosphere of Thailand which can case higher sweat loss, the researcher interest in the comparison study of effect (heart rate, sweat loss and fatigue) from using steel and carbon fiber

SCBA among firefighters to apply the study results as the recommended selection criteria for suitable using SCBA for firefighters in the next time.

1.2 General objective

Compare the effects between using steel and carbon fiber SCBA in firefighters.

1.3 Specific objectives

1.3.1 To compare the heart rate of firefighters between using steel and carbon fiber SCBA.

1.3.2 To compare the sweat loss of firefighters between using steel and carbon fiber SCBA.

1.3.3 To compare the fatigue of firefighters between using steel and carbon fiber SCBA.

1.4 Research hypothesis

1.4.1 The heart rate of firefighters between using steel and carbon fiber SCBA is different.

1.4.2 The sweat loss of firefighters between using steel and carbon fiber SCBA is different.

1.4.3 The fatigue of firefighters between using steel and carbon fiber SCBA is different.

1.5 Operational definitions

1.5.1 Firefighters is the officers of Bangkok Fire and Rescue Department, fire operation section 4

1.5.2 SCBA (Self-Contained Breathing Apparatus) is a carry on air container include with full face mask and back plate made from stainless.

1.5.2.1 Steel SCBA is an European made SCBA with following specification, containing pressure 300 BAR, operating duration 45 minutes, volume 6 liters, cylinder is made from steel with 10 kg operating weight.

1.5.2.2 Carbon fiber SCBA is an European made SCBA with following specification, containing pressure 300 BAR, operating duration 45 minutes, volume 6.8 liters, cylinder is made from carbon fiber with 6.5 kg operating weight.

1.5.3 Evaluation of effect is the assessment of effects on firefighters between using of steel and carbon fiber SCBA. The effect is consists of heart rate, sweat loss and fatigue of firefighters.

1.5.3.1 Heart rate is evaluated by heart rate monitor both before and after firefighting operation.

1.5.3.2 Sweat loss is evaluated by weighing-machine to measure the body weight (nude) both before and after firefighting operation.

1.5.3.3 Fatigue is evaluated by questionnaires (body discomfort) after firefighting operation.

1.5.4 Fatigue is the change of body condition on both physical and mental conditions. The physical fatigue can causes lot of stress on body muscles and reduce work productivity. However, the physical fatigue can be recovered by enough resting. For example, the mental fatigue is boredom from repeated work.

1.5.5 Test station is a rescue operation training building of Bangkhae fire station, it is and 3 story building where on the 3rd floor the location was set up to simulate the actual searching of dummy and rescue operation.

1.6 Conceptual framework

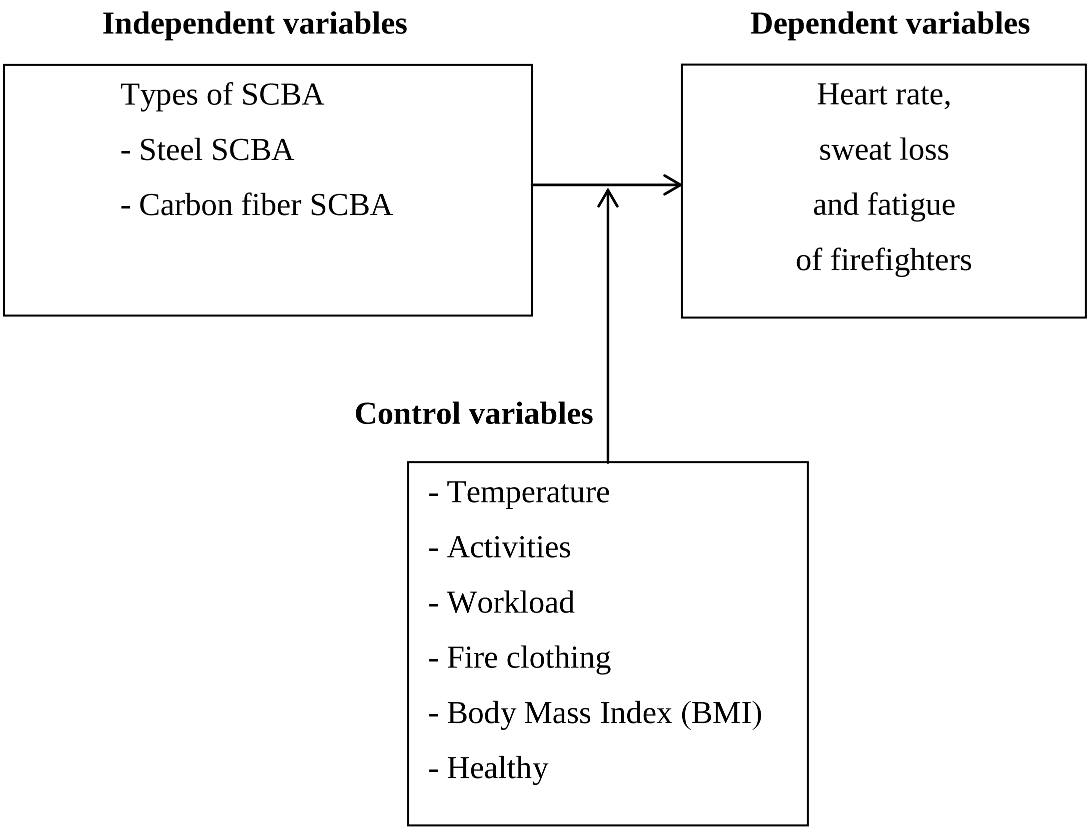

Figure 1.1 Conceptual framework

CHAPTER II
LITERATURE REVIEW

The purpose of this study was to compare the use of steel and carbon fiber SCBA among firefighters. The literature reviews of this study were described in 10 parts as the following:

2.1 SCBA (Self-Contained Breathing Apparatus)
2.2 Heat
2.3 Sweat
2.4 Heart rate
2.5 Workload
2.6 Fatigue
2.7 Firefighters
2.8 Fire suits and chemical protective suits
2.9 Training standard
2.10 Literature cited

2.1 SCBA (Self-Contained Breathing Apparatus)

SCBA (Self-Contained Breathing Apparatus) which commonly called BA, is an air cylinder for carry on shoulder with airline and full face mask. This a device worn by rescue workers, firefighters and others to provide breathable air in an immediately dangerous to life or health atmosphere. When using of SCBA the worker should enter the workplace in pairs for safe operation (7).

2.1.1 Standard and selection of SCBA (7)

The main manufacturers of SCBA are from 2 sources: Europe and America, each manufacturer has their own standard. For America group of manufacturer, they have MSHA (Mine Safety and Health Association), NIOSH

(National Institute for Occupational Safety and Health), NFPA (National Fire Protection Association) and ANSI (American National Standard Institute) as the standard to certify the special characteristics such as cylinder shape of SCBA which constructed from aluminum and covered by fiber with pressure gauge installed at cylinders. The advantage of this type is lightweight in trade off with the disadvantage on expensive and no changeable parts (filter and cylinder) with European SCBA. Moreover, the air regulation system is still the old system which contains too much equipment and complicate for operation. For European group of manufacturer, they has EN standard to certify the special characteristic such as interchangeable of full face mask on both filter and cylinder between different manufacturer of EU through the parts were manufactured under the same standard. The advantages of EU product is lower prices and interchangeable of parts within EU products with disadvantage no changeable of filter and cylinder with American products.

The selection of SCBA should be suitable with scope of work, type of work, frequently and duration of usage. The most important criteria for SCBA selection is the objective of usage. The SCBA using for firefighting should in conformance with National Fire Protection Association (NFPA) standard on 1981. For other purpose, the SCBA should be conformed to the National Institute for Occupational Safety and Health (NIOSH) standard.

For SCBA usage for other purpose except firefighting, the NFPA standard compliance is not necessary criteria for SCBA selection which will save the cost for buyers. The NIOSH standard compliance SCBAs are suitable for industrial usage such as working in confined space or high concentration of chemical contaminated area (Immediately Dangerous to Life or Health, IDLH) or in area of unknown value of contaminated agent or insufficient oxygen level (oxygen concentration < 19.5%).

The NFPA 1981 compliance SCBAs are necessary for firefighting application. Normally, the NFPA SCBAs are also in conformance with NIOSH standard for general protection for industrial application. NFPA 1981 specify testing condition and materials for SCBA construction to ensure equipment durability in severe condition on firefighting situation. The most important condition of NFPA 1981 is material usage for air supply tube must be heat and fire resistant material.

On September 2012, NFPA had enhanced the NFPA 1981 standard to NFPA 1981: Year 2002 to supersede NFPA 1981: Year 1997. The enhancement of 2002 revision affect the certification test of the SCBA in 2 main conditions as follow: first is the head up display (HUD) which made user can monitor the condition more easily. The second is the Rapid Intervention Crew Universal Air Connection or RIC/UAC. The SCBA in compliance with NFPA revision 2002 must have the both equipment.

According to NFPA revision 2002, HUD must equip with LED to display the current status of approximately remaining air in the cylinder in 4 levels: full, ¾, ½ and ¼ remaining. The display can be viewed on the mask by the user with beep and blinking alarm light when remaining air reach ½ and ¼ levels. Moreover, HUD must have LED alarm when battery going low, LED light must appropriated bright enough to see in normal light and not annoy the users when working in low light condition. For the RIC/UAC, the objectives of this equipment is to ensure the connection joints of all SCBA are same which made the air refilling process during emergency situation can be done for firefighters in fire scene.

NFPA 1981 was also revised again in 2007. In this revision, all SCBAs must be certified by NIOSH in CBRN (Chemical, Biological, Radiological and Nuclear) was added to the standard. Another enhancement in this revision is addition of voice communication and water and heat resistant enhancement.

The terrorist attacks by suicide attack by plane at World Trade Center, America (9/11) encourage NIOSH to improve the effectiveness for CBRN (Chemical, Biological, Radiological and Nuclear) SCBA test. In January 2002, NIOSH started to certify SCBA compliance with these new standard conditions.

2.1.2 Types of SCBA (8)

2.1.2.1 Closed circuit SCBA

In closed circuit SCBA, carbon dioxide in breath is captured and the remaining oxygen was recirculated for breathing. The advantage is lightweight when compare with open circuit SCBA at same duration. Normally, closed circuit SCBA can be used for 15 minutes to 4 hours however the equipment is expensive due to its complicated moreover the air for breathing is warmer than normal because the air was recirculated. SCBA from this type has negative and positive pressure system, oxygen storage and oxygen generating system and liquid oxygen container and compressed oxygen container. Oxygen enters the breathing bag by continuous flow of air or pressure regulation system. SCBA user breathing in the oxygen from breathing bag and breathing out to breathing bag again where carbon dioxide from breath captured by sodium hydroxide. The oxygen generating system was depended on chemical reaction between breath and water vapor with potassium superoxide in canister where both made oxygen generating and carbon dioxide captured.

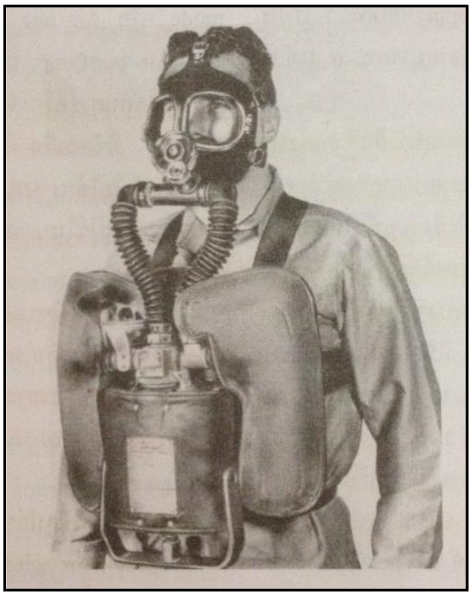

Figure 2.1 Closed circuit SCBA (8)

2.1.2.2 Open circuit SCBA

In open circuit SCBA, breath was vented to atmosphere and inlet air was delivered came from compressed air container (cylinder). The duration of this SCBA is 30-60 minutes. For open circuit SCBA, OSHA certified only the full face mask and pressure demand (positive pressure) type for working in IDLH atmosphere because pressure demand provide better protection for its users.

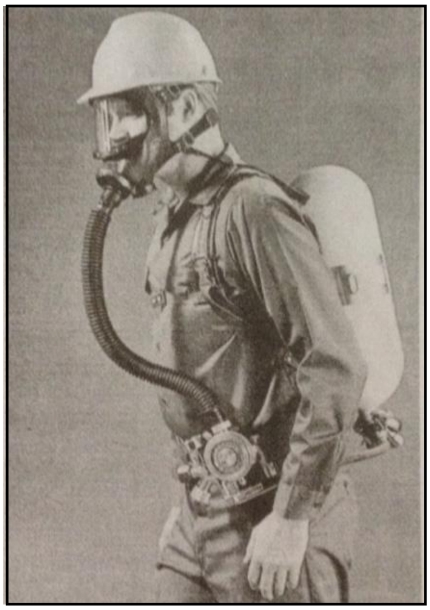

Figure 2.2 Open circuit SCBA (8)

2.1.3 Components of the SCBA

Figure 2.3 Components of the SCBA

2.1.4 Material of SCBA cylinders (7)

Formerly, air contained cylinder was made from steel. Later on, aluminum was used as alternative material for lighter weight. After that manufacturer focus on composite material from aluminum alloys for better weight reduction. In age of composite material cylinders, they have both partially wrapped and fully wrapped cylinders. Recently, Kevlar and carbon fiber material were researched as next generation for cylinder production. Carbon fiber cylinder is the most up to date with lightest weight for SCBA cylinder. While the weight of SCBA continuous decrease the prices of the SCBA increase. Moreover, light weight cylinder has shorter lifetime and need much frequent inspection than aluminum cylinder. Cylinder of all materials needs periodic inspection and the frequency of inspection depends on its materials.

Figure 2.4 Steel SCBA

Figure 2.5 Carbon fiber SCBA

2.1.5 Weight of cylinder and type of SCBA

Weight of air cylinders of SCBAs are different depended on source of manufacturers, brand, model, cylinder material and manufacturing standard. Hereafter, the example of SCBA cylinders with same for equal specification such as volume, pressure and usage duration with different in weight will be shown as the following:

Table 2.1 Comparison the weight of cylinder and different material of SCBA from Asia manufacturers

Description	Types of SCBA	
	Steel SCBA (Alloy)	**Carbon Fiber SCBA**
Volume (liters)	8.0	8.4
Pressure (PSIG)	2,216 (150 BAR)	2,216 (150 BAR)
Duration (minutes)	30	31
Empty weight (kg)	9.8	4.9

Table 2.2 Comparison the weight of cylinder and different material of SCBA from European manufacturers

Description	**Types of SCBA**	
	Steel SCBA	**Carbon Fiber SCBA**
Volume (liters)	9.0	9.0
Pressure (PSIG)	3,000 (200 BAR)	3,000 (200 BAR)
Duration (minutes)	45	45
Empty weight (kg)	13.0	6.8

Table 2.3 Comparison the weight of cylinder and different material of SCBA form European manufacturers

Description	**Types of SCBA**	
	Aluminum SCBA	**Carbon Fiber SCBA**
Volume (liters)	8.0	8.0
Pressure (PSIG)	2,216 (150 BAR)	2,216 (150 BAR)
Duration (minutes)	30	30
Empty weight (kg)	17.50	7.85
Full weight (kg)	20.86	11.21

2.1.6 Usage duration of SCBA (7)

SCBA was certified by NIOSH must have the cylinder which can deliver breathable air for 15, 30, 45, or 60 minutes. NIOSH certified SCBA must be classified separately from escape respirator for evacuation because both have air cylinder to supply breathable air but the escape respirator has shorten duration normally 5-10 minutes due to the main purpose of the equipment is merely for evacuation from toxic gas contaminated or insufficient oxygen concentration area. The SCBA is different from escape respirator because the SCBA was approved for using in hazardous and insufficient oxygen area. The condition was except if user wants to buy 15 and 30 minute cylinder which smaller size and lighter weight than 60 minutes cylinder for cost saver and easy to move during work. Even if, the difference of its weight is too little but it can increase comfortable level for working during carry on a SCBA.

2.1.7 Calculation of working duration of SCBA (7)

Presently, the materials of air cylinders can be divided to 2 different types are carbon fiber and steel or aluminum cylinder. The operating pressures for SCBA classification in 2 types are low pressure cylinder (200 BAR) and high pressure cylinder (300 BAR).

Standard

European standard unit of pressure is BAR

American standard unit of pressure is PSI

1 BAR = 14.78 PSI

300 BAR x 14.78 PSI = 4,500 PSI (approximately)

4500 / 14.78 = 300 BAR (approximately)

Remarkable constants

1 cylinder can contained 6 liters of water.

1 cylinder of 200 BAR can contained 1,200 liters of air from 200 x 6 = 1,200 Liter

1 cylinder of 300 BAR can contained 1,800 liters of air from 300 x 6 = 1,800 Liter

Respiration rate on NFPA at 40 liters/minute

Respiration rate of normal medical condition human at 20 liters/minute

Formula

$$\frac{[\text{Measured pressure (BAR)} \times \text{Cylinder volume (liters of water)}]}{\text{Respiration rate (liters/minute)}}$$

Example

How long of working duration in minutes when pressure of air in cylinder is 300 BAR?

(300 x 6) / 40 = 45 minutes

How long of working duration in minutes when pressure of air in cylinder is 190 BAR?

(190 x 6) / 40 = 28.5 minutes

2.1.8 Frequency of use of SCBA (7)

How frequent and convenient of SCBA usage are important consideration for SCBA selection. For emergency use only SCBA such as emergency maintenance in confined space or leaked valve which the convenient of usage is not important as much as frequently use SCBA. For frequently use SCBA, the convenient and comfortable for usage are the most important criteria for SCBA selection such as lighter weight of SCBA by cylinder weight reduction done by manufacturer, increase volume of air filling in small size cylinder or both of its.

2.1.9 Pressure of SCBA (7)

The way for SCBA weight reduction is increase volume of air filling with 3 different pressure levels as high pressure level: operating pressure at 4,500 psi, moderate pressure level: operating pressure at 3,000 psi and low pressure level: operating pressure at 2,216 psi. High and low pressure levels are appropriated and commonly uses as SCBA and intermediate pressure is suitable for SCUBA diving.

SCBA for 60 and 45 minutes duration are high pressure level type. The high pressure cylinder is important for 45 to 60 minutes with convenient and comfortable for carry on.

SCBA for 30 minutes has both high and low pressure level. The advantage of high pressure cylinder is light weight from its smaller size than low pressure type. However, it has disadvantage on higher in prices.

Another disadvantage of high pressure cylinder is rarely found of high pressure filling station. Normally, firefighting department is the commonly places for high pressure cylinder filling. Later on for moderate and low pressure, cylinders can be filled by local fire station and SCUBA diving shop.

2.1.10 How to wear SCBA (7)

SCBA wearing can be divided to 2 commonly use as the following:

2.1.10.1 Overhead

2.1.10.2 Coat style

2.1.11 Maintenance of SCBA (7)

2.1.11.1 Remove used air cylinder for air filling and replace with new full cylinder.

2.1.11.2 Clean mask by soap water and liquid antiseptic.

2.1.11.3 Inspect cylinder, valve, pressure regulator and high & low pressure air pipe.

2.1.11.4 Cover mask by plastic bag and keep in box or container.

2.1.11.5 Keep mask away from heat and direct sunlight.

2.1.11.6 Always fill cylinders with air do not let it empty (fully filled with air before storage).

2.1.11.7 Perform cylinder strength test when any defect on cylinder was found.

2.1.11.8 Replace diaphragm when deformation, deteriorate and malfunction were found.

2.2 Heat

Heat is one kind of energy caused by vibration or collision of molecules or atoms of matter and make kinetic energy in matter converted to heat energy (9). If human body cannot adjust balance of heat, heat will plays important roles as problems in both public health and medical confession which cause lot of danger. Heat stress from touching heat sources always occurs to both outdoor and indoor workers which can increase risk rate on illness and accident (10).

Heat stress is included with environmental and body factor which cause heat generation in dangerous level to human body. The environmental factor is ambient temperature, radiant heat, wind velocity and vapor pressure. Body heat is generated from metabolism process during working or exercises. Both of these can caused heat stress (8).

Heat strain is the body reflects action to heat stress with cause human feel uncomfortable and abnormal feeling due to heat. The severity level of heat strain depends on the magnitude of heat strain, age, body strength and dehydration familiarity (8).

2.2.1 Heat losses of body

Heat from human body was released by conduction, convection, evaporation of sweat and radiation. The body heat loss by conduction around 2-3 % and by convection 12 % depend on wind velocity (appropriate level of wind velocity caused human comfort). For evaporation, it causes around 20 % of body heat loss which partly included heat loss from breathing. Other factor that affect heat losses of body are clothes and relative humidity (10).

2.2.1.1 Conduction (8, 9, 11, 12, 13)

Heat conduction is the mode of heat transfer by direct contact between human skins and objects or materials in the environment such as bare foot walking on cold floor which lead to walker feel cold because body heat losses or the hot feeling when touch hot machine parts. Heat conduction plays important role only in working with direct contact with hot surfaces because normally human always wear clothes during working.

2.2.1.2 Convection (8, 9, 11, 12, 13)

Heat convection is the mode of heat transfer by fluid between human skins and atmosphere, the most important fluid in working environment is air. The level of convection is depended on temperature difference between skins and environment and air flow rate. Normally, heat losses by convection around 25-30 % of total heat losses.

2.2.1.3 Evaporation of sweat (8, 9, 11, 12, 13)

Evaporation of sweat is important process of heat transfer from human body to atmosphere especially during working in high temperature or high workload condition. In normal condition, 600 kcal or 1 liter of heat loss from human body by evaporation of sweat which can be accounted for one-fourth of total heat loss.

2.2.1.4 Radiation (8, 9, 11, 12, 13)

Hot body can radiated electromagnetic wave that can be absorbed by other object and convert to heat call radiant heat. The radiation is medium less heat transfer process which occurs whole time between human and surface temperature of surroundings objects. The amounts of heat transfer by the radiation depend on temperature difference between human skins and objects. In tropical country, surface temperature of surrounding objects is lower than human skin temperature. Then, human loss body heat by radiation around 40 - 60 % of total body heat loss daily.

Normally, human body always try to adjust the balance between heat generation from activities, radiant heat and other heat input by evaporation of sweat. If the change in body heat remains zero, body can regulate body temperature. However, if the body cannot adjust the body heat balance by evaporation of sweat, body temperature will building due to heat storage increasing (8).

2.2.2 Heat sources (8, 9, 10, 12)

2.2.2.1 External heat sources

In hot climate, when ambient temperature higher than body temperature the body heat will increase because external heat input. Moreover, radiant heat from sun deliver 150 kcal/hour of heat to body which can be accounted as double of heat received from working in production line such as heat from boiler, machines, combustion in vehicles, hot water pipes or direct heat from metal melting.

2.2.2.2 Internal heat sources

Internal heat sources are heat generation from metabolism process due to increasing of thyroxine hormone and stimulation of sympathetic nervous system. Moreover, heat can be generated from high workload and exercise which can cause double internal heat increasing.

Internal body heat transfer process: heat generated from metabolism process transfer to blood stream and human skin and then transfer to surrounding by radiation and convection. Evaporation of sweat causes blood temperature decrease due to heat loss then the lower temperature blood flow back to body core. Blood recirculation at skin accelerate rate of heat transfer in direct proportion to the ratio between metabolism rate and temperature difference between body core and skin (8).

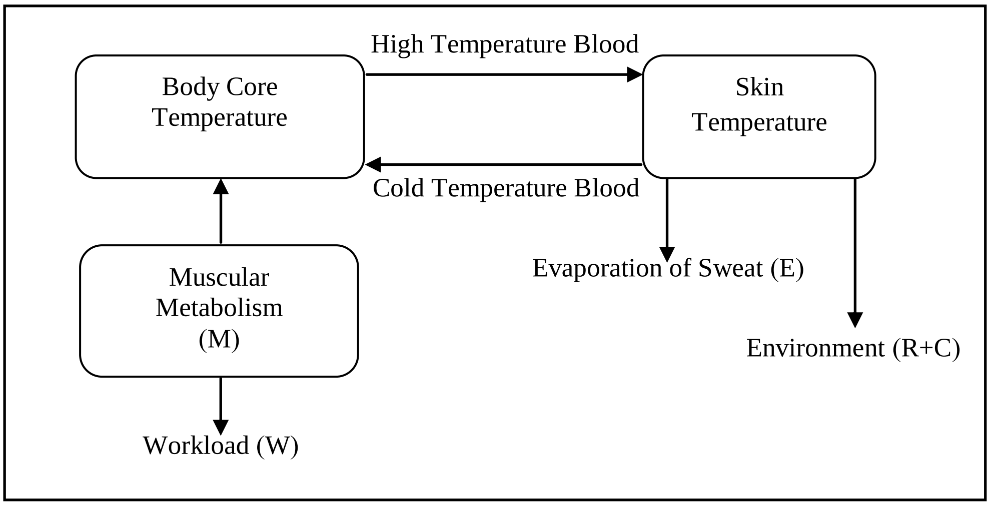

Figure 2.6 Body heat transfer process (8)

Metabolism process generates energy to body and muscular function, increase tissue temperature, increase body core temperature. Blood, as heat carrier, flow through body core to absorb the heat which causes blood temperature increasing after that blood flow to skin for heat releasing to surrounding and then flow back to body core again. Skin working as heat transfer medium between body and surrounding. Heat convection and radiation are depended on the temperature difference between skin and surrounding. The heat transfer can be both heat absorbed process, heat released process and evaporation of sweat (8).

Heart rate is important parameter which indicate heart requirement for blood and heat recirculation from body core to skin. Volume of blood flow through heart is directly proportional to metabolism rate and inverse proportional to difference temperature between body and skin. If body need more energy for high work load the metabolism rate will increase caused much blood flow and increase heart rate. If the evaporation of sweat is not enough or too much body heat absorbed from heat conduction and heat radiation more blood will flow to skin for heat releasing to surrounding to reduce body temperature. Sometime, skin temperature will increase to nearly core body temperature (8).

Evaporation of sweat rate is one mode of heat transfer to reduce body heat. The excessive heat stress can caused too much amount of sweat. Normally, human body has the natural heat protection system by increasing familiar level to the surrounding heat which causes body builds more sweat, increase level of heat releasing by evaporation of sweat and reduce the body temperature (8). The evaporation of sweat is always a negative (or zero) due to heat of skin use for the evaporation of sweat (water) makes the skin and body temperature decrease. The evaporation of sweat depends on clothing, temperature, speed of wind, humidity and surface area (9).

2.2.3 Body response to heat (8)

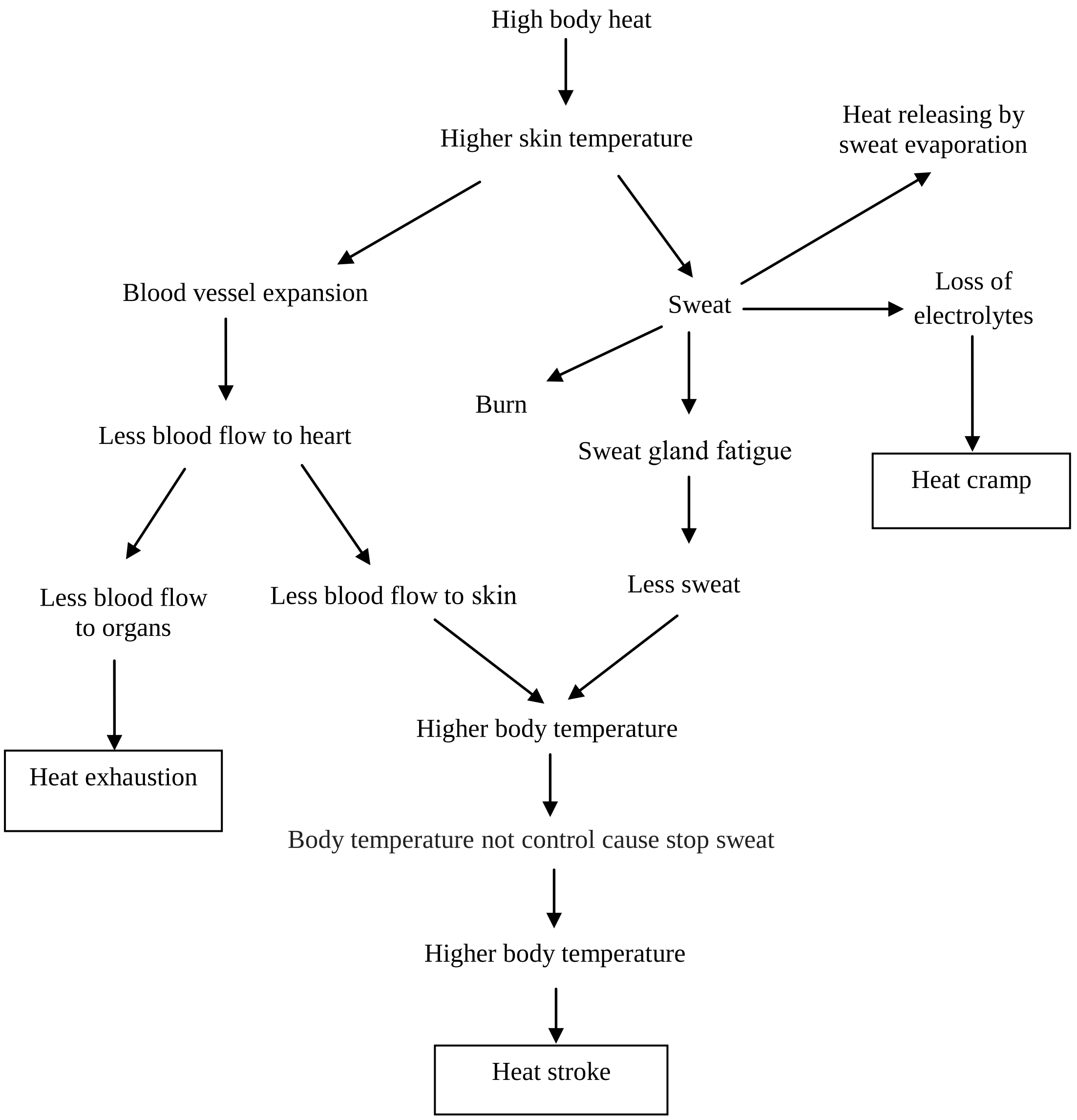

Figure 2.7 Body responses to heat (8)

2.2.4 Factors affect the heat resistance of body (13)

The effect when peoples working on the same hot atmosphere but only some people have negative effect or illness from heat because different in body resistance as the following:

2.2.4.1 Heat acclimatization

Normal health people work in high heat environment for first time will have severe stress, body temperature increasing and high heart rate. These indicate that the body cannot withstand to heat. However, the stress level and other symptom will relieve after working for a while. After 1-2 weeks of working, the body will adapt to familiar with heat and workers can do their work normally. However, after weekend holidays the workers will lose this heat familiar level moreover if the holidays are longer than 2 weeks the loss of heat familiarity clearly occurs and need many days to bring its back again. Heat familiarity of body made the composition of sweat of non-heat familiar person have sodium chloride concentration at 3-5 grams per kilograms of sweat (approximately half of concentration in plasma) that different from heat familiar person which lower sodium chloride concentration around 1-2 grams per kilograms of sweat was found.

2.2.4.2 Ratio of body surface area and body weight

Fat persons or persons who have lower body surface area ratio got more problems on heat release and storage than larger body surface areas because heat transfer is depended on body surface area. Moreover, heat generation is depended on body weight, fat person with heat familiarity who working in hot environment got more health risks than less body weight persons.

2.2.4.3 Age and illness

During heavy load working period, persons on age of 40-65 cannot achieve efficient work like younger persons because during age of 40-65, maximum rate of oxygen consumption reduce 20-30 % of original rate which made reduction in blood recirculation capability under same working and heat conditions. Body heat transfer of old persons also less than younger as can be seen on high body temperature of older with less blood recirculation at skin which cause sweat discharge rate of older lower, more heat generation and need longer time to restoration to normal condition. Heart and blood vessel disease also cause lower heat resistance effect.

2.2.4.4 Water balance

Heat resistance of body depends on amount of water in body and electrolytes discharge. The loss of water can compensate by drinking more water to recover heat resistivity. Worker of 70 kg body weight with heat familiarity can lose 6-8 kg of sweat during 8 hours working duration.

2.2.4.5 Electrolytes balance

Loss of water and electrolytes during working due to sweat can affect heat resistivity. In 1 kilogram of sweat contain 2 grams of electrolytes during working workers can loss 18-30 grams of electrolytes.

2.2.4.6 Alcohol

Alcohol drinkers have less heat resistance level than non-alcohol drinkers. Alcoholic toxic which cause malfunction of body system affect body dehydration was defined as the assumption.

2.2.4.7 Body condition

Different body condition from each person cause different resistance level. The heat resistance in persons with good health condition and always exercise is better. Moreover, the heat resistance level is depended on water consumption and electrolytes discharge rate of human body.

2.2.5 Health effect of heat (12)

2.2.5.1 Low heat storage level cause workers feel uncomfortable, bad tempered, poor concentration and not ready to work.

2.2.5.2 Medium heat storage level cause more mistake during work and less efficient work especially in high skilled working.

2.2.5.3 High heat storage level cause body lose balance on both water and electrolytes, build up stress in blood recirculation system, less efficient skill working obviously found especially during long duration of heat contact, sick and illness occur more often such as heat exhaustion, dehydration, heat cramp, fever or pyrexia, fainting or heat syncope and heat stroke which can cause death.

2.2.6 Protection and control of dangerous from heat (12)

Control and protection of dangerous from heat can be done using 3 principles as the following:

2.2.6.1 Engineering control

For example: reduce heat convection rate in working area, reduce heat radiation rate in working area, increase ventilation rate in working area.

2.2.6.2 Management and operation control

For example: control amount of peoples who working in high heat environment, reduce combustion rate, increase heat resistivity, conduct the training in health and safety for workers and appropriately selection for peoples who work in heat contact duties.

2.2.6.3 Control by personal protective equipment (PPE)

For example: clothes, shoes and gloves.

2.2.7 Heat measurement

Heat measurement is conducted to prevent the occurrence of dangerous condition from heat. The evaluation was done by the measurement of Wet Bulb Globe Temperature (WBGT) in environment and work characteristics. If the value is within the pre-defined standard limit no risks should be found. However, if the value is more than the limit thoroughly analysis should be conducted.

2.2.7.1 Wet Bulb Globe Temperature (WBGT) (9, 12)

Measuring devices for heat consist of 3 types of thermometers as the following: dry bulb thermometer, wet bulb thermometer and globe thermometer.

1) Dry Bulb Thermometer: DB is the thermometer that used mercury or alcohol and measuring substances. The sensitivity (scale) of this type is 0.5 °C with ± 0.5 °C accuracy. The thermometer is protected from the direct sunlight and heat radiation which cause inaccuracy measurement results by shield. Moreover, the thermometer should be periodically calibrate and certify by trusty organization. The measurement range selection should be done properly to ensure reliable result compare to operating condition normally it is between -5 to 50 °C.

2) Natural Wet Bulb Thermometer: NWB is the thermometer covered by water saturated clean cotton cloths. The cotton cloths were dipped in the distilled water filled container with natural air flow pass through the cloths. Natural wet bulb thermometer should have periodically calibrated. The normal measurement range is between -5 to 50 °C with ± 0.5 °C accuracy.

3) Globe Thermometer: GT is used to measure the amount of heat radiation from working. The thermometer is consists of globe which made from thin hollow spherical shape copper with 15 cm diameter. The outer surface

is painted by special black coating which has excellent heat wave absorption properties and the thermometer is installed at the center of the spherical. The measurement range of globe thermometer is between -5 to 100 °C with ± 0.5 °C in accuracy.

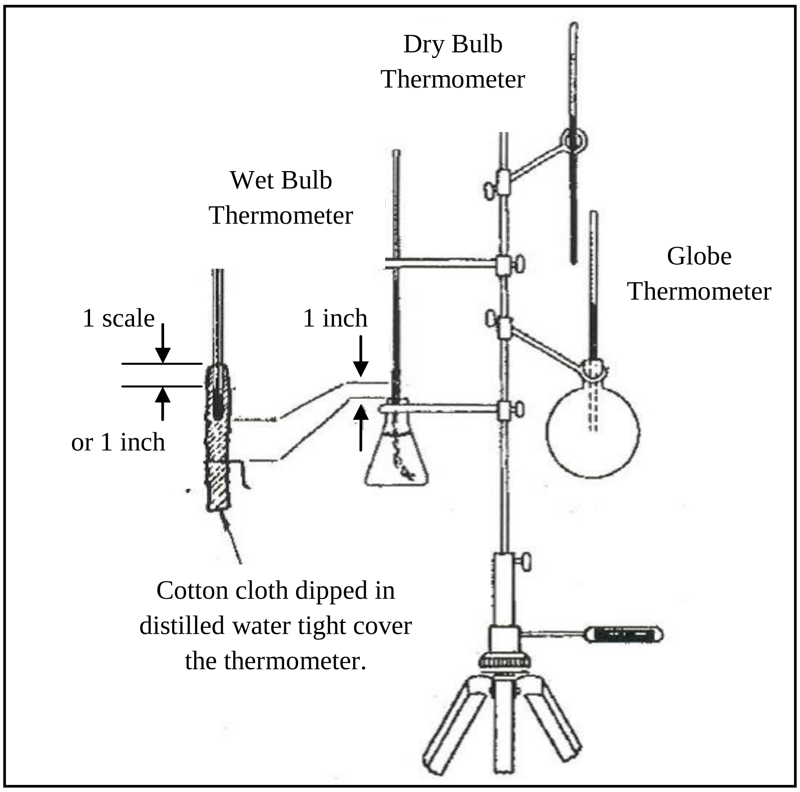

Figure 2.8 Measurement instrument for heat environment (8)

2.2.7.2 Location of heat measurement (8)

The installation of heat measurement devices should be placed in the actual working location to ensure reliable and actual measurement results and conduct the measurement again in the same area during no workers in the location because workers can restrict the heat sources during working. However, if the measurement must be done during working time the shielding effect should be prepared to prevent human effect on heat radiation and wind speed. The proper ways to conduct the measurement is the measuring instruments should install immediately after workers finish working and leave the working location which can ensure the actual heat from environment that effect workers during working. In longer duration working location, the measurement should be done in every hour or half an hour. In less duration working location, the measurement (2-3 minutes working duration on each shift) should be done 2-3 times on each shift. The heat measurement should be focused on the highest heat location, during measurement the outdoor temperature by Psychometric Wet and Dry Bulb Temperature, cloud character report, wind speed also record for better reliable heat effect prediction.

2.2.7.3 Heat measurement procedure (12)

1) Prepare measuring instrument and check the condition of each instrument according to pre-defined standard condition.

2) Install dry bulb thermometer on its supporting legs. During measuring shielding should be installed to prevent thermometer from direct sunlight and other heat radiation sources. The shielding should be installed without any restriction effect to air circulation around the dry bulb thermometer.

3) Drop the distilled water on the cloths that covered bulb of wet bulb thermometer. Other side of the cloths is dipped in distilled water container. The bulb of wet bulb thermometer is installed on the supporting legs and located 1 inch above distilled water level.

4) Install thermometer with measuring range between -5 to 100 °C on the center rubber knob (knob has the same size as open hole of globe). Close the globe hole by pre-installed thermometer rubber knob and install all of them in the supporting legs.

5) Adjust the level of three thermometers to the same level as above the floor to chest level of the workers.

6) Place the supporting legs or hang them in unobstructed air flow area without any obstacles to prevent globe and wet bulb thermometer from environment. Then install the measuring units as close as possible to working location without any obstruction to working process. The measurement still continues during the break of the workers.

7) The installation should be performed at least 30 minutes duration before first data recording of NWB, GT, DB or WBGT and working duration of workers in the area.

Indoor measurement without sunshine

$$WBGT = 0.7\ NWB + 0.3\ GT$$

Outdoor measurement with sunshine

$$WBGT = 0.7\ NWB + 0.2\ GT + 0.1\ DB$$

- WBGT: Wet Bulb Globe Temperature (°C) to measure environment heat indication index.
- NWB: Natural Wet Bulb Temperature (°C) to measure skin temperature. Normally this temperature is lower than ambient temperature after sweat evaporation.
- GT: Globe Temperature (°C) to measure heat radiation.
- DB: Dry Bulb Temperature (°C) to measure ambient temperature and heat convection.

8) If workers are working on more than two different areas of heat environment. The heat evaluation needs to be done in all working areas and then the 2 hours duration of maximum heat condition is chosen for the calculation of average WBGT as the following:

$$\text{Average WBGT} = \frac{(WBGT1 \times t1) + (WBGT2 \times t2) + (WBGT3 \times t3) + \ldots + (WBGTn \times tn)}{t1 + t2 + t3 + \ldots + tn}$$

WBGT1 = WBGT Index at working point 1, t1 = Heat contact duration at working point 1

WBGT2 = WBGT Index at working point 2, t2 = Heat contact duration at working point 2

WBGTn = WBGT Index at working point n, tn = Heat contact duration at working point n

t1 + t2 + t3 + ... + tn = 2 hours of maximum wet bulb globe temperature (WBGT)

9) Define the working duration and work characteristics to evaluate work load during 2 hottest hours are heavy, moderate or light work load by the following formula:

$$\text{Avg. M.} = \frac{M1t1 + M2t2 + M3t3 + \ldots\ldots + Mntn}{t1 + t2 + t3 + \ldots\ldots + tn}$$

When M1, M2 … and Mn is approximate heat amount from metabolism process for daily activities in kcal/hr or kcal/min in duration t1 t2 tn has unit in hours or minutes

10) The heat level calculated from the formula in item 8 and work characteristic on item 9 compare with standard heat level in according to the law.

2.3 Sweat (7)

Sweat is the waste from body which discharged from skins or other corners of body in form of liquid. Sweat has salts as composition which causes its taste salt. Body also discharge sweat during exercise or during stay in hot environment. Sweat is consist of 99 % of water and the remaining 1 % is included with sodium chloride, urea, sugar, fat, amino acid, potassium, magnesium, iron.

2.3.1 Sweat discharge (7)

Sweat is built up when body contact with heat stimulant and emotion which cause brain to stimulate acetycholine secretion from teleneuron. This process cause sweat gland starts to produce sweat. The amount of sweat is depending on 2 factors as the following:

2.3.1.1 Ambient condition and variation of ambient condition: in hot and high humidity ambient condition the amount of sweat is more than during low humidity raining day.

2.3.1.2 Activities: the activities that required more energy can cause more sweat which in contrast to less activities person.

2.3.2 Factors affect to sweat (7)

Some diseases can affect the variation of sweat amounts such as stress depression, thyrotoxicosis, tuberculosis, diabetes, heart disease and menopause all of these can increase the amount of sweat. However, the skin diseases such as prickly heat, rash, psoriasis, excoriation and migraine cause sweat reduction.

2.3.3 Sweat loss and work efficiency (7)

- When the body sweat loss in amount 1-2 % of total body weight the efficiency of work will reduce 30 %.
- When the body sweat loss in amount 4 % of total body weight the efficiency of work will reduce 50 %.

Formula

(Total body weight x Percent of sweat loss) ÷ 100

Example

Total body weight 60 kg and sweat loss as 2%

(60 x 2) ÷ 100 = 1.2 liters

Total body weight 60 kg and sweat loss as 4%

(60 x 4) ÷ 100 = 2.4 liters

2.3.4 Dehydration symptom (7)

Symptom of dehydration is body temperature increase to 40-41 °C, the suffer feeling tired, headache, dizzy (please always keep the sufferer below this state), uncontrollable of movement direction, bad tempered, introspective, unconscious, high blood pressure increase, cold skins, rapid heart rate and loss of consciousness.

2.3.5 Proper practices (7)

The workers should drink lot of water before and after working, especially after working if the workers do not drink sufficient amount of water it will cause negative effect to kidneys. After working the body will recover back to normal condition within 48 hours.

2.3.6 Measurement of sweat loss

The measurement of sweat loss by measuring of body weight (nude) before and after working and calculate the difference amount of weight (5, 8, 12, 14, 15, 16). Normally, the loss of weight is less than 1.5 % of total body weight, if the decreasing of weight more than 1.5 % of total body weight occurs it mean over limit of heat and need to reevaluation the work and provide more water to the workers (8, 12).

2.4 Heart rate

Heart rate of adults in 1 minute between 60-100 beats per minute, in children between 90-130 beats per minute. In adults, the heart rate more than 100 beats per minute is considered as faster rate and normal in the same ways if the heart rate below 60 beats per minute the below normal heart rate occur. The heart rate is depended on compression of heart muscles then the heart rate variation due to factors affect the compression of heart muscles. Moreover, the increasing of body temperature can cause increasing of heart rate as well. The heart rate will increase in 7-10 beats per minute when body temperature increase for 0.56 °C (17).

2.4.1 Factors affect the heart rate (17)

2.4.1.1 Age: heart rate of people is difference according to their age, when the age increase the heart rate become decreasing.

2.4.1.2 Gender: in teenager and adult age female's heart rate is a little bit higher than male.

2.4.1.3 Exercise: normally during exercise the heart rate is increasing because the exercise cause more oxygen required for muscular function which caused higher heart rate to ensure sufficient amount of oxygen can be transferred to muscle by blood circulation system.

2.4.1.4 Emotion: the heart rate also depends on automatic nervous systems that consist of main parts are sympathetic nervous system and parasympathetic nervous system. The emotions such as angry, fear, anxiety stimulate sympathetic nervous system and cause higher heart rate. In the other hand, the stimulation of parasympathetic cause lower heart rate.

2.4.1.5 Heat: long term body heat utilization cause higher heart rate and will be more higher if blood pressure decreasing as a results of blood vessels expansion from heat.

2.4.1.6 Medicines: some kinds of medicine reduce the heart rate and in the other hand some of them increase the heart rate.

2.4.1.7 Bleeding: loss of blood from blood vessel system for more than 10 % of total blood cause higher heart rate.

2.4.1.8 Posture: during standing the heart rate is higher than during sitting or sleeping because heart need to apply more force for blood recirculation.

2.4.2 Energy usage and heart rate (18)

When the energy usage of body increasing the heart rate is also increasing because more required energy means more oxygen required internal body process and the blood vessel and recirculation system need to work harder to ensure sufficient amount of oxygen can be delivered. However, in the same condition the heart rate is also difference depend on the work types. The temperature of working environment also caused increasing in heart rate because more blood recirculation needed for maximum heat releasing out of the body.

Variation of heart rate during work: from the monitoring of heart under the certain time interval, during rest the heart rate is constant at the resting pulse and still constant as long as no increasing workload occurs. Normally, the resting pulse of each persons are difference depend on strength of their bodies. In athletes or good health person, the heart rate of 50-60 beats per minute are obtained and the rate become higher in persons with lower health conditions. After start working, the heart rate is increasing if the work is a constant workload with not too much workload the heart rate will become constant again after 3-5 minutes working duration. This period is called “Adjustment Period” and the heart rates still constant until stop working then the heart rate start to decrease to resting pulse within 5-10 minutes depend on the workload. This second period is called “Recovery Period”. The duration before entering “Recovery Period” depend on the workload before resting (18).

If the workload is high enough, the heart cannot withstand at constant heart rate which mean the workload is harder than body capability that might cause danger. The reason why the heart rate cannot stay constant is because the amount of oxygen needed is higher than body capability which cause higher load to heart to ensure sufficient amount of oxygen is transferred to important organs (18)

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2.4.3 Measurement of heart rate (8)

The heart rate measurement can be done by sphygmopalpation, monitoring heart rate. The use of recovery heart rate is useful for evaluate heat. The measurement of recovery heart rate in normal working persons can be done by immediately measure the heart rate during rest of workers who finish normal working period and sitting for rest. If the heart rate is below 110 beats per minute or the heart rate after 3 minutes is less than 90 beats this condition is considered as normal. However, if the heart rate after rest is higher than the criteria, the heat stress should be verified and evaluated again or perform the average heart rate measurement during working, if the rate higher than 110 beats per minute mean higher heat than the limit moreover if the rate is more than 160 beats per minute the work need to reevaluate.

2.5 Workload

Workload is the characteristic of heat derived from metabolism process for working activities. Workers work on heavy workload will have higher heat generation than lighter workload workers.

Heavy workload is work that use high physically force and high energy which cause effect to heart and lung. The energy usage and heart capability are defined as heavy workload limitation, both are also frequently used for severe evaluation of work on body (18).

2.5.1 Basic energy usage (18)

Body does not energy only during working or movement but during break on standstill such as sleeping or sitting the body continuously using energy. The energy using during break is considered as basic energy usage used for maintain the proper function of important organs such as heart, stomach, intestine. This energy is not too much, the research shown that during break people still uses energy at the constant amount which will be more or less depending on body sizes, weight, and gender. Normally, big size person has higher amount of basic energy usage than small size person.

2.5.2 Energy usage for working (18)

During working the energy usage rate will immediately increasing from the basic energy usage because the muscles need more energy to achieve the higher workload. The more work intensity means the more energy required. The energy usage for working can be utilized as the following:

2.5.2.1 Provide information of energy usage level for each type of workload for comparison.

2.5.2.2 Energy usage level can be used for comparison of tool efficiency, work practices and work ergonomics because appropriate tools and work practices can help work completed with less energy and more efficiency.

2.5.3 Factors affect energy usage (18)

Required energy is more or less depending on many factors that affect the increasing of workload which can be summarized to 3 sections as the following:

2.5.3.1 Force: light or heavy workload can be defined by amount or magnitude of force need to be applied to completed work such as lift of heavier objects, more force applied for cutting of harder objects. When more force need to achieve work target, the need of energy also increase because heavier work load of body muscle, more oxygen consumption and increase of workload for important organ such as heart and lungs.

2.5.3.2 Work posture: accumulation of inappropriate work posture which has be done for long period of time can affect more static force on muscles, more oxygen consumption, more workload on breathing and blood circulation system which results increasing of energy usage even though the work type are still the same.

2.5.3.3 Work environment: especially temperature, the results shown that when working in high temperature environment the body requires more energy for maintain the balance of body heat which causes more workload on important organs and body systems.

2.5.4 Workload evaluation (9, 12, 19, 20)

Workload evaluation by working duration and work types which consist of light, moderate and heavy workload are done in accordance with Notification of Ministry of Industrial: Safety Protection Measures Related to Working Environment for Industrial B.E. 2546 and Ministerial Regulations: Standard for Safety, Health and Environmental Management for Working in Related to Heat, Light and Sound B.E. 2549. The definition of workload has been defined as the following:

Light workload is work which required less energy or the power required for achieve the work is less than 200 kcal/hour such as writing, typewriting, data recording, sewing, product quality check, assembly work of small objects, machine control by foots and work supervision or other equivalent works.

Moderate workload is work which required moderate energy or the power required for achieve the work is between 200 kcal/hour to 350 kcal/hour such as lifting, dragging, pulling and relocation of objects by moderate force, nailing, filing, truck driving, tractor driving or other equivalent works.

Heavy workload is work which required heavy energy or the power required for achieve the work is more than 350 kcal/hour such as digging, wood sawing, hardwood drilling, hammering, lifting or relocation of heavy objects on inclined area or other equivalent works.

Table 2.4 Workload evaluations (9, 12, 13)

Posture and Motion	**kcal/min**	
Sitting Standing Walking on a level surface Walking uphill	0.3 0.6 2.0 - 3.0 0.8 increase for every 1 meter height	
Work Types	**Average (kcal/min)**	**Range (kcal/min)**
Working by hands - Light workload (writing, knitting) - Heavy workload (typewriting, organize document)	 0.4 0.9	0.2 – 1.2
Working by 1 arm - Light workload (sweep or clean the floor) - Heavy workload (hammering, wood sawing)	 1.0 1.7	0.7 – 2.5
Working by 2 arms - Light workload (material feeding, metal filing, gardening) - Heavy workload (wood craving)	 1.5 2.5	1.0 – 3.5
Total body moving - Light workload (driving) - Moderate workload (painting, scrub the floors and carpet cleaning) - Heavy workload (pulling, lifting heavy objects) - Very heavy workload (construction, dig the ground, slag cleaning in foundry)	 3.5 5.0 7.0 9.0	2.5 – 15.0
Basic body metabolism rate	1.0	

Remark: standard value for normal worker with 70 kg weight with 1.8 square meters skin surface area and normal clothes wearing during work (1 kcal = 3.968 Btu / 1 Btu = 0.252 kcal)

Table 2.5 Workload and WBGT standards (9, 12, 19, 20)

Workload	**Energy (kcal/hour)**	**WBGT (°C)**
Light	Less than 200	34
Moderate	201 to 350	32
Heavy	More than 350	30

2.6 Fatigue

Fatigue is the change of body conditions after using of physical and mental ability which cause lot of fatigue and stress on body muscles, lack of enthusiastic, less efficiency work and more failure during work operation (22). The fatigue can be explained as the following:

Fatigue is the confusing and lack of enthusiastic condition of work operation (22).

Fatigue is tiredness, boring, lack of enthusiastic due to worker and related working environment. Fatigue can be divided to 2 main parts such as physical fatigue and mental fatigue. Reduction of work capability due to physical fatigue can recover by resting and relaxation. However, the mental fatigue is come from boring from repeatedly work (21, 22).

Physical fatigue frequently occurs from accumulation of stress and fatigue on body muscles and mental fatigue is the results from reduction of mental capability and tiredness which cause lack of enthusiastic and less efficient work results due to brain signal stimulate by both physical and mental fatigue (22).

2.6.1 Factors affect fatigue (23, 24)

2.6.1.1 Work conditions

Work conditions factors are including with work descriptions, work characteristics, time, working places, responsibility, and work stability and payment.

2.6.1.2 Workers

Workers factors can cause lot effect on fatigue especially on workers who do not take good care of their health which can causes frequently fatigue. Moreover, the fatigue will be less if workers are enthusiasm, eager to learn and focus to improve their works in contradiction if the workers feel tired, it will cause a lot of fatigue. Drug, alcohol, cigarette and gambling are also fundamental causes of workers fatigue.

2.6.1.3 Family and environmental

Workers who face disharmony in family's life such as economic regression, a lot of children, lack of nutrition, lack of resting, lack of sanitary in nearby living environment and lack of social recognition. All of these can cause the fatigue.

2.6.2 Symptoms of fatigues (23, 24)

Symptoms of fatigues can be evaluated by personal feeling and behaviors such as tiredness, drowsiness, faint, lack of enthusiasm, lack of consciousness, and boredom of work which made inefficient.

2.6.3 Fatigues due to work

2.6.3.1 Causes of fatigues due to work (21, 22)

Fatigue due to work is came from stress due to concentration for work together with mental and emotional cause such as anxiety of conflict with other colleagues or management staffs and working environment (such as inappropriate working atmosphere, light, sound etc.). Moreover, some diseases can also cause fatigue. One important cause of fatigue is insufficient sleeping hours. Persons who have fatigue symptom is indicated by tiredness, drowsiness, lack of consciousness and boredom to work which cause deteriorate of physical and mental condition as a result.

2.6.3.2 Protection of fatigue due to work (24)

Management countermeasure to rearrange and reschedule of appropriate working and resting time, control and manage the working tempo for more flexible can reduce fatigue problems. The training should be provided for workers to increase level of knowledge about causes, effects and counter measures of fatigues together with recommended practices.

2.6.4 Evaluation of fatigue (25)

2.6.4.1 Objectives of the evaluation

To evaluate feeling of workers by divided the body of parts. The scores will be given on each part for evaluation the level of fatigues.

2.6.4.2 Utilization of the evaluation

The evaluation is used for preliminary evaluation of ergonomics risk of body's parts for all types of work and the results can be analyzed together with work types for further analysis.

2.6.4.3 Advantages and disadvantages

The results can error due to bias of workers to evaluation feeling.

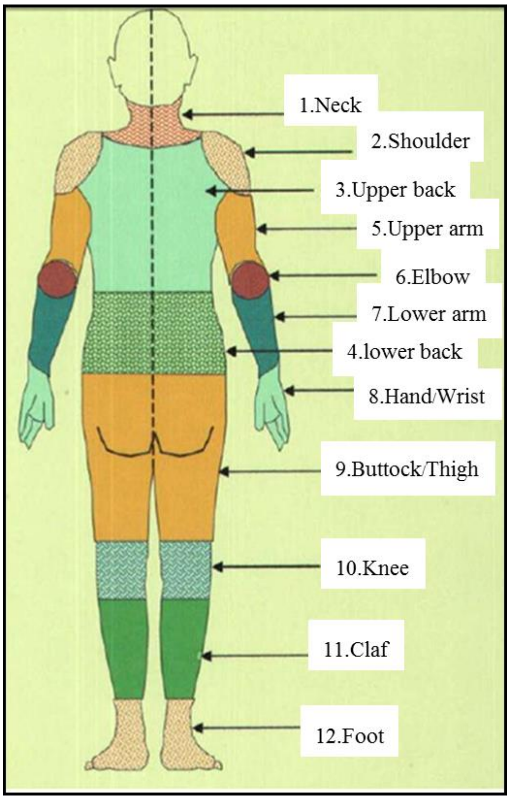

Figure 2.9 The part of body for evaluation of fatigue

2.7 Firefighters

Firefighters are the person who in charged in protection and extinguishing of fire by various types of fire equipment and also another special equipment in case of emergency situations. They also responsible for examination and investigation of fire scenes, maintenance of fire equipment, sharing knowledge and provide the training of firefighting.

2.7.1 Firefighters in Bangkok (26)

Bangkok metropolitan constructed the Fire and Rescue Department in B.E. 2546. The department was relocated from department of fire police under the Royal Thai Police Headquarters with lot of experienced staff together with new recruitment staffs. New staffs had been trained for skills, expertise and knowledge of firefighting and rescue operations.

Bangkok Fire and Rescue Department is responsible in protection and mitigation the public hazards, perform firefighting operation and rescue operation in Bangkok and its vicinity areas or other areas upon requests, specify the countermeasures for fire protection and public hazard effects mitigation with close coordination with both government and private organizations, specify and coordinate between working parties to ensure the operation plan's goals can be achieves according to Bangkok's master plan, legal operation, provide the information on public hazard and its protection to the society and improve the office capability.

The sections under the management of Bangkok Fire and Rescue Department have many difference working scopes which can be divided to secretary office, academic and planning sections, protection & mitigation management sections, fire operation sections. The fire operation sections are the main groups who take responsible on firefighting rescue operation in Bangkok and its vicinity area and also on other area upon request, help and rescue of fire victims, survey for fire risks, prepare firefighting water sources map, maintain the firefighting equipment and vehicles to ensure the readiness of operation in all occasion, provide training and sharing their knowledge to the society and provide the training programs to their staffs to increase capability and expertise of the operations and services for people, government and private sectors upon request.

Fire operation section is consisting of 4 different areas of responsibility which can be divided to 4 fire operation section across Bangkok's area.

The number of firefighters of fire operation section No.1 was 309 persons, fire operation section No.2 was 394 persons, fire operation section No.3 was 394 persons and fire operation section No.4 was 516 persons. The total number of staffs under the fire operation section was 1,661 persons (Source: Bangkok Fire and Rescue Department on June 30th, 2013)

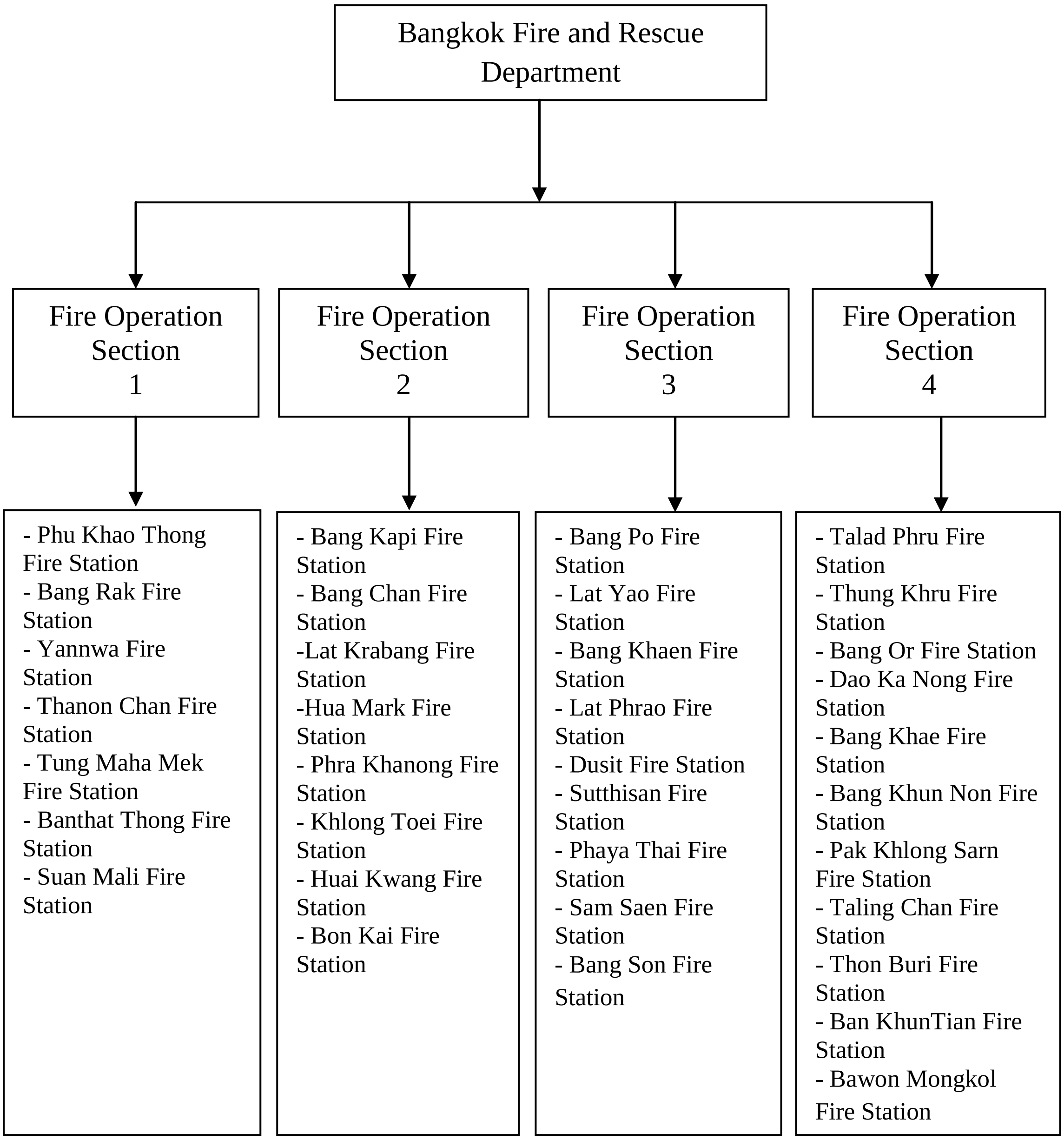

Figure 2.10 Organization chart of Bangkok Fire and Rescue Department (26)

2.7.2 Firefighters in the provincial (27)

Information from Department of Local Administration about prevention and mitigation of public hazard which was collected from the organization abroad country explain about the number of firefighter in each province as the following:

Table 2.6 Number of firefighters in each province (27)

Province	Number of Firefighters	Province	Number of Firefighters	Province	Number of Firefighters
Krabi	121	**Nakhon Pathom**	337	**Phatthalung**	136
Kanchanaburi	396	**Nakhon Phanom**	154	**Phichit**	351
Kalasin	489	**Nakhon Ratchasiam**	1,013	**Phitsanulok**	412
Kampheng Phet	284	**Nakhon Si Thammarat**	521	**Phetchaburi**	293
Khon Kaen	886	**Nakhon Sawan**	698	**Phetchabun**	596
Chanthaburi	414	**Nonthaburi**	470	**Phrae**	286
Chachoengsao	369	**Narathiwat**	510	**Phuket**	286
Chon Buri	876	**Nan**	325	**Mukdahan**	224
Chai Nat	169	**Bueng Kan**	167	**Mae Hong Son**	204
Chaiyaphum	568	**Buriram**	695	**Yasothon**	218
Chumphon	278	**Pathum Thani**	615	**Yala**	418
Chiang Rai	648	**Prachuap Khiri Khan**	286	**Roi Et**	544
Chiang Mai	1,002	**Prachin Bui**	245	**Ranong**	64
Trang	228	**Pattani**	326	**Rayong**	412
Trat	199	**Phra Nakhon Si Ayutthaya**	707	**Ratchaburi**	486
Tak	290	**Phayao**	301	**Lop Buri**	344
Nakhon Nayok	191	**Phangnga**	110	**Lampang**	448

Table 2.6 Number of firefighters in each province (27) (cont.)

Province	Number of Firefighters	Province	Number of Firefighters	Province	Number of Firefighters
Lamphun	358	**Samut Sakhon**	213	**Surin**	532
Loei	299	**Sa Kaeo**	188	**Nong Khai**	303
Si Sa Ket	431	**Saraburi**	599	**Nong Bua Lam Phu**	271
Sakhon Nakhon	597	**Sing Buri**	159	**Ang Thong**	144
Songkhla	498	**Sukhothai**	357	**Amnat Charoen**	160
Maha Sarakham	317	**Suphan Buri**	379	**Udon Thani**	876
Samut Prakarn	847	**Surat Thani**	509	**Uttaradit**	258
Samut Songkhram	149	**Satun**	89	**Uthai Thani**	318
				Ubon Rachathani	738

The information from Department of Local Administration shown that Thailand had 7,842 local administration organizations with 30,199 firefighters (Source: Department of Local Administration)

2.8 Fire clothing and chemical protective clothing

2.8.1 Fire clothing (28)

During firefighting operations, the fire clothing and personal protective equipment need to be wear to ensure personal safety beside the firefighting equipment such as various types of firefighting machines, firefighting hoses, firefighting nozzle and etc. The personal protective equipment for fire fighters as the following:

Helmets are the head protective equipment when enter the fire scenes. It must be painted with easy to visible colors or stacked with luminous tape for quick recognition during working in light limited area. The helmets must have enough strength to prevent any damages from impact with objects in fire scene such as falling wood. The front shield is also important for manufacturer to provide protection from contact of heat and other dangerous source to theirs facial. Normally, the helmets are made from fiberglass due to lightweight when compare with steel helmets.

Eyeglasses during work operation with limited protection in some places cause by non-front shield safety helmets, for example eyes damage from dust, foreign object damage and firefighting operation cause by limited protection, the eyeglasses can help to protect users from damages. Normally, the eyeglasses' lens were made from high durable transparency with reliable strap to ensure the eye glasses can be wear without any slip.

Fire suits (coat and pants) are used to cover the firefighters' bodies. Normally, the fire suit is made to ensure easy to recognize by clearly colors or fluorescent reflect colors installed at clothes which made from toray fabric or canvas fabric with heat resistant properties. The inside of cloth is covered by fabric to prevent the heat effect. The normal length of fire suits are covered to the knees of the wearer which can be tightened by buttons and sticky tape. The advantages of fire suits (both coat and pants) are to prevent the heat form fire and to indicate that the persons who wear these suits are responsible as the firefighters.

Gloves are made from high quality wool or leathers. The gloves should be covers all portion of the wearers' hands. Moreover, the gloves can be withstanding the heat and external cutting forces to ensure these gloves can be used in fire scenes without any obstruction.

Boots are a rubber boots with steel addition foot soleplates which use in fighting purposes especially in the emergency fire scenes. Normally, the fire boots are high enough cover wearers' foot and calf.

SCBA (Self-Contained Breathing Apparatus) is used by emergency searching teams for rescue and firefighting operations which cause limited air and oxygen amount (less than 16 %) . The low concentration of oxygen can caused severe health effect or death. The equipment is included with full face mask, voice communication equipment, air storage cylinders and high reliable pressure regulator with standard compliance.

2.8.1.1 Fire clothing standard

NFPA standard (29)

NFPA standard from United States of America as the following:

1) Garment design requirements: optional requirements, garment composite, liner attachment, liner coverage, garments and closure systems, collar, sleeves, sewing thread, cargo pockets, metallic closure systems/metal components, liner system, sizing, trim, drag rescue device required in coats, coat required to have wristlet, reinforcement.

2) Garment performance requirements: THL, TPP, tear resistance, shell breaking strength, cleaning shrinkage, fastener tape, seam breaking strength, heat and thermal shrinkage, thread, flame test on all textiles, metal hardware, label, radiant protective performance, outer shell water absorption, water penetration resistance, liquid penetration resistance, viral penetration resistance, resistance to heat transfer, DRD fabrics/seams/splices, DRD function test, transmitted and stored thermal energy test, garment trim, wet flex, adhesion after wet flex, flex at low temperatures, resistance to high temperature blocking.

EN standard (30)

EN standard from European, the European standards for fire clothing are consisting of 6 topics as the following:

1) EN 469 Protective clothing for firefighters
2) EN 443 Helmet for firefighters
3) EN 659 Gloves for firefighters
4) EN 345, Part 2 Footwear for firefighters
5) EN 13911 Hood for firefighters
6) EN 1486 Reflective protective clothing for proximity firefighting

Protective clothing for firefighters according to recently EN 469: 2005 as the main topic as the following:

1) Performance level classification
2) Sizing determination

3) Practical performance testing clause 4.5 and annex D

4) Sampling and pre-treatment clause 5

5) Visibility clause 6.14

6) Whole garment testing clause 6.15 and annex E

2.8.1.2 Dangerous from fire clothing wearing (28)

1) Water is a main factor related to fire. Under the normal environment, heat accumulation is continuously occurring under firefighters' fire clothing which can be cause severe damage without any consciously. The factors associated to faster heat accumulation of fire clothing is water because it is better quality as a heat conductor and can be transferred heat from environment to the inside like boiled water. However, in the users is under the lower heat environment, the heat accumulation by water can cause skin burn.

2) Heat is an important factor which can cause heat accumulation under fire clothing. Heat and compression pressure that replaced the presence of air and infiltrate to internal of clothing which can cause compression effect as many locations such as back and neck area which wearing SCBA, elbows and knees which direct contact to heat between sitting or creeping in fire scenes. In case of wetted clothes are worn during creeping in fire scenes floor, the firefighters will receive the heat directly through medium of water and pressure if the fire clothing are designed with limited protection provide that can cause damages to firefighters' bodies which called wet compression burns. Unless the only heat accumulation under fire clothing, the water at outside surfaces of fire clothing also cause abnormal feeling during entering high heat and dryness area due to the heat extraction by outside water which made the wearer feeling of less than normal temperature by water evaporation. The cooling effect will stop after water evaporation process finished and suddenly firefighters feeling of high heat environment and inside heat accumulation inside fire clothing occur suddenly. These can cause severe burn of firefighters' skins.

3) Physical danger: fire clothing which has lot of clothes thickness and heavy weight that cause inconvenient movement and cause danger such as slip, collapse during firefighting operation. The fatigue of firefighters' bodies also due to heavy weight carrying and workload during operation are also occurs.

2.8.1.3 Dangerous protection from fire clothing wearing (28)

1) Water is an important factor which can cause burn. The fire clothing must include the barrier to prevent water ingestion which consist of two level of protection are outer barrier and inner barrier. The outer barrier are made to prevent the water ingestion to the inner barrier and the inner barrier duties is to prevent water inside fire clothing such as sweat from firefighters (normally 1.8 liters per hour occur during firefighting operation) leak to outside.

2) Heat with compression pressure will replace the air inside fire clothing and leak to inside of fire clothing. Fire clothing must have insulation to prevent the heat transfer process which use inside air as medium. Normally, the insulations are installed in high risk of heat contact are such as shoulder, back, nape of the neck, elbows and knees.

3) Physical damages are also cause damage to firefighters due to heavy weight of fire clothing that cause inconvenient movement. The firefighters need to practice about wearing process and operation with actual fire clothing to get familiar and ensure trustful operation with minimum risk to firefighters' life.

2.8.2 Chemical protective clothing (31)

Chemical Protective Clothing (CPC) is protective clothes which used to prevent the chemical agents come to contact with skins or eyes and also work as a barrier to prevent the chemical seeping to human skin which can cause negative effect to internal organs.

The chemical protections of workers' skin are performed by high quality chemical protective clothing and the most important part is a selection of chemical protective clothes. The chemical protective clothes must be made from chemical resistant material. The type of chemical protective clothes are also important and it should be done in accordance to type to chemical agent such as agents are withstand on the air or not, it can be spill or not, it is a solid or liquid substances. The other important criteria for chemical protective clothing selection are probability of chemical contact, movement during wearing chemical protective clothing, durable of chemical protective clothing and prices.

Material which made for chemical protection purpose can be categorized depends on which chemical agents its can protected. However, the materials that can withstand all chemical agents do not exist. Therefore, the selection of chemical protective clothing should be done in accordance with working substances or the most probably contacted substances.

The appropriate selection of chemical protective clothing can reduce risk related to contact of chemical agent. However, it cannot prevent any other physical risk such as fire, radiation, electrical. Therefore, other personal protective equipment (PPE) should be provided to ensure safety operation such as eye protection by safety eyeglasses which made from impact resistant lens or goggles, head protection by safety helmet, noise protection by earmuffs or ear plugs and foot protection by safety shoes.

2.8.2.1 Dangerous from chemical protective clothing wearing

1) Heat: normally, human body always try it best to control constant body temperature within 37 °C then the heat losses should equal to inlet heat to human body. If the heat losses are more than inlet heat, the body temperature will decrease. In the other hand, if the heat losses are less than inlet heat the body temperature will continuously increase. In emergency situation that related to high heat intensity, the body mechanism that control the body heat balance cannot withstand its function which cause too much fatigue and also increasing of body temperature. The body will reflect high heat condition by basically a heat cramp or heat stroke in severe cases. The severity level due to heat effect is depended on health condition and heredity.

2) Physical risk: wearing of chemical protective clothing can increase the risk of accident due to heavy of chemical protection clothing which made inconvenient to move, limit eyesight, lower hear ability and increasing of forces applied to do works and the severity level of risk is depended on the types of protective clothes. Working environments are also related to level of risk such as slippery, fall down or struck narrow ways.

2.8.2.2 Dangerous protection from chemical protective clothing wearing

1) Heat: workers need to know their limit and avoid doing heavier work more than limits. Normally, human is the best indicator for heat measurement.

2) Physical risk: to reduce physical risk, workers who wear chemical protective clothing need to change working practices. The periodic health inspection should be performed to collect information and health monitoring. The workers are allowed to change working and resting time as necessary. To prevent loss of water and electrolytes, more water and salts should be added to workers' meal. The compensation of food nutrition shall be added to standard operation procedures to ensure safety work practices and reduce related risks.

2.9 Standard practices

Firefighting operations are divided to 2 standard practices: actual operation and training operation. The training operations are considered as the main achievement to ensure reliable operation results during actual situations. The main purposes of the training are to increase level of expertise and familiarity of fire scenes to the firefighters.

2.9.1 Standard training of American firefighters (32)

American's firefighters give priority on the training as one of their main job duties. The training for firefighters in America has many different levels with the most important training is simulation of actual emergency situation high performed every 3-6 months or other frequently as per fire station specified. The lower important is the standard practice or training of special equipment usage when new equipment acquired and the test or training should be done before.

The standard training practice is a fundamental training of station firefighters to increase level of expertise and ensure the operation can be done with safety in life of firefighters who engage in actual emergency situations. Normally, the training can be performed on every day, every week or every month basis as per necessary. A lot of useful techniques and training are provided to ensure safety firefighting operation can be performed. Although, the most frequently used training practices that considered as heart of firefighting whatever high or less critical situations are consist of 10 items as the following:

2.9.1.1 Wearing fire clothing and SCBA within 90 seconds time limit

The practices can be done everywhere which has enough spaces. The fire clothing and SCBA are prepared and the trainee need to finish all equipment wearing within 90 seconds or 1 ½ minutes. The reason of the limited time duration is during the actual situations, firefighters need to do everything in timely manner to reduce the loss from fire situation then the firefighters must always ready for firefighting operations. The more time spending on wearing their uniforms can cause a lot of damages that maybe never to recover it back so, the time limit for wearing fire clothing and SCBA is limited by 90 seconds.

2.9.1.2 Preparation for risks in responsible area

Fire is an unforeseen situation that cannot predicted on when and where it will be occur. Firefighters need to aware of the mistakes cause by unexpected fire in unexpected places with unreachable firefighting supports. Therefore, the firefighters need to collect and list all of possible fire risk area, perform the in advance survey by sightseeing and talk with nearby peoples who can give more useful information for further preparation such as the number of entrance ways or the location of emergency water sources for firefighting. If this step is correctly done, it will be more useful for the future and better than go straight to the fire scenes without any information.

2.9.1.3 Mayday practices

The one of most horrible words of firefighters is a “Mayday” call from their walky-talky because this word mean some of his colleagues are under face the risk of their own life in the emergency situations. Therefore, firefighters need to practice on how to response on the “Mayday” call which already have their own standard format and operation procedures because the rescue operation is must be done immediately without any exception due to the humanity principles and teamwork.

2.9.1.4 Rope knots practices

The correct rope knots with reliable strength is one of the most important parts for successful operation and can also save one or more persons' life. American firefighters were instructed to know how to do the correct rope knots in short duration. The training is performed in monthly basis and persons who have highly skill in rope knots will be accepted by their colleague because the rope knots are always used in many operations such as rescue operation for person at height. The rope knots are always important for firefighting work.

2.9.1.5 Routine check and inspection of equipment in fire truck

Firefighters can always spend some time every day to check for the availability of firefighting equipment and fire truck to get familiar to equipment installed in fire truck, equipment function and location. If the fire station has more than one fire truck, absence of routine fire truck and its installed equipment check can lead to confusing during firefighting operation. The benefits of routine check and inspection are to increase the level of expertise and familiarity of firefighters on firefighting equipment which can cause lot of benefits during actual situation. The most three things to do during routine check and inspection are check for total number and detailed of equipment, remember the location of each equipment and check for its availability and if any equipment are malfunction, the responsible persons need to be notified and the maintenance of equipment performed immediately.

2.9.1.6 Knowledge sharing on firefighting equipment

In the discussion between firefighters, more than the main issue on planning and development of firefighting plan the discussion on using of tools are also need to be included. This issue can be discussed in daily basis by explaining of the detail of equipment specification and its utilization, demonstration of how to use the equipment, open discussion for staffs questions and feedbacks and also give the opportunities to staffs to practice the use of equipment with assistant by specialists or operating instructions. Moreover, not only the special or new equipment are used during the discussion, the common and frequently use equipment is also important because the discussion might lead to the new ways or standard of practices from experienced staffs. The inspection and maintenance of equipment and expertise of equipment using are also important because these can lead to higher quality, safety and efficiency of firefighting operation.

2.9.1.7 Installation of hydrant practices

During the fire extinguishing in houses and nearby shops which need of water supply from fire hydrant (normally installed at the corner of the road) for firefighting operation, firefighters teams make their decision on which sources of water will be used for firefighting depended on situation. It can be directly use of water storage on fire truck, use of fire hydrant or both of them. The firefighters need to be familiar with how to install and remove fire hose and fire hydrant because it is one of their routine work which how fast and shorter duration they can achieved mean less of fire effect.

2.9.1.8 Inspect of length and water capacity of all fire and pumping hoses

Firefighters must do check and inspect on water capacity and length measurement for all of fire and pumping hoses in their own station as much as possible to increase their recognition of length, water flow rate capacity and pressure limitation of each hose. During inspection, firefighters need to perform the training of fire and pumping hoses by both dry and wet practices. The purpose of the inspection and training is to ensure the firefighters can select most suitable hose for their operation within short duration which can reduced the effect of duration of their operations and consider as required skill for firefighters. Absence of this skill, the firefighters need to take some time to do the calculation which might cause increase severity level of fire.

2.9.1.9 Ladder practice

One of most important equipment of firefighters is a carry-on ladder. The carry-on ladder is used in firefighting and rescue operation because only the installed ladder of fire trucks might not enough to facilitate the operation in some place or situations which cause negative effect to the operation. Some firefighters are directly climbing on the building with their fire clothing which can added more risk to their life and it must be avoid. In specific operation the use of carry-on ladder is a simple and safety practice, the two firefighters with one carry-on ladder which can be installed as any places as required with one man on the ladder and other one to secure the ladder base. Normally, firefighters are trained for skillful and efficient ladder usage because the ladder that used in firefighting purpose is longer than normal ladder so, the routine practice needs to be performed to ensure skillful of ladder installation and operation.

2.9.1.10 Searching training

The purpose of firefighting operation is to distinguish the fire. Moreover, the searching and rescue of victims who struck in the building especially, wounded persons who cannot do thing like his normal condition. Normally, the wounded persons do not lay down at the door but can be located inside the fire building in the area of limited visible range by 1 foot due to smoke from fire. Therefore, the firefighters need to be trained about the specific techniques on searching and rescue operation from the firefighting college. During rescue operation, the firefighters will face lot of smoke that reduce visible range and breathing system capability, heat, flames and destruction of building due to damage from fire, the searching and rescue operation must finish as soon as possible and need highly skillful of firefighters to ensure quickly, correct and efficient operation are applied. The important of this issue is the periodic training under simulation of actual situation must be performed continuously which made firefighters become more familiarly to heat, flame, darkness of this situation for increasing of level of expertise for quickly and reliable operation of the firefighters.

2.9.2 Standard training of Germany firefighters (5)

Griefahn et al (2003) had researched in the topic of "Evaluation of performance and load in simulated rescue tasks for a novel design: effect of weight, volume and weight distribution". The research compare 3 types of SCBA: steel cylinders (15 kg), carbon fiber cylinder (11.7 kg) and the new innovation which has rucksack shape (13.7 kg). In this joint research with Dortmund Fire Station (FWDO) which has the standardized exercise as the following:

Table 2.7 Standardized exercise (5)

Start	S1	In the instrumentation room, weighting of the nude subjects, applying sensors, donning clothing and personal protective equipment.
	S2	Leaving the instrumentation room, walking to a fire engine shouldering the SCBA within the vehicle, leaving the vehicle and walking speedy to the entrance of the building (29 m) while carrying two hose carrying baskets (25.1 kg)
Training	T1	At the entrance opening the valve of the SCBA, climbing speedy (with the two hose carrying baskets) a staircase up to the second floor (36 steps, total height difference 6.6 m)
	T2	Before the flat fixing an opaque foil onto the window of the mask, then creeping through three rooms while taking with a fire hose under pressure (C-size,37 m)
	T3	Finding the dummy (70 kg) in the third room, crawling backward with the dummy along the hose (14 m) to the entrance of the flat
	T4	Creeping back to the nozzle of the hose, continuing search, taking the hose, then back to the entrance
	T5	Removing the foil from the window of the mask, going downstairs towards a training course at the ground level
	T6	Creeping through the training course (upwards a stair of 1.8 m, climbing into the man hole of a tank 1.8 m downwards, 6 m on the level, finally through a tube diameter 80 cm, length 2 m)
	T7	Carrying the cylindric container with a powder extinguisher (19.7 kg) to a ladder in the backyard (70 m), putting down the container

Table 2.7 Standardized exercise (5) (cont.)

	T8	Climbing the ladder (14 m) to the third floor of a training tower (height difference 10 m), lifting and carrying a skip (17.2 kg), climbing downstairs the tower to the backyard, putting down the skip
Recovery	R1	Speedily going to the instrumentation room (70 m)
	R2	In the instrumentation room removing personal protection equipment, undressing or opening the jacket of the suit, 10 min sitting (recovery) while completing a questionnaire to evaluate the SCBA just use
	R3	End of recording, weighing the nude subjects.

2.10 Literature cited

In 1992, Bennett et al. (33) studied "Heat strain during shipboard firefighting: skin and core temperature convergence". The 9 male firefighters were performed the rescue operations from 3 days. The results shown the maximum core body temperature was 39.9 ± 1.2 $^{\circ}$C for the first day. On the second and third day, core body temperature was 38.4 ± 0.2 $^{\circ}$C and 38.9 ± 0.1 $^{\circ}$C respectively. The maximum heart rate for first day was 200 ± 4 beats per minute. For the second and third day, the maximum heart rate was 184 ± 10 beats per minute and 174 ± 10 beats per minute respectively. For the body heat storage, the result from first day showed 224 $kcal.m^{-2}.hr^{-1}$ with 191 $kcal.m^{-2}.hr^{-1}$ and 78 $kcal.m^{-2}.hr^{-1}$ for second and third day respectively. The result from this study shown important of body durability in working in high heat intensity is very important.

In 1992, Ilmarinen and Makinen (14) studied "Heat strain in fire-fighting drills". The 27 male firefighters students had joined the simulation of rescue operation which can be divided to 3 main works (work A: a maximal physical work training 1.5 hours / work B: operational training in flashover 25-30 minutes / work C: operational work training during wintertime in small burning house). The results shown that the anal temperature measurement (Tr) continuously increasing during training in A and B scope with maximum value as 39.95 ˚C after finish of training scope C. For skin temperature the value become increasing and cause injure and pains at upper arm, shoulder and knees in the experiment group in work scope B and C. The average value for sweat loss was 1.91 for work scope A and 0.81 for work scope B. For the average heart rate, the value was 197 beats per minute for work scope A, 183 beats per minute for work scope B and 170 beats per minute for work scope C. The heart rate from work scope A was close to maximum heart rate (HRmax) of each person in experiment group.

In 1992, Louhevaara et al. (34) studied "Evaluation of test drill for the assessment of the firefighter' work ability" by experiment of 5 different work scopes of rescue operation by 53 male firefighters the work scope consist of (1: walk & carrying / 2: stair climbing / 3: hammering / 4: over & under bar / 5: hose rolling). The results shown that heart rate was related to maximum oxygen consumption rate (VO2max) with significant statistical level ($p < 0.001$). However, during the repeated test for evaluate of muscular strength and durability, the results do not indicate any statistical related significant. This study shown the physical strength and capability of firefighting and rescue staff is high. However, the protective equipment and breathing protection system need to provide.

In 1997, Ilmarinen et al. (15) studied "Thermal responses to consecutive strenuous fire-fighting and recue tasks in the heat". The 12 male firefighters were tested by rescue operation which divided to 2 tests consist of (Test 1: physical strength test of the firefighters, Test 2: rescue operation under hot atmosphere). The results shown that the measured anal temperature during test no.2 was statistical significant ($p < 0.001$) higher than test no.1 and average measured anal temperature is increasing with related to duration and ambient temperature (Ta) during recovery period with significant statistical relation ($p < 0.001$) and ($p < 0.05$) respectively. The average skin temperature (Tsk) also related to duration (Ta) during recovery period with significant statistical relation ($p < 0.001$) and ($p < 0.01$) respectively. In the other hand, the duration and ambient temperature were not statically related to sweat loss. Moreover, during test no.2, the firefighters feel much hot and uncomfortable condition.

In 1998, Ilmarinen and Koivistoinen (16) studied "Heart rate and thermal responses in prolonged job-related fire-fighting drills". In the study, 83 male firefighter's students were tested by 3 different work scope of rescue operation as the following: 1) firefighting work such as hammering, ladder climbing, and fire hose lifting, 2) rescue operation and 3) searching of model of the fire victim in building. The results shown that the heart rate was quickly increased during the first minutes of each tasks until closely reach the HRmax limit of each persons. The maximum heart rate for work no.1 was 171-196 beats per minute, work no.2 was 169-199 beats per minute and work no.3 was 175-206 beats per minute. The average measured anal temperature (Tre) increase after finish of all experiment. For average sweat loss after the experiment finished, the value was 0.8 ± 0.2 $kg.m^{2}.h^{-1}$. Moreover, after the experiment finished, the firefighters students need to tell about their feeling during test such comfortable or uncomfortable, hot or cold to the researcher, the results shown that their feeling after finished experiment was they got hot, uncomfortable and wet skin feeling.

In 2001, Hooper et al. (4) studied "An evaluation of physiological demands and comfort between the use of conventional and lightweight Self-Contained Breathing Apparatus". The 22 male firefighters were divided to 2 groups (group 1: carrying 11 persons / group 2: wearing and breathing 11 persons) and the experimental study was made by simulated stage rescue operation including with 3 main stages (stage 1: baseline with 5 sub stages / state 2 and state 3: operation with firekit together with light or heavy SCBA wearing with 4 sub stage on each main stage). The results shown that average heart rate had low significant statistical related level during using of light SCBA, the heart rate of group no.2 were more than group no.1 in all cases and the heart rate from heavy SCBA was more than light SCBA in all cases. Moreover, light SCBA had significant statistically related to level of comfort more than heavy SCBA. However, the non-significant statistical related were indicated on any statistical related on both kits and workload and energy consumption and aerobic fitness.

In 2003, Griefahn et al. (5) studied "Evaluation of performance and load in simulated rescue tasks for a novel design: effect of weight, volume and weight distribution" by divided group of 12 male firefighters for simulated rescue operation using 3 different type of SCBA (A: steel SCBA with 15 kg / B: carbon fiber SCBA with 11.7 kg / C: rucksack SCBA with 13.7 kg). The results shown that sweat loss, rate of breathing, measured anal temperature and rating of perceived exertion (RPE) do not change whenever which types of SCBA were used. However, the heart rate and post personal evaluation of firefighters had statistically significant related to the types of SCBA were used. The new ergonomics based design of rucksack type SCBA had better weight distribution on back and core body than other 2 remaining types which had cylinders in shape. The rucksack type SCBA cause less cardiac strain improve movability of firefighters and the results also indicated that the weight amounts of SCBA had less effects than the weight distribution.

In 2003, Punakallio el al. (6) studied “Protective equipment affect balance abilities differently in younger and older firefighters”. The groups of 29 male firefighters were divided to 2 groups depending on age. (younger group age 33-38 years for 14 persons / older group age 43-56 years by 15 persons). The balance test had performed (1: functional balance / 2: postural balance) and indicated that the wearing of fire protective equipment reduce both postural and functional balance as significant level. Especially the postural balance due to the limited visible range can affect a lot in the older group than the younger group. Moreover, age is statistically significant for functional balance on both wearing and not wearing protective equipment. One important thing is the SCBA equipment causes statistical significant reduce in functional balance on both age levels. The results from this study show that the attention for protective equipment of older staffs need to give a special care on them and the protective equipment need continuous development.

In 2005, Napaporn (35) studied “Comparison of back pains at lumbar portion of the spine in group of services staffs” The survey was taken from 100 male firefighters. The result from the surveys indicate the load lifting has strongly connection to the back pains (oswestry score: OSW) with statically significant level. The lifting of more than 20 kg cause highest and maximum OSW score 23 (±16.43) %, the latters is 10-20 kg lifting with OSW 23 (±11.58) %. For turn and twist of the body it can cause statistically effect on back pains with maximum OSW as 13.5 (±10.27) %. The bend down or bend over also had statistically significant effect on OSW value with maximum OSW value as 14.3 (±10.55) %. The working spaces are also have statistically effect in OSW and the working in limited and inconvenient area cause maximum OSW as 36 (±2.19) %. Almost 85 % of OSW was score between 0-

20 % which mean less effect in daily life and the rest 15 percent scored on 20-40 % severity level with medium effect in their daily life the most influential parts of firefighter’s back pain was from the heavy load weight lifting such as emergency dislocate of fire victims during firefighting operations which cause careless in operation for 66.6 %.

In 2007, Bruce-Low et al. (36) studied “Effect of wearing personal protective clothing and Self-Contained Breathing Apparatus on heart rate, temperature and oxygen consumption during stepping exercise and live fire training exercise”. The 6 males had joined the step test experiment that consist of 5 levels are 15, 20, 25, 30, 35 steps/minutes for 3 days duration. During the experiment the uniform were changed day by day (1: gym kit, GK / 2: weighted gym kit, WGK / 3: PPE+SCBA). The result show that no statistically significant difference of heart rate between WGK and PPE+SCBA and no effect were found on heart rate during using of PPE in normal temperature condition but the increasing of heart rate is depended on body weight. The skin temperature also had statistical relation in higher level. For the rating of perceived exertion (RPE) in WGK, the statistical relation level increase in during high level when compare with GK together with statistical relation for increasing of RPE during using of PPE+SCBA. For oxygen consumption rate, the statistical relation on low level increasing during WKG usage compare with GK. The oxygen consumption rate during PPE+SCBA usage also had significant statistical relation in higher level when compare to GK. In the MFTEs (mock fire training exercises) and LFTEs (live fire training exercises) by 6 males BAIs (breathing apparatus instructors) shown that the average rate of oxygen consumption during MFTEs had lower significant statistical relation level than LFTEs and the average heart rate has significantly increasing during LFTEs (134 beats per minute) when comparing with MFTEs (84.2 beats per minute). For rating of perceived exertion: RPE, the value is increasing a little bit before and after MFTEs executions but much more increasing occurs before and FFTEs executions. For the measured temperature (skin, aural, microclimate), the little increasing occur during the first and last 5 minutes of MFTEs execution and significantly increase the first and last 5 minutes of LFTEs executions.

In 2011, Coca et al. (3) studied “Field evaluation of a new prototype Self-Contained Breathing Apparatus”. The 15 firefighters (12 male and 3 female) in an rescue operation experiment which divided on 1 step of ergonomic feature evaluation and 5 steps of field rescue operation (1: reduced profile exercise / 2: window egress exercise / 3: entanglement exercise / 4: SCBA confidence course / 5: roof venting exercise). The results shown that the prototype SCBA had much better statistical relation than standard SCBA especially in range of motion (ROM), movement ability, level of convenient, fatigue and operation capability of the firefighters.

CHAPTER III
MATERIALS AND METHODS

The purpose of this study was to compare the use of steel and carbon fiber SCBA among firefighters. The materials and methods of this study were described in 6 parts as the following:

3.1 Study design
3.2 Population and subjects
3.3 Research equipment
3.4 Data collection
3.5 Experimental procedures
3.6 Statistical analysis

3.1 Study design

The study design was an experimental research (crossover design) (37).

3.2 Population and subjects

3.2.1 Population

The populations were 516 persons from fire operation section 4, Bangkok Fire and Rescue Department.

3.2.2 Subjects

The subjects were choose from firefighters of fire operation section 4, Bangkok Fire and Rescue Department, the number of firefighter was calculated by average 2 related group comparison formula (38) with reference from related research by Hooper et al (2001) (4).

$$n = \frac{\left(Z_{\frac{\alpha}{2}} + Z_{\beta}\right)^2 \cdot 2\sigma^2{}_D}{\mu_D^2}$$

$$n = \frac{(1.96 + 1.645)^2 .2(4.72)^2}{(6.94)^2}$$

$$n = 12.01$$

n = amount of pair samples and repeated sample

Z = Z-score of normal distribution curve by the two-tailed test ($Z_{\frac{\alpha}{2}} = Z_{0.025}$ = 1.96, $Z_{\beta} = Z_{0.05}$ = 1.645)

$\sigma^2{}_D$ = difference of standard deviation of 2 group which related value or repeated 1 group ($\sigma^2{}_D$ = 4.72)

Hooper et. al (2001): ± S.D. of steel SCBA = 17.98

± S.D. of carbon fiber SCBA = 13.26

μ_D = difference between average values of 2 group which related value or repeated 1 group (μ_D = 6.94)

Hooper et. al (2001): Average HR of steel SCBA = 144.33

Average HR of carbon fiber SCBA = 137.39

The result from the calculation showed that the number of sample size for statistically significant at 95 % confidence interval level was 12 firefighters. During the experiment process performed 18 firefighters and included criteria as the following:

Inclusion criteria

1) Age 25 years old and over.
2) Body weight 60 kilograms and over.
3) Body Mass Index (BMI) within normal (18.50-22.90) or overweight (23.00-24.90) (39).
4) Pass the yearly medical examination and have no underlying disease.
5) Voluntarily joined the research project.

3.3 Research equipment

3.3.1 WBGT (Wet-Bulb Globe Temperature) equipment: used for measurement of ambient temperature and thermometer has been calibrated (see Appendix B).

3.3.2 Blood pressure monitor: (Microlife, Model: BP3AG1, Measurement rang: 30-280 mmHg, Resolution: 1 mmHg, Static accuracy: pressure within ± 3 mmHg, Standard: IEC60601-1-2) used for measurement of blood pressure of subjects and device has been calibrated.

3.3.3 Finger heart rate monitor: (Fingertip Pulse Oximeter, Pulse rate measurement rang: 30-240 BPM, Accuracy: ± 1BPM or ± 1%, Standard: IEC60601-1-2) used for measurement of heart rate of subjects and device has been calibrated.

3.3.4 Weighing-machine: (Electronic Family Scale, Max. Capacity: 180 kg, Readability: 50 g, Auto step ON: 2.5 kg, Minimum weight: 200 g) used for measurement of sweat loss (5, 8, 12, 14, 15, 16) of subjects and device has been calibrated.

3.3.5 Questionnaires

3.3.5.1 Body discomfort evaluation form

Primary section: Evaluation of fatigue or discomfort level (in each body part) which developed from the prior study (4, 23). The evaluation divided the body into left and right portions with sub-divided to 12 parts on each portions as the following: neck, shoulder, upper back, lower back, upper arms, elbows, lower arms, hand and wrist, hip and thigh, knees, calf and foots, the 4 scale levels of severity from 0 to 3.

Secondary section: Evaluation of fatigue or discomfort level (in all body part) which developed from the prior study (4, 23), the 4 scale levels of severity from 0 to 3.

The meaning of each scale level on evaluation of fatigue or discomfort of both each and all body part can be categorized as the following:

0 = No fatigue/discomfort; mean have no fatigue/ discomfort occur in the defined portion.

1 = Light fatigue/discomfort; mean light fatigue/discomfort occur in the defined portion without any negative effect on working.

2 = Moderate fatigue/discomfort; mean moderate fatigue/ discomfort occur in the defined portion with little negative effect on working.

3 = Heavy fatigue/discomfort; mean heavy fatigue/ discomfort occur in the defined portion with required to rest or stop working.

3.3.5.2 Posture and motion evaluation form

In the study, posture and motion evaluation form developed from the prior study (5). Using the questionnaire to evaluation of posture and motion as the following:

- How about you were feeling during walking in plain area with steel SCBA?
- How about you were feeling during walking upstairs with steel SCBA?
- How about you were feeling during creeping with steel SCBA?
- How about you were feeling during pulling the dummy with steel SCBA?
- How about you were feeling during walking downstairs with steel SCBA?

The same questions were applied to carbon fiber SCBA, the 4 scale levels of severity from 0 to 3.

The meaning of each scale level on evaluation of posture and motion can be categorized as the following:

0 = No heavy; mean no feeling of SCBA weight and work can be done without any work obstruction.

1 = Light heavy; mean light feeling of SCBA weight and work can be done without any work obstruction.

2 = Moderate heavy; mean moderate feeling of SCBA weight and work can be done little effect on obstruction and movement.

3 = Very heavy; mean heavy feeling of SCBA weight and work cannot continue doing and need to rest.

3.4 Data collection

3.4.1 Heat

Researcher use WBGT equipment to measure the value of ambient temperature on both outside (1 point ground area) and inside building (1 point inside the testing room and 1 point in front of the testing room). The ambient temperature collected before start of the rescue operation. The detailed measurement of ambient temperature can be explained as the following:

Prepare measuring instrument and check the condition of each instrument according to pre-defined standard condition. Install dry bulb thermometer on its supporting legs. During measuring shielding should be installed to prevent thermometer from direct sunlight and other heat radiation sources. The shielding should be installed without any restriction effect to air circulation around the dry bulb thermometer. Drop the distilled water on the cloths that covered bulb of wet bulb thermometer. Other side of the cloths was dipped in distilled water container. The bulb of wet bulb thermometer was installed on the supporting legs and located 1 inch above distilled water level. Install thermometer with measuring range between -5 to 100 °C on the center rubber knob (knob has the same size as open hole of globe). Close the globe hole by pre-installed thermometer rubber knob and install all of them in the supporting legs. Adjust the level of three thermometers to the same level as above the floor to chest level of the workers. Place the supporting legs or hang them in unobstructed air flow area without any obstacles to prevent globe and wet bulb thermometer from environment. Then install the measuring units as close as possible to working location without any obstruction to working process. The measurement still continues during the break of the workers. The installation should be performed at least 30 minutes duration before first data recording of NWB, GT, DB or WBGT and working duration of workers in the area.

3.4.2 Blood pressure

The blood pressure of subjects collected before start of the rescue operation. The detailed measurement of blood pressure can be explained as the following:

The subjects avoid activity, eating or smoking immediately before the measurement. Sit down for at least 5 minutes before the measurement and relax. Always measure on the same arm (normally left). Remove close-fitting garments from the upper arm. To avoid constriction, shirt sleeves should not be rolled up - they do not interfere with the cuff if they were laid flat. Always ensure that the cuff was positioned correctly. Fit the cuff closely, but not too tight. Make sure that the cuff was 2 cm (0.75 inch) above your elbow with the tube on the inside of your arm. Support your arm so it was relaxed. Ensure that the cuff was at the same height as your heart. Press the ON/OFF to start the measurement. The cuff will now pump up automatically. Relax, do not move and do not tense your arm muscles until the measurement result was displayed. Breathe normally and do not talk. When the correct pressure was reached the pumping stops and the pressure falls gradually. If the required pressure was not reached, the instrument will automatically pump some more air into the cuff. During the measurement, the heart symbol flashes in the display and a beep sounds every time a heartbeat was detected. The result, comprising the systolic and the diastolic blood pressure and the pulse was displayed and longer beep was heard. When the measurement has finished, removes the cuff and witch off the instrument and recorded in data form.

3.4.3 Heart rate

The heart rate of subjects collected both before and after the rescue operation. The detailed measurement of heart rate can be explained as the following:

Before rescue operation: measure the heart rate at heart rate measure site before wearing of fire clothing and SCBA. The subjects sit down for at least 5 minutes before the measurement and relax. Plug one finger into rubber hole of the heart rate monitor before releasing the clamp with the nail upwards. Press button on the front panel. Do not tremble finger when the heart rate monitor was working and body was not moving. Measure the heart rate before rescue operation for 1 minute and recorded in data form.

After rescue operation: measure the heart rate at heart rate measure site after the subjects leaving the building. The subjects take off their fire clothing and SCBA before begin the measurement. Then measure the heart rate for 1 minute duration recorded in data form and continuously measure until the heart rate reach the before rescue operation then recorded in data form again. The process measurement of heart rate was same before rescue operation.

3.4.4 Sweat loss

The sweat loss of subjects collected both before and after the rescue operation. The detailed measurement of sweat loss can be explained as the following:

Before rescue operation: measure the body weight (nude) at weight measure site before wearing of fire clothing and SCBA. The subjects weigh nude in the room and removing of the suits before weighing, wait for the scale to read “0.00”. The subjects standing on weighing-machines and wait a few seconds for the scale to stabilize, the subjects informed the body weight to researcher and then recorded in data form.

After rescue operation: measure the body weight (nude) at weight measure site after finished questionnaire filling. The subjects weigh nude in the room, removing of the suits and rub the body by towel to ensure dry condition before weighing, wait for the scale to read “0.00”. The subjects standing on weighing-machines and wait a few seconds for the scale to stabilize, the subjects informed the body weight to researcher and then recorded in data form.

3.4.5 Questionnaires

The questionnaires (body discomfort evaluation form/ posture and motion evaluation form) collected after the rescue operation. The subjects filling of the questionnaires at questionnaire filling site and done during 5 minutes resting period.

3.5 Experimental procedures

3.5.1 Fire clothing and equipment

The subjects wear fire clothing in accordance to Bangkok Fire and Rescue Department which including inner suits (shirt and trousers), coat and pants, helmet, hood, gloves, boots and auxiliary equipment including with full face mask, back plate.

Table 3.1 Weight of fire clothing and equipment

Fire Clothing and Equipment	Weight (kg)
Inner suits (shirts and trousers), coat and pants, helmet, hood, gloves and boots	10.6
Full face mask, back plate	4.4
Total weight of fire clothing and equipment	**15**

Figure 3.1 Fire clothing and equipment

3.5.2 SCBA

Table 3.2 Data of the two SCBA

Data	Steel SCBA	Carbon Fiber SCBA
Shape	Cylinder	Cylinder
Container material	Steel	Carbon fiber
Height (mm)	610	546
Width (mm)	140	152.5
Pressure (BAR)	300	300
Volume (liters)	6.0	6.8
Duration (minutes)	45	45
Operating weight (kg)	10.0	6.5
Operating weight + full face mask + back plate (kg)	14.4	10.9
Operating weight + fire clothing and equipment (kg)	**25**	**21.5**

Figure 3.2 Two SCBA in the experiment

3.5.3 Experimental design

The experimental design was an experimental research (crossover design), simulated rescue operation in Bangkhae fire station. The test station was located in the room on 3rd floor of 3-story building. Eighteen male firefighters test will perform 2 times on each person. The test had been done on both steel and carbon fiber SCBA for each person (the time difference between 1st and 2nd test is approximately 1 week). The rescue operation will perform at the same time 2 persons, the pairing of the firefighters were done by reasonable similar of age, weight, height, BMI (4). The duration of the test from the beginning till finish will take about 1 hour and the durations spend on rescue operation about 10 minutes from entering and leaving the building.

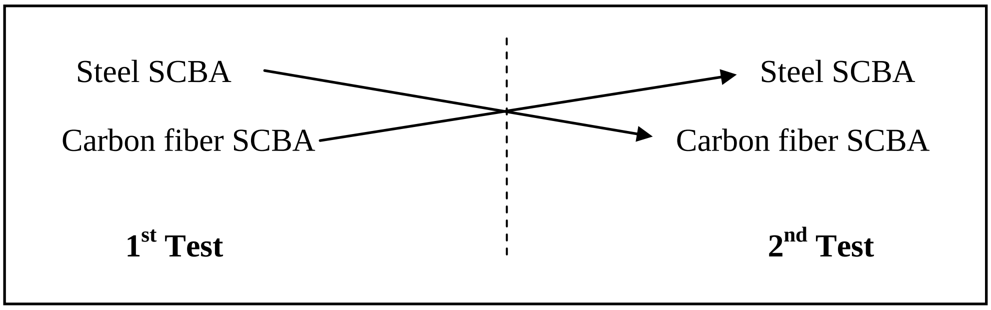

Figure 3.3 Crossover design

Experimental criteria of the subjects

1) The subjects need to sufficient sleep for at least 6-8 hour on the night before the experiment start.

2) The subjects need to avoid drinking of alcohol for at least 12 hours before the experiment start.

3) The subjects should have normal blood pressure and heart rate before the experiment start.

4) If the subjects had any illness condition before the experiment, the researcher informs the subjects to rearrange new appointment date for experiment performing.

5) If the subjects get in charge in any emergency firefighting or rescue operation. The researcher informs the subjects to rearrange new appointment date for experiment performing.

6) During the execution of experiment, if any risk or dangerous occur which can cause injured or severe damage to the subjects. The experimental have their own right to stop the experiment.

7) During 2 times experiment, if the subjects get injured or illness during the test, the researcher will wait until the condition of the subjects become normal. However, if the waiting period was too long or the subjects got severe injured, the researcher will chose the spare pair of the subjects as replaced.

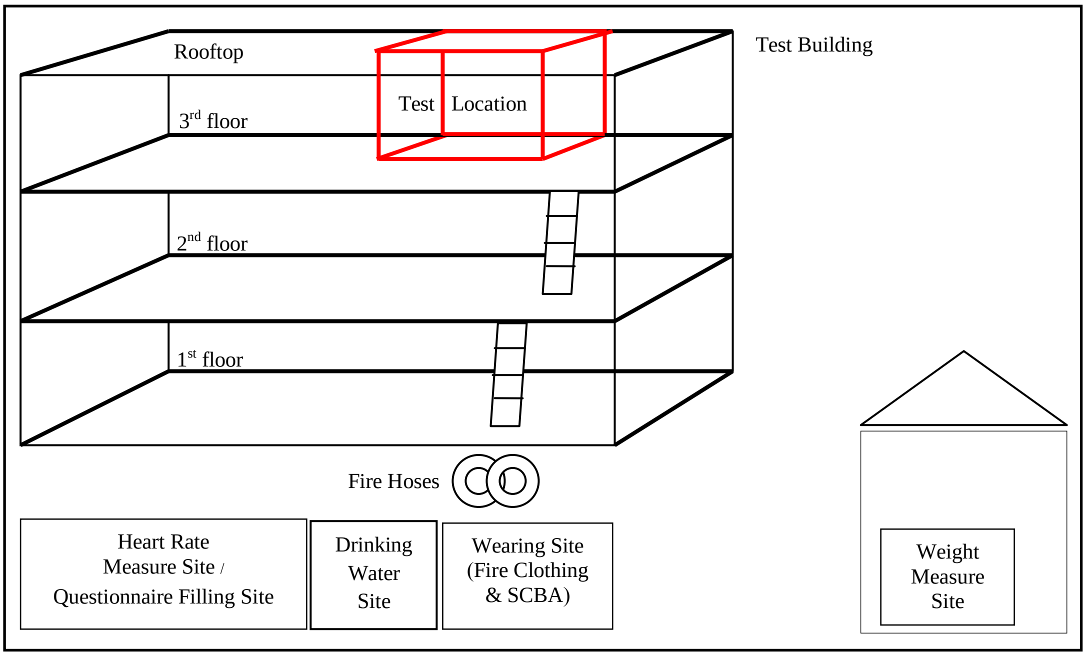

Figure 3.4 Diagram of the test stations

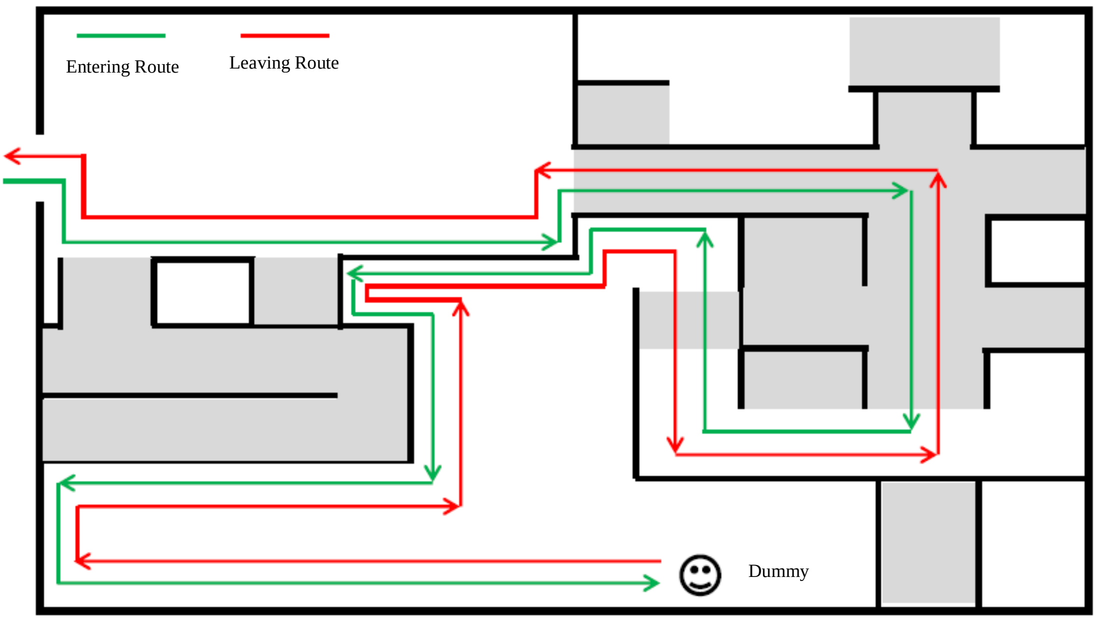

Figure 3.5 Entering and leaving routes of testing room

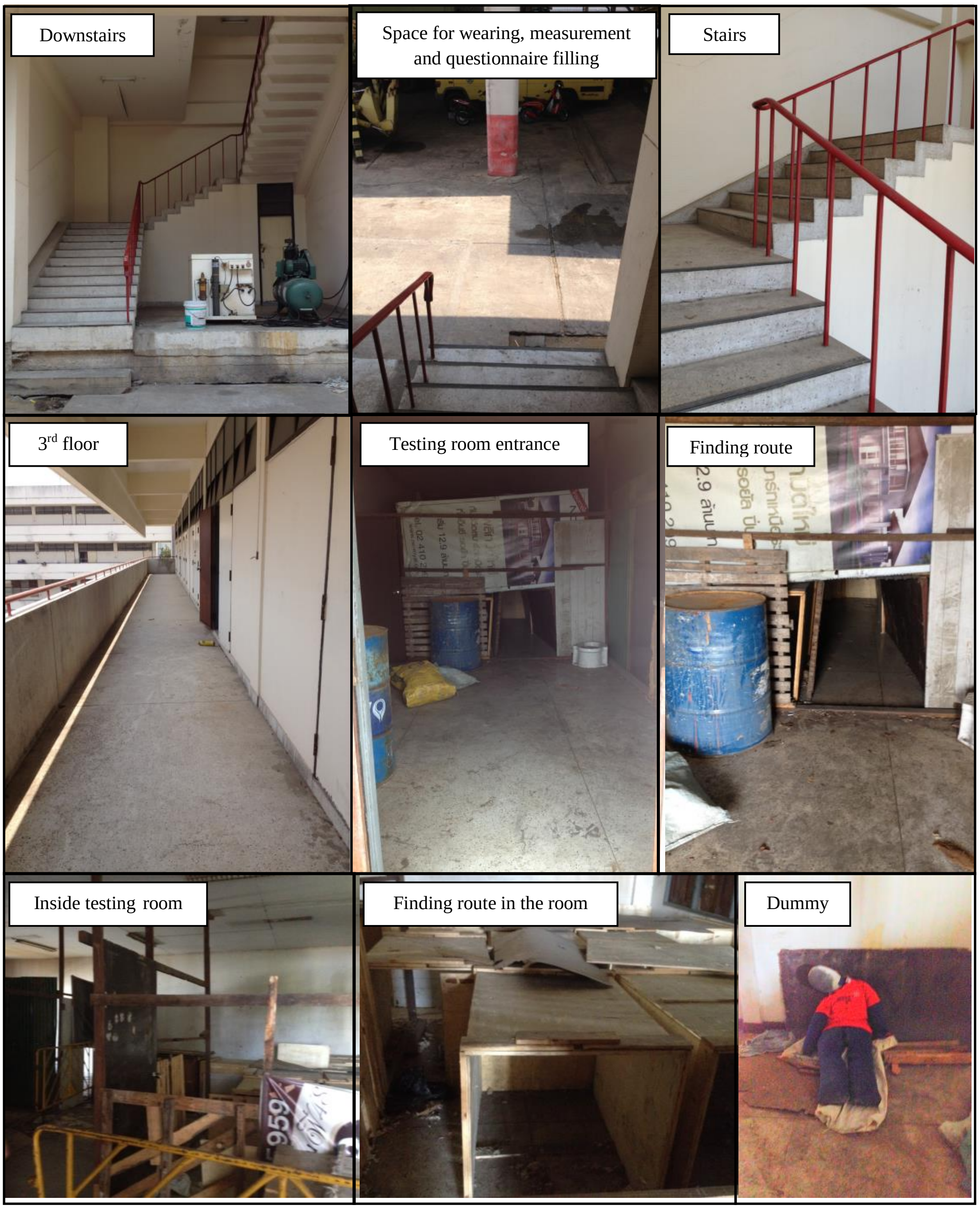

Figure 3.6 Building and environmental of testing site

3.5.4 Experimental

3.5.4.1 Before starting experiment, measured the ambient temperature both inside and outside of the building by WBGT equipment and measured the relative humidity and then recorded in data form.

3.5.4.2 Measured blood pressure of the subjects by blood pressure monitor, the blood pressure should within the normal range.

3.5.4.3 Measured heart rate of the subjects for 1 minute duration by finger heart rate monitor and recorded in data form, the heart rate should within the normal range.

3.5.4.4 Measured body weight (nude) of the subjects by weighing-machine and recorded in data form.

3.5.4.5 The subjects wearing fire clothing and SCBA.

3.5.4.6 The subjects walking to front of the building and carrying the fire hose. (fire hose 1 piece, diameter 2½ inch, length 20 meters, weight 13.2 kg)

3.5.4.7 The subjects carrying one fire hose and walking upstairs to the 3rd floor of the building (stairs have 54 steps, height 9.70 meters)

3.5.4.8 The subjects lay down the fire hose in front of the testing room and then creeping for finding the dummy (weight 60 kg) in the dark room.

3.5.4.9 After the subjects found the dummy, pulling the dummy to the outside of testing room and lay it down in front of the room (the distances from room entrance until the lay down point of the dummy 87 meters). Then carrying one fire hose and walking downstairs to the ground.

3.5.4.10 The subjects walking to the heart rate measure site and then take off SCBA and fire clothing before measurement the heart rate. Measured the heart rate 1 minute duration and recorded in data form, continuously measured until the heart rate become as the same level as before value and then recorded in data form.

3.5.4.11 The subjects walking to the wearing site and resting for 5 minutes during resting period filling in the questionnaires on body discomfort, posture and motion after using SCBA.

3.5.4.12 The subjects walking to the weight measure site and rub the body by towel to ensure dry condition before weighing and recorded in data form.

3.5.4.13 The rescue operation finished, the subjects were in normal condition without any load.

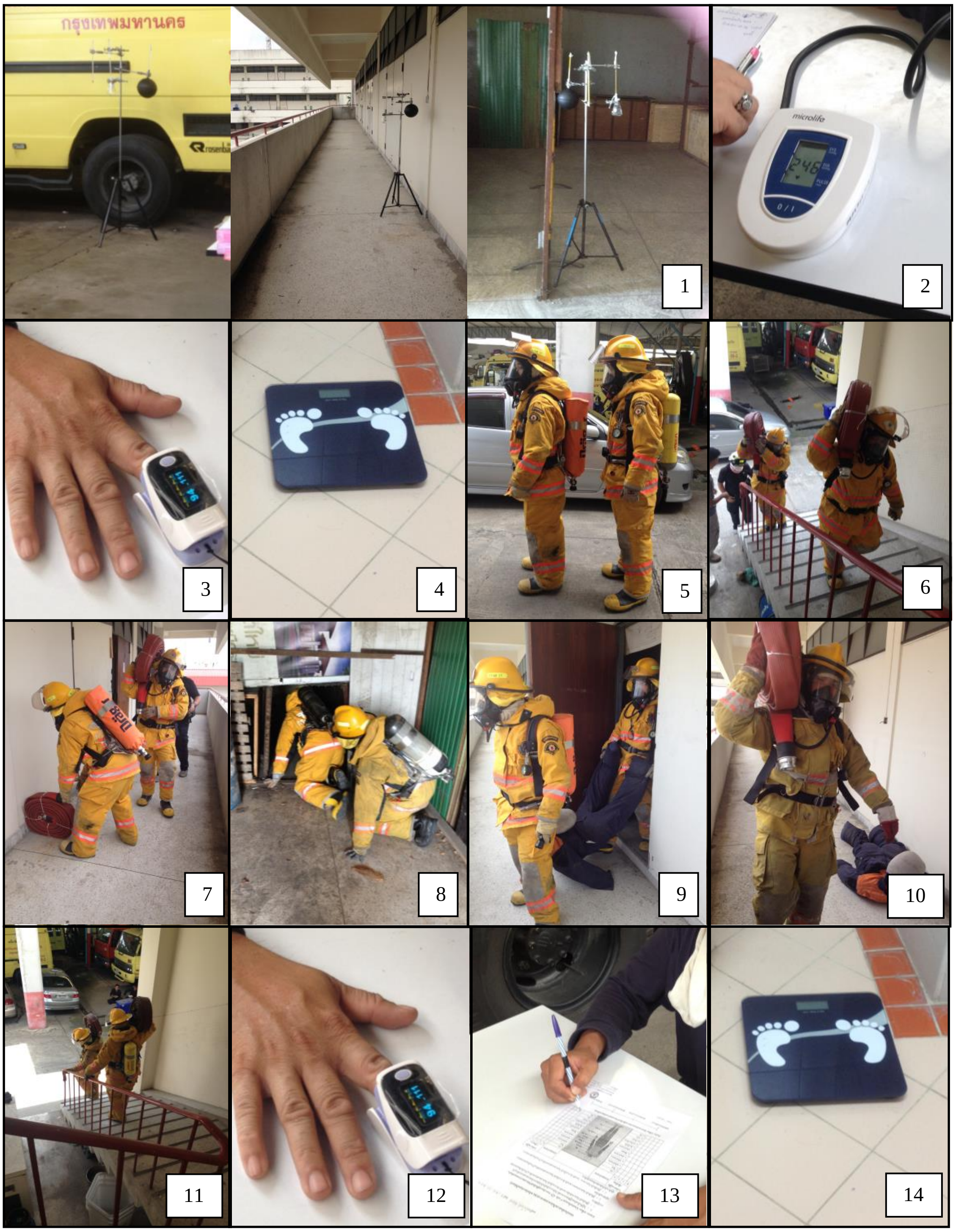

Figure 3.7 Procedure of rescue operation

3.6 Data analysis and statistical analysis

3.6.1 Data analysis

After all data were collected, the data were correctly checked and were analyzed by SPSS (Statistical Package for the Social Sciences) version 17.0 for window.

3.6.2 Descriptive statistics

The general characteristics of all data were analyzes in terms of descriptive statistics such as mean, standard deviation and percentage.

3.6.3 Inferential statistics

3.6.3.1 Heart rate

The comparison the heart rate before and after using steel SCBA, the heart rate before and after using carbon fiber SCBA was compared by Paired t-test (40). The comparison difference (Delta) of heart rate between using steel and carbon fiber SCBA was compared by Independent t-test (40).

3.6.3.2 Sweat loss

The comparison the sweat loss before and after using steel SCBA, the sweat loss before and after using carbon fiber SCBA was compared by Paired t-test (40). The comparison difference (Delta) of the sweat loss between using steel and carbon fiber SCBA was compared by Independent t-test (40).

3.6.3.3 Questionnaires

1) Body discomfort evaluation form

The comparison of difference fatigue/discomfort between using the different types of SCBAs was compared by Chi-square test.

2) Posture and motion evaluation form

The comparison of difference posture and motion between using the different types of SCBAs was compared by Chi-square test.

3.6.2 Heat

Table 3.3 Workload evaluation from using of steel SCBA

Work Activities	Energy Calculation (Kcal)	Remark
1. Carrying one fire hose from downstairs to in front of the testing room • Carrying of fire hose on plain area 1 minute Posture-Walking in plain area Activities-Work done by single arm (heavy workload) • Carrying of fire hose upstairs 1 minute Posture-Walking upstairs Activities-Work done by single arm (heavy workload)	3.0 x 1 = 3.0 Kcal 2.5 x 1 = 2.5 Kcal 7.76 x 1 = 7.76 Kcal 2.5 x 1 = 2.5 Kcal Total energy = 15.76 Kcal/2 minutes	Fire hose weight 13.2 kg Stairs height 9.70 m (9.70 x 0.8 = 7.76)
2. Creeping for finding the dummy in the testing room (6 minutes) Posture- Creeping (Walking in plain area) Activities-Work done by total body (Very heavy workload)	3.0 x 6 = 18 Kcal 9.0 x 6 = 54 Kcal Total energy = 72 Kcal/6 minutes	
3. Carrying one fire hose from the testing room to downstairs • Carrying of fire hose on plain area 1 minute Posture-Walking in plain area Activities-Work done by single arm (Heavy workload) • Carrying of fire hose downstairs 1 minute Posture-Walking downstairs Activities-Work done by single arm (Heavy workload)	3.0 x 1 = 3.0 Kcal 2.5 x 1 = 2.5 Kcal 6.79 x 1 = 6.79 Kcal 2.5 x 1 = 2.5 Kcal Total energy = 14.79 Kcal/2 minutes	Fire hose weight 13.2 kg Stairs height 9.70 m (9.70 x 0.7 = 6.79)
4. Rest (50 minutes) Posture-Walking in plain area Posture-Sitting	2.5 x 10 = 25 Kcal 0.3 x 40 = 12 Kcal Total energy = 37 Kcal/50 minutes	
5. Basal Metabolism (60 minutes)	1.0 x 60 = 60 Kcal	
Total energy for 60 minutes (1 hour)	15.76+72+14.79+37+60 = 199.55 Kcal/hr	**Light workload**

Table 3.4 Workload evaluation from using of carbon fiber SCBA

Work Activities	Energy Calculation (Kcal)	Remark
1. Carrying one fire hose from downstairs to in front of the testing room • Carrying of fire hose on plain area 1 minute Posture-Walking in plain area Activities-Work done by single arm (heavy workload) • Carrying of fire hose upstairs 1 minute Posture-Walking upstairs Activities-Work done by single arm (heavy workload)	2.5 x 1 = 2.5 Kcal 2.0 x 1 = 2.0 Kcal 7.76 x 1 = 7.76 Kcal 2.0 x 1 = 2.0 Kcal Total energy = 14.26 Kcal/2 minutes	Fire hose weight 13.2 kg Stairs height 9.70 m (9.70 x 0.8 = 7.76)
2. Creeping for finding the dummy in the testing room (6 minutes) Posture- Creeping (Walking in plain area) Activities-Work done by total body (Heavy workload)	2.5 x 6 = 15 Kcal 8.0 x 6 = 48 Kcal Total energy = 63 Kcal/6 minutes	
3. Carrying one fire hose from the testing room to downstairs • Carrying of fire hose on plain area 1 minute Posture-Walking in plain area Activities-Work done by single arm (Heavy workload) • Carrying of fire hose downstairs 1 minute Posture-Walking downstairs Activities-Work done by single arm (Heavy workload)	2.5 x 1 = 2.5 Kcal 2.0 x 1 = 2.0 Kcal 6.79 x 1 = 6.79 Kcal 2.0 x 1 = 2.0 Kcal Total energy = 13.29 Kcal/2 minutes	Fire hose weight 13.2 kg Stairs height 9.70 m (9.70 x 0.7 = 6.79)
4. Rest (50 minutes) Posture-Walking in plain area Posture-Sitting	2.0 x 10 = 20 Kcal 0.3 x 40 = 12 Kcal Total energy = 32 Kcal/50 minutes	
5. Basal Metabolism (60 minutes)	1.0 x 60 = 60 Kcal	
Total energy for 60 minutes (1 hour)	14.26+63+13.29+32+60 = 182.55 Kcal/hr	**Light workload**

3.7 Ethical Considerations

The research protocol was reviewed and approved by Ethical Review Committee for Human Research Faculty of Public Health, Mahidol University (protocol number MUPH 2014-141) (see Appendix A).

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CHAPTER IV
RESULTS

The study results of the comparison study of the use of steel and carbon fiber SCBA among firefighters: the evaluation of effects. The researcher had collected data, before and after using SCBA from firefighters performed the practice training under the simulate rescue operation in test stations. The results of this study were described in 6 parts as the following:

4.1 Personal data
4.2 Climatic conditions data
4.3 The results of the 1st hypothesis
4.4 The results of the 2nd hypothesis
4.5 The results of the 3rd hypothesis
4.6 The results of posture and motion

4.1 Personal data

The personal data of 18 male firefighters shown that the average age was 37.17 ± 6.27 years old (29-55 years old), average body weight (nude) was 66.94 ± 4.27 kilograms (62-75 kilograms), average height was 169.89 ± 4.33 centimeters (161-179 centimeters), average Body Mass Index was 23.33 ± 1.49 (19.66-24.69) and average working experiences was 8.61 ± 4.62 years (5-22 years), all of firefighters have no underlying disease and from the last 1 year all of the firefighters have no severe accident which cause major health impact (such as surgical operation, bone fracture). For the frequency of smoking, most of firefighters were none smoking 66.67 %, the secondary frequently smoking 22.2 % and rarely smoking 11.1 %. For the frequency of alcoholic drinking, most of firefighters were rarely drinking 55.6 %, later on none drinking 33.3 % and frequently drinking 11.1 %. The details as shown in table 4.1.

Table 4.1 Personal data of male firefighters (n = 18)

Personal data	Mean ± SD	Minimum	Maximum
Age (Years old)	37.17 ± 6.27	29	55
Body weight (Kilograms)	66.94 ± 4.27	62	75
Height (Centimeters)	169.89 ± 4.33	161	179
Body Mass Index, BMI	23.33 ± 1.49	19.66	24.69
Work experience (Years)	8.61 ± 4.62 (Median = 7.00)	5	22

4.2 Climatic conditions data

The climatic conditions data, the average WBGT varied between 26.43-31.10 °C and relative humidity varied between 62-75%. The details as shown in table 4.2.

Table 4.2 Climatic conditions (n = 18)

Temperature and Relative Humidity	Mean ± SD	Minimum	Maximum
Average WBGT (°C)	28.95 ± 1.23	26.43	31.10
Relative humidity (%)	66.94 ± 4.27	62	75

4.3 The results of the 1st hypothesis

The 1st hypothesis "The heart rate of firefighters between using steel and carbon fiber SCBA is different"

4.3.1 The comparison of heart rate before and after using SCBA

The results from the comparison of heart rate before and after using SCBA were analyzed by Paired t-test shown that the data had normality. The average of heart rate from using steel SCBA was 86.89 ± 7.41 beats per minute for before using steel SCBA and 125 ± 16.84 beats per minute for after using steel SCBA. The comparison of difference heart rate before and after using steel SCBA was statistically significantly different at 95 % confidence interval level ($t = -10.961$, $p < 0.001$) where the heart rate after using steel SCBA was increased from before using SCBA. The details as shown in table 4.3.

The average of heart rate from using carbon fiber SCBA was 85.50 ± 7.77 beats per minute for before using carbon fiber SCBA and 118.44 ± 11.08 beats per minute for after using carbon fiber SCBA. The comparison of difference heart rate before and after using carbon fiber SCBA was statistically significantly different at 95 % confidence interval level ($t = -12.093$, $p < 0.001$) where the heart rate after using carbon fiber SCBA was increased from before using SCBA. The details as shown in table 4.3.

Table 4.3 Comparison of heart rate before and after using SCBA (n = 18)

	Heart Rate (Beats per Minute)			
	Mean	**± SD**	**t**	**p-value***
Steel SCBA				
Before	86.89	7.41		
After	125.17	16.84	-10.961	<0.001
Carbon fiber SCBA				
Before	85.50	7.77		
After	118.44	11.08	-12.093	<0.001

* p-value for Paired t-test

4.3.2 The comparison difference (Delta) of heart rate between using steel and carbon fiber SCBA

The results from the comparison difference (Delta) of heart rate were analyzed by Independent t-test shown that the data had normality. The average difference (Delta) of heart rate from using steel SCBA was 38.28 ± 14.81 beats per minute and 32.94 ± 11.55 beats per minute for using carbon fiber SCBA. The comparison difference (Delta) of heart rate between using steel and carbon fiber SCBA was not statistically significantly different at 95 % confidence interval level (t =

1.204, p = 0.237) which not conform to the above hypothesis. The details as shown in table 4.4.

Table 4.4 Comparison difference (Delta) of heart rate (n = 18)

	Heart Rate (Beats per Minute)			
	Mean	**± SD**	**t**	**p-value***
Difference (Delta)				
Steel SCBA	38.28	14.81		
Carbon fiber SCBA	32.94	11.55	1.204	0.237

* p-value for Independent t-test

4.4 The results of the 2nd hypothesis

The 2nd hypothesis "The sweat loss of firefighters between using of steel and carbon fiber SCBA is different"

4.4.1 The comparison of sweat loss before and after using SCBA

The results from the comparison of sweat loss before and after using SCBA were analyzed by Paired t-test shown that the data had normality. The average of sweat loss from using steel SCBA was 67.50 ± 4.52 kilograms for before using steel SCBA and 66.86 ± 4.68 kilograms for after using steel SCBA. The comparison of difference sweat loss before and after using steel SCBA was statistically significantly different at 95 % confidence interval level (t = 6.264, p < 0.001) where the body weight (nude) after using steel SCBA was decreased from before using SCBA. The details as shown in table 4.5.

The average of sweat loss from using carbon fiber SCBA was 67.55 ± 4.47 kilograms for before using carbon fiber SCBA and 66.99 ± 4.46 kilograms for after using carbon fiber SCBA. The comparison of difference sweat loss before and after using carbon fiber SCBA was statistically significantly different at 95 % confidence interval level ($t = 6.887$, $p < 0.001$) where the body weight (nude) after using carbon fiber SCBA was decreased from before using SCBA. The details as shown in table 4.5.

Table 4.5 Comparison of body weight (nude) before and after using SCBA (n = 18)

	Body Weight (Nude) (Kilograms)			
	Mean	**± SD**	**t**	**p-value***
Steel SCBA				
Before	67.50	4.52		
After	66.86	4.68	6.264	<0.001
Before - After	0.63	0.42		
	(95% CI: 0.41-0.84)			
Carbon fiber SCBA				
Before	67.55	4.47		
After	66.99	4.46	6.887	<0.001
Before - After	0.55	0.34		
	(95% CI: 0.38-0.72)			

* p-value for Paired t-test

4.4.2 The comparison difference (Delta) of sweat loss between using steel and carbon fiber SCBA

The results from the comparison difference (Delta) of sweat loss were analyzed by Independent t-test shown that the data had normality. The average difference (Delta) of sweat loss from using steel SCBA was 0.63 ± 0.42 kilograms and 0.55 ± 0.34 kilograms for using carbon fiber SCBA. The comparison difference (Delta) of sweat loss between using steel and carbon fiber SCBA was not statistically significantly different at 95 % confidence interval level ($t = 0.559$, $p = 0.580$) which not conform to the above hypothesis. The details as shown in table 4.6.

Table 4.6 Comparison difference (Delta) of body weight (nude) (n = 18)

	Body Weight (Nude) (Kilograms)			
	Mean	**± SD**	**t**	**p-value***
Difference (Delta)				
Steel SCBA	0.63	0.42		
Carbon fiber SCBA	0.55	0.34	0.559	0.580

* p-value for Independent t-test

4.5 The results of the 3rd hypothesis

The 3rd hypothesis "The fatigue of firefighters between using steel and carbon fiber SCBA is different"

4.5.1 The comparison of fatigue in all body parts between using steel and carbon fiber SCBA

The results from the comparison of fatigue in all body parts from using SCBA were analyzed by Chi-square test shown that the using steel SCBA 61.1% of its user feeling fatigue, in the other hand the fatigue of carbon fiber SCBA user only 16.7 %. The comparison of difference fatigue between using steel and carbon fiber SCBA was statistically significantly different at 95% confidence interval level (p = 0.006) where the using steel SCBA caused more fatigue than using carbon fiber SCBA which conform to the above hypothesis. The details as shown in table 4.7.

Table 4.7 Comparison of fatigue in all body parts (n = 18)

Fatigue	Type of SCBA (%)			95% CI		p-value
Level	**Steel**	**Carbon Fiber**	**OR**	**Lower**	**Upper**	**for χ^2**
Fatigue	61.1	16.7				
No fatigue	38.9	83.3	7.85	1.65	37.40	0.006

4.5.2 The comparison of fatigue in each body part (left portions) between using steel and carbon fiber SCBA

The results from the comparison of fatigue in each body part (left portions) from using SCBA were analyzed by Chi-square test. The comparison of fatigue in each body part (left portions) between using steel and carbon fiber SCBA was statistically significantly different at 95% confidence interval level on shoulder (p = 0.034) and calf (p = 0.001). The fatigue on shoulder when using steel SCBA 50.0 %, in the other hand the fatigue when using carbon fiber SCBA user only 16.7 %. The fatigue on calf when using steel SCBA 44.4 % but in cases of carbon fiber SCBA usage have no fatigue on calf, which conform to the above hypothesis. The details as shown in table 4.8.

Table 4.8 Comparison of fatigue in each body part (left portions) (n = 18)

Parts of Body (Left Portions)	**Type of SCBA (%)**		**OR**	**95% CI**		**p-value for χ^2**
	Steel	**Carbon Fiber**		**Lower**	**Upper**	
Neck						
Fatigue	22.2	11.1	2.28	0.36	14.43	0.371*
No fatigue	77.8	88.9				
Shoulder						
Fatigue	50.0	16.7	5.00	1.06	23.46	0.034
No fatigue	50.0	83.3				
Upper Back						
Fatigue	33.3	22.2	1.75	0.39	7.70	0.457
No fatigue	66.7	77.4				
Lower Back						
Fatigue	33.3	11.1	4.00	0.68	23.40	0.109*
No fatigue	66.7	88.9				
Upper Arm						
Fatigue	38.9	11.1	5.09	0.88	29.26	0.054*
No fatigue	61.1	88.9				

* Fisher's Exact Test

Table 4.8 Comparison of fatigue in each body part (left portions) (n = 18) (cont.)

Parts of Body (Left Portions)	Type of SCBA (%)		OR	95% CI		p-value for χ^2
	Steel	Carbon Fiber		Lower	Upper	
Elbow						
Fatigue	22.2	11.1	2.28	0.36	14.43	0.371*
No fatigue	77.8	88.9				
Lower Arm						
Fatigue	22.2	11.1	2.28	0.36	14.43	0.371*
No fatigue	77.8	88.9				
Hand/Wrist						
Fatigue	16.7	11.1	1.60	0.23	10.94	0.630*
No fatigue	83.3	88.9				
Buttock/Thigh						
Fatigue	27.8	11.1	3.07	0.51	18.53	0.206*
No fatigue	72.2	88.9				
Knee						
Fatigue	38.9	22.2	2.22	0.51	9.59	0.278
No fatigue	61.1	77.8				
Calf						
Fatigue	44.4	0.0	2.80	1.70	4.60	0.001*
No fatigue	55.6	100.0				
Foot						
Fatigue	16.7	5.6	3.40	0.31	36.27	0.289*
No fatigue	83.3	94.4				

* Fisher's Exact Test

4.5.3 The comparison of fatigue in each body part (right portions) between using steel and carbon fiber SCBA

The results from the comparison of fatigue in each body part (right portions) from using SCBA were analyzed by Chi-square test. The comparison of fatigue in each body part (right portions) between using steel and carbon fiber SCBA was statistically significantly different at 95% confidence interval level on shoulder (p

= 0.034), upper arm (p = 0.007), elbow (p = 0.034) and calf (p = 0.035). The fatigue on shoulder when using steel SCBA 50.0 %, in the other hand the fatigue when using carbon fiber SCBA user only 16.7 %. The fatigue on upper arm when using steel SCBA 33.3 % but in cases of carbon fiber SCBA usage have no fatigue on upper arm. The fatigue on elbow when using steel SCBA 22.2 % but in cases of carbon fiber SCBA usage have no fatigue on elbow. Finally, the fatigue on calf when using steel SCBA 33.3 %, in the other hand the fatigue when using carbon fiber SCBA user only 5.6 %, which conform to the above hypothesis. The details as shown in table 4.9.

Table 4.9 Comparison of fatigue in each body part (right portions) (n = 18)

Parts of Body (Right Portions)	**Type of SCBA (%)**		**OR**	**95% CI**		**p-value for χ^2**
	Steel	**Carbon Fiber**		**Lower**	**Upper**	
Neck						
Fatigue	22.2	5.6	4.85	0.48	48.57	0.148*
No fatigue	77.8	94.4				
Shoulder						
Fatigue	50.0	16.7	5.00	1.06	23.46	0.034
No fatigue	50.0	83.3				
Upper Back						
Fatigue	33.3	16.7	2.50	0.51	12.13	0.248*
No fatigue	66.7	83.3				
Lower Back						
Fatigue	27.8	11.1	3.07	0.51	18.53	0.206*
No fatigue	72.2	88.9				
Upper Arm						
Fatigue	33.3	0.0	2.50	1.61	3.87	0.007*
No fatigue	66.7	100.0				
Elbow						
Fatigue	22.2	0.0	2.28	1.54	3.38	0.034*
No fatigue	77.8	100.0				

* Fisher’s Exact Test

Table 4.9 Comparison of fatigue in each body part (right portions) (n = 18) (cont.)

Parts of Body (Right Portions)	Type of SCBA (%)		OR	95% CI		p-value for χ^2
	Steel	Carbon Fiber		Lower	Upper	
Lower Arm						
Fatigue	22.2	16.7	1.42	0.27	7.54	0.674*
No fatigue	77.8	83.3				
Hand/Wrist						
Fatigue	16.7	5.6	3.40	0.31	36.27	0.289*
No fatigue	83.3	94.4				
Buttock/Thigh						
Fatigue	22.2	11.1	2.28	0.36	14.43	0.371*
No fatigue	77.8	88.9				
Knee						
Fatigue	33.3	16.7	2.50	0.51	12.13	0.248*
No fatigue	66.7	83.3				
Calf						
Fatigue	33.3	5.6	8.50	0.90	80.02	0.035*
No fatigue	66.7	94.4				
Foot						
Fatigue	22.2	5.6	4.85	0.48	48.57	0.148*
No fatigue	77.8	94.4				

* Fisher's Exact Test

4.6 The results of posture and motion

Except the study according to the hypothesis, in this study also found results of posture and motion. The results from the comparison of posture and motion from using SCBA were analyzed by Chi-square test. The comparison of posture and motion between using steel and carbon fiber SCBA was statistically significantly different at 95% confidence interval level on walking in plain area (p = 0.011), walking upstairs (p = 0.040), creeping (p = 0.007) and walking downstairs (p = 0.008).

The heavy feeling of SCBA during walking in plain area when using steel SCBA was 50.0 %, in the other hand the heavy feeling when using carbon fiber SCBA user only 11.1 %. The heavy feeling of SCBA during walking upstairs when using steel SCBA was 77.8 %, in the other hand the heavy feeling when using carbon fiber SCBA was 44.4 %. The heavy feeling of SCBA during creeping when using steel SCBA was 77.8 %, in the other hand the heavy feeling when using carbon fiber SCBA was 33.3 %. Finally, the heavy feeling of SCBA during walking downstairs when using steel SCBA was 72.2 %, in the other hand the heavy feeling when using carbon fiber SCBA user only 27.8 %. The details as shown in table 4.10.

Table 4.10 Comparison of posture and motion (n = 18)

Posture/ Motion	**Type of SCBA (%)**		**OR**	**95% CI**		**p-value for χ^2**
	Steel	**Carbon Fiber**		**Lower**	**Upper**	
Walking in Plain Area						
Heavy	50.0	11.1	8.00	1.40	45.40	0.011
No heavy	50.0	88.9				
Walking Upstairs						
Heavy	77.8	44.4	4.37	1.02	18.62	0.040
No heavy	22.2	55.6				
Creeping						
Heavy	77.8	33.3	7.00	1.59	30.80	0.007
No heavy	22.2	66.7				
Pulling the dummy						
Heavy	94.4	72.2	6.53	0.67	62.98	0.074*
No heavy	5.6	27.8				
Walking Downstairs						
Heavy	72.2	27.8	6.76	1.57	29.06	0.008
No heavy	27.8	72.2				

* Fisher’s Exact Test

The rescue operation in the completed test the subjects were recommended as the following:

- Steel SCBA had heavy and inconvenient for use, fatigue on shoulder, more fatigue during the walking upstairs and rust or metallic smell during using steel SCBA.
- Carbon fiber SCBA had light and convenient for use.
- Fire clothing had heavy.

CHAPTER V
DISCUSSION

The discussion of the comparison study of the use of steel and carbon fiber SCBA among firefighters was described in 3 parts as the following:

5.1 Discussion of study design

5.2 Discussion of study results

5.3 Limitations

5.1 Discussion of study design

The discussion of study design as the following:

5.1.1 Human error

5.1.1.1 Human error from the researcher: the ambient temperature measurement which reading of the thermometer scale by eyes on different types of thermometer (Dry-bulb thermometer, Wet-bulb thermometer and Globe thermometer) which can lead to error of measurement. Therefore, the researcher has specified the same person and reading angle of thermometer scale.

5.1.1.2 Human error from the researcher: inappropriate instrument types for measurement and data collection. Therefore, the researcher has thorough study on instrument types and limitation to ensure correct instrument had been selected for data collection.

5.1.1.3 Human error from the subjects: health condition of subjects during rescue operation such as illness, fatigue or insufficient sleep. Therefore, the researcher has specified criteria and conditions of the subjects before rescue operation to ensure the subjects in healthy condition. However, if the subjects in bad condition or not ready for rescue operation, the experiment need to reschedule and perform later.

5.1.2 Method error

5.1.2.1 The inappropriate of study design can lead to error of the results. Therefore, the researcher has studied appropriate study design and conforms to research objectives.

5.1.2.2 The standard training practices of firefighters were not correctly performed. Therefore, the researcher has studied standard training practices the correct to do the training from firefighting organizations or related research papers.

5.1.3 Instrument error

5.1.3.1The instruments or measuring devices for data collection of heart rate, blood pressure and body weight can lead to error of the results. Therefore, the researcher verifies the calibrated instrument for the experiment to ensure all of instruments or measuring devices are in good condition with reliable and accuracy reading.

5.1.3.2 The inappropriate of questionnaire can lead to error of the results. Therefore, the researcher studied format or description of the questionnaire applied from international related research papers.

5.1.3.3 The condition of SCBA and auxiliary equipment's in rescue operation which some of them might have damaged parts or not in good condition then leads to error of the results. Therefore, the researcher check and verify the condition of SCBA and auxiliary equipment to ensure all parts in good condition without any damages or defects before rescue operation.

However, although the attempt to reduce the error but also in this study found that the error as the following:

- Human error from the subjects: cannot control the subjects enough sleep or rest before the experiment start because the subjects shift work.
- Instrument error: the heart rate measurement (finger heart rate monitor) was not sensitivity and specificity enough. The sweat loss measurement (weighing-machine) was not sensitivity and high enough resolution.
- Instrument error: the questionnaire for evaluation of fatigue or discomfort cans error due to bias of feeling.

- The ambient temperature on both outside and inside building cannot control because field experiment.

5.2 Discussion of study results

The discussion of study results according to the hypothesis as the following:

5.2.1 Discussion of study results according to the 1st hypothesis (The heart rate of firefighters between using steel and carbon fiber SCBA is different)

5.2.1.1 Discussion of heart rate before and after using SCBA

The comparison of heart rate before and after using steel SCBA shown that the heart rate after using steel SCBA was increased from before using SCBA. In the same way, the heart rate after using carbon fiber SCBA was also increased from before using carbon fiber SCBA. Because, before using SCBA the subjects were in normal metabolism condition without an excessive activities then the body energy consumption in the basic energy usage and the heart rate was in the normal level (18). Later on, after using steel or carbon fiber SCBA the subjects' bodies and muscles need more energy to achieve the higher workload than the basic energy usage caused metabolism rate increasing, heat generated inside the body, more blood flow through the heart and lead to increased heart rate after using SCBA (8, 17, 18).

Heart rate is important parameter which indicate heart requirement for blood and heat recirculation from body core to skin. Volume of blood flow through heart is directly proportional to metabolism rate and inverse proportional to difference temperature between body and skin. If body need more energy for high work load the metabolism rate will increase caused much blood flow and increase heart rate. If the evaporation of sweat is not enough or too much body heat absorbed from heat conduction and heat radiation more blood will flow to skin for heat releasing to surrounding to reduce body temperature. Sometime, skin temperature will increase to nearly core body temperature (8).

When the energy usage of body increasing the heart rate is also increasing because more required energy means more oxygen required internal body process and the blood vessel and recirculation system need to work harder to ensure sufficient amount of oxygen can be delivered. However, in the same condition the heart rate is also difference depend on the work types. The temperature of working environment also caused increasing in heart rate because more blood recirculation needed for maximum heat releasing out of the body (18).

5.2.1.2 Discussion difference (Delta) of heart rate between using steel and carbon fiber SCBA

The difference (Delta) of heart rate between using steel and carbon fiber SCBA were not different which not conform to the hypothesis. Because, the instrument for heart rate measurement (finger heart rate monitor) was not sensitivity and specificity enough. The weight of steel SCBA was 10 kilograms and the weight of carbon fiber SCBA was 6.5 kilograms which had the different in weight of 3.5 kilograms. The experiment duration from entering to leaving building approximately 10 minutes (the duration of rescue operation in the dark room for finding the dummy 6 minutes.) which a short duration. Moreover, the results from the evaluation of average workload from using steel and carbon fiber SCBA were both light workload, light energy consumption or the rate of energy consumption less than 200 kcal/hour such as control of machine by foot, standing for work supervision, assembly of small parts or other equivalent works (9, 12, 19, 20), which made heat generated inside the body, metabolism rate, blood flow through the heart and lead to the difference (Delta) of heart rate between using steel and carbon fiber SCBA were not different.

The result of this study was different from the result of Hooper et al. (2001) (4) that clarify the higher of heart rate was found on steel SCBA when compare with carbon fiber SCBA. Because, the protocol were three conditions to the experiment and each conditions with four or five stage of 4 minutes duration, 4 minutes rest between each stage and increasing intensity through increased stepping rate, subjects rested for 24 hour between conditions which the experiment a long duration and variety of different types of activities. A Polar 300 Heart Rate Monitor used for measurement of heart rate which sensitivity and specificity well enough. The

SCBA used for testing were a lightweight composite cylinder (carbon fiber, 10 kilograms) and a conventional steel cylinder (22 kilograms) which had more the different in weight of 12 kilograms. Therefore, the result of Hooper et al. was different from this study.

The result of this study was different from the result of Griefahn et al. (2003) (5) which shown that the heart rate has statistically significantly relation with the different types of SCBA. Because, the standard exercise consisted of eight periods which were arranged in two parts, part 1 a simulated rescue work in a dwelling on the second floor, and part 2 strongly standardized elements of strenuous firefighting action which the mean time was 14.6 ± 2.1 minutes and variety of different types of activities. Heart rate recorded and stored in a recorder (Par) which was worn beneath the protective jacket before the chest, heart rate was continuously registered from leaving the instrumentation room until the end of recovery. Heart rate was calculated from the electrocardiogram which sensitivity and specificity well enough. Therefore, the result of Griefahn et al. was different from this study.

Even though, the difference (Delta) of heart rate between using steel and carbon fiber SCBA were not different, but the recovery duration which the subjects spend to recovery the heart rate level back to the normal condition (equal to before using SCBA) of carbon fiber SCBA less than the recovery duration of steel SCBA. Because, carbon fiber SCBA light weight and the recovery duration also depends on personal factors such as age, emotion, health condition and body strength (17).

5.2.2 Discussion of study results according to the 2nd hypothesis (The sweat loss of firefighters between using steel and carbon fiber SCBA is different)

5.2.2.1 Discussion of sweat loss before and after using SCBA

The comparison of sweat loss before and after using steel SCBA shown that the body weight (nude) after using of steel SCBA was decreased from before using SCBA. In the same way, the sweat loss after using carbon fiber SCBA shown that the body weight (nude) after using carbon fiber SCBA was decreased from before using SCBA. Because, before using SCBA the subjects were in normal metabolism condition without an excessive activities, then the body energy consumption in the basic energy usage (18), without any contact to heat or emotional stimulant which lead to the before using SCBA the body weight (nude) in normal level. However, after the subjects finished rescue operation with using steel or carbon fiber SCBA the body energy consumption was increasing more than the basic energy usage due to higher workload with heat generation from heavy weight and thickness of fire clothing wearing during the rescue operation. The higher heat generation caused increasing in skin temperature and body attempt to release the excess heat to the surrounding by the recirculation of blood, as heat carrier to skin and the evaporation of sweat which lead to loss of body weight after using SCBA (8, 18).

Metabolism process generates energy to body and muscular function, increase tissue temperature, increase body core temperature. Blood, as heat carrier, flow through body core to absorb the heat which causes blood temperature increasing after that blood flow to skin for heat releasing to surrounding and then flow back to body core again. Skin working as heat transfer medium between body and surrounding. Heat convection and radiation are depended on the temperature difference between skin and surrounding. The heat transfer can be both heat absorbed process, heat released process and evaporation of sweat (8).

Evaporation of sweat rate is one mode of heat transfer to reduce body heat. The excessive heat stress can caused too much amount of sweat. Normally, human body has the natural heat protection system by increasing familiar level to the surrounding heat which causes body builds more sweat, increase level of heat releasing by evaporation of sweat and reduce the body temperature (8). The evaporation of sweat always a negative (or zero) due to heat of skin use for the evaporation of sweat (water) makes the skin and body temperature decrease. The evaporation of sweat depends on clothing, temperature, speed of wind, humidity and surface area (9).

During heavy load working period, persons on age of 40-65 cannot achieve efficient work like younger persons because during age of 40-65, maximum rate of oxygen consumption reduce 20-30 % of original rate which made reduction in blood recirculation capability under same working and heat conditions. Body heat transfer of old persons also less than younger as can be seen on high body temperature of older with less blood recirculation at skin which cause sweat discharge rate of older lower, more heat generation and need longer time to restoration to normal condition (13). Fat persons or persons who have lower body surface area ratio got more problems on heat release and storage than larger body surface areas because heat transfer is depended on body surface area. Moreover, heat generation is depended on body weight, fat person with heat familiarity who working in hot environment got more health risks than less body weight persons (13).

5.2.2.2 Discussion difference (Delta) of sweat loss between using steel and carbon fiber SCBA

The different (Delta) of sweat loss between using steel and carbon fiber SCBA were not different which not conform to the hypothesis, because the instrument for sweat loss measurement (weighing-machine) was not sensitivity and high enough resolution. The weight of steel SCBA was 10 kilograms and the weight of carbon fiber SCBA was 6.5 kilograms which had the different in weight of 3.5 kilograms. The experiment duration from entering to leaving building approximately 10 minutes (the duration of rescue operation in the dark room for finding the dummy 6 minutes.) which a short duration. Moreover, the results from the evaluation of average workload from the using steel and carbon fiber SCBA were both light workload, light energy consumption or the rate of energy consumption less than 200 kcal/hour such as control of machine by foot, standing for work supervision, assembly of small parts or other equivalent works (9, 12, 19, 20), including with the surrounding temperature which vary between 26.43-31.10 °C that within the average WBGT for light workload at 34 °C and the rain during the day, which made the body heat generation, skin temperature, heat release rate and lead to the difference (Delta) of sweat loss between using steel and carbon fiber SCBA were not different.

The result of this study conform to the result of Griefahn et al. (2003) (5) which shown that the sweat loss was not varied with types of SCBA. Because, the weight of steel SCBA was 15 kilograms and the weight of carbon fiber SCBA was 11.7 kilograms which had the different in weight of 3.3 kilograms. The sweat loss over the entire exercise was indicated by the difference between the weights of the nude subjects before the exercise and after recovery (Sauter-Mettler scale). In the dwelling (Part 1) air temperature and humidities varied between 17.4 °C and 19.2 °C and between 59% and 80%, respectively, and in the exercise course (Part 2) between 23.5 °C and 24.9 °C and between 43% and 50%, respectively. Outdoor temperatures were between 11 °C and 16 °C, humidity between 50% and 94% (rain). Therefore, in this study was similar to the result of Griefahn et al.

5.2.3 Discussion of study results according to the 3rd hypothesis (The fatigue of firefighters between using steel and carbon fiber SCBA is different)

5.2.3.1 Discussion of fatigue in all body parts between using steel and carbon fiber SCBA

The fatigue in all body parts between using steel and carbon fiber SCBA indicate that the fatigue from using steel SCBA higher than carbon fiber SCBA which conform to the hypothesis. Because, in the rescue operation the subjects performed the same 2 times with different in the types of SCBA. The steel SCBA higher weight than the carbon fiber SCBA caused heavier workload of body muscle, more oxygen consumption and more energy consumption which lead to higher fatigue (18).

The result of this study conform to the result of Hooper et al. (2001)(4) which shown that the fatigue from using steel SCBA was statistically significantly different to using carbon fiber SCBA through steel SCBA more fatigue than carbon fiber SCBA. Because, discomfort was assessed at all stages of the SCBA testing by use of a body part discomfort scale (BPD) based on Corlett and Wilson. Subjects were presented with the body map immediately after completion of each test and asked to rate discomfort in terms of numbered body parts and a numeric scale. The steel SCBA (22 kilograms) higher weight than the carbon fiber SCBA (10 kilograms). Therefore, in this study was similar to the result of Hooper et al.

5.2.3.2 Discussion of fatigue in each body part (left portions) between using steel and carbon fiber SCBA

The fatigue in each body part (left portions) between using steel and carbon fiber SCBA shown that the using steel SCBA caused more fatigue on shoulder and calf, because during rescue operation the weight of SCBA was transferred to shoulder caused more fatigue in shoulder muscles. The walking upstairs and downstairs with carrying fire hose (13.2 kilograms) caused more fatigue in calf muscles. Moreover, the steel SCBA higher weight than the carbon fiber SCBA then heavier workload and higher energy consumption which leads to different feeling of fatigue after finished using two different types of SCBA.

5.2.3.3 Discussion of fatigue in each body part (right portions) between using steel and carbon fiber SCBA

The fatigue in each body part (right portions) between using steel and carbon fiber SCBA shown that the using steel SCBA cause more fatigue on shoulder, upper arm, elbow and calf. Because during rescue operation the weight of SCBA was transferred to shoulder caused more fatigue in shoulder muscles. The carrying fire hose (13.2 kilograms) on the shoulder with hand grab the fire hose and most preferred side of subjects were right side caused more fatigue in upper arm, and elbow muscles. The walking upstairs and downstairs with carrying fire hose caused fatigue in calf muscles. Moreover, the steel SCBA higher weight than the carbon fiber SCBA then heavier workload and higher energy consumption which leads to different feeling of fatigue after finished using two different types of SCBA.

The results of this study (the fatigue in each body part left and right portions) conform to the feedback from the subjects' feeling after finished the rescue operation indicate that more force pressing on their shoulder and more fatigue during the walking upstairs when using steel SCBA because the steel SCBA higher weight than the carbon fiber SCBA which caused more fatigue on shoulder and calf (left portions), more fatigue on shoulder, upper arm, elbow and calf (right portions).

5.2.4 Discussion of study results of posture and motion

Except the study according to the hypothesis, in this study also found results of posture and motion. The results shown that during using steel SCBA the subjects' feeling heavy weight during walking in plain area, walking upstairs, creeping and walking downstairs because the steel SCBA higher weight than the carbon fiber SCBA then more energy to performed rescue operation when compare with using carbon fiber SCBA.

The results of this study conform to the feedback from the subjects' feeling after finished the rescue operation indicate that steel SCBA reduce mobility and efficiency of the operation. The results of this study conform to the result of Griefahn et al. (2003) (5) which shown that the postures and movements when using carbon fiber SCBA was significantly better than using steel SCBA. The results of this study conform to the result of Punakallio et al. (2003) (6) which shown that the SCBA was the most significant single piece of equipment to decrease performance in the functional balance test, functional balance test was measured by a test in which the subjects walked forwards and backward on a wooden plank.

5.3 Limitations

5.3.1 The heart rate measurement by finger heart rate monitor was not sensitivity and specificity enough. The sweat loss measurement by weighing-machine was not sensitivity and high enough resolution.

5.3.2 The questionnaire for evaluation of fatigue or discomfort was assessed feeling of the subjects which the results can error due to bias of feeling.

5.3.3 The sweat loss measurement limitation of clothing, temperature, speed of wind, humidity and surface area.

5.3.4 The ambient temperature on both outside and inside building cannot be controlled because field experiment.

5.3.5 The rescue operation was done within only 10 minutes which a short duration and not variety of different types of activities.

CHAPTER VI
CONCLUSION

The conclusion and recommendation of this study were described in 3 parts as the following:

6.1 Conclusion

6.2 Recommendation from the findings of this study

6.3 Recommendation for the further study

6.1 Conclusion

The comparison study of the use of steel and carbon fiber self-contained breathing apparatus (SCBA) among firefighters: the evaluation of effects. The experimental study performed by eighteen firefighters and tested the heart rate, sweat loss and fatigue while using the different types of SCBAs. The results from this study can be concluded as the following:

6.1.1 The heart rate before and after using both steel and carbon fiber SCBA were different where the heart rate after using SCBA was increased from before using SCBA on both cases.

6.1.2 The difference (Delta) of heart rate between using steel and carbon fiber SCBA were not different.

6.1.3 The sweat loss before and after using both steel and carbon fiber SCBA were different where the body weight (nude) after using SCBA was decreased from before using SCBA on both cases.

6.1.4 The different (Delta) of sweat loss between using steel and carbon fiber SCBA were not different.

6.1.5 The fatigue in all body parts between using steel and carbon fiber SCBA were different where the using steel SCBA caused more fatigue than using carbon fiber SCBA.

6.1.6 The fatigue in each body part (left portions) between using steel and carbon fiber SCBA were different where the using steel SCBA caused more fatigue on shoulder and calf than using carbon fiber SCBA.

6.1.7 The fatigue in each body part (right portions) between using steel and carbon fiber SCBA were different where the using steel SCBA caused more fatigue on shoulder, upper arm, elbow and calf than using carbon fiber SCBA.

6.2 Recommendation from the findings of this study

6.2.1 In this study, the heart rate measurement by finger heart rate monitor was not sensitivity and specificity enough. Therefore, the heart rate measurement should be measured by heart rate monitor (Electrocardiogram: EKG) was continuously registered which sensitivity and specificity well enough but high cost.

6.2.2 In this study, the sweat loss measurement by weighing-machine was not sensitivity and high enough resolution. Therefore, the sweat loss measurement should be measured by weighing-machine was sensitivity and high enough resolution.

6.2.3 The sweat loss measurement should be controlled of clothing, temperature, speed of wind, humidity and surface area.

6.2.4 In this study, the questionnaire for evaluation of fatigue or discomfort was assessed feeling of the subjects which the results can error due to bias of feeling. Therefore, the fatigue or discomfort should be measured by Electromyography (EMG).

6.2.5 In this study, the rescue operation was done within only 10 minutes which a short duration than the duration in actual rescue or firefighting operation and not variety of different types of activities. Therefore, the experiment of rescue operation should be done more than 10 minutes and variety of different types of activities.

6.2.6 In this study was a field experiment which difficult to control such as ambient temperature and environment etc. Therefore, the experiment of rescue operation should be testing in experiment control room.

6.2.7 To control workload and metabolism should be studied quasi-experimental such as walking on the belt, walking on a wooden plank, aerobic fitness and step test etc.

6.2.8 When the firefighters operation with SCBA for a long duration should be used carbon fiber SCBA because light weight, convenient and less fatigue than steel SCBA.

6.3 Recommendation for the further study

6.3.1 The rescue operation in the completed test the subjects were recommended about rust smell during using steel SCBA. Therefore, the further studies should study the health effect of firefighters from rust inside steel SCBA.

6.3.2 The rescue operation in the completed test the subjects were recommended about heavy weight of fire suits (SCBA excluded). Therefore, the further studies should study the weight of fire suits and firefighting operation of firefighters.

6.3.3 The Researcher found that the most of firefighters had disproportionate body. Therefore, the further studies should study the different level of Body Mass Index (BMI) and firefighter’s work efficiency.

6.3.4 For further studies should study the health effects of firefighters from actual rescue or firefighting operation such as smoke, dust, fumes, chemicals etc. to disease surveillance.

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APPENDICES

APPENDIX A
DOCUMENTARY PROOF OF ETHICAL CLEARANCE

Certificate of Approval
Ethical Review Committee for Human Research
Faculty of Public Health, Mahidol University

COA. No. MUPH 2014-141

Protocol Title :	THE COMPARISON STUDY OF THE USE OF STEEL AND CARBON FIBER SELF-CONTAINED BREATHING APPARATUS (SCBA) AMONG FIREFIGHTERS: THE EVALUATION OF HEALTH EFFECT
Protocol No. :	92/2557
Principal Investigator :	Miss Pornwimon Tanpradid
Affiliation :	Master of Science Program in Occupational Health and Safety Faculty of Public Health, Mahidol University
Approval Includes :	1. Project proposal 2. Information sheet 3. Informed consent form 4. Data collection form/Program or Activity plan
Date of Approval :	8 July 2014
Date of Expiration :	7 July 2015

The aforementioned project have been reviewed and approved according to the Declaration of Helsinki by Ethical Review Committee for Human Research, Faculty of Public Health, Mahidol University.

(Assoc. Prof. Dr. Sutham Nanthamongkolchai)
Chairman of Ethical Review Committee for Human Research

(Assoc. Prof. Dr. Phitaya Charupoonphol)
Dean of Faculty of Public Health

420/1 Rajvithi Road, Bangkok, Thailand 10400
Tel. (662) 3548543-9 ext. 1127, 7404 Fax. (662) 6409854

A.1 Documentary proof of ethical clearance of Faculty of Public Health, Mahidol University

APPENDIX B
CERTIFICATE OF CALIBRATION
(LIQUID-IN GLASS THERMOMETER)

TECHNOLOGY PROMOTION ASSOCIATION (THAILAND-JAPAN)
CALIBRATION SERVICES AND ENVIRONMENTAL ANALYSIS DEPARTMENT
534/4 PATTANAKARN ROAD SOI 18, SUANLUANG, SUANLUANG, BANGKOK 10250
TEL. 0-2717-3000-24 FAX. 0-2719-9484

NSC-TISI-TIS17025
CALIBRATION 0008

Certificate of Calibration

Certificate No. : 14T1086
Page : 1 of 2

Equipment : Liquid-in Glass Thermometer
Manufacturer: SK
Model : -
Serial No.: -
ID No.: 6
Condition As-Received: Used Item
Received Date: 19 March 2014
Calibration Date: 24 March 2014 to 26 March 2014
Reference: 1403-0874WN
Ambient Temperature: (25 ± 3) °C
Relative Humidity: (50 ± 20) %

This certificate may not be reproduced other than in full, except with the prior written approval of the head of Calibration Services and environmental analysis department.

Submitted by: Department of Occupational Health and Safety Faculty of Public Health, Mahidol University
420/1 Ratchawithi RD., Ratchawithi District, Bangkok 10400

Procedure used: Calibration were conducted using in-house calibration procedure CP-T02 according to comparison with Industrial Platinum Resistance Thermometer (IPRT) into liquid bath temperature controller.
The temperature scale used was based on ITS-90.

Condition of this result of calibration

1.Reference standards instuments :

Instrument	Model	Serial No.	Certificate No.	Due Date
1) Digital Thermometer	1529	A7A609	131900	14 Aug 2014
2) Industrial Platinum Resistance Thermometer	5627-12	571975	131900	14 Aug 2014
3) Industrial Platinum Resistance Thermometer	5627-12	571970	131900	14 Aug 2014

2.The UUC* was immersed into liquid bath temperature controller and the top about 12 mm of the liquid column above the bath medium in every calibration points.

3.This result of calibration was found accurate as shown on date and place of calibration only.

4.This Certification is traceable to the International System of Unit maintained at:-
-National Institute of Metrology Thailand (NIMT)

Calibrated by : Thatchanan Chankong
Issue Date : 31 March 2014

Approved Signatory :
[✓] Mitr Veeratham
[ ] Phalinee Prabpaipal
[ ] Teerayooth Chuleelertwittayapon

B.1 Certificate of calibration (Liquid-in Glass Thermometer)

APPENDIX C
CLIMATIC CONDITIONS DATA

Table C.1 Climatic conditions data

Subjects	Climatic Conditions (° C)							
	Steel SCBA				Carbon Fiber SCBA			
	Average WBGT	Standard of Light load	Relative Humidity	Remark	Average WBGT	Standard of Light load	Relative Humidity	Remark
1	29.97	34	66	sunshine	29.74	34	74	sunshine
2	29.74	34	74	sunshine	29.97	34	66	sunshine
3	31.10	34	66	sunshine	29.49	34	74	sunshine
4	29.49	34	74	sunshine	31.10	34	66	sunshine
5	28.22	34	66	rain	29.61	34	74	sunshine
6	29.61	34	74	sunshine	28.22	34	66	rain
7	26.43	34	88	rain	29.50	34	74	sunshine
8	29.50	34	74	sunshine	26.43	34	88	rain
9	30.60	34	66	sunshine	28.37	34	74	sunshine
10	28.37	34	74	sunshine	30.60	34	66	sunshine
11	28.08	34	88	no sunshine	28.48	34	74	sunshine
12	28.48	34	74	sunshine	28.08	34	88	no sunshine
13	27.66	34	88	cloudy, rain	29.19	34	74	sunshine
14	29.19	34	74	sunshine	27.66	34	88	cloudy, rain
15	27.78	34	88	cloudy	27.49	34	74	rain
16	27.49	34	74	rain	27.78	34	88	cloudy
17	30.78	34	66	cloudy, rain	28.68	34	74	sunshine
18	28.68	34	74	sunshine	30.78	34	66	cloudy, rain

APPENDIX D
HEART RATE DATA

Table D.1 Heart rate data

Subjects	Heart Rate (beats per minute)					
	Steel SCBA			**Carbon Fiber SCBA**		
	Before	After	Difference (Delta)	Before	After	Difference (Delta)
1	86	126	40	75	116	41
2	91	109	18	92	139	47
3	74	118	44	78	95	17
4	90	112	22	97	123	26
5	80	132	52	82	121	39
6	87	121	34	77	137	60
7	89	149	60	81	120	39
8	93	121	28	77	116	39
9	108	172	64	98	128	30
10	88	140	52	92	124	32
11	90	113	23	94	103	9
12	82	115	33	91	115	24
13	85	131	46	82	120	38
14	91	108	17	84	105	21
15	84	139	55	80	115	35
16	88	111	23	91	119	28
17	76	108	32	76	109	33
18	82	128	46	92	127	35

APPENDIX E
SWEAT LOSS DATA

Table E.1 Sweat loss data

Subjects	Sweat Loss (Kilogram)					
	Steel SCBA			**Carbon Fiber SCBA**		
	Before	After	Difference (Delta)	Before	After	Difference (Delta)
1	70.00	69.25	0.75	69.10	68.75	0.35
2	66.95	66.20	0.75	67.60	66.95	0.65
3	62.50	61.30	1.20	62.30	62.15	0.15
4	60.05	59.25	0.80	61.00	60.25	0.75
5	68.30	67.65	0.65	68.05	67.90	0.15
6	71.65	71.25	0.40	71.80	71.20	0.60
7	70.30	69.55	0.75	69.55	68.80	0.75
8	72.05	71.40	0.65	72.00	71.70	0.30
9	62.70	60.75	1.95	62.30	61.60	0.70
10	61.65	61.45	0.20	61.70	60.70	1.00
11	69.05	68.45	0.60	68.95	68.70	0.25
12	70.00	69.70	0.30	70.50	70.35	0.15
13	74.55	74.25	0.30	74.10	72.65	1.45
14	71.40	70.60	0.80	72.20	71.35	0.85
15	61.70	61.30	0.40	62.35	61.60	0.75
16	63.95	63.50	0.45	63.65	63.35	0.30
17	65.05	64.75	0.30	64.95	64.50	0.45
18	73.15	73.05	0.10	73.80	73.35	0.45

APPENDIX F
FATIGUE DATA

Table F.1 Fatigue in each body part data (steel SCBA)

Parts of body	Steel SCBA							
	Left Portions (Percentage)				Right Portions (Percentage)			
	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue
1. neck	22.2	55.6	11.1	11.1	27.8	50.0	16.7	5.6
2. shoulder	22.2	27.8	38.9	11.1	16.7	33.3	44.4	5.6
3. upper back	16.7	50.0	16.7	16.7	16.7	50.0	16.7	16.7
4. lower back	16.7	50.0	33.3	0.0	22.2	50.0	27.8	0.0
5. upper arm	22.2	38.9	33.3	5.6	27.8	38.9	27.8	5.6
6. elbow	27.8	50.0	22.2	0.0	27.8	50.0	22.2	0.0
7. lower arm	16.7	61.1	22.2	0.0	27.8	50.0	22.2	0.0
8. hand/wrist	38.9	44.4	11.1	5.6	33.3	50.0	11.1	5.6
9. Buttock/Thigh	38.9	33.3	16.7	11.1	44.4	33.3	16.7	5.6
10. knee	22.2	38.9	22.2	16.7	22.2	44.4	22.2	11.1
11. calf	22.2	33.3	44.4	0.0	22.2	44.4	33.3	0.0
12. foot	33.3	50.0	16.7	0.0	38.9	38.9	22.2	0.0

Table F.2 Fatigue in each body part data (carbon Fiber SCBA)

Parts of body	Carbon Fiber SCBA							
	Left Portions (Percentage)				Right Portions (Percentage)			
	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue
1. neck	27.8	61.1	11.1	0.0	27.8	66.7	5.6	0.0
2. shoulder	11.1	72.2	16.7	0.0	16.7	66.7	16.7	0.0
3. upper back	38.9	38.9	16.7	5.6	33.3	50.0	11.1	5.6
4. lower back	33.3	55.6	5.6	5.6	33.3	55.6	5.6	5.6
5. upper arm	33.3	55.6	11.1	0.0	27.8	72.2	0.0	0.0
6. elbow	38.9	50.0	11.1	0.0	38.9	61.1	0.0	0.0
7. lower arm	38.9	50.0	11.1	0.0	38.9	44.4	16.7	0.0
8. hand/wrist	27.8	61.1	11.1	0.0	33.3	61.1	5.6	0.0
9. Buttock/Thigh	44.4	44.4	11.1	0.0	38.9	50.0	11.1	0.0
10. knee	44.4	33.3	22.2	0.0	33.3	50.0	16.7	0.0
11. calf	27.8	72.2	0.0	0.0	33.3	61.1	5.6	0.0
12. foot	33.3	61.1	5.6	0.0	33.3	61.1	5.6	0.0

Table F.3 Fatigue in all body parts data

	Steel SCBA (Percentage)				Carbon Fiber SCBA (Percentage)			
	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue	No Fatigue	Light Fatigue	Moderate Fatigue	Heavy Fatigue
Total body	11.1	27.8	44.4	16.7	11.1	72.2	16.7	0.0

APPENDIX G
POSTURE AND MOTION DATA

Table G.1 Posture and motion data

Posture and motion	Steel SCBA (Percentage)				Carbon Fiber SCBA (Percentage)			
	No Heavy	Light Heavy	Moderate Heavy	Very Heavy	No Heavy	Light Heavy	Moderate Heavy	Very Heavy
Walking in Plain Area	5.6	44.4	50.0	0.0	11.1	77.8	11.1	0.0
Walking Upstairs	0.0	22.2	50.0	27.8	5.6	50.0	44.4	0.0
Creeping	0.0	22.2	44.4	33.3	5.6	61.1	33.3	0.0
Pulling the dummy	5.6	0.0	55.6	38.9	0.0	27.8	61.1	11.1
Walking Downstairs	5.6	22.2	55.6	16.7	11.1	61.1	22.2	5.6

APPENDIX H
BODY DISCOMFORT EVALUATION FORM

<u>ส่วนแรก</u> : <u>คำชี้แจง</u> โปรดทำเครื่องหมาย ✓ ลงใน "☐" ตามระดับความรู้สึกเมื่อยล้าของร่างกายแยกเป็นส่วน

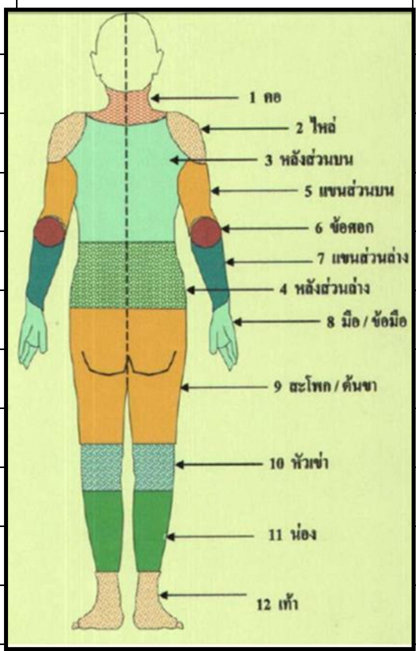
0 = ไม่รู้สึกเมื่อยล้าเลย/รู้สึกสบาย หมายถึง ไม่มีอาการเมื่อยล้าหรือไม่มีอาการไม่สบายตามตำแหน่งที่ระบุไว้

1 = รู้สึกเมื่อยล้า/ไม่สบายเล็กน้อย หมายถึง มีอาการเมื่อยล้า/ไม่สบายตามตำแหน่งที่ระบุไว้ แต่ไม่เป็นอุปสรรคต่อการปฏิบัติงาน

2 = รู้สึกเมื่อยล้า/ไม่สบายปานกลาง หมายถึง มีอาการเมื่อยล้า/ไม่สบายตามตำแหน่งที่ระบุไว้ จนเป็นอุปสรรคต่อการปฏิบัติงานเล็กน้อย

3 = รู้สึกเมื่อยล้า/ไม่สบายมาก หมายถึง มีอาการเมื่อยล้า/ไม่สบายตามตำแหน่งที่ระบุไว้ จนเป็นอุปสรรคต่อการปฏิบัติงานถึงขั้นต้องพักหรือหยุดปฏิบัติงาน

ระดับความรู้สึก (ซีกซ้าย)				ส่วนของร่างกาย		ส่วนของร่างกาย	ระดับความรู้สึก (ซีกขวา)			
0	1	2	3				0	1	2	3
				1. คอ		1. คอ				
				2. ไหล่		2. ไหล่				
				3. หลังส่วนบน		3. หลังส่วนบน				
				4. หลังส่วนล่าง		4. หลังส่วนล่าง				
				5. แขนส่วนบน		5. แขนส่วนบน				
				6. ข้อศอก		6. ข้อศอก				
				7. แขนส่วนล่าง		7. แขนส่วนล่าง				
				8. มือ/ข้อมือ		8. มือ/ข้อมือ				
				9. สะโพก/ต้นขา		9. สะโพก/ต้นขา				
				10. หัวเข่า		10. หัวเข่า				
				11. น่อง		11. น่อง				
				12. เท้า		12. เท้า				



<u>ส่วนสอง</u> : <u>คำชี้แจง</u> โปรดวงกลมตัวเลขระดับความรู้สึกเมื่อยล้า/ไม่สบายของร่างกายโดยรวมทั้งหมด

0	1	2	3
ไม่รู้สึกเมื่อยล้าเลย/รู้สึกสบาย	รู้สึกเมื่อยล้า/ไม่สบายเล็กน้อย	รู้สึกเมื่อยล้า/ไม่สบายปานกลาง	รู้สึกเมื่อยล้า/ไม่สบายมาก

APPENDIX I
POSTURE AND MOTION EVALUATION FORM

ท่าทาง/การเคลื่อนไหว จากการใช้ SCBA แบบชนิดถังเหล็ก

<u>คำชี้แจง</u> โปรดทำเครื่องหมาย ✓ ลงใน "☐" ตามระดับความรู้สึกที่มีต่อท่าทาง/การเคลื่อนไหว

0 = ไม่รู้สึกหนักเลย หมายถึง ไม่มีความรู้สึกหนักและไม่เป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน

1 = รู้สึกหนักเล็กน้อย หมายถึง มีความรู้สึกหนักแต่ไม่เป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน

2 = รู้สึกหนักปานกลาง หมายถึง มีความรู้สึกหนักจนเป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงานเล็กน้อย

3 = รู้สึกหนักมาก หมายถึง มีความรู้สึกหนักจนเป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน ไม่สามารถปฏิบัติงานต่อได้หรือต้องหยุดพัก

ท่าทาง/การเคลื่อนไหว	ระดับความรู้สึก			
	0 ไม่รู้สึกหนักเลย	**1** รู้สึกหนักเล็กน้อย	**2** รู้สึกหนักปานกลาง	**3** รู้สึกหนักมาก
1. เมื่อเดินบนพื้นราบโดยใช้งาน SCBA ชนิดถังเหล็กท่านรู้สึกอย่างไร				
2. เมื่อเดินขึ้นบันไดโดยใช้งาน SCBA ชนิดถังเหล็กท่านรู้สึกอย่างไร				
3. เมื่อคลานโดยใช้งาน SCBA ชนิดถังเหล็กท่านรู้สึกอย่างไร				
4. เมื่อลากหุ่นจำลองโดยใช้งาน SCBA ชนิดถังเหล็กท่านรู้สึกอย่างไร				
5. เมื่อเดินลงบันไดโดยใช้งาน SCBA ชนิดถังเหล็กท่านรู้สึกอย่างไร				

ท่าทาง/การเคลื่อนไหว จากการใช้ SCBA แบบชนิดถังคาร์บอนไฟเบอร์

<u>คำชี้แจง</u> โปรดทำเครื่องหมาย ✓ ลงใน "☐" ตามระดับความรู้สึกที่มีต่อท่าทาง/การเคลื่อนไหว

0 = ไม่รู้สึกหนักเลย หมายถึง ไม่มีความรู้สึกหนักและไม่เป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน

1 = รู้สึกหนักเล็กน้อย หมายถึง มีความรู้สึกหนักแต่ไม่เป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน

2 = รู้สึกหนักปานกลาง หมายถึง มีความรู้สึกหนักจนเป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงานเล็กน้อย

3 = รู้สึกหนักมาก หมายถึง มีความรู้สึกหนักจนเป็นอุปสรรคต่อท่าทาง/การเคลื่อนไหวในการปฏิบัติงาน ไม่สามารถปฏิบัติงานต่อได้หรือต้องหยุดพัก

ท่าทาง/การเคลื่อนไหว	**ระดับความรู้สึก**			
	0 ไม่รู้สึกหนักเลย	**1** รู้สึกหนักเล็กน้อย	**2** รู้สึกหนักปานกลาง	**3** รู้สึกหนักมาก
6. เมื่อเดินบนพื้นราบโดยใช้งาน SCBA ชนิดถังคาร์บอนไฟเบอร์ท่านรู้สึกอย่างไร				
7. เมื่อเดินขึ้นบันไดโดยใช้งาน SCBA ชนิดถังคาร์บอนไฟเบอร์ท่านรู้สึกอย่างไร				
8. เมื่อคลานโดยใช้งาน SCBA ชนิดถังคาร์บอนไฟเบอร์ท่านรู้สึกอย่างไร				
9. เมื่อลากหุ่นจำลองโดยใช้งาน SCBA ชนิดถังคาร์บอนไฟเบอร์ท่านรู้สึกอย่างไร				
10. เมื่อเดินลงบันไดโดยใช้งาน SCBA ชนิดถังคาร์บอนไฟเบอร์ท่านรู้สึกอย่างไร				

APPENDIX J
QUESTIONNAIRE

คำชี้แจง โปรดกรอกข้อมูลลงใน "……." หรือทำเครื่องหมาย ✓ ลงใน "☐

1. เพศ……………………….

2. อายุ………………………..ปี

3. น้ำหนัก……………………กิโลกรัม

4. ส่วนสูง……………………เซนติเมตร

5. ประสบการณ์ในการทำงานเป็นพนักงานดับเพลิง……………ปี…………เดือน

6. ในช่วงระยะเวลา 1 ปีที่ผ่านมาท่านได้เกิดอุบัติเหตุที่ส่งผลกระทบรุนแรงต่อสุขภาพร่างกายหรือไม่ (เช่น การผ่าตัด กระดูกหัก เป็นต้น)

☐ ไม่เคย ☐ เคย ระบุ……………………………

7. ท่านมีโรคประจำตัวหรือไม่

☐ ไม่มี ☐ มี ระบุ………………………………

8. ความถี่ในการสูบบุหรี่

☐ เป็นประจำ ☐ นานๆครั้ง ☐ ไม่สูบเลย

9. ความถี่ในการดื่มแอลกอฮอล์

☐ เป็นประจำ ☐ นานๆครั้ง ☐ ไม่ดื่มเลย

10. ข้อเสนอแนะ……………………………………………………………………………......

BIOGRAPHY

NAME	Miss Pornwimon Tanpradid
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