THE EFFECT OF VAPOR PERMEABLE VERSUS NON-VAPOR PERMEABLE SHIRTS ON HEAT STRESS

by

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ABSTRACT

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Everything in a paper mill operates on a gargantuan scale, including the hazards, which can include everything from falls to in-running nip points to heat stress. While heat stress would not be considered one of the major hazards, it can still put some employees at a high risk of developing heat stress-related injuries.

To combat the threat posed by heat stress, a variety of different engineering and administrative controls such as work restrictions, ventilation changes and vapor permeable clothing have been developed. Two separate tests were conducted to study the effects of clothing and ventilation controls on worker heat strain. In the first test, five subjects wore a shirt containing vapor permeable material followed by a cotton shirt while conducting normal work duties. The vapor permeable material was manufactured by Nike, Inc. and marketed under the trade name Dri-FIT. A Questemp II personal heat stress monitor was used to determine body core temperatures and a subjective evaluation of the two shirts was conducted. Results indicate the vapor permeable shirt reduced core temperatures by about 0.3-0.5ºC compared to the cotton shirt. In addition, the vapor

permeable shirt was rated to be more comfortable and to have a faster drying time than the cotton shirt. The data suggests that vapor permeable shirts allow more skin cooling to take place, thereby reducing the body core temperature.

In the ventilation test, environmental heat stress readings were taken with a Metrosonics hs-360 heat stress monitor and were used to determine if increasing building make-up air and adding a new exhaust fan would reduce temperatures in the pulp and paper production areas. Results indicated a 1-1.5ºC temperature reduction in the pulp production area and about a 5ºC temperature reduction in the paper production area. The data suggests increasing make-up air and adding an exhaust fan can decrease temperatures in the pulp and paper production area, however, temperatures outside the mill dropped by about 5-8ºC between ventilation changes, which may have had an effect on the temperature inside the mill.

It was concluded that using vapor permeable clothing and modifying the building's ventilation by increasing make-up air and adding an exhaust fan could reduce heat stress and worker heat strain. Recommendations were made for the mill to suggest the vapor permeable shirt as a heat stress control for affected employees and to install additional exhaust fans and increase make-up air in areas where the tested ventilation modifications had no effect.

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CHAPTER ONE

Introduction

Everything in a paper mill operates on large scale; four-story tall, 600 ft. long machines produce 4,000 ft. of paper per minute (B. Weihs, personal communications, June 20, 2001) and wind the paper onto rolls that can weigh as much as 65,000 lbs. ("Mill Manufacturing Process," n.d.). Mills may also have several power plants and a waste treatment plant on-site to handle the needs of the mill.

Similar to the size issue of a paper mill, the hazards are also significant and can include everything related to confined spaces, fall protection, and multiple nip points. The paper manufacturing process uses steam and pressure to turn wood chips into pulp and to force water out of the pulp ("Mill Manufacturing Process," n.d.). These processes generate high temperatures and humidity as a byproduct, which can cause heat stress related issues among the mill employees.

XYZ paper mill, located in the Upper Midwest has many of these hazards in its operations; the mill employs 600 people in the production of lightweight coated paper for magazines and catalogs ("Mill Manufacturing Process," n.d.). Two areas in the mill generate hot, humid conditions; the first one is the pulping building, where steam and high pressure are used to convert wood chips into pulp slurry that is almost 100% water ("Mill Manufacturing Process," n.d.). The second hot, humid area is the paper machine building, where the pulp is sprayed onto a moving belt and steam and pressure are used to remove water from the pulp, leaving paper behind. Temperatures in these areas can average 30ºC (86ºF) wet bulb globe temperature (WBGT) (*Industrial Hygiene Survey-Heat Stress*, 2001).

Because of the difficulty of controlling the internal environment, the mill has adopted several engineering and administrative controls to reduce the risk of heat stress related injuries. From an engineering standpoint, most of the machinery is automated so employees usually stay in air-conditioned control rooms or booths during normal operations. These employees would only need to be in a hot, humid environment such as the operating floor during a paper breakage or during monthly maintenance on the machine. Other engineering controls include shielding for the hot sections of the paper machine, water fountains on the operating floor and several large ventilation ducts on the operating floor that bring in outside air. The mill has also added new exhaust fans and increased make-up air in an attempt to reduce the temperature in the hot, humid areas. Administrative controls utilized to minimize heat stress include frequent rest breaks for employees, having ice water available and providing ice vests for the employees. When maintenance/repair duties dictate, millwrights, utility workers and clothing technicians spend several hours at a time in hot and humid environments. Because of their duties and the areas they are performed in, these employees are at a high risk of developing heat stress-related injuries.

Purpose

The purpose of this study is to examine means of minimizing heat stress for employees working in the pulp and paper production areas of the mill.

Goals

1. To compare vapor permeable and non-vapor permeable shirts as a method for reducing heat stress among millwrights, utility workers and clothing technicians.

2. To analyze environmental heat stress data before and after the installation of new exhaust fans and an increase in ventilation to see if these modifications reduced temperature and humidity in the pulp and paper production areas.

Background and Significance

Temperatures in the pulp and paper production areas in the mill average around 30ºC (86ºF) WBGT and these temperatures can climb even higher after a series of hot, humid days. Table 1 shows temperature readings in both pulp and paper areas during normal operations during the summer. Exterior temperatures were around 80ºF (26.6ºC) with around 35% relative humidity. Table 2, on the other hand shows the increase in temperatures after several days of abnormal hot and humid conditions. The exterior conditions that existed while readings were taken for table 2 were around 85- 90ºF (29.4-32ºC) with a relative humidity (RH) of 80-90%. The temperature only increased 5-10ºF, but the relative humidity jumped from 35% to between 80-90%. Mill employees worked a normal schedule during the average 30ºC (86ºF) WBGT conditions, but curtailed most work in the pulp and production areas during the high temperature and humidity conditions presented in Table 2.

Even though mill employees worked a normal schedule during the average 30ºC (86ºF) WBGT conditions, they may still be at risk for heat stress related injuries that can range from heat cramps to heat stroke, which is a life threatening medical emergency (Olishifski, 1988). Two high profile football player deaths during the summer of 2001 demonstrate the seriousness of heat stroke. First Eraste Autin, an incoming freshman at Florida, died of heat stroke after finishing a workout in 88ºF (31ºC) dry bulb temperatures and 72% RH (Associated Press, 2001a). Then, Korey Stringer, an offensive tackle on the Minnesota Vikings football team, died of heat stroke during training camp after spending several hours outdoors performing hitting drills in 85ºF (29.4ºC) dry bulb temperatures and 77% RH. (Associated Press, 2001b).

Table 1:

Heat stress readings in pulp & paper production area during summer/fall 2001

Location (pulp area)	Temp. (WBGT)		Location (paper area)	Temp. (WBGT)
Basement	30.5ºC (86.9ºF)		Wet end	30.0ºC (86.0ºF)
Operating floor	28.1ºC (82.5ºF)		Fourdrinier	32.2ºC (89.9ºF)
Mezzanine	31.4ºC (88.5ºF)		First dryer	32.6ºC (90.6ºF)
Chip bins	32.0ºC (89.6ºF)		First coater	29.7ºC (85.4ºF)
Hi rise	31.2ºC (88.2ºF)		Second coater	29.8ºC (85.6ºF)

Note. Data collected with Metrosonics Hs-360 Heat Stress Monitor, SN 1723

Table 2:

Heat stress readings in pulp & paper production areas during higher than normal temperature conditions in summer/fall 2001.

Location	Temp. (WBGT)
Pulp-operating floor	35.2ºC (95.3ºF)
Pulp-hallway	37.5ºC (99.5ºF)
Paper machine-press controls	34.2ºC (93.5ºF)
Paper machine-first dryer controls	34.4ºC (93.9ºF)
Paper machine-first coater controls	33.5ºC (92.3ºF)
Paper machine-second coater controls	33.8ºC (92.8ºF)

Note. Data collected with Metrosonics Hs-360 Heat Stress Monitor, SN 1723

In addition to causing injuries and fatalities, heat stress may also cost money in workers' compensation claims. For example, the average claim cost for heat stress injuries in Wisconsin for 1998-2000 was $14,061.66. (Wisconsin Division of Workplace Development, 2001). This number can represent an even greater cost to the company over time since insurance companies typically apply a loss factor of $1.00 to $3.00 on average to each claim to determine the cost to the company over three years (C. Jameson, personal communications, September 17, 2001).

Abnormal hot, humid conditions represented in Table 2 may have reduced worker productivity, but they enhanced the productivity of the paper machine. During those conditions, the paper machine ran with fewer paper breaks than normal (B. Weihs, personal communications, August 9, 2001). On the other hand, hot, humid conditions may cause a problem is if they occur during a scheduled maintenance day or if the machine breaks down. During maintenance or machine break down, most employees are out in the hot, humid environment while cleaning and conducting maintenance work on the machine. Despite the increased machine productivity, worker productivity may suffer during these hot, humid conditions.

Limitations

Several limitations have been identified by the researcher. They are:

1. Not all the subjects work in the same areas during sampling.
2. Due to financial and workload limitations, only one subject was sampled per day. Different days can have different outside temperatures.
3. Instructions for the heat stress monitor used for this study require a re-calibration if the environment changes more than 10ºC. The calibration procedure takes 10 minutes each time. Trying to re-calibrate each time a subject moved between different environments would have been impossible since subjects are always moving around to different areas and environments in the mill.

Definition of Terms

- Wet Bulb Globe Temperature (WBGT). A temperature index of the environmental conditions that may contribute to heat stress (American Conference of Governmental Industrial Hygienists (ACGIH), 2001). It combines temperature, radiant heat and humidity into one number. The WBGT is based on two different equations depending on exposure to direct sunlight (radiant heat). The equations are:

I. For use with exposure to direct sunlight

$WBGT_{out}=0.7T_{wb} + 0.2T_g + 0.1T_{db}$

II. For use without exposure to direct sunlight

$WBGT_{in}=0.7T_{wb} + 0.3T_g$ (ACGIH, 2001)

- T_{db}=dry bulb temperature. This is used to determine ambient temperature and does not account for effects from humidity and radiant heating (ACGIH, 2001)
- T_g=globe temperature. This is used to determine temperature from radiant heating (ACGIH, 2001).
- T_{wb}=wet bulb temperature. This is used in combination with the dry bulb temperature to arrive at a relative humidity reading (ACGIH, 2001).
- Make-up air. Outside air brought into a building to replace air that has been exhausted out (Occupational Safety and Health Administration [OSHA], 2001b).

CHAPTER TWO

Literature Review

Introduction

Heat related injuries such as heat stroke have affected humans and changed history for many years, especially in military encounters. Hot conditions decimated an entire Roman army in 24 B.C. (United States Army, n.d.). During the Civil War of 1861-1865, 313 soldiers on the Union side died of heat stroke, although this number may be low considering a little over 250,000 soldiers died of diseases and other non-battle injuries (Weeks, 1997) and most soldiers fought in heavy uniforms during the heat of the summer. These conditions could make a soldier more at risk for heat stroke. This hazard has affected Civil War Re-enactors as well, several websites offer information and tips to avoid heat stroke while re-enacting Civil War battles (Carson & Rhodes, 2001; Peters, 2001). More recently, during the 1967 war, 20,000 Egyptian soldiers died of heat stroke while Israeli soldiers had only 128 casualties due to the heat (Department of the Army, 1989). Possibly because of these losses, the U.S. military has heat stress standards in place and conducts many studies on heat stress, including studies comparing heat stress in different types of uniforms.

In addition to military operations, heat stress may affect workers in many different occupations including foundries, glass products facilities, bakeries, commercial kitchens, laundry facilities, paper mills, construction work, asbestos removal and hazardous waste sites. Possibly due to the dangers posed by hot, humid conditions, much research has been performed on heat stress in various industries. For example, mining industries in Australia and South Africa have performed research on heat stress since these industries can spend up to half their production costs on ventilating and cooling deep mines where conditions can exceed 60ºC (140ºF) and almost 100% humidity (Honeyager, 1998).

Background

Heat stress factors.

Heat stress is defined as the total heat load from the human body's metabolic processes and environmental factors such as high temperature and high humidity (American Conference of Governmental Industrial Hygienists [ACGIH], 2001). The body's physiological response to heat stress is referred to as heat strain (ACGIH, 2001) and can be influenced by other factors including: a person's age, weight, physical fitness, metabolism, degree of acclimatization to the heat and use of alcohol or drugs. A variety of existing medical conditions such as hypertension and previous cases of heat injuries can also affect sensitivity to heat (OSHA, 1999). In contrast, heat stress can be caused by environmental factors including ambient air temperature, radiant heat, air movement, relative humidity and sweat evaporation (OSHA, 1999). These environmental and physiological factors, either alone or in combination may affect a person's sensitivity to hot, humid conditions.

Despite the environmental and physiological factors that can increase the amount of heat stress on a worker, their body can counteract some of the heat stress by transferring heat from the body core to the skin through increasing heart rate and dilating the skin capillaries. This brings more blood near the skin surface to increase the rate of cooling (Olishifski, 1988). Sweating will also increase since the evaporation of sweat also cools the body (OSHA, 1999). Once heat has been transferred to the skin, it is then transferred to the environment by four different methods (OSHA, 1999).

Convection is the transfer of heat by circulation of fluid. Air flowing past a person can cool him or her if the air temperature is below 35ºC (95ºF). Standing in front of an air conditioner is an example of heat transfer from the person to the cooler air via convection (OSHA, 1999).

Conduction is the transfer of heat by direct contact of one body to another, usually from a warmer object to a cooler one. A person holding an ice cube conducts heat from their body to the ice because the ice is cooler than the person (OSHA, 1999).

Radiation is the transfer of heat energy through space to a solid object. Standing in the sun increases body heat by energy from the sun being absorbed into the body through radiation (OSHA, 1999).

Evaporative Cooling is the transfer of heat by sweat evaporation from the skin. This is one of the body's primary cooling systems and high humidity situations can reduce its effectiveness by reducing the rate of sweat evaporation (OSHA, 1999). The combination of these physiological and environmental heat transfer methods can help maintain the body's core temperature within 2-3ºC of 37.6ºC (99.6ºF), the narrow range of temperatures required for the body processes to function properly (Olishifski, 1988).

Heat stress-related injuries.

Despite the physiological and environmental heat transfer methods, in some cases the body will store more heat than its mechanisms can dissipate to the environment (Ohnaka, Tochihara, & Muramatsu, 1993). As the body stores heat, the core temperature starts to increase (Ohnaka, et.al., 1993) and once the temperature rises above 100.4ºF (38ºC), human performance can be impaired (National Institute of Occupational Safety and Health [NIOSH], 1986). As the body begins to store heat, several different heat injuries may occur, starting with heat cramps, leading to heat exhaustion and finally heat stroke (OSHA, 1999).

Heat cramps. This condition can occur after working in a hot environment and can be caused by a loss of sodium, magnesium and potassium in the body (Merck & Co, Inc., 2001). Water replenishment alone does not cure heat cramps since it doesn't replace the depleted sodium, magnesium and potassium. Symptoms involve painful cramping in the muscles of the arms and legs, followed by cramping of the abdominal muscles (Merck & Co, Inc., 2001). Treatment involves drinking fluids or eating foods that contain sodium chloride to replace the depleted salts in the body (Merck & Co, Inc., 2001).

Heat exhaustion. This condition is the next step and occurs when work in a hot environment continues and fluids lost through sweating are not replenished. Symptoms include increased fatigue, weakness and anxiety, followed by a slow, thready pulse, cold, pale, clammy skin and possible unconsciousness (Merck & Co, Inc., 2001). Treatment involves getting the victim to rest in a cool environment and providing fluid replacement with small doses of a cool, slightly salty solution (Merck & Co, Inc., 2001).

Heat stroke. This condition is the third and final step in heat injuries and occurs when the body's internal temperature regulation system fails (OSHA, 1999) and core temperatures rise to life threatening levels. Symptoms include headache, confusion, vertigo, lack of sweating, hot, dry flushed, skin and a rapid pulse. This can lead to unconsciousness, convulsions and eventually death (Merck & Co, Inc., 2001). Heat stroke requires immediate medical treatment to save the victim. If the victim cannot be taken to the hospital immediately, the core temperature should be cooled by immersing the victim in wet blankets, a cool stream or even ice and snow. During the cooling, core temperature must be monitored so it doesn't fall below 101ºF (38.3ºC), otherwise hypothermia can set in (Merck & Co, Inc., 2001). Continued exposure to hot, humid conditions could lead to any or all of these types of heat stress related injuries, from heat exhaustion to the life-threatening emergency of heat stroke.

Heat Stress Injury Statistics

Heat stress related injuries are only a small part of the total injuries suffered by workers. For example, lost-time heat stroke injuries averaged 268 cases between 1992 and 1999 (Bureau of Labor and Statistics [BLS], 2001d), while lost-time injuries from falls averaged 33,9502 cases for the same time period (BLS, 2001c). In terms of fatal injuries, there were 24 deaths related to heat stroke between 1992 and 1999 compared to 635 deaths from falls during the same period (BLS, 2001a; BLS 2001b). Injuries at XYZ paper mill also follow this trend, in which it experienced three non-OSHA recordable heat stress related injuries between 1997 and 2001 (J. Sand, personal communications, October 16, 2001). Heat stress-related injuries rank low in terms of numbers of injuries and fatalities. However, the low number of injuries may be due to factors such as non-reporting of symptoms by employees and improper record keeping in the OSHA 200 log, which suggests heat stress related injuries may be more prevalent than recorded.

Heat Stress Standards

There are several standards and regulations available to help control heat stress exposure. One such standard is the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for heat stress. This standard is often referenced by other agencies including the Occupational Safety and Health Administration (OSHA) and the United States military for their own heat stress programs. The ACGIH standard consists of five separate tables that are used to determine a safe heat stress exposure limit and provide information for controlling exposures that are above that limit (ACGIH, 2001). As indicated in the ACGIH TLV, table 1 provides an adjustment factor for the Wet Bulb Globe Temperature (WBGT) index depending on the types of clothing worn while table 2 provides screening criteria for heat stress. Table 3 contains examples of activities that fall within each work demand category in table 2. Table 4 provides physiological guidelines for heat stress and table 5 provides a list of engineering and administrative controls for heat stress (ACGIH, 2001). Of the five tables that make up the standard, Table 2 is the heart of it; it is designed to determine the amount of work that can be done at a specific WBGT. Table 2 compares work/rest percentages against the work demands for acclimatized and non-acclimatized workers to determine a WBGT number for safe exposure (ACGIH, 2001). The other tables in the standard either provide more information for determining a safe exposure from Table 2 or provide additional information for monitoring the signs and symptoms of heat stress and the different types of controls for heat stress (ACGIH, 2001). The standard has some limitations such as trying to fit an employee's work load and work/rest ratio into one of four categories to determine a safe exposure, however, to its benefit, the standard also provides additional information that could be used with the safe exposure determination to help an organization start its own heat stress program.

Military heat stress standards.

The ACGIH standard provides information for a company or organization to control heat stress exposure, but the standard's method of using WBGT to determine the amount of work that can be done in a hot, humid environment is also used in at least two branches of the United States military. For example, the Army's Field Hygiene and Sanitation manual contains several pages addressing the control of heat stress (Department of the Army, 1989). The manual provides general information on heat stress and related injuries. Specific information is also provided for water intake, the adjusting of work schedules and the acclimatization of workers in hot environments. The manual also provides limits to physical activity based on WBGT index readings and additional information regarding protection from the environment and educating personnel about heat stress (Department of the Army, 1989). This manual provides more information on heat stress than the ACGIH standard, but it does not have the same amount of information as heat stress standards in other branches of the armed forces.

One example of a standard with more information than the US army standard is the U.S. Air Force's Air Education Training Command (AETC) standard for heat stress prevention and control. This standard differs from the Army's in the level of information given and the number of specific requirements to comply with. One difference between the two standards is the assigning of responsibilities for controlling heat exposure to specific positions within each training wing (Air Education Training Command [AETC], 1994). Other methods of heat stress control (such as acclimatization and work restrictions) are also covered by using specific standards regarding the amount of heat adaption required for new and returning personnel and the amount of work activity allowed depending on the WBGT index (AETC, 1994). The AETC standard also provides extra heat stress guidance for flying activities in fighter or trainer aircraft, specifically those with bubble canopies that may increase heat in the cockpit by the greenhouse effect. This guidance is provided by using a Fighter Index of Thermal Stress

(FITS) chart to determine limitations on flying activities during hot or humid days (AETC, 1994). The FITS chart compares dry bulb temperatures and dew point temperatures to arrive at a FITS value temperature. This value falls into either a normal, caution or danger category with a corresponding list of work and/or flight restrictions (AETC, 1994). The heat stress issues covered in the AETC standard could also be supplemented by specific standards at each air force base.

One example of a base with its own specific heat stress standards is Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio. Their standard covers heat and cold stress injuries and similar to the AETC standard, responsibilities for prevention and control are assigned to specific positions at the base (Wright-Patterson Air Force Base [WPAFB], 2000). However, the WPAFB standard also includes the treatment of cold stress injuries and provides less information than the AETC standard regarding acclimatization to the heat (WPAFB, 2000). The WPAFB standard also provides reference tables for controlling heat and cold stress. One example is the heat injury prevention chart, which takes information from the WBGT index temperature, the type of clothing worn and amount of water intake to provide guidance for recommended work/rest cycles (WPAFB, 2000). The WPAFB standard also includes a table for heat stress injury and treatment as well as another table for heat stress controls (WPAFB, 2000). Compared to the AETC standard, this base-specific standard offers less information regarding heat stress controls and includes cold stress in the standard as well. Given that the AETC and the WPAFB standards both lack information regarding heat stress, perhaps both standards could be used together to provide more guidance to control heat stress exposures.

New and modified standards.

Even though there are several existing standards for heat stress, new ones are being developed and information in existing ones is being modified by new research. In Britain, research was conducted for a new standard to supplement two existing standards for estimating heat stress (Hanson, 1999). The existing standards are the WBGT index and the required sweat rate equation. The new standard will allow interpretation of the existing standards for workers wearing personal protective clothing since the existing standards assumed the wearing of vapor permeable, lightweight clothing. Unlike that type of clothing, personal protective clothing tends to be vapor impermeable and have a high insulation value (Hanson, 1999). Adding the effects of personal protective clothing to the existing standards could increase their functionality since compensating for protective clothing while applying the existing sweat rate and WBGT index standards might be more representative of conditions in the work environment, rather than just using the sweat rate and WBGT standards alone.

In addition to investigations on new standards, research is also being conducted to modify existing standards. The ACGIH Threshold Limit Values (TLV) for heat stress are an example of an existing standard that is being modified by new research. The existing 2001 TLV provides WBGT adjustment factors for three types of clothing; a summer work uniform, cloth overalls and double-cloth overalls (ACGIH, 2001). A review of research on clothing adjustment factors by Bernard (1999) included a table of 16 different types of protective clothing and WBGT adjustment factors for each type (Bernard, 1999). Similar to the research being conducted on the new British standard for protective clothing, adding adjustment factors to the existing ACGIH standard could make it more representative of conditions in the work environment.

Heat Stress Regulations

Both private and military organizations have standards regarding heat stress prevention and control, however there are few legal regulations for heat stress. Federal OSHA does not have any regulations regarding heat stress (OSHA, 2001a), but some state programs have developed their own regulations. For example, Minnesota OSHA (MnOSHA) standard 5205.0110 subpart 2(a) covers heat stress exposure for indoor environments by providing a table comparing the amount of work activity with a two-hour time-weighted average WBGT exposure limit for type of work activity (Minnesota Occupational Safety & Health Administration [MnOSHA], 2001). This standard is limited because it does not address acclimatized versus non-acclimatized workers, nor does it account for work/rest periods (MnOSHA, 2001). Using the ACGIH standard in place of the MnOSHA standard may be a better way to control worker heat stress.

Even though the federal OSHA does not have any specific standards for heat stress, it can still cite employers for heat stress violations under the General Duty Clause of the OSHact and the associated fines can add up. For example, between 1988 and 1993, OSHA issued over $5 million in fines for heat stress violations alone (Bove, 1994). Violations usually involved failure to provide controls to reduce heat stress, failure to establish a heat stress management program, failure to allow adequate break time and failure to allow employees adequate access to water (Bove, 1994). One case involved employees working on a steam generator who were required to wear double cotton overalls, plastic protective suits and a respirator in an environment that ranged from

82ºF(27.7ºC) WBGT to 102ºF(38.8ºC) WBGT (Bove, 1994). Consequently, employers may need to consider possible heat stress controls for any hot, humid environments their employees might work in.

Heat Stress Data Collection

A variety of different measurements have been used to collect data on heat stress in humans. Specifically, studies by Griffith, et.al., (1992); Holmér, et.al., (1992); Kenney, et.al., (1993); Ohnaka, et.al., (1993); Reneau, et.al.(1999) and White & Hodous, (1988), all of which evaluated the effects of different clothing on heat strain, used several different measurements to collect data. These measurements included sweat rate, sweat evaporation rate, amount of heat storage in the body, skin wetness, skin temperature, heart rate and rectal temperature to determine the body's response to heat strain. These measurements all can be used to generate quantitative data that indirectly displays the body's response to high heat or humidity conditions.

Of all the heat strain measurements, the most common ones used are heart rate, skin temperature and rectal temperature. Heart rate is used as a heat stress indicator because as workload and heat strain on the body increases, the blood flow is divided between the working muscles for oxygen supply and the skin for heat transfer from the body's core. As the heat strain increases, the heart rate rises in order to supply more blood to skin and working muscles (NIOSH, 1986). In addition to heart rate, rectal and skin temperatures also can be used as a measurement of heat transfer because they show a relationship between core body heat and the amount of heat transferred to the skin. If there are no restrictions on heat loss through the skin, the rectal temperature is usually higher than the skin temperature by about 3ºC (NIOSH, 1986) and if workload increases, the difference between skin and rectal temperatures increases by about 1ºC (1.8ºF) for every 100 watts of work performed (NIOSH, 1986). Changes in skin and rectal temperatures occur as clothing is added because it interferes with heat loss from the skin and causes a rise in skin temperature as heat loss is reduced (NIOSH, 1986). As the skin temperature increases due to reduced heat loss, so does the rectal temperature. The heart rate will also increase as the body tries to transfer more heat from the body core to the skin to accommodate for the increased heat storage (NIOSH, 1986). Because heart rate, rectal temperature and skin temperature can be used to indirectly indicate how much heat is being transferred from the body core to the skin, they may be the most effective measurements to use for heat stress, especially in field studies or if financial and other limitations prevent measuring more than two to three variables.

Alternatives to rectal thermometers.

Of the three common measurements, heart rate, rectal temperature and skin temperature, rectal temperature may be the most accurate for determining the body core temperature. However due to the impracticality of using rectal thermometers, especially in field studies and because of the thermometer's offensiveness to subjects, other methods for determining core temperature have been developed (Bauman, Beaird, & Leeper, 1996). One study, conducted by Bauman, et.al. (1996) compared tympanic and oral temperatures against rectal temperatures during testing of heat stress in chemical protective clothing. Twenty subjects wore a U.S. military chemical defense ensemble (CPC) during a 1.5 hr baseline session on a treadmill and during a 4 hr exercise session in a laboratory environment of 21ºC (69.8ºF) dry bulb (Bauman, et.al., 1996). Results showed average tympanic and rectal temperature readings to be within 0.75 ºC of each other with a standard deviation of around 0.5, while the average oral temperatures were at least 2ºC lower than rectal temperatures and had a higher degree of standard deviation, around 1.0, than either tympanic or rectal temperatures (Bauman, et.al., 1996). Tympanic and rectal temperatures also compared favorably in average rise in temperature over time, both rose at the same rate. Compared to tympanic temperatures, oral temperatures rose slower and were more variable than either tympanic or rectal temperature (Bauman, et.al., 1996). The data from this study suggests that using tympanic temperatures as a prediction of body core temperature is a more reliable method than using oral temperatures.

Research pointing out the advantages of tympanic and skin temperatures as alternatives to rectal temperatures may have lead to the development of portable personal heat stress monitors that have become available for purchase. These units measure skin or tympanic temperatures and predict core body temperature based on those temperatures. The units usually clip onto the wearer's belt and have attached probes that record the tympanic or skin temperatures and other variables such as heart rate and environmental temperatures. Bishop and Reneau (1996) conducted a study evaluating one such monitor, the Metrosonics hs-3800 personal heat strain monitor. The hs-3800 monitor has a sensor belt that contains a heart rate monitor, a skin temperature monitor and an audible alarm. This belt was worn around the subject's chest with the skin temperature sensor placed against the skin to the right of the sternum. The belt was then attached to a monitor module that recorded information from the heart rate and skin temperature sensors on the belt (Bishop & Reneau, 1996). In the evaluation of the hs-3800, Bishop & Reneau (1996) tested 15 subjects who wore two different types of vapor-permeable suits while conducting two 2-hour work sessions in a 26ºC (78.8ºF) WBGT environment. Eight subjects of the original 15 also performed a third test using a vapor-barrier suit (Bishop & Reneau, 1996). Subjects conducted a work bout consisting of 15-minute treadmill walking sessions and 5-minute arm curl sessions, these bouts were repeated for the 2-hour period until volitional fatigue was reached or the rectal temperature rose to 38.7ºC (101.6ºF). This temperature was 0.2ºC over the alarm set limit of the hs-3800 and would allow time for the alarm to sound and alert the subject (Bishop & Reneau, 1996). At the completion of the testing, Bishop & Reneau (1996) conducted a statistical analysis of the data and recorded a correlation coefficient of 0.58 between the hs-3800 temperatures and rectal temperatures in the vapor permeable suits and a coefficient of 0.53 in the vapor barrier suits (Bishop & Reneau, 1996). Correlation coefficients are ranked on a scale of +1 to –1 to determine the strength of a relationship. The closer the coefficient is to either +1 or –1, the stronger the relationship; the closer to zero, the weaker the relationship (Crowl, 1993). The coefficients recorded by Bishop & Reneau (1996) only indicated a moderate relationship between rectal temperatures and hs-3800 temperatures. Sensitivity (the percentage of true positive responses by the hs-3800) and specificity (the percentage of true negative responses by the hs-3800) were also recorded and yielded a sensitivity of 0% and 17% in the vapor permeable suits and 63% in the vapor barrier suit. Specificity for the suits were recorded as 78% and 75% for the vapor permeable suit while no specificity was recorded for the vapor barrier suit (Bishop & Reneau, 1996). The authors concluded that due to the low correlations and low sensitivity measures, the hs-3800 was not sensitive enough for use in either type of protective clothing (Bishop & Reneau, 1996).

In addition to hs-3800 monitor, similar research was also conducted by Bishop, et.al. (1999) using a Questemp II personal heat stress monitor. This monitor differs from the hs-3800 in that it only records tympanic and environmental temperatures and does not record heart rate. Because of these differences, the Questemp II may be an easier to operate and more comfortable monitor to use since subjects would not need to take their shirts off to wear a sensor belt like they would with the hs-3800. For the evaluation of the Questemp II, Bishop, et.al. (1999) tested 16 subjects who conducted walking and arm curl exercises over a period of 4 hours while wearing a vapor barrier suit in 18ºC (64.4ºF), 23ºC (73.4ºF) and 27ºC (80.6ºF) WBGT environments. In addition to the Questemp II data, heart rate, skin temperatures and rectal temperatures were also collected during the test (Bishop, Clapp, Green, Gu, 1999). Data collected during this test was analyzed using Pearson r correlation coefficients between rectal and Questemp II temperatures in all three environmental conditions listed above. The coefficients were as follows: 0.48 in the 18ºC WBGT environment, 0.42 in the 23ºC WBGT environment and 0.38 in the 27ºC WBGT environment (Bishop, et.al., 1999). Based on this and other data collected in the study, the authors concluded the tympanic temperatures measured by the Questemp II did not closely correlate with rectal temperatures and did not reflect change over time or to predict rectal temperatures at peak temperatures (Bishop, et.al, 1999). Both the hs-3800 and the Questemp II heat stress monitors only showed a moderate relationship between rectal temperature and predicted body core temperatures. The monitors also had trouble with false positives and false negatives and did not accurately reflect temperature changes over time or peak temperatures. Despite the lack of accuracy of these monitors, the ease of use and the possibility of increased subject compliance are two factors that might favor the use of these portable monitors instead of rectal thermometers.

In addition to personal heat stress monitors, other alternative methods for measuring body core temperatures exist. One such alternative is an ingestible telemetry pill that records body core temperature. The pill is manufactured by Human Technologies, Inc, St. Petersburg Florida and is sold under the trade name CorTemp (Kolka, Levine & Stephenson, 1997). The pill contains a quartz temperature sensor that vibrates at different frequencies depending on body temperature; the vibration of the sensor creates a magnetic flux that is transmitted to a pager sized monitor device clipped to the subject's belt (Goode, 1998). Once data is collected by the monitor, it can be transferred to a computer disk for later analysis (Goode, 1998). Ingestible telemetry pills have been used to measure core temperatures in several different experimental protocols (Kolka, et.al. 1997) and were even used during Senator John Glenn's trip into space on STS-95 aboard the space shuttle Discovery (Goode, 1998).

Perhaps due to the wide use of ingestible telemetry pills in space shuttle missions and in other experimental protocols, Kolka, et.al. (1997) conducted research comparing results from the CorTemp pill against esophageal temperatures. This is unlike previous studies by Bishop & Reneau (1996) and Bishop, et.al. (1999) that compared heat stress monitor temperatures against rectal temperatures. Esophageal temperatures may have been used because they react very quickly to changes in body temperature as compared to rectal temperatures that have a slower reaction time (Kolka, et. al., 1997). During the evaluation of the CorTemp pill, four women subjects conducted treadmill exercises for 60 minutes while wearing chemical protective suits. Exercises were conducted in an environmental chamber set at 30ºC(86ºF) ambient temperature and 11.5ºC(52.7ºF) dew point temperature (Kolka, et.al., 1997). Results from the testing showed resting temperatures averaged 37.11 ºC (98.8ºF) esophageal temperature and 37.17 ºC (98.9ºF) ingestible sensor temperature. Temperatures after a period of exercise climbed to 38.6ºC (101.4ºF) esophageal and 38.7ºC (101.6ºF) ingestible sensor. Based on this data and additional statistical analysis, the authors concluded the ingested sensor could provide accurate, useful core temperature data (Kolka, et.al., 1997). In addition to accuracy, pill size may also be an additional advantage to using the CorTemp system. The pill measures 2 cm long by 1.5 cm in diameter, which is only slightly larger than a Tylenol PM caplet, (1.8 cm long by 0.7 cm in diameter). However, price may offset some of these advantages; the disposable pills cost approximately $35 each and the monitor module costs about $2,500 (Owens, 2001). In comparison, a Questemp II heat stress monitor costs about $1,300 to purchase or it can be rented for $145/week (Quest Technologies, 2001).

Heat Stress Control Methods

Heat stress is an issue in many different types of industries, from foundries to paper mills and there are different engineering and administrative controls that can be used to control it (OSHA, 1999). Environmental engineering controls can include the following:

General ventilation: This usually involves increasing the amount of make-up air, or air brought in from outside the building. This type of cooling is not effective if the outside air temperatures are above 80ºF (26.6ºC) (Graham, 1984).

Air conditioning: This method is the most expensive to install and operate (OSHA, 1999), but probably can be the most effective. An alternative is to pass the ventilation system air over water-cooled heat exchangers, which is more efficient in cool or dry climates (OSHA, 1999).

Local air cooling: This can involve different methods such as providing air conditioned cool rooms or portable blowers with air chillers built in or providing fans in the work area (OSHA, 1999).

Insulation and shielding: This involves either insulating or providing shields between workers and heat sources. Shields or insulation surfaces that are cooler than the environment are also beneficial because worker's body heat will then radiate towards the cooler shield (OSHA, 1999).

Personal engineering controls are also available for workers, they include:

Ice vests: These types of vests carry packets of regular or dry ice and can cool a worker for 2-4 hours before the ice melts. The vests are heavy and require frequent replacement of ice packs, but they are inexpensive and provide maximum mobility to the worker (OSHA, 1999).

Water-cooled garments: These use some type of cool liquid and a pump to circulate the liquid throughout channels in the garment. Cooling capability, however is limited and they can only be used continuously for about 20 minutes (OSHA, 1999).

Circulating air: This clothing is similar to water cooled garments, except it uses compressed air instead of a cool liquid. This type of cooling is more effective than water-cooling but requires a compressed air source, usually an air hose, which can reduce mobility in the suit (OSHA, 1999).

Wetted clothing: This method involves using wetted coveralls and or cotton suits where cooling occurs as the water in the suits evaporates to the environment. This method is simple and inexpensive, but works best in low humidity conditions (OSHA, 1999).

In addition to engineering controls, administrative controls can also be performed (OSHA, 1999). The list of administrative controls include, reducing physical demands of the work, providing recovery areas (e.g. air conditioned rooms), providing relief workers, adjusting worker pacing and assigning extra workers to the task but limiting the number of workers in any one area (OSHA, 1999). Additional administrative controls include the following:

Training: involves educating workers to heat stress and its hazards, signs and symptoms of heat stress related injuries and awareness of first aid procedures for them.

Work practices: involves adjusting work schedules so jobs in hot environments are done during the cool part of the day. Work practices can also involve scheduling more frequent breaks during hot work and providing fluid replacement to workers (OSHA, 1999).

Worker monitoring: This can include measuring heart rate and recovery heart rate, checking the worker's oral temperature and measuring body water loss by weighing a worker at the beginning and end of a shift (OSHA, 1999).

Hydration.

There are many different personal heat stress controls available along with an equal number of studies testing their efficiency. One possible control is providing enough water to workers in hot environments to ensure they stay properly hydrated

(OSHA, 1999). Inadequate water intake can create increased heat strain on a worker by reducing the amount of circulating blood volume (NIOSH, 1986), which reduces the amount of blood available to transfer heat from the body core to the skin (NIOSH, 1986). The effects of hydration on exercise tolerance time is known, however these effects are unknown during times of uncompensated heat stress, such as while wearing vapor barrier clothing (Cheung, et.al., 1999).

To determine the effects of hydration on heat strain while wearing protective clothing, a study conducted by Cheung, et.al. (1999) tested the effects of pre-existing under-hydration (hypo hydration) and exercise on heat stress generated by future exercises in protective clothing. The testing was set up to create a dehydrated state in subjects during a morning exercise session followed by a return to proper hydration, then more exercise in an afternoon session while wearing a chemical protective suit (Cheung, et.al., 1999). During the morning testing, 10 subjects performed walking exercises on a treadmill for 100 minutes in a 35ºC(95ºF)WBGT environment while wearing cotton shorts and t-shirts. Some subjects were provided fluids to either keep them euhydrated (at a normal water balance in the body) or dehydrated. This session was designed to generate mild dehydration (2.5% loss of body weight). The afternoon session was similar to the first, except subjects wore a nuclear, biological chemical (NBC) suit and no fluids were provided, although subjects were hydrated after the first session to return them to normal hydration status (Cheung, et.al., 1999). Data collected at the end of the two test sessions indicated a drop in average body weight from a baseline of 76.6 kg (168.5 lbs) to 76.0 kg (167.2 lbs) in the euhydrated subjects and 74.2 kg (163.2lbs) in the previously dehydrated subjects (Cheung, et.al., 1999). Euhydrated subjects also recorded a longer exercise tolerance time than dehydrated subjects (59 minutes vs. 47.7 minutes). In addition, sweat rate and evaporation rate also were lower for the dehydrated subjects (Cheung, et.al., 1999). Results from this testing points out the advantages of staying hydrated over the course of a day instead of starting the day dehydrated then drinking fluids to return to euhydration. The previously dehydrated condition still can cause the reduction of body weight and exercise tolerance time even after a return to euhydration.

While Cheung, et.al. (1999) conducted a study on the effects of previous exercise and dehydration on heat stress, Cheung & McLellan (2000) conducted a study that only tested the impact of fluid versus no fluid on the body's heat storage while exercising in a NBC suit. In the Cheung & McLellan study, eight subjects conducted one of two treadmill exercise trials at light (3.5 km/hr)or heavy (4.8 km/hr with 4% grade) exercise while in a 40ºC (104ºF) dry bulb and 30% relative humidity environment. At the start of each trial and at 15-minute intervals, subjects were either given warm water or no fluid at all (Cheung & McLellan, 2000). Results from the light and heavy trials indicated little change in sweat rate, rectal temperature or heat storage between fluid and no fluid tests. Heart rate, however, was approximately five beats per minute (bpm) lower in the tests with fluids than in the tests without fluids (Cheung & McLellan, 2000). Exercise tolerance time increased to 106.5 minutes in the light work level with fluid test versus 93.1 minutes for the light work level with no fluid test. Fluid replacement had little effect in the heavy work level tests, only increasing tolerance time to 59.8 minutes with fluid from 58.3 minutes without fluid (Cheung & McLellan, 2000). Based on this data, providing water to drink during work in a protective suit increased the amount of time an employee could work in the suit. Interestingly, though, providing water had little effect on tolerance time if the employee conducted work similar to the heavy exercise level. This increased workload may generate more heat than the body is capable of dissipating, especially since the protective suit may severely limit the amount of sweat evaporation.

Data from both Cheung, et.al. (1999) and Cheung & McLellan (2000) studies suggest that proper hydration over an entire work day helps to reduce the effects of heat strain on employees, especially if they are wearing protective clothing. Additional testing of electrolyte replacement fluids such as Gatorade was not discussed in these studies, however Klomberg (1990) conducted an employee survey that asked the employees' qualitative assessment if such a drink helped them work in hot periods. One hundred percent of the respondents indicated the drink would help them (Klomberg, 1990). This suggests advantages to providing Gatorade as an alternative or supplement to water, however more quantitative testing and data would need to be acquired to determine if Gatorade had any advantages over water in a hot work environment.

Forced air cooling.

Providing forced air ventilation by portable fans or floor level vents may also reduce heat stress by increasing sweat evaporation rates and increase heat transfer from the skin to the environment via convection. To determine the effectiveness of forced air ventilation, Banister, et.al. (1997 & 1999), conducted two separate studies testing the effect of forced air fans on firefighters in a high heat stress condition. During the first study, Banister, et.al. (1997) tested 12 firefighters who wore full turnout gear and a self-contained breathing apparatus (SCBA) while stepping on and off a bench for 20 minutes in a 40ºC (104ºF) 70% relative humidity (RH) environment. At the end of each exercise period, a firefighter rested for 10 minutes in either an optimal or normal recovery period

(Banister, Carter, Morrison, 1997). During the optimal recovery period, the firefighter removed his/her coat, hood, gloves, SCBA and sat in front of a 16 inch fan that blew air on the firefighter's head and torso. During the normal recovery period the firefighter removed his/her gloves, hood and helmet but only unbuckled the coat (didn't remove it) and left the SCBA on his/her back. No fan cooling was provided during the normal recovery period (Banister, et.al., 1997). Results from the two recovery periods indicated a greater reduction in heart rate during the recovery period with a fan than during the recovery period without a fan. Rectal temperature also climbed higher during the rest period without a fan than it did during the rest period with a fan (Banister, et.al., 1997). Data collected during this study suggests that forced air-cooling can reduce the amount of heat strain in the body, however since the firefighters removed their turnout gear during the recovery period, the effect of forced air cooling while wearing full turnout gear is not known.

In addition to their 1997 study, Banister, Carter and Morrison also conducted a study in 1999 that also tested the effects of using a forced air fan on firefighter heat strain. The 1999 study used an identical methodology and recorded identical results as compared to the 1997 study (Banister, et.al., 1999). Data collected during the 1999 study indicated lower heart rates and a smaller rise in rectal temperatures during the recovery period with the fan than during the recovery period without a fan (Banister, et.al., 1999). The data collected during the 1997 and 1999 studies by Banister, et.al., could help validate the reduction in heat stress offered by forced air-cooling. However, neither the 1997 or the 1999 study tested the effects of forced air cooling on heat strain while wearing any type of protective clothing that might reduce the effectiveness of forced air cooling.

Air, water and ice cooled garments.

In some situations forced air-cooling may not be effective due to protective clothing, which may reduce the effect of the sweat evaporation and convective cooling offered by forced air-cooling. In these situations, an air, water or ice cooled garment may be an alternative method for reducing worker heat strain in protective clothing. In order to test the effectiveness of pre-frozen jackets and water-cooled vests, Van Rensburg, et.al. (1972) conducted a study at the Chamber of Mines in Johannesburg, South Africa comparing these cooling garments in two different hot/humid environments. Two subjects conducted normal work activities at a rate similar to moderately hard industrial work, while wearing either a water-cooled or a pre-frozen jacket in two different hot/humid environments for a four-hour time and one environment for a six-hour time. (Van Rensburg, Mitchell, Van Der Walt, Stydrom, 1972). The two environmental conditions used were 33.9ºC (93ºF) dry bulb, 32.3ºC (90.1ºF) wet bulb temperature and 35.6ºC (96ºF) dry bulb, 33.9ºC (93ºF) wet bulb temperature.

When the four-hour test with the water cooled vest in the 33.9ºC (93ºF) dry bulb, 32.3ºC (90.1ºF) wet bulb environment was completed, the data collected showed that heart rate and rectal temperatures had little variation compared to the neutral control, but were lower than the hot control while sweat rate showed a greater variation. Rectal temperature rose steadily from 36.5ºC to approximately 37.5ºC with the vest and the neutral control, while the hot control rose to 38ºC and above. Heart rate spiked to 100 bpm for both controls and the vests, then leveled out for the rest of the test, but the heart rate for the hot control continued to climb until it was approximately 30 bpm higher than the heart rate with the vest on. Sweat rate for the vest and the neutral control remained similar, below 5 g/min while the rate for the hot control spiked to 15 g/min at the two hour mark then fell to around 10g/min at the end of the test (Van Rensburg, et.al., 1972). When the pre-frozen jackets were tested for the same time period and environmental conditions as the water-cooled jackets, the results were similar to those with the water-cooled jacket, although the pre-frozen jacket showed slightly higher heart rates and rectal temperatures than the neutral control. Sweat rate with the pre-frozen jacket showed a linear increase over time from about 3 g/min at the start to 8 g/min at the end of the four hours (Van Rensburg, et.al, 1972). In the next part of the testing, the environmental temperature was increased from 33.9ºC (93ºF) dry bulb, 32.3ºC (90.1ºF) wet bulb to 35.6ºC (96ºF) dry bulb, 33.9ºC (93ºF) wet bulb and both water-cooled and pre-frozen garments were used. Data from the water-cooled vest testing pointed out the rectal temperature and heart rate were stable instead of showing a linear increase over time while the sweat rate decreased over time with one subject and showed a sharp increase in the last two hours of the test for the other subject (Van Rensburg, et.al., 1972). Unlike the water-cooled vests, the pre-frozen jackets tended to follow the curve of the hot control. The pre-frozen jackets showed a linear increase in heart rate and rectal temperature while the neutral control stayed level, also sweat rate slowly increased over time in one subject while it showed a sharp decrease with the other (Van Rensburg, et.al., 1972). At the end of the four-hour tests, the pre-frozen and water-cooled garments were tested for six-hours in a 35.6ºC (96ºF) dry bulb and 33.9ºC (93ºF) wet bulb environment. After the water-cooled vest was tested, results showed a stable heart rate and rectal temperature over time while the sweat rate decreased over time. When the pre-frozen jacket was tested, heart rate and rectal temperature were stable with one subject, but showed a strong increase in rectal temperature and heart rate with the other subject. In comparison, sweat rate decreased over time with both subjects (Van Rensburg, et.al., 1972). Both the pre-frozen jacket and the water-cooled vest can reduce worker heat strain, however it appears that the water-cooled vest was more effective at reducing heat strain over longer periods of time than the pre-frozen vest. Perhaps this is due to the stable rate of cooling provided by the water-cooled vest versus the pre-frozen jacket. Also, there were several anomalies between the two subjects that call into question some of the results of this study, which might have more validity had more subjects been used.

Additional research on cooled garments has also been conducted by Shapiro, et.al. (1982) who conducted a study at the U.S. Army Research Institute of Environmental Medicine that compared water-cooled and air-cooled vests in hot/dry and hot/wet environments. In order to simulate a workload found in the military, twelve subjects were divided into three "tank" crews of four subjects and each crew was composed of a driver, commander, loader and gunner. Each subject did specific work, depending on his or her position. A driver did cycling, a commander did bench stepping, a gunner did arm cranking and the loader did weight lifting (Shapiro, et.al., 1982). Subjects conducted this testing for total time of 120 minutes per day, divided into four exercise periods of five minutes each with the remainder of time used for resting (Shapiro, et.al, 1982). Two environmental conditions were used in these tests, a hot/dry condition and a hot/wet condition. The hot/dry condition was set at 49ºC (120.2ºF) and 20% RH with additional radiant heat added by the use of seventy-two, 375 watt infrared lamps to yield a black globe temperature of 68ºC (154.4ºF). The hot/wet condition was set at 35ºC(95ºF) and 75% RH with no radiant heat added. During the tests, all subjects wore underwear, coveralls, helmets, hoods, gas masks, gloves, boots, boot liners, ballistic vests and a semi permeable chemical protective over garment. During each exercise day, subjects used either an air or water-cooled vest. Two versions of the air-cooled vest were used, one vented by cool air, the other vented by ambient air, although the ambient air vest was not used in the hot-dry conditions because of skin irritation while wearing the vest during the first day of testing (Shapiro, et.al., 1982).

As indicated by data collected during the previously mentioned testing, all three vests reduced the amount of heat storage in the body for both hot/dry and hot/wet conditions (Shapiro, et.al., 1982). Skin temperatures and heart rates also dropped between vests and compared to a predicted temperature and heart rate with no auxiliary cooling (Shapiro, et.al., 1982). Skin temperatures for the three vests were as follows: 33.3ºC(91.9ºF) for the water-cooled vest, 34.5ºC(94.1ºF) for the air-cooled vest and 36.6ºC(97.8ºF) for the ambient air-cooled vest these are all lower than the predicted skin temperature with no auxiliary cooling of 37ºC(98.6ºC). Heart rates for the vests were as follows: 124 bpm for the water-cooled vest, 112 bpm for the air-cooled vest and 139 bpm for the ambient air-cooled vest (Shapiro, et.al., 1982). Unlike skin temperature and heart rate, rectal temperatures changed little between vests and predicted rectal temperature with no auxiliary cooling. The data from these tests suggests that both water-cooled and air-cooled vests can reduce heat strain in workers wearing protective clothing, although some vests cooled better than others. The water-cooled and air-cooled vests were more effective at reducing heat strain than the ambient air-cooled vest.

In addition to using air, water and ice, Freon also has possibilities as a cooling medium. To test the effectiveness of Freon, White, et.al. (1991) compared the effectiveness of ice and Freon cooling systems when used with a fully encapsulated chemical protection suit and a SCBA (White, Glenn, Hudnall, Rice & Clark, 1991). For this evaluation, nine subjects were selected and wore four different clothing ensembles while performing four 45-minute exercise tests on a treadmill. Two ensembles consisted of the following: a control, which consisted of a SCBA with shorts, t-shirt, helmet and running shoes and the treatment that involved a chemical resistant suit (CRS) ensemble, which used a chemical protective suit worn over the control. The other two ensembles used in the test were the ice ensemble, which added a closed loop ice cooling system to the CRS and a Freon ensemble, which replaced the ice cooling system with a Freon cooling system (White, et.al., 1991). Environmental conditions were set at 33.9ºC and 82% RH and Subjects alternated work and rest periods to achieve a total of 45 minutes per test (White, et.al., 1991).

Data collected at the end of the above mentioned Freon-based test sessions indicated some changes in heart rate and minimal changes in rectal temperature. Heart rate in all four ensembles varied approximately 40 bpm over time with the decrease in heart rate corresponding to the rest periods. The control heart rate stayed under 100bpm while the rate for the three ensembles rose to 140bpm at the 45-minute mark. Heart rates for all three ensembles remained similar with a difference of about 5bpm (White, et.al., 1991). Compared to the control ensemble, rectal temperatures varied little between the three test ensembles, but compared to the control ensemble, the temperatures rose slightly over time to about 38ºC at the 50-minute mark (White, et.al., 1991). In contrast to the rectal temperatures, skin temperatures showed a greater variance between the ensembles. Overall, the skin temperature rose steadily from 35ºC to a peak of 37ºC at the 45-minute mark in all ensembles, but stayed the coolest in the ice vest ensemble followed by the control and the Freon ensembles, where skin temperature was about 1ºC warmer than the ice vest ensemble. Compared to the other ensembles, the CRS ensemble had the highest skin temperatures, but even those were only about 1ºC above the control and Freon ensembles and 2ºC warmer than the ice ensemble (White, et.al., 1991). The three ensembles tested (CRS, ice and Freon) provided some relief from heat strain, however they didn't provide as much relief as the control ensemble did. This may be due to the vapor impermeability of the chemical resistant suit, which might reduce sweat evaporation and increase the heat strain on the wearer.

In addition to cooling garments that use air, water, ice or Freon, Liquid air has also been tested as a possible cooling medium. Gleeson & Pisani (1966) tested this type of cooling medium when they conducted a study for the Australian Defense Scientific Service that tested a cooling system for use in impermeable clothing. The system uses liquid air as a refrigerant instead of Freon. The liquid air is stored in a tank and distributed throughout the suit, where the wearer's heat evaporates the air, which removes the heat energy from the worker. The used air then returns to the tank where it is cooled to a liquid and the cycle begins again (Gleeson & Pisani, 1966). In their evaluation of liquid air cooling, Gleeson & Pisani (1966) only used one subject who wore three different types of clothing ensembles while walking on a treadmill in an environment kept at around 40ºC (104ºF) dry bulb and 25-30% RH. The three ensembles tested were as follows: The first ensemble included cotton underwear, shorts, sandshoes and socks;

the second ensemble added an unventilated overall made of PVC which was worn over the first ensemble, and an aluminum helmet and PVC skirt; the third ensemble consisted of the liquid air cooled overall worn over the first ensemble. The third ensemble also included rubber boots, gloves and headgear, all welded to the suit to make a sealed enclosure (Gleeson & Pisani, 1966).

During 50-minute test periods for the above mentioned research, exercise was done on a treadmill with alternating five-minute periods of walking and resting while wearing the different ensembles. In addition to measuring the subject's heart rate and skin temperature, used air leaving the liquid air-cooled suit and returning to the storage tank was also measured for temperature and humidity (Gleeson & Pisani, 1966). During the testing, results indicated a steady rise in the subject's skin temperature and heart rate while wearing the PVC suit until the subject was forced to stop at the 25 minute mark (Gleeson & Pisani, 1966). Unlike the PVC suit, the results from the control and the liquid air cooled suit testing indicated a reduction in heat strain despite the hot, humid environment (Gleeson & Pisani, 1966). During the liquid air-cooled suit and the control garment testing, the subject's heart rate climbed to 120 bpm and leveled out for the duration of the test while skin temperature decreased over time until the end of the test period (Gleeson & Pisani, 1966). Based on the data collected during the testing, the liquid cooled suit was very effective at reducing heat strain. However the suit does have a couple of drawbacks, mainly its lack of mobility due to having a hose going from the suit to the air tank and the limitations of the liquid air itself, which was only effective for about an hour (Gleeson & Pisani, 1966).

The Effect of Clothing on Heat Stress.

The human body can reduce heat strain by transferring heat from the body core to the environment via blood transfer to the skin and sweat evaporation on the skin's surface (NIOSH, 1986) However, protective clothing can increase the effect of heat stress on a human body by limiting the amount of sweat evaporation and convective cooling between the skin and the environment (NIOSH, 1986). In order to test how much the limitation of sweat evaporation and convective cooling can increase heat strain, studies have been conducted that compare different types of protective clothing and their effects on worker heat strain.

Vapor impermeable clothing.

Several types of clothing can be used as personal protective equipment (PPE) in toxic or high heat environments. One common use of this type of clothing is in the asbestos removal industry where the risk of exposure to asbestos fibers is great enough to require the use of protective clothing and a respirator (Holmér, Nilsson, Rissanen, Herata, & Smolander, 1992). Other risks in this industry include the work environment since asbestos removal is usually done in warm and confined spaces with light to moderately heavy workloads and strenuous postures (Holmér, et. al., 1992) and the protective clothing itself since it allows no skin exposure and therefore limits cooling of the body by convection and sweat evaporation (Griffith, Reddan, & Schmitz, 1992).

The asbestos removal industry uses a variety of different protective suits, including Tyvek suits. In order to test the effect these suits have on heat stress, Griffith, et.al., (1992) conducted a study at the University of Wisconsin-Madison to determine if heat stress was associated with wearing a Tyvek suit. In the study, eight subjects walked on a treadmill for 45 minutes while wearing Tyvek coveralls, a Tyvek hood and rubber gloves over t-shirts, shorts and tennis shoes (Griffith, et.al., 1992). Exercise sessions were done in two separate workloads, 20% load, which represented moderate work and 40% load, which represented heavy work. Two separate environmental conditions were also used; 22.2ºC(80ºF) with 50% RH and 32.3ºC(90ºF) with 60% RH, the workload and sessions were then combined to create four different test conditions. Condition 1 was set at 22.2ºC(80ºF) with 50% RH and 20% workload while Condition 2 was set at the same environmental conditions but workload was increased to 40%. During Condition 3, environmental conditions were changed to 32.3ºC(90ºF) with 60% RH and workload was set to 20% while Condition 4 was set at the same environmental conditions as Condition 3 but workload was increased to 40%. Work sessions were also separated by at least one day to allow time for recovery (Griffith, et.al., 1992).

At the conclusion of the above-mentioned testing, the results show little variation of rectal and esophageal temperatures between the four conditions. However the heart rate, sweat rate and heat storage in the body increased more between conditions 1 & 2 and conditions 3 & 4, than between conditions 1 & 3 and 2 & 4 which indicates an increase in workload will cause a greater increase in heart rate, sweat rate and heat storage than an increase in temperature and humidity (Griffith, et.al., 1992). Therefore, an employee's workload may need to be monitored more than the environment since an increased workload may lead to greater employee heat strain.

Another evaluation of Tyvek suits and their effect on heat stress was also conducted by Ohnaka, et.al., (1993) at the Institute of Public Health in Tokyo, Japan. In this study seven subjects performed work on an ergometer under three different thermal conditions:

35ºC (95ºF) with 85% RH (hot conditions); 20ºC (68ºF) with 85% RH (cool conditions) and hot/cool conditions where the subject worked in the hot conditions and rested in the cool conditions. Each test was done up to 100 minutes with repeated work/rest intervals while each subject wore shorts, Tyvek coveralls with hoods and shoe covers (Ohnaka, et.al., 1993).

At the conclusion of the testing performed by Ohnaka, et.al. (1993), data collected indicated the rectal temperature steadily increased over time from 37.5º C (99.5ºF) to approximately 38.5ºC (101.3ºF) and did not drop during the rest period in the hot and hot/cool conditions. Unlike the higher temperature and humidity conditions, the rectal temperature remained around 37.5ºC (99.5ºF) during the cool conditions test (Ohnaka, et.al., 1993). Similar to rectal temperatures, mean skin temperature changes also showed a steady increase from 34ºC (93.2ºF) to 38ºC (100.4ºF) in the hot and hot/cool conditions, the exception being during the rest periods for the hot/cool conditions, where the temperature spiked back down to 34ºC (93.2ºF). Also in a similar trend to the rectal temperatures, skin temperature during cool conditions remained around 32ºC (89.6ºF) (Ohnaka, et.al., 1993). Another test variable, the heart rate showed the same trends as the skin and rectal temperatures. The heart rate steadily increased approximately 50bpm over time for the hot and hot/cool conditions while the rate during cool conditions leveled out at 100 bpm. All three conditions showed a 25-50bpm drop in heart rate during the rest periods (Ohnaka, et.al., 1993). Another test variable, heat storage in the body indicated that during work periods, the body stored heat at a rate of around 130 W/m^2 during hot/cool conditions and below 100 W/m^2 during the hot and the cool conditions environment (Ohnaka, et.al., 1993) while during rest periods, the body released heat at a rate of around 50 W/m^2 in the cool conditions and 200 W/m^2 in the hot/cool conditions. The exception was in the hot conditions test where the body continued to store heat at a rate of 30 W/m^2 (Ohnaka, et.al., 1993). In addition to quantitative data, subjects were also asked to record their discomfort level during the tests. All subjects recorded “no discomfort” during the cool conditions test and recorded that discomfort gradually increased over time during the hot/cool conditions with some decrease during the rest periods (Ohnaka, et.al., 1993). During the hot conditions, discomfort increased linearly during all periods of work or rest until the level of “very discomfort” was reached at the end of the fourth rest period (Ohnaka, et.al., 1993). The increased level of subjective discomfort combined with the higher than normal rectal temperature and the continued heat storage suggest that the body was unable to properly cool itself during the hot conditions test.

The research done by Griffith, et.al. (1992) and Ohnaka, et.al. (1993) suggest that Tyvek suits increase worker heat strain, possibly by reducing the ability of the body to cool itself through sweat evaporation. The data collected by Griffith, et.al. (1992) also indicates that increasing workload can cause a greater increase in heat strain than an increase in temperature and humidity would. However if a worker was in the suit for a longer period of time, temperature and humidity would play a bigger role as suggested by Ohnaka, et.al. (1993).

In addition to Tyvek clothing, other materials such as polypropylene and Gore-Tex have been used in protective gear for asbestos abatement. To test the effectiveness of these types of clothing on heat strain, Holmér, et.al., (1992) conducted a study comparing protective clothing made of polypropylene or Gore-Tex versus protective clothing made of Tyvek. In this study, four subjects performed a 50 minute test on a bicycle ergometer while wearing one of four different ensembles, at two different environments; 25ºC (77ºF) with 47% RH and 36ºC (96.8ºF) with 26% RH. Clothing ensembles included a no protective suit control (noPS), a Tyvek suit (TYV), a polypropylene suit (PP) and a Gore-Tex suit (GT). Cotton shorts, socks and a pair of shoes were worn underneath each suit (Holmér, et.al., 1992). The three types of protective clothing also had different permeability and evaporative resistance characteristics. Both Tyvek and polypropylene were water permeable, polypropylene had the greatest air permeability and lowest evaporative resistance while Tyvek had the highest evaporative resistance. In contrast, Gore-Tex had no water permeability, low air permeability and low evaporative resistance (Holmér, et.al., 1992).

Data collected during the course of the study by Holmér, et.al. (1992) indicated that rectal temperatures in both environmental conditions and in all four different ensembles were clustered together and rose slightly by about 0.3-0.4ºC over time. In contrast, skin temperatures varied between the ensembles and the environmental conditions. Skin temperatures in the 25ºC (77ºF) condition were approximately 2-3ºC higher for all three protective clothing combinations than the control condition. However, during the 36ºC (96.8ºF) condition, skin temperatures were about 2ºC higher overall than in the 25ºC (77ºF) conditions, but the skin temperatures were the same for all four ensembles (Holmér, et.al., 1992). Skin wetness, another variable tested, also increased over time, starting at around 20% and ending at 60-80% in the 25ºC condition and starting at around 50% and climbing to 80-90% in the 36ºC condition. Unlike skin temperature, skin wetness in the three protective ensembles was about 20-30% higher than the control ensemble (Holmér, et.al., 1992). Heat storage, another variable tested, ranged from a high of 6 W/m^2 for the Tyvek clothing to a low of -1 W/m^2 for the Gore-Tex clothing. (Holmér, et.al., 1992). The data collected suggests that Gore-Tex would reduce heat strain the most compared to the Tyvek and Polypropylene ensembles. However all three protective clothing ensembles couldn't reduce worker heat strain as well as the control ensemble.

Additional testing comparing the effects of Tyvek protective suits versus polypropylene protective suits on heat stress has been conducted by Reneau, et.al., (1999) This study used 15 subjects wearing Tyvek and Polypropylene suits while walking on a treadmill for 15 minutes, then performing arm curls for five minutes. Testing was done in two different environmental conditions, one with a Wet Bulb Globe Temperature index (WBGT) of 26ºC (78.8ºF) and the other with a WBGT of 18ºC (64.4ºF) (Reneau, Bishop, & Ashley, 1999). Results of the testing indicated a 1 g/min higher sweat rate and a 0.1 g/min higher evaporation rate in the Tyvek suit versus the polypropylene suit during the 18ºC (64.4ºF) WBGT condition. During the 26ºC (78.8ºF) WBGT conditions, the sweat rate and evaporation rate in the Tyvek suit were 2 g/min and 0.3 g/min higher respectively than the polypropylene suit (Reneau, et.al., 1999). In contrast, body heat storage in the 18º (64.4ºF) WBGT condition varied between 63.5 W/hr for the polypropylene suit versus 65.3 W/hr in the Tyvek suit. However, during the 26ºC (78.8ºF) WBGT condition, variation between suits increased to 73.9 W/hr for the polypropylene suit versus 90.8 W/hr in the Tyvek suit (Reneau, et.al., 1999). The data suggests that the polypropylene suit would be more effective at reducing worker heat strain than the Tyvek suit. These results are similar to those reported by Holmér, et.al.,

(1992) in their study comparing Tyvek, polypropylene and Gore-Tex suits. However it appears that while polypropylene and Gore-Tex suits are more effective at reducing worker heat strain than Tyvek, the suits still provide some barrier to sweat evaporation and thus contribute to additional heat strain, especially when compared against a non protective suit ensemble, which has a markedly lower level of heat strain associated with it (Holmér, et.al., 1992).

Vapor permeable clothing.

Studies done by Holmér, et.al. (1992), Griffith, et.al. (1992), Ohnaka, et.al. (1993) and Reneau, et.al. (1999) indicate protective clothing plus work and high temperatures lead to increased body temperatures, heart rates, sweat rates and increased worker heat strain. One possible method to lower these physiological factors is by use of a vapor permeable suit that allows evaporated sweat to leave the body but still protect the worker from particulate or liquid hazards (Reneau, et.al., 1999). One of these types of fabrics was developed by W.L. Gore & Associates and is known by its trade name as Gore-Tex (Kenney, Hyde, Bernard, 1993). Gore-Tex is a type of expanded polytetraflouroethylene, a polymer that has big enough pores for water vapor molecules to pass through, but not big enough to let water droplets penetrate (White & Hodous, 1988).

In order to test the effectiveness of Gore-Tex, Kenney, Hyde and Bernard (1993), conducted a study comparing Gore-Tex coveralls with another set of unbranded vapor transmitting coveralls. This study compared how much heat exchange occurs between the subject in vapor permeable clothing and the environment as workload stays constant and environmental conditions change. To test this exchange, six subjects wore two different types of suits while walking on a treadmill or using a bicycle ergometer, both adjusted so the subject generated the same workload of 350 watts (Kenney, et.al., 1993).

Two different test protocols were used by Kenney, et.al. (1993). The first protocol set the temperature at 28ºC (82.4ºF) for the first 30 minutes then increased it by 1ºC every 5 minutes as the subject worked on the bike or the treadmill. In the other protocol, the temperature was fixed at either 33ºC (91.4ºF) for four tests or 28ºC 82.4ºF) for two tests. After 30 minutes the water vapor pressure was increased by 1 torr every 5 minutes (Kenney, et.al., 1993). The results of these tests determined the critical temperature and vapor pressure where subjects could no longer maintain heat balance with the environment and started storing heat. The critical temperature and vapor pressure points marked the temperature and water vapor pressure condition where an increase in one or the other, or both resulted in heat storage in the body due to a heat imbalance with the environment. Once heat is stored in the body, the time of safe heat exposure becomes limited (Kenney, et.al., 1993). In addition to collecting the data from the test protocols, Kenney, et.al. (1993) also compared these results against results from previous studies of different types of clothing (Kenney, et.al., 1993).

When the results from the testing conducted by Kenney, et.al. (1993) were compared against data from existing studies, one trend emerged; the critical temperature and vapor pressure scores dropped as impermeability of the clothing increased, with vapor impermeable clothing scoring the lowest critical temperature and pressure (Kenney, et.al., 1993). The two vapor permeable ensembles tested by Kenney, et.al., (1993) scored higher critical temperature and pressure points, but double cotton coveralls had a similar set of points (Kenney, et.al., 1993) and single cotton coveralls and regular work clothes scored the highest in critical temperature and pressure (Kenney, et.al, 1993). This research suggests that Gore-Tex has some properties that may allow some reduction in worker heat strain in hot conditions. However, when used in protective clothing, Gore-Tex still may inhibit some sweat evaporation, which might lead to additional heat strain compared to cotton coveralls or regular work clothes. Data from a study conducted by Holmér, et.al., (1992) that compared Tyvek, polypropylene and Gore-Tex suits suggested the same conclusion.

In addition to its use in the asbestos abatement industry, Gore-Tex has also been used in the fire fighting industry as a water barrier in turnout coats. In order to test the effectiveness of Gore-Tex in this use, White & Hodous (1988) conducted a study comparing Gore-Tex vapor barriers with neoprene vapor barriers. Unlike Gore-Tex, neoprene is a synthetic rubber that is impermeable to water and water vapor (White & Hodous, 1988). In this study, 8 subjects wore each vapor barrier under full turnout gear (coat, pants, boots, gloves, hood, helmet and self contained breathing apparatus (SCBA)) while walking on a treadmill. Two workloads were determined, a low workload that simulated the type of work that could be continued over an entire shift and a high work load that simulated the type of work done during an escape maneuver. Both workloads were performed at one environmental condition, 27.6ºC (81.7ºF) and 50% RH. In addition, subjects were asked to complete a subjective evaluation of the two types of vapor barriers in different workload conditions (White & Hodous, 1988)

Data collected from the White & Hodous (1988) study pointed out that heart rate, skin and rectal temperatures varied little over time between the neoprene and Gore-Tex barriers (White & Hodous, 1988). In addition to the quantitative data, subjective responses taken during the last minute of the test also showed little difference in perceived comfort of the clothing. Subjects were asked to rate the vapor barriers in terms of perceived exertion, comfort, breathability, temperature in clothing and sweating in clothing on a scale of 0-20, with 20 being the least favorable. This evaluation was done with both high work and low work tests and during the low work test neither of the fabrics scored above 18 on any of the ratings and both fabrics were rated similar, usually only about 1-2 points difference. Ratings for the high work test were lower than in the low work test with the highest score being an 11.9. Ratings between the fabrics were similar with only about 1-2 points difference between them (White & Hodous, 1988). Despite the differences in vapor permeability, both fabrics scored similar in this subjective evaluation as well as in the quantitative indicators such as heart rate, skin temperature and rectal temperature. White & Hodous (1988) suggest this may be due to the other components of firefighter gear such as the turnout coat over the Gore-Tex that may minimize any benefits from the Gore-Tex liners.

Although studies by White & Hodous (1988), Holmér, et.al., (1992), Kenney, et.al. (1993), tested the efficiency of Gore-Tex and other types of vapor permeable fabrics such as polypropylene, research on the efficiency of two types of commercially available non-water barrier vapor permeable fabrics is more difficult to find. Nike, Inc. sells various types of clothing with a proprietary vapor permeable fabric under the trade name Dri-FIT. E.I. duPont de Nemours and company also manufactures a vapor permeable fabric under the trade name CoolMax. Searches of Ebscohost (a library search engine) and Google (an internet search engine) failed to yield any independent studies on these two vapor permeable fabrics. DuPont's website does have some basic research information comparing drying rates of CoolMax versus other fabrics (DuPont, 2001). This data indicates Coolmax will lose approximately 40% of moisture in the shirt in 10 minutes as compared to cotton that will only lose approximately 10% of its moisture in the same time period. This relationship continues after 30 minutes of drying, Coolmax loses approximately 90% of its moisture compared to cotton that has lost 50% of its moisture over the same amount of time (DuPont, 2001). This data points out one advantage to using CoolMax over cotton, however because the data comes from a company website, its reliability is somewhat suspect.

Conclusion

Heat stress and its effects on human physiology have probably been around forever and have affected military operations from at least 24 B.C. to the soldiers in the 1967 Egypt-Israel war and possibly during the 1991 Gulf War. As it affects military operations, heat stress also affects a variety of different occupations, especially those that involve hot, humid environments. The costs of heat stress related injuries that occur in an occupational or other environment can be quite high, from days off to death. Possibly due to these costs, many different types of engineering and administrative controls have been developed to reduce or eliminate them.

One control that can also be a factor in increasing heat strain is the type of clothing worn by the worker. Because of this dual role, many studies have been conducted testing how clothing can increase heat strain and how certain types of clothing such as cooled vests and vapor permeable garments might reduce it. In order to conduct these tests, a variety of measurements are used on either one subject or a group of subjects (ranging from 2 – 12 subjects) who are tested while wearing different types of clothing.

The most common measurements used in studies of clothing effects on heat stress are heart rate, skin temperature and rectal temperature, however due to the impracticality and offensiveness of rectal temperatures, alternative methods for predicting body core temperature have been developed. The most promising is the CorTemp telemetry sensor pill, which produced accurate results compared to esophageal temperature in a study by Kolka, et.al. (1997). The main drawback of the CorTemp pill, however, is the cost, the remote receiver costs around $2,500 while each pill (which are disposable) costs around $35 each (Owens, 2001). Even though the pill is only slightly larger than a Tylenol PM caplet, subjects with problems swallowing pills may have difficulty participating. Another alternative to rectal thermometers are personal heat stress monitors which predict core temperature by measuring either aural (ear) temperature or a combination of skin temperature and heart rate. Despite some accuracy-based limitations, these monitors are easier to use and are more practical for field studies-a factor that cannot be overlooked, especially when compared to the impracticality and offensiveness to subjects associated with using a rectal thermometer.

Body core temperature measurements along with skin temperature, heart rate and other measurements have been used to determine the effect of various cooling systems vapor permeable clothing and vapor impermeable clothing on worker heat strain. Studies conducted by Holmér, et.al. (1992), Griffith, et.al. (1992), Ohnaka, et.al. (1993) and Reneau, et.al. (1999) have pointed out an increase in heat strain associated with wearing vapor impermeable clothing. In comparison, other studies conducted by White & Hodous (1988) Holmér, et.al. (1992) and Kenney, et.al., (1993) pointed out a reduction in heat strain while wearing vapor permeable clothing, although some heat strain was still recorded with the vapor permeable clothing.

The use of controls such as vapor permeable clothing, cooling garments and other engineering and administrative controls might be used to help implement a facility's heat stress program. In addition to the controls, existing standards by the ACGIH and the U.S. military could also be used to implement a heat stress program to help reduce the risk of worker's compensation dollar and human injury losses from heat stress related injuries and to reduce the chance of incurring a fine from OSHA for noncompliance with the OSHact.

CHAPTER THREE

Methodology

Introduction

The purpose of this study is to examine means of minimizing heat stress for employees working in the pulp and paper production areas of the mill. In order to meet the purpose of this study, two goals were created:

1. To compare vapor permeable and non-vapor permeable shirts as a method for reducing heat stress among millwrights, utility workers and clothing technicians.
2. To analyze environmental heat stress data before and after the installation of new exhaust fans and an increase in ventilation to see if these modifications reduced temperature and humidity in the pulp and paper production areas.

To meet these goals, two different variables affecting heat stress in a paper mill were studied. The first variable compared vapor permeable vs. non-vapor permeable shirts and their effects on worker heat stress while the second variable studied the effects of modifications to the mill's ventilation system on reducing the amount of heat and humidity on the operating floor. Even though this would be considered one study that looked at the effects of shirts and ventilation on heat stress, it included two separate studies, one that looked at how shirts affected worker heat stress and the other that looked at how ventilation changes affected environmental heat stress.

Subjects

Five subjects were selected for testing the effects of two different types of shirts on heat stress. Each subject was currently employed at the paper mill and had job duties that required them to spend several hours of each shift in hot, humid environments in the mill. As noted in Table 3, the mean age of the subjects was 43.6 years old, the mean height was 67.9 inches and the mean weight was 200.6 lbs.

Table 3:

Physical characteristics of subjects selected for study

Age	**Gender**	**Height**	**Weight**
46	Female	65”	159 lbs
49	Male	67.5”	214 lbs
39	Male	70”	232 lbs
35	Male	66.5”	172 lbs
49	Male	70.5”	226 lbs

Subject selection.

Three supervisors were contacted and given information about the study and then asked if any of their employees would be interested in participating in the study and if the supervisor could provide the names of these employees to the researcher. These specific supervisors were used because their employees spent several hours of each shift in hot, humid environments.

The employees selected by the supervisors were then contacted, given information about the study and asked if they would like to participate. If the response was affirmative, a meeting time was set up between the employee and the researcher to provide additional information about the study to the subject. During the meeting, the researcher presented information contained in the “Purpose of Study” form to the subject and allowed the subject time to ask any questions he/she may have. The subject was then provided an opportunity to read the consent form, ask any questions that they may have regarding the form, then sign the form. After signing the form, a meeting time was set up for the subject to wear the two shirts and the heat stress monitor.

Shirt Selection

Two different types of shirts were tested in the study; both were manufactured by Nike, Inc. and were purchased at a sporting goods store in the area. The vapor-permeable shirt was a short-sleeve collarless shirt made of 100% polyester and contained Nike's proprietary vapor-permeable fabric marketed under the trade name Dri-FIT. The non-vapor permeable shirt was also a short-sleeve collarless shirt, but was made of 100% cotton instead and contained no vapor permeable fabric.

Instrumentation

Four different types of instrumentation were used in the study, two instruments were used to collect quantitative environmental and personal heat stress data and the other two instruments collected additional qualitative environmental and subjective data. Two different forms were created to collect the qualitative data. One form was used to collect subject's opinions on the comfort of the two different shirts while the second form was used to collect workload, work/rest percentages and environmental heat stress data.

Heat stress monitors.

For environmental heat stress readings, a Metrosonics hs-360 heat stress monitor, serial number 1723, was used. This instrument records dry bulb, wet bulb and globe temperatures separately and calculates a Wet Bulb Globe index Temperature (WBGT) based on these temperatures. For personal heat stress monitoring, a Questemp II personal heat stress monitor, serial number JU6110029, was used. This instrument collected body temperatures by a probe inserted into the subject's ear canal and predicted body core temperatures based on the aural (ear) temperature. The ear probe consisted of a foam ear plug, similar to an E.A.R. classic plug and a small module which contained the aural temperature sensor, an environmental sensor and an alarm, designed to alert the subject if the core temperature rose above 38ºC(100.4ºF). The aural sensor fit inside the foam plug and the entire module was fitted into the subject's ear canal. The Questemp II also included a monitoring module that collected and stored data from the ear probe, provided a control panel for calibrating the instrument and adjusting settings if necessary. Stored data in the module could be downloaded to a computer later if needed.

Survey forms.

To determine subjective comfort levels of the shirts, a survey questionnaire entitled, "Shirt Comfort Survey Form" was designed. The questionnaire consisted of four questions ranking each shirt on a scale of 0-20 in terms of overall comfort, body temperature in clothing, sweating in clothing and the amount of time it took for the clothing to dry out during rest periods. A space for additional comments was also included in the questionnaire. A second form, the "Personal & Area Monitoring Sampling Form" was created to record workload and environmental WBGT readings. The form consisted of blank columns for time and location of sampling, work load, percent rest, percent work followed by columns for collecting WBGT and dry bulb temperatures in ºC and ºF. The form also contained a copy of the American Conference of Governmental Industrial Hygienists (ACGIH) workload categories and descriptions. A copy of each of these forms can be found at the end of this chapter.

Data Collection

I. Vapor-permeable v. non-vapor permeable shirts.

1. During the initial meeting between the subject and researcher, several pieces of data were collected, these included:

   a. The date of sampling and the amount of time the subject would be in the hot, humid environment on that date. The time in the hot environment was then split in half to provide equal amounts of time in both shirts.
   b. The subjects were weighed and measured for height while fully clothed in a normal work uniform which usually consists of denim jeans, a cotton T-shirt and steel-toed boots. Quite often the subjects also carried extra locks and one or two tools on their belts. This height and weight information was only collected to provide a record of the physical characteristics of the subjects used in the study.
   c. Subject numbers were assigned. A range of numbers was generated from 1010 to 1080, every tenth number starting at 1010 was written down on a separate blank consent form until every tenth number in the range was used. The consent forms were then shuffled and placed in a folder, when one of the consent forms was given out to the subject, it was randomly selected from the folder. By using this method, each subject was randomly assigned a subject number.
2. On the date of sampling, the researcher and subject met in a break room near the subject's work location and the subject changed into the Dri-FIT shirt, clipped the Questemp II monitor to his/her belt and threaded the probe through the shirt collar. Tucking in the shirt was left up to the subject's discretion.
3. Once this was completed, the subject moved to a hot, humid environment outside the break room that would be similar to the one he/she would be working in during the

day. The subject then inserted the temperature probe into his ear and waited five minutes for the probe temperature to stabilize.

4. The instrument was calibrated by using the supplied oral thermometer to calibrate the subject's aural temperature with oral temperature.
5. The calibration procedure included plugging the oral thermometer probe into the Questemp II monitor module and placing a sterile cover over the oral probe. The subject placed the probe in his/her mouth under the front of the tongue and waited five minutes for the oral temperature to stabilize. After stabilization, the calibration procedure was run on the instrument's monitor module. For detailed information about calibrating the Questemp II, see the Appendix.
6. The temperature alarm was tested to make sure it worked and the subject could hear the alarm. The subject was also instructed to leave the hot area for a cooler environment such as a break room or laboratory if the alarm went off or they felt overheated.
7. The subject then conducted his/her customary work duties.
8. At the conclusion of the first half of the sampling period, the subject switched from a Dri-FIT shirt to a cotton shirt.
9. The subject then answered the questions given in the Shirt Comfort Survey Form and returned to his/her duties until the end of the sampling period.
10. At the end of the sampling period, the subject removed the cotton shirt and put his/her regular work shirt back.

11. The subject then answered the questions given in the Shirt Comfort Survey Form and returned to his/her customary duties. At this time, the subject's involvement in the study was considered complete.
12. During the sampling period the subject was monitored to determine the amount of workload being conducted and the work/rest percentages. Environmental heat stress measurements were also taken with the Metrosonics hs-360 monitor to provide additional information about the work environment. This data was recorded on the "Personal & Area Monitoring Sampling Form."
13. At the end of the sampling period, data collected by the Questemp II was downloaded through a RS232 cable supplied with the Questemp II to a Dell Optiplex GX1 computer, serial number 7E7WD. Capture software used was Hyperterminal, version 690170, Hilgraeve, Inc., Monroe, Michigan, USA. The data collected by the capture software was saved as a text (.txt) file and was then formatted in a Microsoft Word 2000 document and a Microsoft Excel 2000 spreadsheet. The text, Microsoft Word and Excel files collected each day were backed up three times, two copies on separate 3 ¼" floppy disks and one copy on the Dell computer's internal hard drive. The original data was stored on one of the Mill's shared drives.

II. Environmental heat stress conditions before and after ventilation modifications.

1. Data was also collected to compare temperatures in the pulp and production areas of the mill before and after ventilation modifications were made. These modifications were done in the summer of 2001 and included adding two new exhaust fans in the pulp production area and increasing the make-up air into the building by 10%.

2. Baseline data in the paper production area had already been collected during the summer of 2000, using the same Metrosonics hs-360 heat stress monitor used in this study. The exact location of the monitor during baseline sampling was not given in this data, however the baseline information for the pulp production area was generated in the summer of 2001 and included specific location data for the heat stress monitor.
3. After one of the two new exhaust fans was installed and operating and the building make-up air had been increased, the Metrosonics hs-360 monitor was used to collect WBGT data from all five levels in the pulp production area and along the operating floor in the paper production area. This data was recorded on a pocket notebook and later transcribed into a Microsoft Word 2000 document. Due to time limitations, no data collection was done after the second exhaust fan went into operation.

Data Analysis

No statistical analysis was done for any of the data collected.

Assumptions

There are three assumptions with this research:

1. Predicted core temperature as recorded with the Questemp II heat stress monitor will stay within 2ºF of the body's core temperature of 98.6ºF while wearing the Dri-FIT shirt.
2. Employees will rate the vapor permeable shirt more comfortable.
3. The addition of new exhaust fans and increased ventilation will reduce the temperature in pulp & paper production areas of the mill.

Limitations

Several limitations have been identified, they include:

1. Not all subjects work in the same areas of the mill, they all work in hot, humid conditions, but the temperature and humidity in the subject's work areas may be different.
2. Due to financial and workload limitations, only one subject was sampled per day. Different days can have different outside temperatures.
3. Instructions for the heat stress monitor used for this study require a re-calibration if the environment changes more than 10ºC. The calibration procedure takes 10 minutes each time. Trying to re-calibrate each time a subject moved between different environments would have been impossible since subjects are always moving around to different areas and environments in the mill.
4. Lack of physical fitness, increased age and being overweight are both factors that can increase heat stress in the body (OSHA, 1999). Subjects used in this study were older and may be heavier and in poorer physical condition than those usually used in laboratory research. This change in physical and health characteristics of the subjects being tested may have an effect on the results, especially compared to studies using younger and physically fit individuals. Conducting a physical fitness test on the subjects was discussed, however due to time; financial limitations and possible subject non-compliance, physical fitness tests and/or screening were not conducted for this study.

Survey Form

Subjective response to garments

Subject Number		**Date:**	
Garment Worn			

Circle the best response to the following questions.

0 being worst, 20 being best

1. How would you rate the garment's comfort overall?

Very Uncomfortable   Comfortable   Very Comfortable

0   5   10   15   20

2. How would you rate your temperature in the clothing?

Cool   Warm   Hot

0   5   10   15   20

3. How much did you sweat in the clothing?

Very little   Moderate   Excessive

0   5   10   15   20

4. While you were resting, how long did it take for clothing to dry out?

Within 30 minutes   1 hour   4 hours or more

0   5   10   15   20

Feel free to add any additional comments below:

Sampling Form

Personal & Area Monitoring

Subject #:	Date:	Shirt Worn:

Personal Monitoring		**Area Monitoring**	
Monitor: Questemp II	SN: JU6110029	Monitor: Metrosonics Hs-360	SN: 1723

					Area Monitoring Meter Readings			
Spatial Information		**ACGIH Work Guidelines**			WBGT		Dry Bulb	
Location	Time	Work load	% rest	% work	ºC	ºF	ºC	ºF

ACGIH Work Rate Categories & Descriptions

Category	Job Duties/Activities
Light Work	Sitting with moderate movements, standing with light work at a machine or bench while using mostly arms, or standing with light or moderate work at a machine or bench and some walking about.
Moderate Work	Scrubbing in a standing position, walking about with moderate lifting or pushing, or walking on level at about 6 km/hr while carrying a 3 kg weight load
Heavy Work	Sawing by hand, shoveling dry sand, heavy assembly work on a noncontinuous basis, or intermittent heavy lifting with pushing or pulling (i.e.: pick-and-shovel work)
Very Heavy Work	Shoveling wet sand

CHAPTER FOUR

Results

Introduction

This study compares the effects of two types of controls on heat stress, clothing and ventilation. Since two controls are tested, the study consists of two sub-studies, one that tests the effectiveness of Dri-FIT clothing versus cotton clothing on heat stress and the other that tests the effectiveness of adding two new exhaust fans and increasing make-up air by 10% on heat stress. Accordingly, the first section of this chapter concerns the results from the Dri-FIT and cotton shirt testing, while the second section concerns the results from the ventilation changes.

Sampling Locations

Environmental heat stress readings conducted for both the ventilation and the shirt studies were taken at several locations in the pulp and paper production areas of the mill. Generally, readings were taken on each floor of the pulp area and at each major production section of the paper machine in the paper production area. The readings were taken with a Metrosonics hs-360 heat stress monitor, which was usually placed in a location such as control panels, etc., where employees would be more likely working at. The monitor was left at each location for one hour during which time a reading was recorded every half hour. The first reading at each location was discarded since the monitor requires up to 15 minutes to stabilize at the new temperature. Sampling locations are pointed out in Figure 2 and Figure 3.

Figure 1

Relationship between Pulp Production and Paper Production areas

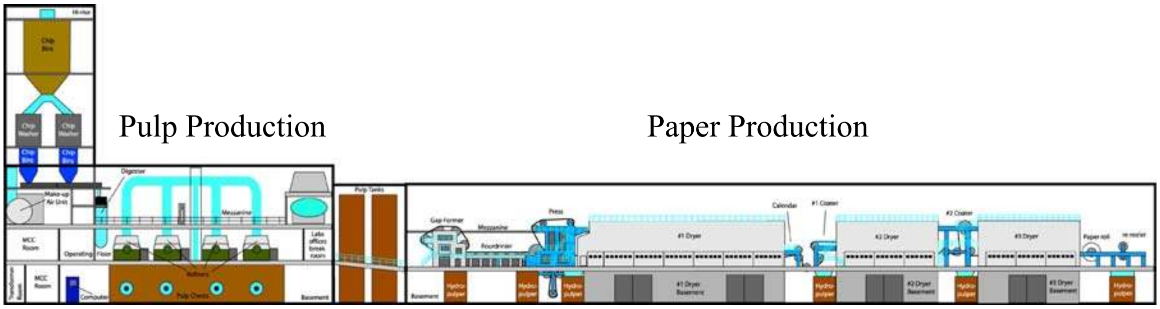


Figure 2

Sampling Locations in Pulp Production area

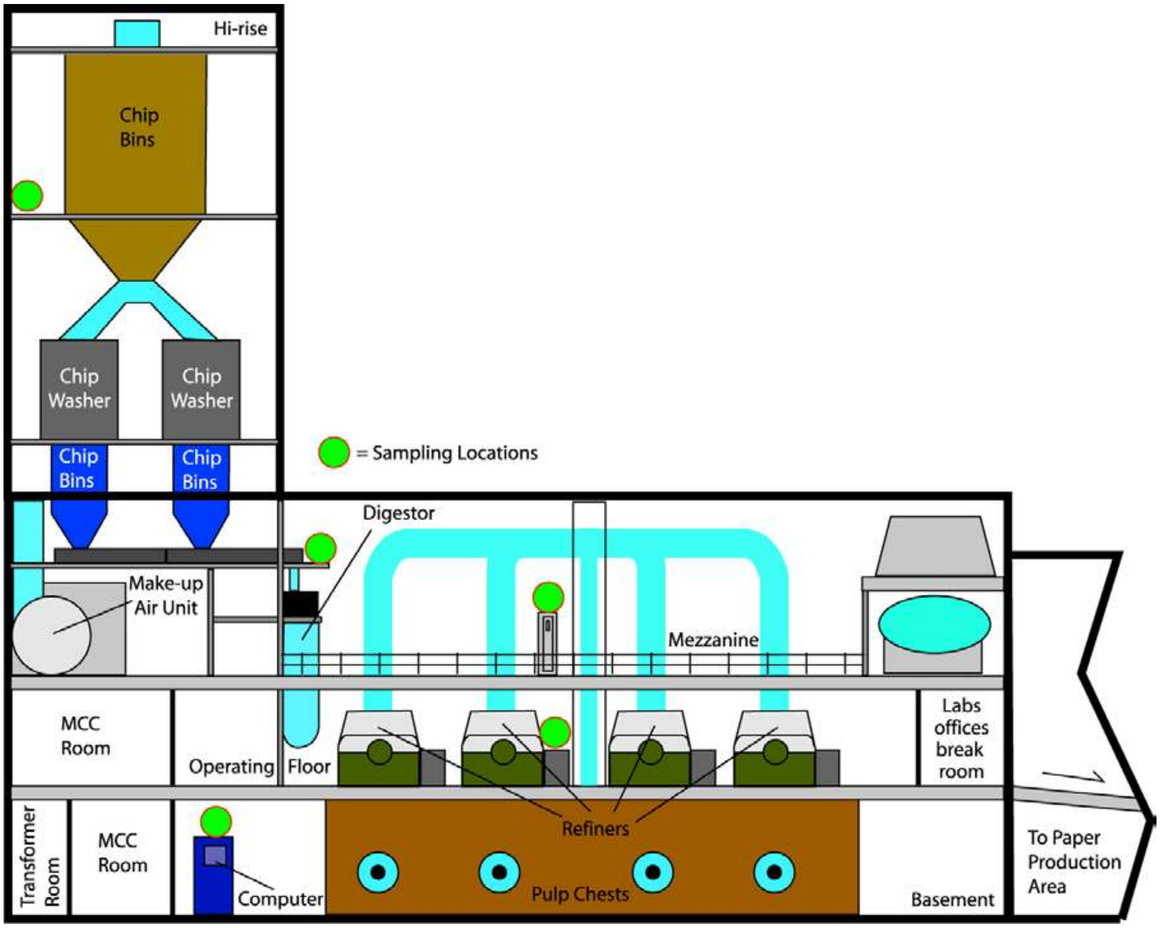
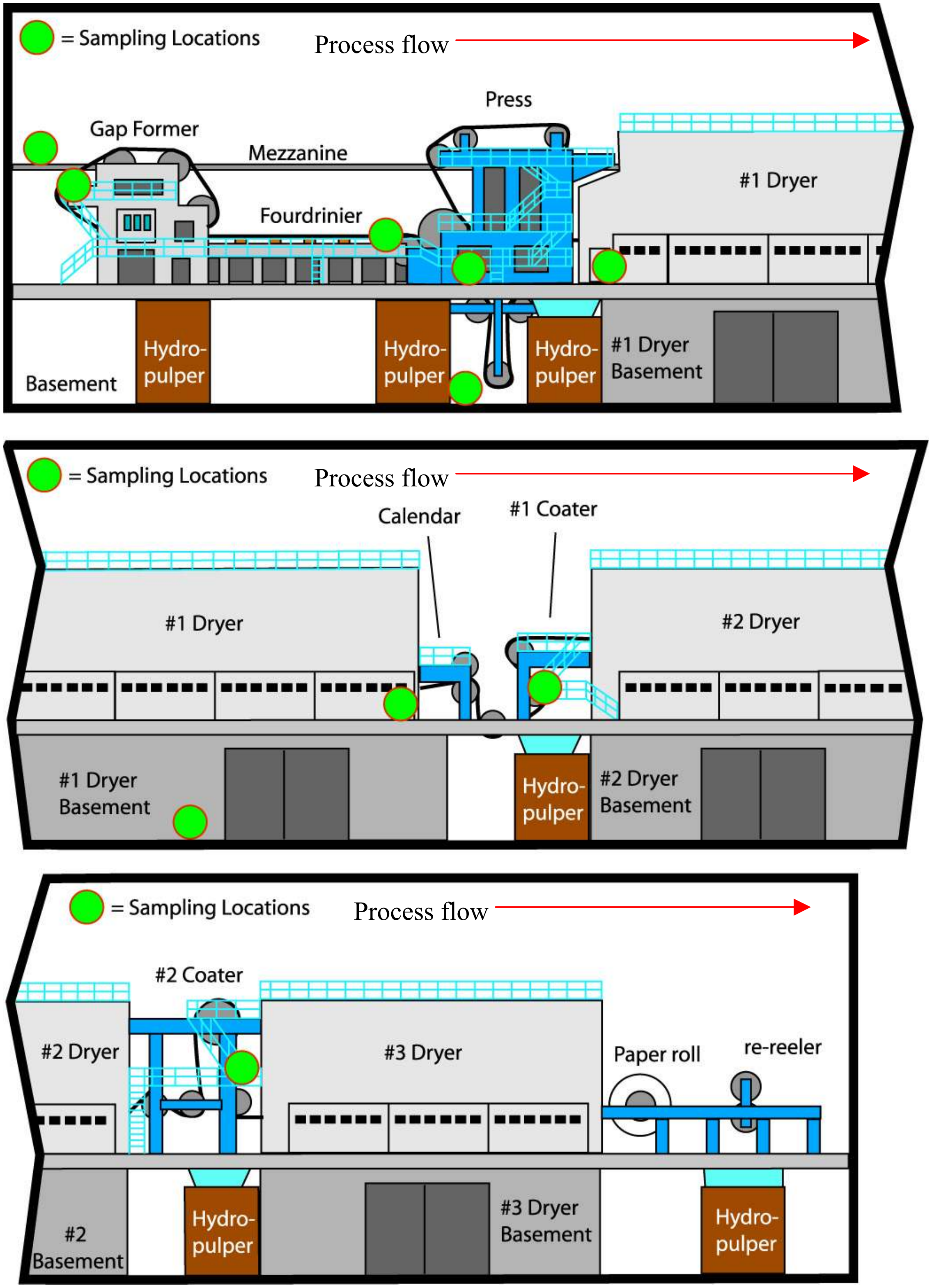


Figure 3

Sampling Locations in Paper Production area



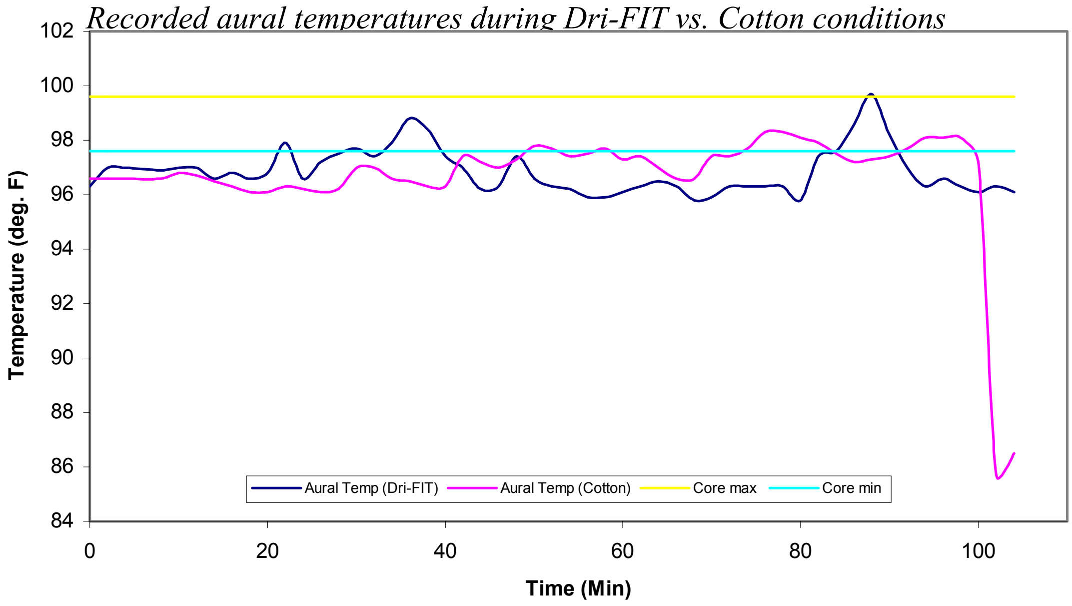
Effects of Shirt Materials on Heat Stress

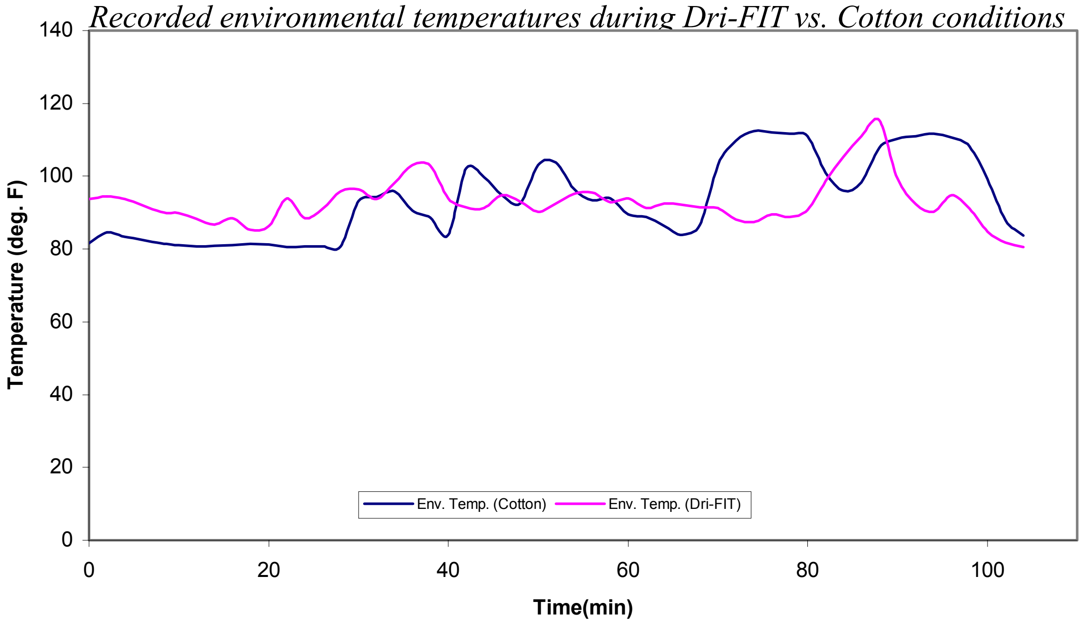
Two types of shirt, manufactured by Nike, Inc., were tested. One shirt was made of 100% polyester and contained a vapor permeable material marketed under the trade name Dri-FIT and the other was made of 100% cotton and contained no vapor permeable material. Five subjects were recruited and asked to sign consent forms and given information about the study protocol in accordance with the University of Wisconsin-Stout Instructional Review Board for the Protection of Human Subjects. The subjects wore the Dri-FIT shirt for the first half of the sample period, followed by the cotton shirt for the second half of the sample period. During testing, each subject wore a personal heat stress monitor that measured environmental dry bulb temperature and the subject's aural temperature. The monitor predicted the subject's core temperature based on the aural temperature. Both environmental and aural temperatures were recorded at 10 second intervals during testing, however due to the large amount of data collected, only temperatures recorded at the first 10 second time period of every two minute time period are presented in this chapter. Also, rest periods when subjects exchanged shirts were not recorded.

In previous studies on heat stress and clothing by Holmér, et.al. (1992), Griffith, et.al. (1992), Ohnaka, et.al. (1993), Reneau, et.al. (1999), White & Hodous (1988) Holmér, et.al. (1992) and Kenney, et.al., (1993), environmental temperatures over time were not recorded since testing was done in controlled environmental chambers. In this current study comparing Dri-FIT and cotton shirts, the environmental temperatures, WBGT temperatures and subject workload are presented because the environment that one subject works in can be different than environment encountered by another subject.

Subject 1080.

Figure 4.


Recorded aural temperatures during Dri-FIT vs. Cotton conditions

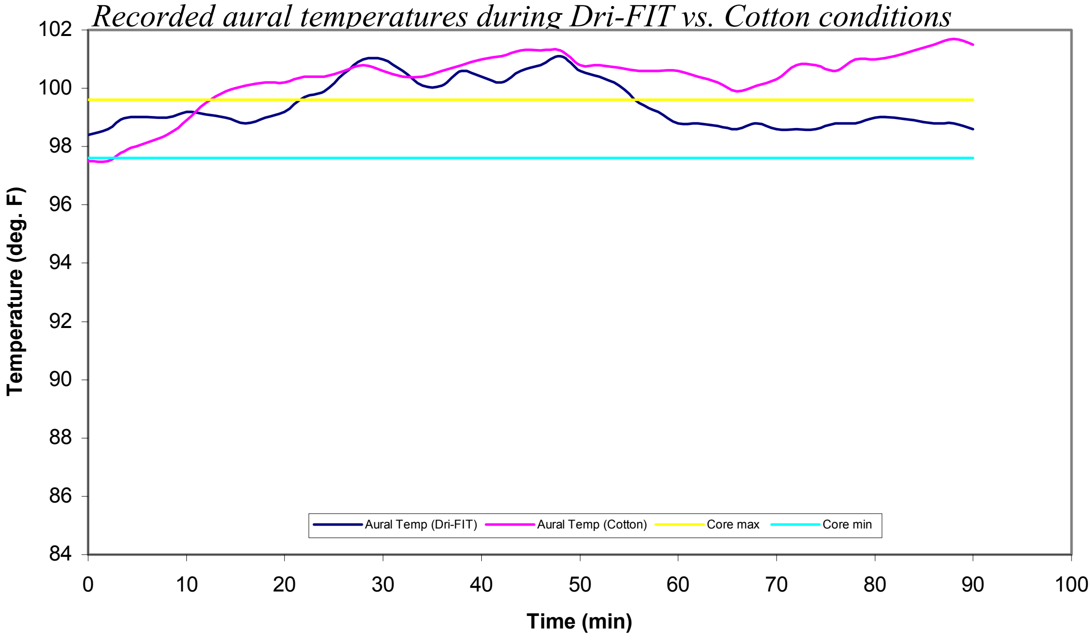

Recorded environmental temperatures during Dri-FIT vs. Cotton conditions

Subject 1080 was observed one time, conducting work at a light workload with a work/rest split of 90%/20% at an average WBGT temperature of 84ºF (28.8ºC).

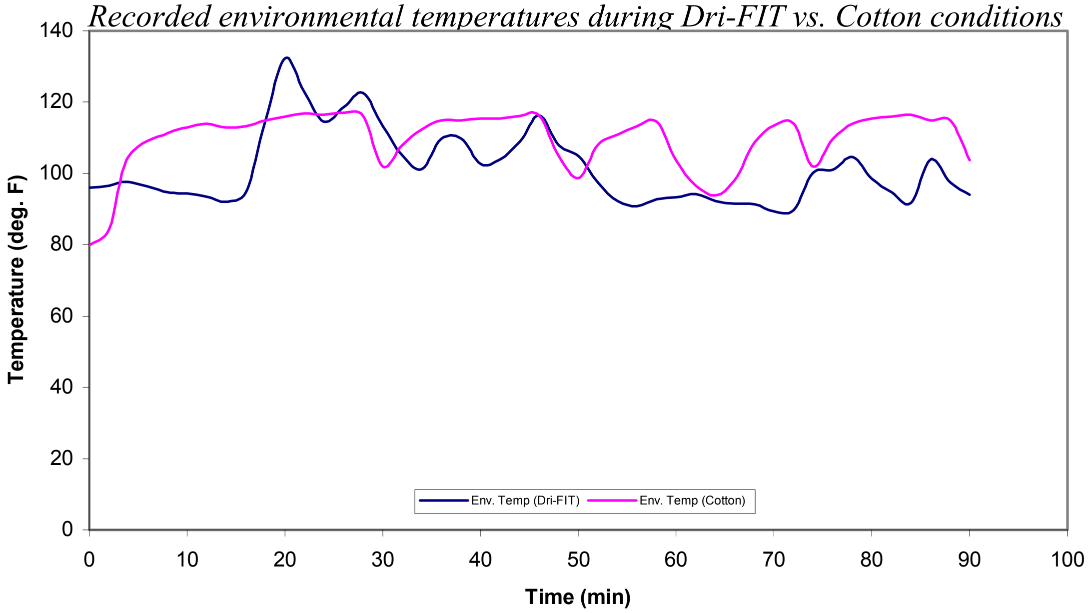
Subject 1010.

Figure 5.

Recorded aural temperatures during Dri-FIT vs. Cotton conditions



Recorded environmental temperatures during Dri-FIT vs. Cotton conditions

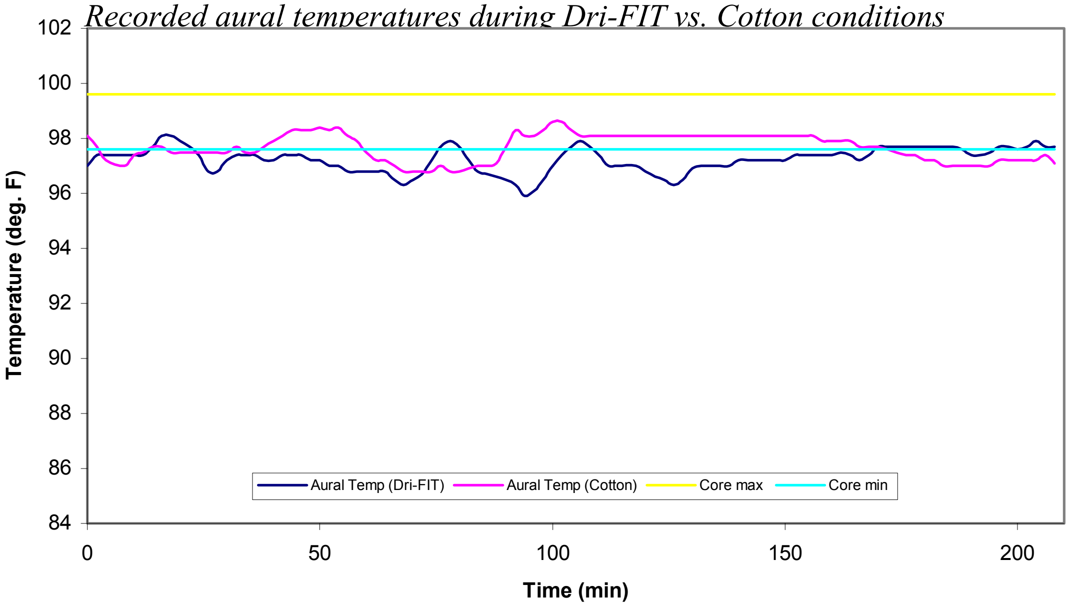


Subject 1010 was observed three times conducting work at a light to moderate workload with a work/rest split of between 60%/40% and 90%/10% at an average WBGT temperature of 91.5ºF (33.0ºC).

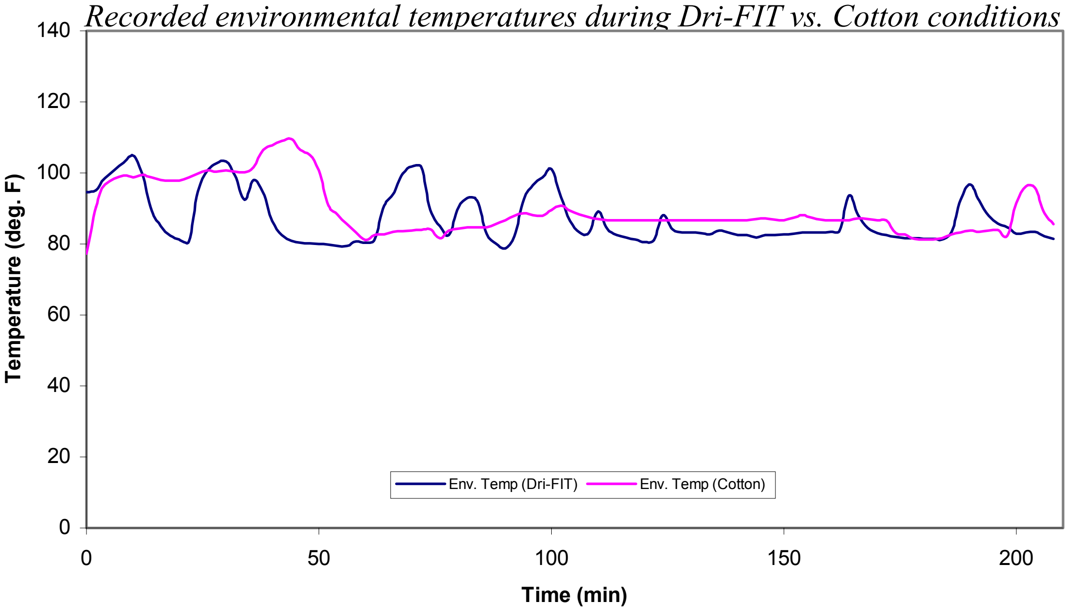
Subject 1050.

Figure 6.

Recorded aural temperatures during Dri-FIT vs. Cotton conditions



Recorded environmental temperatures during Dri-FIT vs. Cotton conditions

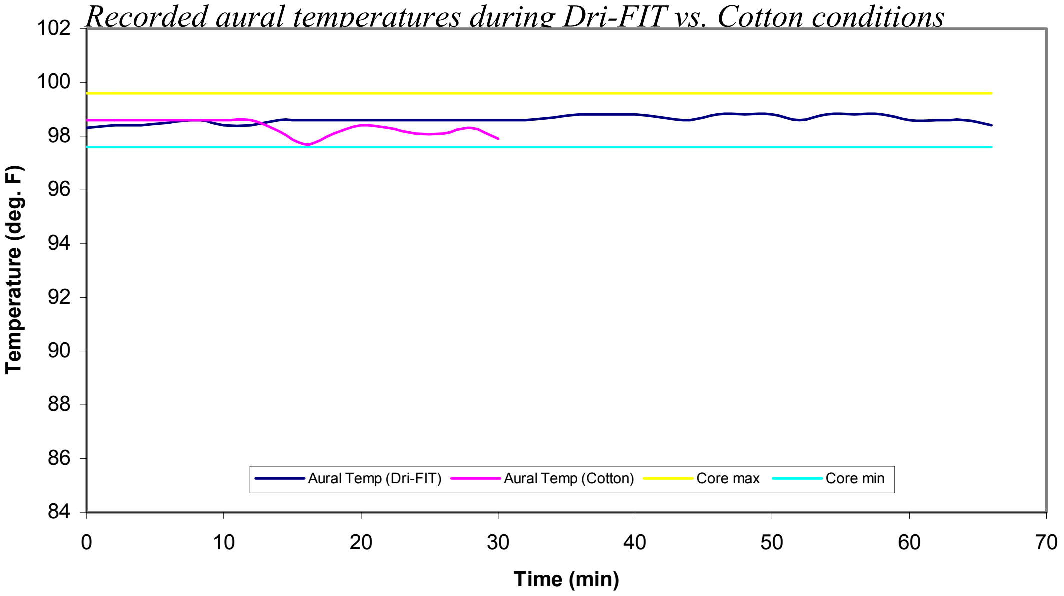


Subject 1050 was observed three times conducting work at a light workload with a work/rest split of between 90%/10% and 25%/10% at an average WBGT temperature of 83.6ºF (28.6ºC).

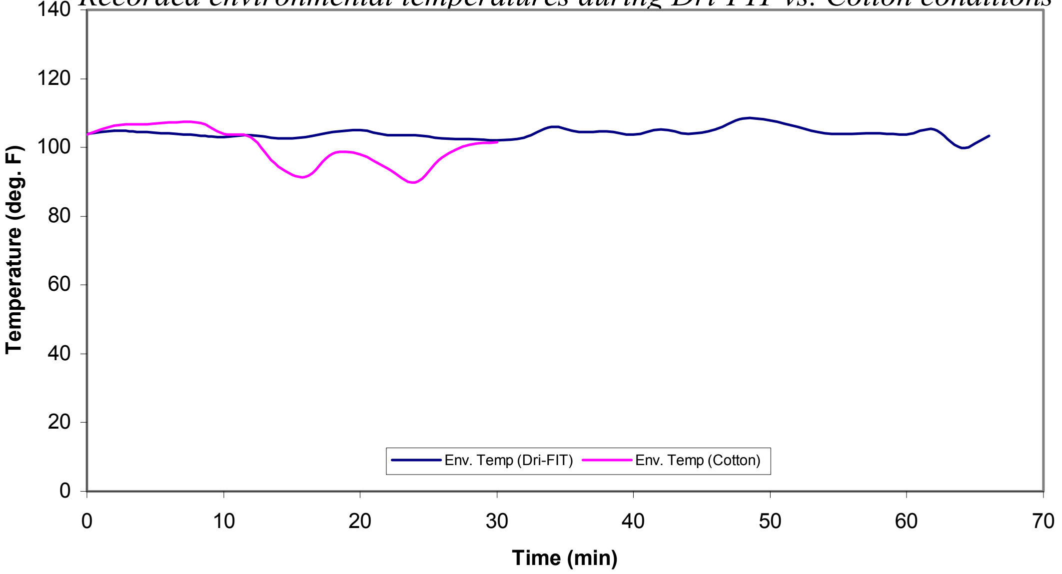
Subject 1020.

Figure 7.

Recorded aural temperatures during Dri-FIT vs. Cotton conditions



Recorded environmental temperatures during Dri-FIT vs. Cotton conditions

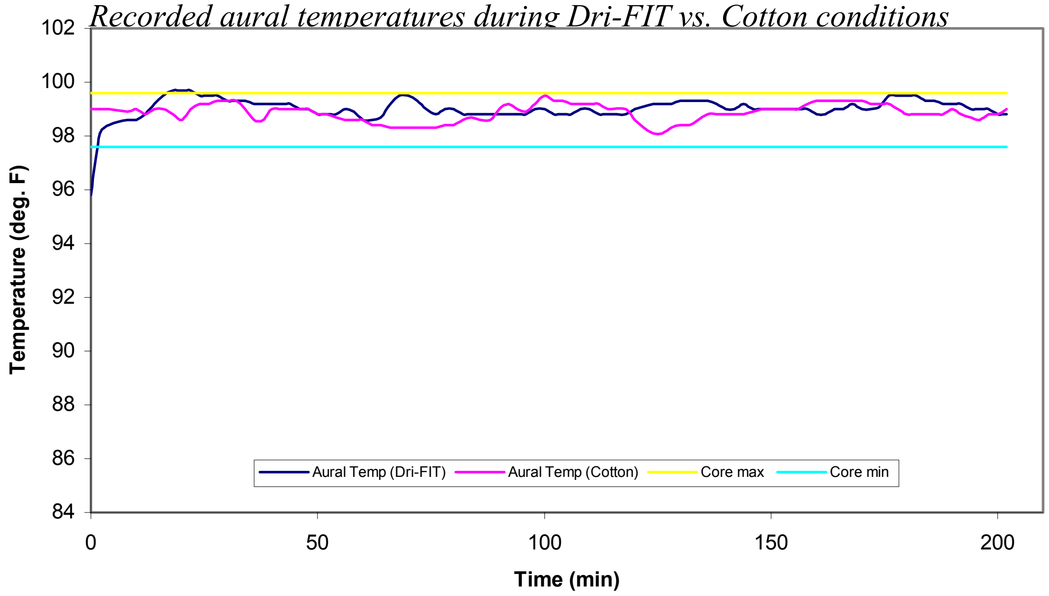


Subject 1020 was observed two times conducting work at a moderate workload with a work/rest split of 90%/10% at an average WBGT temperature of 88.2ºF (31.2ºC).

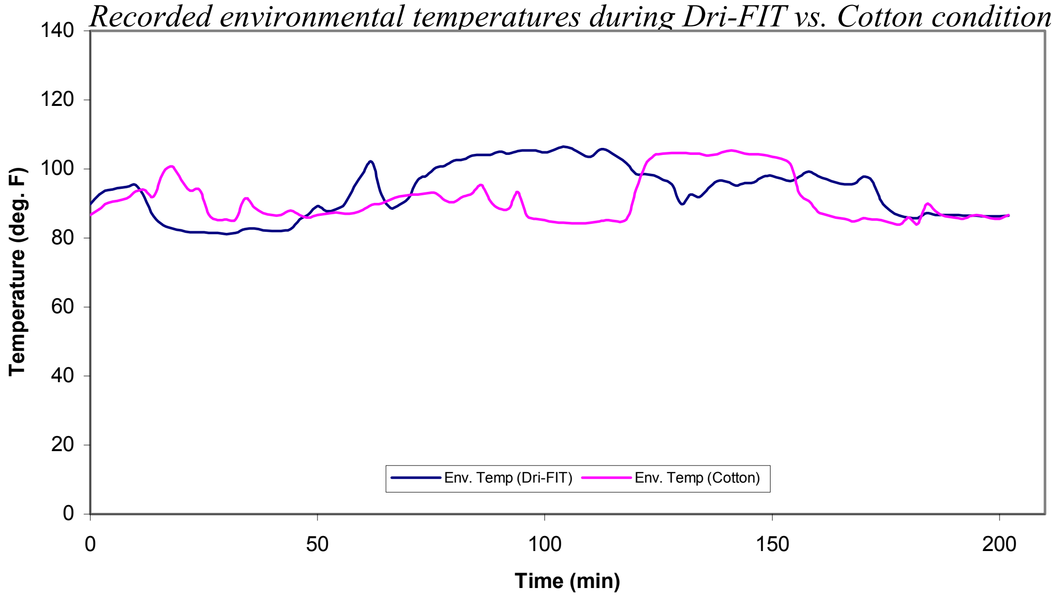
Subject 1040.

Figure 8.

Recorded aural temperatures during Dri-FIT vs. Cotton conditions



Recorded environmental temperatures during Dri-FIT vs. Cotton conditions



Subject 1040 was observed five times conducting work at a light workload with a work/rest split of 90%/10% at an average WBGT temperature of 83.2ºF (28.4ºC).

Results of subject survey.

During the sampling period, the subjects were asked to respond to four survey questions regarding the subjective comfort of the shirts. Two surveys were conducted for each subject, one per shirt and were given at the end of each shirt session.

Table 4

Results of shirt surveys

Topic	Subject #	Dri-FIT	Cotton
1. overall comfort 0 = least comfortable, 20=most comfortable	1020	15	12
	1080	15	15
	1040	20	10
	1050	15	10
	1010	15	5
2. Body temperature 0 = Coolest 20=Hottest	1020	15	17
	1080	20	20
	1040	15	15
	1050	10	15
	1010	20	20
3. Sweating 0 = Little sweating 20=Excessive sweating	1020	15	17
	1080	20	20
	1040	5	15
	1050	12	12
	1010	20	20
2. Shirt dry time 0 = within 30 min 20= > 4hrs	1020	n/a	n/a
	1080	0	n/a
	1040	0	0
	1050	5	10
	1010	0	n/a

Note. Columns marked "n/a" indicate subject did not rest in cool environment during sample time

Table 5

Average responses to survey questions

Topic	Dri-FIT	Cotton
1. Overall Comfort 0=least comfortable, 20=most comfortable	16	10.4
2. Body temperature in clothing 0=coolest, 20=hottest	16	17.4
3. Amount of sweating in clothing 0=little sweating, 20=excessive sweating	14.4	16.8
4. Time for clothing to dry while at rest 0=w/in 30 min, 20=> 4hrs.	5	10

Effect of Ventilation Changes on Heat Stress

Environmental heat stress readings were taken in the pulp, paper production areas before and after new exhaust fans were added, and building make-up air was increased by 10%. Table 4 lists the temperatures recorded in the pulp production area before and after the ventilation changes were made while Table 5 lists the temperatures recorded in the paper production area before and after the ventilation changes were made. Table 4 does not list baseline temperatures because this data was not collected before the installation of the new exhaust fans.

Table 4:

Comparison of temperatures in Pulp Production before & after modifications

	Before Increased Make-Up Air		**After Increased Make-Up Air**	
	Mean External Conditions 83.1ºF (28.4ºC) 39% RH		**Mean External Conditions** 77.8ºF (25.4ºC) 69% RH	
Location	**Time**	**Temp. (WBGT)**	**Time**	**Temp. (WBGT)**
Basement	11:34am	Stabilization	8:15am	Stabilization
	12:02pm	30.5ºC (86.9ºF)	8:45am	31.9ºC (89.4ºF)
	12:34pm	30.1ºC (86.2ºF)	9:15am	34.9ºC (94.8ºF)
Operating Floor	12:40pm	Stabilization	10:15am	Stabilization
	1:10pm	28.1ºC (82.6ºF)	10:45am	30.3ºC (86.5ºF)
	2:10pm	28.3ºC (82.9ºF)	11:20am	30.4ºC (86.7ºF)
Mezzanine	2:15pm	Stabilization	11:25am	Stabilization
	2:45pm	31.4ºC (88.5ºF)	12:10pm	30.2ºC (86.4ºF)
	3:15pm	31.2ºC (88.2ºF)	12:45pm	29.1ºC (84.4ºF)
Chip Bins	3:20pm	Stabilization	12:50pm	Stabilization
	3:50pm	32ºC (89.6ºF)	1:25pm	30.6ºC (87.1ºF)
	4:20pm	38.0ºC (100.4ºF)*	2:05pm	31.8ºC (89.2ºF)
Hi Rise	9:00am	Stabilization	2:10pm	Stabilization
	9:30am	31.2ºC (88.2ºF)	2:35pm	27.4ºC (81.3ºF)
	10:15am	28.8ºC (83.8ºF)	3:05pm	28.8ºC (83.8ºF)

Note. Wet bulb wick had dried by this time

Temperatures recorded before and after an increase in make-up air decreased by about 1-2ºC in the mezzanine, chip bins and hi-rise areas, while temperatures rose by about 1-2ºC in the basement and operating floor of the Pulp Production area.

Table 5

Comparison of temperatures in Paper Production before & after modifications

	Baseline 8/14/00		**TMP Exhaust Fan Installed 7/13/01**		**Increased Make-up air 8/30/01**	
	Mean External Conditions 83ºF (28.3ºC) RH=n/a		**Mean External Conditions** 86.4ºF (30.2ºC) 41% RH		**Mean External Conditions** 75ºF (23.9ºC) 55% RH	
Location	**Time**	**Temp. (WBGT)**	**Time**	**Temp. (WBGT)**	**Time**	**Temp. (WBGT)**
Gap Former	12:50pm	Stabilization	1:10pm	Stabilization	9:15am	Stabilization
	1:05pm	33.6ºC (92.5ºF)	1:40pm	30.0ºC (86ºF)	9:45am	28.7ºC (83.7ºF)
	1:15pm	33.7ºC (92.7ºF)	2:10pm	30.1ºC (86.2ºF)	10:15am	29.2ºC (84.6ºF)
Fourdrinier	1:15pm	Stabilization	2:10pm	Stabilization	10:17am	Stabilization
	1:45pm	32.9ºC (91.2ºF)	2:40pm	32.2ºC (90.0ºF)	10:45am	32.7ºC (90.9ºF)
	2:05pm	33.2ºC (91.7ºF)	3:10pm	32.0ºC (89.6ºF)	11:15am	33.7ºC (92.7ºF)
1rst Dryer	2:05pm	Stabilization	12:35pm	Stabilization	11:15am	Stabilization
	2:35pm	30.8ºC (87.4ºF)	1:05pm	32.6ºC (90.6ºF)	12:00pm	27.0ºC (80.6ºF)
	2:50pm	31.0ºC (87.8ºF)	1:32pm	32.6ºC (90.6ºF)	12:30pm	26.8ºC (80.2ºF)
1rst Coater	10:05am	Stabilization	1:40pm	Stabilization	12:30pm	Stabilization
	10:25am	29.9ºC (85.8ºF)	2:05pm	29.7ºC (85.5ºF)	1:00pm	26.1ºC (70.9ºF)
	10:40am	30.5ºC (86.9ºF)	2:30pm	30.3ºC (86.5ºF)	1:30pm	26.4ºC (79.5ºF)
2nd Coater	10:45am	Stabilization	2:40pm	Stabilization	1:30pm	Stabilization
	11:00am	29.8ºC (85.6ºF)	3:10pm	29.8ºC (85.6ºF)	2:00pm	26.3ºC (79.3ºF)
	11:20am	29.7ºC (85.5ºF)	3:40pm	30.3ºC (86.5ºF)	2:30pm	26.6ºC (79.9ºF)

Recorded temperatures decreased by about 4-5ºC at the gap former location after both ventilation modifications were completed while temperatures recorded at the other locations also decreased, however only by about 1-3ºC. Temperatures increased at the 1rst dryer location by about 1-2ºC after the installation of new exhaust fans, but dropped 3-4ºC after make-up air was increased.

Conclusion

This study compared the effects of two different variables, shirt material and ventilation changes, on heat stress. In the process, large amounts of data were generated and presented in this chapter. Any discussion and conclusions regarding this data can be found in chapter five.

CHAPTER FIVE

Discussion, Conclusions and Recommendations

Introduction

Paper mills can generate hot and humid conditions due to the processes they use to make paper. This excess of heat and humidity has the potential to cause heat stress-related injuries to mill employees, specifically those who spend several hours per shift in hot and humid conditions. In order to reduce the risk of injury to these employees, a variety of different engineering and administrative controls have been used. Two of these controls, ventilation changes and the use of vapor permeable clothing, were tested and the results reported in chapter four. A discussion of these results continues in this chapter.

Effects of Shirt Materials on Heat Stress

Heat stress monitor data.

To determine the effectiveness of vapor permeable shirts made of a Dri-FIT material versus cotton shirts without the Dri-FIT material, predicted body core temperature was measured by using a Questemp II personal heat stress monitor. Overall, core temperatures were approximately 0.3-0.5ºF cooler in the Dri-FIT shirt condition versus the cotton shirt condition, however, individual subject results show some interesting variations. For example, the results from subject 1080 indicate that the core temperatures in the Dri-FIT shirt condition started approximately 0.5-1.0ºF higher than the cotton shirt condition before dropping to approximately 1.0ºF below the cotton condition at about the 40-minute mark. Subject 1080's core temperatures were also consistently recorded below the 96.6ºF (35.8ºC) lower core temperature limit. This may be due to the subject spending time in a cool environment after calibration in a hot environment, which may have lead to heat stress monitor inaccuracies.

In contrast to subject 1080, subject 1010's core temperature readings were almost 2ºF above the 99.6ºF (37.5ºC) upper core temperature limit, causing the monitor's high temperature alarm to sound on at least three occasions. During the first alarm, the subject reported he had gone to a cooler environment such as a control room to reduce his body temperature. However, after the second and third alarms, the subject reported he continued to work in the hot environment so he could complete his task. It should also be noted that the subject was cleaning out excess paper in the basement of the #1 dryer of the paper machine. Environmental conditions in this area were recorded at around 101ºF (38.3ºC) WBGT, which is approximately 10º-15º higher than conditions recorded in other areas of the mill. The subject's workload in this environment would be classed as moderate, which would be greater than the light workload recorded with the other subjects in other areas of the mill. Consequently, an increased workload and increased temperatures could have caused subject 1010's core temperature to rise above the 99.6ºF (37.5ºC) limit.

In contrast to subject 1010 and 1080, the results of aural temperature testing for subject 1020 indicated little or no change in body core temperatures between the Dri-FIT and cotton shirts, although this may be due to the short sampling time (70 minutes) compared to sampling time of 100-200 minutes for the other subjects. Perhaps a longer sampling time with this subject would have yielded more conclusive results. Similar to subject 1020, subject 1040 also indicated only about a 0.2-0.3ºF change in core body temperatures between shirts. Interestingly, the temperature in the Dri-FIT shirt stayed stable over most of the sampling period while the temperature in the cotton shirt varied by as much as 0.1ºF over time.

In a situation similar to that of subject 1080, subject 1050's core temperature was also recorded consistently below the lower temperature limit of 96.6ºF (35.8ºC). As part of his job duties, subject 1050 alternated between cool (67.8ºF/19.9ºC WBGT) and hot (86.4ºF/30.3ºC) environments, spending about 20 minutes in each environment. One of the limitations of the Questemp II heat stress monitor is it must be re-calibrated if subjected to temperatures greater than 10ºC from the environment it was calibrated in. The difference between the two environments subject 1050 worked in was around 11-12ºC. This change in temperature may have affected the Questemp II's accuracy and resulted in the low core temperature readings.

Despite the variations in core temperatures that occurred either above or below the safe core temperature limits in data collected from subjects 1080, 1050 and 1010 and the inconclusive data collected from subject 1020, core temperatures overall were approximately 0.3-0.5ºF cooler in the Dri-FIT shirt condition versus the cotton shirt condition. This concurs with other studies by Holmér, et.al., (1992) and White & Hodous, (1988) that tested the effects of vapor permeable clothing on heat stress and recorded small (0.3-0.4ºC) changes in rectal temperature between the vapor permeable and non-vapor permeable clothing being compared.

Subject surveys.

In addition to data collected from the Questemp II personal heat stress monitor, subjects were also asked to subjectively rate the cotton and Dri-FIT shirts by answering a short survey after wearing the Dri-FIT and then the cotton shirt. The subjects rated the shirts on a scale of 0-20 in four areas, comfort, body temperature, sweating and drying time. Results indicated a higher rating for the Dri-FIT shirt in all four categories with overall comfort and drying time showing the greatest difference, on average about 5 points higher than the cotton shirt. The Dri-FIT shirt also scored better than the cotton shirt in the body temperature and sweating categories, although only 2 points separated the shirts in these categories and some subjects rated both shirts the same.

Effects of Ventilation Changes on Heat Stress

In order to determine if increasing building make-up air and adding new exhaust fans would reduce heat stress in the mill, readings were taken with an environmental heat stress monitor before and after the ventilation changes were made. No baseline data from the pulp production area was available so data collected only show changes due to increased make-up air. The results suggest that increasing make-up air by 10% only decreased temperatures in the mezzanine, chip bin and hi rise areas by about 1-1.5ºC (3-4ºF) WBGT while temperatures in other areas increased by about 1.5-5ºC (4º-8ºF) WBGT. The temperature reduction in the mezzanine area could be best explained by the increase in make-up air since the incoming air vents are directly above the mezzanine level. However the chip bins and hi-rise areas are separated from the mezzanine by a concrete floor so the reduction in temperature may be due to infrequent operation of heat producing machinery in the hi rise and chip bin areas. The operating floor and basement are also separated from the incoming air vents by around 12-15ft. in addition to a concrete floor between the basement and operating floor. Because of the separation from the incoming air flow, the increased temperatures in the basement and operating floor areas may be due to an almost 30% increase in relative humidity outside the mill between the two days of sampling.

In contrast to the pulp production area, temperatures in the paper production area decreased by almost º5C (8ºF) WBGT in some areas after the ventilation changes were made. The make-up air units and the exhaust fans are both located in the pulp production area, which is connected to the paper production area by a short tunnel. Thus the data suggests that adding the exhaust fans and increasing make-up air has a greater affect on and around the gap former section of the paper machine, which is closest to the pulp production area. Other sampling locations along the paper machine were located progressively further away from the pulp production area, but in most cases the results collected from these locations also indicate about a 4ºC (6ºF) WBGT drop in temperature after the ventilation controls were put in place. The only locations that did not follow this trend was the first dryer, where temperatures actually increased by about 2ºC (3ºF) WBGT after the exhaust fans were installed and dropped by about 4ºC (10ºF) WBGT after make-up air was increased. It should be noted, however that external conditions during sampling on 8/30/01 were about 8-10ºF (5-8ºC) colder than during sampling on either 7/13/01 or 8/14/00. This drop in external temperatures may have accounted for some of the temperature reduction after changes in ventilation were made.

Conclusions

Based on the data collected during this study, three conclusions can be reached:

1. Vapor permeable shirts containing Dri-FIT fabric reduced heat load in the body better than cotton shirts without Dri-FIT fabric.

2. Vapor permeable shirts containing Dri-FIT were subjectively more comfortable to wear and dried faster than cotton shirts without Dri-FIT.
3. Adding new exhaust fans and increasing make-up air inside the mill only slightly reduced the temperature in the pulp production area, but caused a greater reduction in temperature in the paper production area.

Recommendations to Minimize Heat Stress at XYZ mill

1. It is recommended that the Dri-FIT shirt be used as a heat strain reducing method for employees who work in hot and humid areas of the mill. Data collected during this study points out the reduction in worker heat strain and increase in subjective comfort associated with the Dri-FIT shirt. This combination of reduced heat strain and increased subjective comfort may lead to greater productivity by allowing workers to spend more time in a hot and humid environment than they would be able to with a cotton shirt. The ideal option would be for the mill to purchase and provide Dri-FIT shirts to affected employees, however this may be difficult to implement since the shirts cost approximately $30 each and to provide one to each of the mill's 457 employees who work in hot, humid areas would cost a total of $13,710. The mill has had only three non-recordable heat exhaustion cases in the past four years (J. Sand, personal communications, October 16, 2001), a statistic that would make it difficult to cost-justify spending $13,000 on Dri-FIT shirts for a problem that has resulted in very few losses. In addition, Dri-FIT shirts may not be as fire-resistant as cotton shirts, which would limit their utility for workers who use cutting torches and other tools that may create a fire hazard.

2. While increasing make-up air another 10-20% may also yield lower temperatures in the pulp and paper production areas, a better recommendation may be to increase make-up air and add new exhaust air fans to the pulp production area basement to help increase airflow through that area. This might help to reduce heat stress in the basement since data from this study indicated that temperatures in that area dropped less than 1ºC after the ventilation modifications were made.

Recommendations for Further Study

Several suggestions are offered for further study on the effect of vapor permeable versus non-vapor permeable clothing on heat stress. They include:

1. Increasing the sample size from five to ten or more subjects might improve consistency and reduce the affect that different environmental conditions might have on the results.
2. Limiting sampling periods to either 4-hour, 6-hour or 8-hour times would allow for a more even division of time between the cotton and the Dri-FIT shirts. This might reduce the chance of collecting almost unusable data as was the case with subject 1020, where the sample time was just over one hour for the Dri-FIT shirt and just over one half hour for the cotton shirt. These short sample times make it difficult to determine the effectiveness of either shirt by limiting the ability to observe the wearer's core temperature over a longer period.
3. Using two heat stress monitors might reduce the inaccuracy of the Questemp II heat stress monitor. Two problems associated with the Questemp II include the requirement for re-calibration if the monitor is in an environment greater than 10ºC from the calibration environment and the inaccuracies of the monitor in reporting core

body temperature, as reported by Bishop, et.al. (1999) in their study of the the Questemp II monitor. These problems may be reduced by combining the Questemp II monitor with a Metrosonics hs-3800 personal heat stress monitor. The Metrosonics also has problems with accuracy in predicting core body temperature, as reported by Bishop & Reneau (1996). However, the hs-3800 provides heart rate and skin temperature data and if this data is combined with the aural temperature data provided by the Questemp II, a clearer picture of human heat strain may emerge since heart rate and skin temperature are both variables that can be used to determine the amount of heat strain on the body.

4. In addition to using both the Questemp and the Metrosonics monitors, the CorTemp core temperature pill could also be included if the financial situation allows. Data collected by Kolka, et.al. (1997) suggested the CorTemp pill might provide more accurate core temperature readings than the Questemp or Metrosonics heat stress monitors. Using the CorTemp pill along with the heat stress monitors in a future study may further reduce the inaccuracies of the Questemp II and hs-3800.

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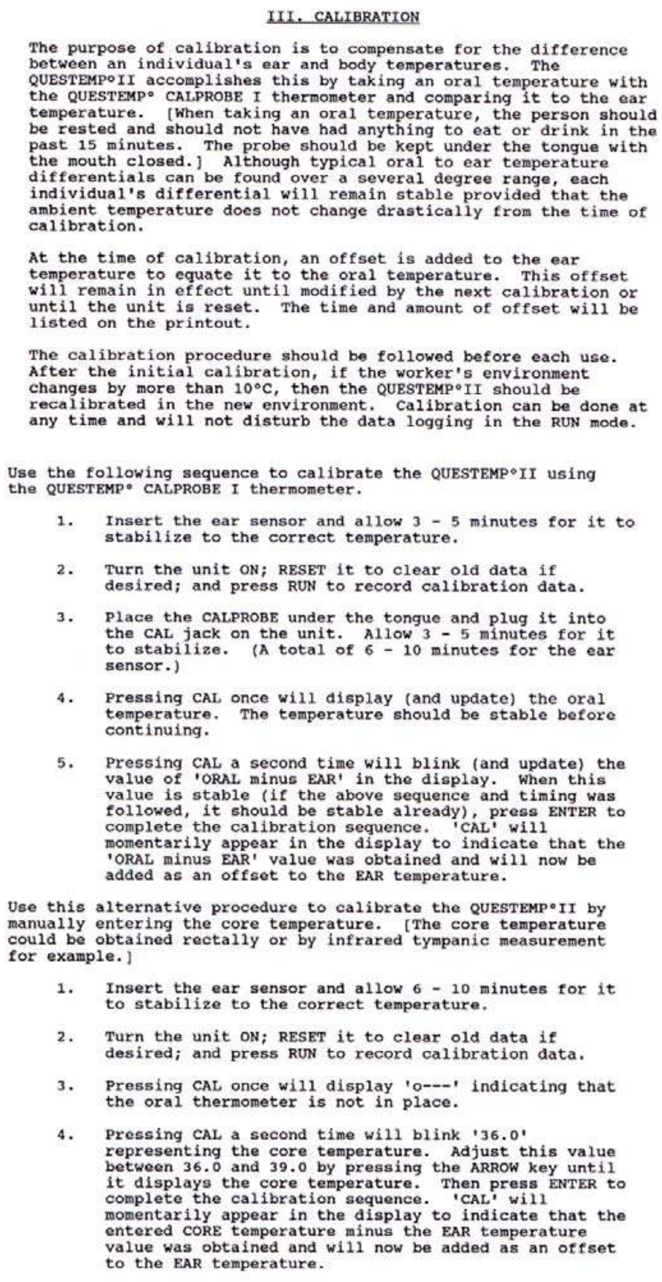
APPENDIX

Figure 1.

Detailed calibration procedure for the Questemp II personal heat stress monitor.



III. CALIBRATION

The purpose of calibration is to compensate for the difference between an individual's ear and body temperatures. The QUESTEMP°II accomplishes this by taking an oral temperature with the QUESTEMP° CALPROBE I thermometer and comparing it to the ear temperature. [When taking an oral temperature, the person should be rested and should not have had anything to eat or drink in the past 15 minutes. The probe should be kept under the tongue with the mouth closed.] Although typical oral to ear temperature differentials can be found over a several degree range, each individual's differential will remain stable provided that the ambient temperature does not change drastically from the time of calibration.

At the time of calibration, an offset is added to the ear temperature to equate it to the oral temperature. This offset will remain in effect until modified by the next calibration or until the unit is reset. The time and amount of offset will be listed on the printout.

The calibration procedure should be followed before each use. After the initial calibration, if the worker's environment changes by more than 10°C, then the QUESTEMP°II should be recalibrated in the new environment. Calibration can be done at any time and will not disturb the data logging in the RUN mode.

Use the following sequence to calibrate the QUESTEMP°II using the QUESTEMP° CALPROBE I thermometer.

1. Insert the ear sensor and allow 3 - 5 minutes for it to stabilize to the correct temperature.

2. Turn the unit ON; RESET it to clear old data if desired; and press RUN to record calibration data.

3. Place the CALPROBE under the tongue and plug it into the CAL jack on the unit. Allow 3 - 5 minutes for it to stabilize. (A total of 6 - 10 minutes for the ear sensor.)

4. Pressing CAL once will display (and update) the oral temperature. The temperature should be stable before continuing.

5. Pressing CAL a second time will blink (and update) the value of 'ORAL minus EAR' in the display. When this value is stable (if the above sequence and timing was followed, it should be stable already), press ENTER to complete the calibration sequence. 'CAL' will momentarily appear in the display to indicate that the 'ORAL minus EAR' value was obtained and will now be added as an offset to the EAR temperature.

Use this alternative procedure to calibrate the QUESTEMP°II by manually entering the core temperature. [The core temperature could be obtained rectally or by infrared tympanic measurement for example.]

1. Insert the ear sensor and allow 6 - 10 minutes for it to stabilize to the correct temperature.

2. Turn the unit ON; RESET it to clear old data if desired; and press RUN to record calibration data.

3. Pressing CAL once will display 'o---' indicating that the oral thermometer is not in place.

4. Pressing CAL a second time will blink '36.0' representing the core temperature. Adjust this value between 36.0 and 39.0 by pressing the ARROW key until it displays the core temperature. Then press ENTER to complete the calibration sequence. 'CAL' will momentarily appear in the display to indicate that the entered CORE temperature minus the EAR temperature value was obtained and will now be added as an offset to the EAR temperature.

Note. From *Instructions for Questemp II personal heat stress monitor* by Quest Technologies, 1994, 56-025 Rev. C, pp11-12