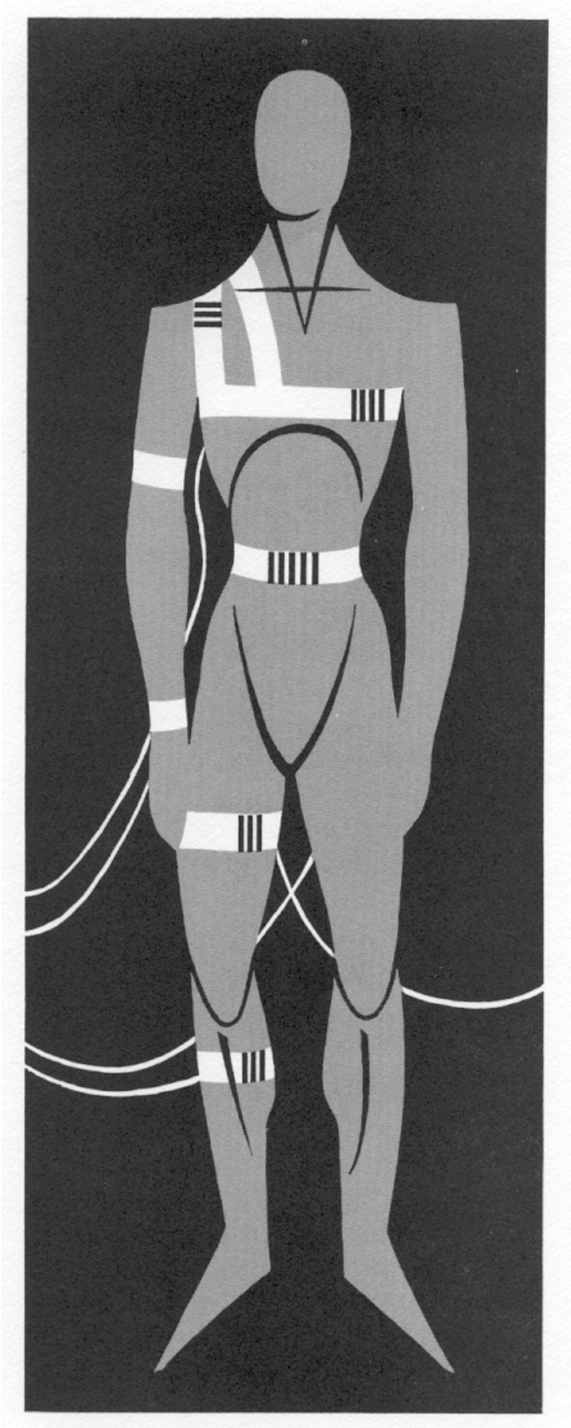

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Technical Report 3-06 on the Human Subject Evaluation of Personal Cooling Systems for Soldiers – Part I

Project: A Comprehensive Evaluation of Personal Cooling Systems (PCS) for Soldiers

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submitted to

Project Manager Soldier and Equipment

by

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Introduction

There is an immediate need for personal cooling systems (PCS) that can mitigate heat stress for Soldiers deployed in the Middle East – particularly during the summer months when the high air temperatures and radiant load from the sun and hot surfaces can cause the body to gain heat. These environmental conditions, combined with the use of heavy protective clothing and carrying a load of supplies and equipment, can put a thermal strain on Soldiers – especially when they are working and their metabolic heat production increases.

In extremely hot environments and/or at high activity levels, the only way the body can lose excess heat is by the evaporation of sweat from the body surface. The rate of evaporative cooling is dependent upon the vapor pressure gradient between the skin surface and the environment and the rate of air movement around the body and between clothing layers. Unfortunately, protective clothing such as body armor and helmets can inhibit the evaporation of sweat. In addition, the weight, rigidness, and design of protective garments may increase the energy cost associated with wearing them during activity. Consequently, Soldiers operating in hot environments often experience heat stress symptoms that affect performance on extended operations.

To overcome these limitations, the Army has been searching for new technological advances in personal cooling systems (PCS) that have been developed by manufacturers and evaluating their effectiveness for military use. These systems are designed to enhance the performance and comfort of people working in hot environments. Active cooling has been successfully applied in many HAZMAT situations where the user is completely sealed in a protective suit. This protective suit often requires supplemental air supply, and it is impermeable to the transport of evaporated sweat to the environment – thus severely limiting evaporative cooling of the body. In these work applications, the wearer can be tethered to a system (e.g., PCS circulating chilled water in tubes over the body torso) so that the cooling never stops. Alternatively, the worker may have direct access to replacement cooling components (e.g., frozen gel packs). The Soldier on the other hand is not completely isolated from the surroundings; however, he is often working at high metabolic rates, carrying a load, and moving from one place to another. This creates a unique set of operational and technical requirements for the successful application of an active cooling system in the field.

A wide range of technologies have been promoted as possible solutions to Soldier cooling requirements in extreme environments. In fact, a list of approximately 300 personal cooling systems has been compiled by military scientists (***Microclimate Cooling Database*** by Walter Teal and Brad Laprise, 2005). The range of potential products is so diverse that it is very difficult to identify the most promising products. A successful active cooling system will meet the operational characteristics required by the Soldier (size, weight, support systems, cooling time, etc.) for the particular environment selected. It is obvious that testing the products in the laboratory or field will identify those products that do not meet the desired performance requirements. However, human subject testing is time-consuming and expensive, and it should not be done in an arbitrary, "hit-and-miss" manner. An organized, comprehensive approach is needed. (See the reference list for selected books and articles on the responses of people working in hot environments and studies on active cooling systems.)

Purpose

The purpose of this study is to provide an efficient, logical, and scientifically sound procedure for assisting military personnel in screening, selecting, and evaluating the personal cooling systems (PCS) available on the market that have potential for use in military applications in desert environments. Specific objectives are:

- **Phase I.** To develop a **technology report** and **systems analysis matrix** for military personal to use in evaluating potential performance and effectiveness of personal cooling systems available on the market – prior to conducting any testing. The matrix will provide a mechanism for quantifying the positive and negative attributes of different PCS, enabling military personnel to rank these systems and identify the ones that have the most potential for manikin and human testing. The technology report will summarize and analyze the current types of cooling systems available.

- **Phase II.** To measure the heat removal rate and cooling duration of selected PCS using a **sweating manikin** in an environmental chamber. The manikin test will provide a repeatable, unbiased, quantitative method for comparing the cooling effectiveness of a variety of different PCS. Data comparing the base ensemble with the PCS in cooling mode and turned off (or used up) will be collected.

- **Phase III.** To measure the cooling effectiveness and cooling duration of selected PCS using **human subjects** (Soldiers) under hot desert conditions in an environmental chamber. These tests will provide physiological data on the cooling effectiveness of different PCS worn with the desert combat uniform, body armor, and helmet.

Separate reports have been prepared for each phase of the project. This report focuses on the results of the first set of human subject trials on three personal cooling systems.

Phase III: Human Subject Trials – PCS Set #1

The cooling effectiveness of selected personal cooling systems was evaluated using Soldiers walking on treadmills in an environmental chamber under hot desert conditions. The basic procedures in ASTM F 2300, Standard Test Method for Measuring the Performance of Personal Cooling Systems Using Physiological Testing (ASTM, 2005) were followed except that the environmental conditions were hotter (i.e., to simulate a desert climate in the summer).

Project Design

Groups of four subjects – two in the morning and two in the afternoon – evaluated three personal cooling systems and the baseline condition without a PCS over a seven-day period (including three days for heat familiarization). The design of the experiment was a 4 x 4 Latin square design where subjects and test days serve as blocks. Each subject wore all four PCS treatments in a different order. The Latin square design was repeated two more times for a total of 12 test subjects. (See Table 1.) Although the standard requires a minimum of five subjects, 12 subjects were used because 1) human variability is high, 2) a subject might quit the experiment prior to completing all trials and none of his data would be used, and 3) data from different groups of subjects may ultimately be combined when additional PCS are compared in subsequent sessions.

Personal Cooling Systems and Clothing

Project Manager Soldier Equipment (PM SEQ) selected three personal cooling systems to evaluate based on information generated in Phase I of the project and product availability. We purchased the experimental cooling garments/systems from the manufacturers/developers. The Army provided us with the garments used in the basic desert combat uniform ensemble with body armor in a variety of sizes so that each subject was able to select garments for optimum fit. The ensembles that were evaluated are listed below. The mass (weight) of the garments and the fully charged PCS were recorded before the experiment began (Table 2.) This information was needed each day for use with the met cart and for calculating the proper speed on the treadmill for each subject.

0. **Basic ensemble.** This ensemble consisted of the Army lightweight desert combat uniform (DCU) with belt, underwear briefs, T-shirt, Kevlar® helmet with internal pads, interceptor body armor (IBA) – outer tactical vest (OTV) with enhanced small arm protective insert plates (ESAPI), deltoid auxiliary protection system (DAPS), enhanced side ballistic inserts (ESBI), socks, and athletic shoes. The subjects wore their own athletic shoes instead of boots because 1) they are required by the standard and 2) they will help to prevent blisters from forming during the treadmill trials (as opposed to using new boots). The basic ensemble weighs approximately 42-47 pounds – depending upon garment size.

1. **Basic Ensemble Plus the Summitstone ForcedAIR Vest (FAV).** FAV is designed to circulate ambient air inside the body armor. Twin blowers circulate ambient air at a rate of 15 cubic feet per minute through an airspace incorporated in the vest. Cooling occurs when sweat absorbed by the vest is evaporated by the air circulating through the airspace. The FAV is worn under body armor and over the DCU shirt. The vest covers the torso and is secured in front by Velcro straps. The controls and battery pack are located in the front of the vest. The FAV weighs 4.2 lbs., including the C alkaline battery pack. Lighter weights and extended life times can be achieved by utilizing advanced battery technology. The complete ensemble weighs 46-51 lbs. (See Appendix A.)

2. **Basic Ensemble Plus the Global Secure Safety Body Ventilation System (BVS).** The BVS is designed to circulate ambient air inside the body armor. A small blower assembly mounted to the back of the body armor blows ambient air at a rate of 10 cubic feet per minute into a lining on the inside of the body armor. The lining absorbs sweat and the circulating air evaporates the sweat providing cooling to the Soldier. From the back section, the air wraps around the body into pockets covering the side and front of the body armor. The air leaves the lining from the front pockets through a mesh blowing air against the shirt. This allows for additional sweat evaporation. The BVS consists of the lining and the blower compartment. The top of the vest is secured to the body armor with straps going through the preexisting loops. The bottom of the vest is secured to the waist through the blower compartment. The vest uses Velcro straps to close the front. The blower compartment contains the batteries, blower, and controls enclosed in a protective casing.

The blower compartment is mounted on a belt and positioned in the small of the back as well as strapped to the back of the body armor. The top of the compartment anchors to the vest. The BVS weighs 3.6-3.8 lbs. including vest blower compartment and batteries. The complete ensemble weighs 45-51 lbs. (See Appendix B.)

3. **Basic Ensemble Plus the NASA Active Cooling System (NACS).** The NACS is designed to circulate ambient air inside a moisture wicking cavity. The fabric wicks sweat from the body into the cavity while two fans circulate air through the cavity. The resulting evaporation of sweat causes the NACS to cool thus removing energy from the body. The N ACS is designed to be placed under the body armor. One NACS is to be worn on the front of the torso and another on the back. The NACS is controlled by a control switch located between the fans on the bottom. The unit is 1 inch thick and provides sufficient space for air circulation. Two small exhaust fans are placed at the bottom of the unit. The air is pulled through vents on the upper corners of the device and exhausted out the bottom of the vest. The exhaust air is cool and humid and poses no hazard to the Soldier. The two NACS pieces weigh 1.1 lbs. total with batteries. The complete ensemble weighs 42-48 lbs. (See Appendix C.)

Volunteer Subjects

The target population for this study was male Soldiers on patrol in a hot desert environment. ASTM F 2300 requires that PCS be evaluated with either all males or all females. According to the Demographics Chief of the Office of the Deputy Chief of Staff, G1, there are more males (85%) than females (15%) in the Army, and an even higher percentage of males serve in combat situations in Iraq. Therefore, only males were recruited for this study. The Institutional Review Board at Kansas State University and the DOD Human Subjects Research Review Board approved the protocol and consent form prior to the recruitment of subjects. The Soldiers were recruited from the 4th Brigade, 1st Infantry Division at Ft. Riley, Kansas.

Criteria for Inclusion/Exclusion of Volunteers. The Soldiers had to meet the following criteria in order to participate:

1. Be a male between 19-40 years of age (ASTM F 2300).
2. Weigh between 65-100 kg (143-220 lb.) (ASTM F 2300).
3. Have a height between 1.70-1.95 m (67-77 in.) (ASTM F 2300).
4. Be free of chronic disease and generally in good health (ASTM F 2300).
5. Meet the Army height and weight standards and have passed their most recent Army Physical Fitness Test.
6. Have no history of heat-related illness/injury (heat exhaustion, heat stroke, etc.)
7. Have no recent history of respiratory illness.
8. Have no history of orthopedic problems that could be made worse by walking in the DCU with body armor and helmet.
9. Have no recent history of skin disorder or disease.
10. Have no known allergy to adhesive tape.
11. Be willing to refrain from the use of any medications (prescription or over-the-counter) or dietary supplements throughout the length of the study, unless approved by both the Principal Investigator and staff providing medical coverage. Volunteers already taking

medications or dietary supplements will not be admitted as test volunteers unless approved by both the Principal Investigator and staff providing medical coverage.

12. Refrain from the use of any caffeine or nicotine-containing product for at least 12 hours prior to the start of any test (ASTM F 2300).
13. Refrain from the use of alcohol for at least 24 hours before the start of any test (ASTM F 2300).
14. Avoid moderate-to-high exercise 22 hours prior to the test session (i.e., participate in no other exercise other than the test sessions during the test week) (ASTM F 2300).
15. Have not had a vaccine in the preceding month.

Two Army chaplains from Ft. Riley served as the ombudsman to assist Dr. McCullough with the recruiting effort. Chaplain (CPT) Barron Wester and Chaplain (1LT) Troy Parson participated in the recruitment session to ensure that the Soldiers understood that participation was voluntary. The Soldiers were not coerced into participating in any way. Dr. McCullough explained the protocol, distributed the protocol/consent forms to Soldiers to read, and answered questions. After the volunteers signed the consent form, they were cleared for participation by an Army physician, Captain Brian Derrick. The physician reviewed the Soldiers' medical records (if they were less than 1 year old) or gave the Soldiers a new physical exam which included an assessment of their cardio-respiratory status. The physician provided the principal investigator with written documentation regarding the fitness of each volunteer to participate in the project. Then TDY orders were issued for one week of testing. The subjects did not receive any benefits for participating in the study.

Test Schedule

The subjects were expected to participate in either seven morning sessions or seven afternoon sessions held on consecutive days. Two men were tested at one time in the morning, and two different men were tested in the afternoon. Heat familiarization sessions were scheduled for the first three days (i.e., Saturday, Sunday, and Monday), and the subjects became familiar with the test procedures and got used to exercising in the heat. The next four days, the subjects used the different PCS (or no PCS). The evaluation of three PCS and the basic ensemble with no PCS took three weeks (four subjects per week for a total of 12 subjects). (See Table 1.)

Environmental Conditions

The experimental setup was housed in two environmental chambers at the Institute for Environmental Research. The primary chamber (18 x 23 x 12.5 ft) was set up with two treadmills, two fans (Figure 1), and solar lights (Figure 2). The second chamber (11.2 x 11.2 x 9 ft) was used as a preconditioning chamber and contained the dressing rooms and instrumentation stations (Figure 3). The environmental conditions in both chambers were maintained by external air handling units that kept the dry bulb and dew point at specified levels.

According to NASA Surface Meteorology and Solar Energy Tables, the highest average environmental values for June and July for central Iraq are: air temperature, 42.2°C (108°F); relative humidity, 31%; wind speed, 4.7 m/s; and a high solar radiant load. The ASTM standard requires using an air temperature of 35°C (95°F), a relative humidity of 50%, and still air conditions (0.15 m/s). We decided to use conditions that would more closely simulate those found in Iraq. We used these conditions in a previous study on passive cooling, and the subjects were able to complete the 2-hour trial when no cooling was provided. However, they had a 10 minute rest in the middle of the session (McCullough, Eckels, & Harms, 2005).

- Air (dry bulb) temperature = 40°C (104°F)
- Dew point temperature = 12.8°C (55°F)
- Relative humidity – 20%
- Air velocity = 2 m/s (4.5 mph) average in chamber
- Mean radiant temperature = 54.4°C (130°F)

The small chamber (adjacent to the large one) was held at approximately 30°C and 25% RH in order to expose subjects to the same warm conditions for 45 minutes prior to the test session while they were getting instrumented and dressed.

Data Acquisition System

An HP VXI bus data acquisition system was used to measure eight skin temperatures on each Soldier, core body temperature, two chamber dry bulb temperatures, and two dew point temperatures. A Labview® interface was developed to read and store each of the instrument readings during testing. Dry bulb temperatures were measured with type K thermocouples; skin and core temperatures were measured with type T thermocouples. Dew point temperatures were measured with General Eastern hygrometers. Heart rates were measured with Polar™ S810i heart rate monitors which consist of a chest strap – with electrodes and a transmitter – and a watch. Oxygen consumption and metabolic rate were measured with a ParvoMedics True One 2400 Metabolic Measuring System.

Prior to the beginning of the project, the entire system was calibrated. Each thermocouple was calibrated in a constant temperature bath. The average air speed was set with a vane anemometer positioned at chest level for a person standing on the treadmill. Specifically, the speed of the fan located in front of each treadmill was varied until an average velocity of 2 m/s was obtained. The environmental conditions in the chamber were set by three primary variables: the dry bulb temperature, the wet bulb temperature, and the mean radiant temperature. The dry bulb and relative humidity were actively controlled by the chamber during the experiments. The wattage and number of lights in the solar simulator controlled the mean radiant temperature. The method outlined in the ASHRAE Handbook (ASHRAE, 1995) was used to measure this temperature. A small black ball with four thermocouples mounted on the surface was placed under the solar lights. The average temperature of the bulb, the dry bulb temperature of the air, and the air speed was then used to calculate the mean radiant temperature. The spectral distribution of the light emitted by the solar simulator was also measured by a photo spectrometer. The solar simulator consisted of approximately 40 150 W GE heat lamp bulbs laid out in a square matrix above the treadmills (Figure 2). The dry bulb, wet bulb, and mean radiant temperature were also used to calculate the WBGT Index (ISO, 1982).

Test Procedures

Determining work load. According to the ASTM standard, an energy expenditure between 250-400 W could be selected for the evaluation of PCS (ASTM, 2005). We selected an energy expenditure of 350 W for this study. To determine the speed of the treadmill at 1% incline that would generate 350 W of metabolic heat production, the following equation was used (ACSM, 2006). Note: oxygen consumption is directly related to energy expenditure.

$$VO_2 = R + H + V$$

<u>where</u>

VO_2 = rate of oxygen consumption (ml/kg/min)

R = resting component of energy expenditure (3.5 ml/kg/min)

H = horizontal component of energy expenditure (0.1 × walking speed in m/min × 26.8 to convert to mph = 2.68 mph)

V = vertical component of energy expenditure (1.8 × walking speed in m/min × 26.8 to convert to mph × grade expressed as a decimal) In this study, grade was 1% (0.01), so V = 0.48.

To determine the speed of the treadmill (at a specific grade) that will result in a particular metabolic expenditure, the watts must first be converted to VO_2 in ml/kg/min to solve the equation above. To equate oxygen consumption (VO_2) with energy expenditure (W):

1 W = 0.0143 kcal/min
1 liter O_2/min = 4.825 kcal/min
Therefore: 1 W = 0.00296 liter O_2/min

To determine 350 W: (350 x 0.00296) = 1.036 liter O_2/min.

To convert to correct units for VO2 (ml/kg/min):

$$\frac{(1.036 \text{ liter O2/min x } 1000)}{\text{body + clothing weight (kg)}} = \text{VO2 ml/kg/min}$$

For a 150 lb. subject wearing 50 lb. of protective clothing (total 200 lb. or 90.9 kg):

$$\frac{(1.036 \text{ liter O2/min x } 1000)}{90.9 \text{ kg}} = \text{VO2 ml/kg/min} = 11.4$$

Example: The original equation can be turned around to determine the treadmill speed in mph (s) at a 1% incline that would generate 350 W of metabolic heat production for a 200 lb. subject:

$$s = \frac{(\text{desired metabolic rate in W x } 0.00296 \text{ x } 1000 \text{ / weight of clothed subject in kg}) - 3.5}{3.16}$$

s = (11.4 – 3.15) / 3.16 = 2.5 mph

Each day of the experiment, the weight of each subject and his clothing and PCS (if worn) were entered into a computer program that calculated the treadmill speed that would produce 350 W of energy expenditure using the equation above.

Heat familiarization sessions. When a person gets acclimated in the heat, his/her heart rate and core temperature under a certain set of conditions will become lower and his/her sweat rate will become higher. Consequently, the physiological strain of exercising in a hot environment becomes less as the person conditions his/her body. Unfortunately, we were not able to schedule a week or more of acclimatization sessions for the subjects. However, we planned several days of heat familiarization sessions for each subject prior to the test sessions. There was still a chance that a subject might feel more comfortable on the last day of the experiment – regardless of what he was wearing – simply because he had become fully acclimatized by that time. Therefore, a statistical analysis using "day" as a factor was used to indicate whether any differences in between the subjects confounded the results in any way.

During the first three days of each week of testing, the subjects participated in a 2-hour exercise/rest test session under the same environmental conditions used in the study. They followed the exercise/rest protocol given below.

- 0-10 minutes: sitting for 10 minutes
- 10-55 minutes: walking for 45 minutes
- 55-65 minutes: sitting for 10 minutes
- 65-110 minutes: walking for 45 minutes
- 110-120 minutes: sitting for 10 minutes

The purpose of these sessions was to familiarize the subjects with the hot environment, instrumentation, and procedures. The procedures used and measurements taken during the heat familiarization sessions were the same as those described for the experiment (see test protocol below) except that skin temperature and oxygen consumption were not measured during the first two days of heat familiarization. Although considerable data were collected, they were not used in the analysis.

Day 1: On the first day of the experiment, the subjects provided their demographic information (age, race). Their height and weight were measured, and their Body Mass Index was determined. The appropriate size garments were assigned to each subject. Then the physiological instrumentation and test protocol were explained to them in detail. They wore the DCU ensemble and helmet – without the interceptor body armor – in the first 2-hour heat familiarization session.

Day 2: On the second day, the subjects wore the DCU ensemble and helmet – without the interceptor body armor – in the second 2-hour heat familiarization session.

Day 3: On the third day, the subjects wore the DCU ensemble, helmet, and *body armor*. The treadmill speed was adjusted to account for the increase in weight due to wearing the body armor.

Test Protocol. When the subjects arrived for an experiment, they entered a small, warm environmental chamber adjacent to the large one. All of the garments and the PCS that each subject was assigned to wear in the test session were placed at numbered stations. (See Figure 3.) The subjects undressed in a private area, put on a pair of briefs, and got weighed. Then they went back into the dressing area and inserted a sterilized, flexible Physitemp rectal thermocouple (for monitoring body core temperature) 10 cm into their rectum. Each subject had his own rectal sensor during the project. The nurse and an experimenter put thermocouples on the subjects' skin with transpore hospital tape. This tape minimized the heat transfer barrier effect and discomfort to the subjects. If the subject was very hairy in a location where a sensor was to be taped, some of the hair was shaved so that the sensor was securely attached. Skin temperature was measured in eight locations on the body: forehead, right scapula, left upper chest, right upper arm, left lower arm, left hand, right anterior thigh, and left calf. The nurse put the Polar™ S810i heart rate strap and watch on the subjects. The subjects also wore a wrist strap to provide an electrical ground so that they did not build up a static charge and cause electrical interference. An example of an instrumented subject is shown in Figure 4.

The nurse and experimenter helped the subjects dress in the appropriate baseline ensemble and PCS. (See Figures 5, 6, 7, and 8.) Then the nurse gave the subjects 250 ml of water to drink.

During the heat familiarization sessions, both subjects entered the chamber and got hooked up to the data acquisition system at the same time. During the experimental test sessions, one subject entered the chamber 15 minutes before the other and got hooked up to the data acquisition system and the oxygen analyzer. To start the experiment, his PCS was activated according to the manufacturer's instructions, and he started walking on the treadmill at his predetermined speed. The nurse monitored him for 15 minutes, adjusting the speed if necessary based on his metabolic rate. (See Figure 9.) This gave the subject enough time to equilibrate at the required work rate while preventing a potential increase in metabolic cost due to the weight of the clothing and PCS and exercise-induced stress. This was repeated with the second subject starting 15 minutes after the first. Each subject walked for 2 hours with no rest periods. (See Figure 10.) The nurse measured each subject's metabolic rate during the last 15 minutes of the test period also. She asked the subjects to drink 250 ml of water every 30 minutes to prevent dehydration (i.e., 30, 60, 90 minutes from the time their treadmill run started). Subjects were permitted to listen the music of their choice. If a subject needed to urinate, he did so in a hand-held urinal in the chamber. The nurse recorded all fluid intake and excretion.

The test session ran for 2 hours for each subject unless one of the following removal criteria was met (ASTM F 2300):

- The subject's rectal temperature reaches 39°C or increases 0.6°C in a 5 minute period (whichever occurs first).
- The subject's heart rate reaches 90% of his age predicted maximum.
- The subject's skin temperature at any site reaches 38°C (see note below)
- The subject experiences heat exhaustion symptoms, including headache, extreme weakness, dizziness, vertigo, "heat sensations" on the head or neck, heat cramps, chills, "goose bumps", vomiting, nausea, and irritability (Hubbard & Armstrong, 1998).
- The subject wants to quit the experiment.

Note: The 38°C limit was not used for the hand sensor because it was not shielded from the radiant heat of the lights.

After a 2-hour test session, the subjects returned to the small chamber and removed all of their garments except for their briefs. After the subjects remove their instrumentation (i.e., thermocouples, heat rate monitor, rectal sensor), the nurse weighed each of them again. The subjects then put on their own clothes. If the subject's weight after the experiment was not within

1% of his initial weight, he was asked to drink cool water or Gatorade® and stay for observation for about 15 minutes or until his target body mass was achieved.

The experimenter laundered the garments and PCS garment (if necessary) and returned them to the small chamber prior to the next day's test. The skin sensors and wires were cleaned with makeup remover toilettes to remove perspiration oils and tape residue. They were cleaned with alcohol swabs between uses also. The 12 subjects in each test session each had their own rectal sensor which was sterilized prior to use. Each subject cleaned his sensor with an alcohol wipe when he finished using it for the day. Then the experimenter soaked the rectal sensors for 20 minutes in Cidex Plus™ (an FDA cleared sterilant and high level disinfectant) to disinfect them for use by the same subject the next day. Each sensor was stored in a plastic bag labeled with the subject's identification number between uses. After the test session was complete, (and before using the rectal sensors a second time on another group of subjects), the sensors were thoroughly cleaned and sterilized by soaking them for 10 hours.

Personnel. Several people participated in running the test sessions. A registered nurse with heat stress training was in the chamber with the subjects at all times. She monitored the subjects' oxygen consumption, heart rate, and overall well being. An engineer continuously monitored the other physiological responses of the subjects and the environmental conditions on a computer outside the chamber. A graduate student cleaned the sensors and garments between sessions, weighed the clothing and PCS, and assisted the nurse and investigators with the instrumentation of the subjects and other tasks. The investigators supervised all project activities and checked the data files daily. At least one investigator was present during all test sessions.

Army requirements. Army requirements regarding the subjects' safety and anonymity are given in Appendix D.

Data Collection

The characteristics of the subjects are given in Table 3. Subject #11 quit the experiment mid-week due to a family emergency; therefore, none of his data was used.

The subjects' skin temperatures, heart rate, and rectal temperature were measured every 5 seconds during the exercise protocol using a computerized data acquisition system. The data were averaged to produce a data point every minute for the analysis and report. The oxygen consumption and metabolic rate were measured for the first and last 15 minutes of the test session. The whole body sweat rate for each subject was determined by subtracting the subject's weight after the experiment from his weight before the experiment – subtracting the amount of fluid consumed during the experiment and adding the amount of urine to post body mass. The environmental conditions were also monitored continuously throughout the experiment. At the end of the week of test sessions, the subjects were asked which PCS they preferred and why, and to provide comments regarding each PCS (see Appendices E and F for case report forms).

Graphic Analysis: Environmental Conditions in the Chamber

During the course of the study, the average air (dry bulb) temperature was consistently between 39.5 and 40°C (Figure 11), and the average relative humidity was 20 $\pm$ 1% (Figure 12).

A mean radiant temperature of 54.5°C and the air velocity of 2 m/s were maintained in the chamber also.

Graphic Analysis: Physiological Responses of Soldiers Wearing Different PCS

The physiological responses of the Soldiers that were measured continuously – core temperature, mean skin temperature, and heart rate – were averaged and graphed over time for each PCS. Mean skin temperature (T_s) was supposed to be estimated by weighting eight skin temperatures according to ISO 9886 (ISO, 2004). However, the hand temperature was eliminated from the calculation because the radiant heat from the lights elevated its temperature and skewed the mean. The hand's weighting factor (determined by its surface area) was evenly distributed over the other sensors in the equation for determining the mean skin temperature. In addition, the skin temperatures measured on the chest and back were graphed since the three PCS were designed to increase convective and evaporative heat flows from these areas (i.e., under the body armor). (See Figures 13-17.)

Statistical Analysis

The design of the experiment was a 4 x 4 Latin square where subjects and test days served as blocks. The test days (acclimatization effect) were the rows, the subjects were the columns, and the PCS were the treatments. The purpose of this design was to remove unwanted variation when looking at the clothing effects that might occur between subjects and over the test days due to acclimatization. This was a concern since the soldiers had only three days of acclimatization before the first test day. There were three replications of the Latin Square, where each replication was run in a different week. Separate analyses of variance and post hoc comparison tests were used to determine the effect of the different PCS (including the baseline condition with no PCS) on the following dependent variables:

- exposure time (duration of test)
- final core temperature
- change in core temperature
- final mean skin temperature
- final average temperature of the chest and back
- final oxygen consumption
- final metabolic rate
- whole body sweat rate
- final heart rate.

The final values were taken at 120 minutes or when the subject met one of the removal criteria and the experiment was stopped. None of the subjects quit the experiment early, so there was no need to analyze the effect of PCS on exposure time; it was 120 minutes for all tests. The change in core temperature was calculated from minute 1 to minute 120. The level of statistical significance was set at $p \leq 0.05$.

Analysis of variance. The separate analyses of variance are given in Table 4. Test day was not significant for any dependent variables, indicating that there were no confounding effects due to differences in acclimatization of the subjects. The effect of subject was significant for all but one of the dependent variables because human variability was higher than experimental variance due to the personal cooling systems. Since each subject wore all of the PCS, this was not a problem in the study.

The effect of type of PCS was not statistically significant for final core body temperature, change in core temperature, or metabolic rate. The most important physiological indicator of thermal stress is core temperature, and none of the PCS lowered core temperature significantly as compared to the baseline ensemble with no PCS. The mean values for these variables are given in Table 5. We did not want to find a difference in metabolic heat production because we tried to estimate the speed of the treadmill for each subject so that all subjects would be working at the same rate. Therefore, all of the subjects were producing the same amount of heat during the test sessions with the different PCS. This was a desired result.

The effect of PCS was statistically significant for final oxygen consumption, final mean skin temperature, final average back and chest temperature, final heart rate, and whole body sweat rate (Table 4). Tukey post hoc comparison tests were used to determine which PCS were significantly different from each other on each dependent variable. (See Table 6.) The order of means was the same for every variable: PCS0 baseline ensemble was the worst (i.e., the Soldiers had the least desirable response while wearing it), followed by PCS3 NASA Active Cooling System, PCS2 Global Secure Body Ventilation System, and PCS1 Summitstone ForcedAir Vest (the best).

All of these systems were designed to increase convective and evaporative heat loss from the body under the body armor. This effect is best shown on the graphs of the average back and chest temperatures (Figures 15 and 16). The skin temperature on the torso was significantly hotter when a PCS was not worn (Table 6). The mean skin temperature of the subjects wearing no PCS was significantly higher than the mean skin temperature when wearing PCS2 BVS and PCS1 FAV (Figure 14).

The sweat rate and oxygen consumption were significantly higher when the subjects were not wearing PCS as compared to wearing PCS1 FAV. If the sweat under the body armor could not evaporate and provide cooling, the body would have to work harder and produce more sweat.

The heart rate of the subjects was significantly higher when they were not wearing PCS or they were wearing PCS3 NACS as compared to PCS1 FAV, where it was lower. Apparently, the body was not as stressed when exercising in the heat and wearing the FAV system. (See Figure 17.)

Soldier Preferences

Six of the 11 soldiers who completed the study preferred PCS1 ForcedAir Vest. This information and the subjects' comments (Table 7) generally agree with their physiological responses. Although the focus of this study was on the heat mitigating performance of the PCS, the subjects had many other ergonomic concerns such as the restriction of mobility, the added weight and bulkiness, etc., caused by the PCS.

Conclusions

The three personal cooling systems selected for study circulated air between the desert combat uniform and the body armor on the upper torso of the body. These ambient air systems were designed to increase convective and evaporative heat loss from the body to the environment. In a desert environment where the air temperature is higher than the skin temperature, evaporation of sweat from the skin surface is the primary means for losing heat and cooling the body. None of the PCS lowered the core temperature of the Soldiers significantly as compared to the baseline ensemble with no PCS. However, PCS1 – the ForcedAir Vest – seemed to provide the most overall body cooling (as evidenced by the other dependent variables), followed by PCS2 – the Global Secure Body Ventilation System.

Discussion. All of the personal cooling systems might have worked better if they had been worn between the T-shirt and the DCU instead of over the DCU. However, the shirttail of the DCU would have interfered with the air motion in the systems, and it would have to go over the battery pack in the front of PCS2. A change in the design of the PCS or an adjustment mechanism to the shirt to allow the PCS to be placed over the T-shirt might improve performance. The PCS evaluated in this study all added weight, bulk, and cost to the Army desert ensemble, and they failed to significantly lower body core temperature (as compared to not using a PCS). However, the Soldiers could perceive differences in their comfort while wearing some of the systems, and PCS1 FAV offered some improvement in physiological performance.

Limitations of the Study

The goal of this study was to identify the most effective cooling system of those tested using human subjects in a controlled laboratory setting. The metabolic heat production of the Soldier was controlled at a relatively high level. Variables such as the weight of the clothing worn and loads carried (packs, weapons, etc.) and the activity levels of the Soldiers will affect the heat production of the Soldier during military operations. Therefore, the best PCS found in this study may be ineffective in providing enough cooling for Soldiers under some sets of conditions. In addition, the PCS may have other logistical or ergonomic problems that are not being evaluated in this study. Further testing on Soldiers in the field would be necessary to determine the overall effectiveness and durability of a PCS. This study is limited to quantifying the amount and duration of cooling provided by the PCS, and its affect on the physiological and subjective responses of human subjects under controlled conditions.

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Table 1. Schedule of Test Sessions for One Series of Tests

Date	Morning (8:15 a.m. – 12:00 p.m.)	Afternoon (1:00 – 4:45 p.m.)
Sat. and Sun. Day 1-2 Heat familiarization		Subjects 11, 12, 13, 14 DCU and helmet
Monday Day 3 Heat familiarization	Subject 11, PCS0 Subject 12, PCS0	Subject 13, PCS0 Subject 14, PCS0
Tuesday Day 4	Subject 11, PCS0 Subject 12, PCS1	Subject 13, PCS3 Subject 14, PCS2
Wednesday Day 5	Subject 11, PCS1 Subject 12, PCS3	Subject 13, PCS2 Subject 14, PCS0
Thursday Day 6	Subject 11, PCS3 Subject 12, PCS2	Subject 13, PCS0 Subject 14, PCS1
Friday Day 7	Subject 11, PCS2 Subject 12, PCS0	Subject 13, PCS1 Subject 14, PCS3
Sat. and Sun. Day 8-9 Heat familiarization		Subjects 15, 16, 17, 18 DCU and helmet
Monday Day 10 Heat familiarization	Subject 15, PCS0 Subject 16, PCS0	Subject 17, PCS0 Subject 18, PCS0
Tuesday Day 11	Subject 15, PCS0 Subject 16, PCS1	Subject 17, PCS3 Subject 18, PCS2
Wednesday Day 12	Subject 15, PCS1 Subject 16, PCS3	Subject 17, PCS2 Subject 18, PCS0
Thursday Day 13	Subject 15, PCS3 Subject 16, PCS2	Subject 17, PCS0 Subject 18, PCS1
Friday Day 14	Subject 15, PCS2 Subject 16, PCS0	Subject 17, PCS1 Subject 18, PCS3
Sat. and Sun. Day 15-16 Heat familiarization		Subjects 19, 20, 21, 22 DCU and helmet
Monday Day 17 Heat familiarization	Subject 19, PCS0 Subject 20, PCS0	Subject 21, PCS0 Subject 22, PCS0
Tuesday Day 18	Subject 19, PCS0 Subject 20, PCS1	Subject 21, PCS3 Subject 22, PCS2
Wednesday Day 19	Subject 19, PCS1 Subject 20, PCS3	Subject 21, PCS2 Subject 22, PCS0
Thursday Day 20	Subject 19, PCS3 Subject 20, PCS2	Subject 21, PCS0 Subject 22, PCS1
Friday Day 21	Subject 19, PCS2 Subject 20, PCS0	Subject 21, PCS1 Subject 22, PCS3

Table 2. Weights of Army Clothing and Personal Cooling Systems

Clothing and PCS	Weight (kg)	(lb)
Army lightweight desert combat uniform (DCU), underwear briefs, belt, T-shirt, socks, and athletic shoes (size small)	2.864	6.31
Army lightweight desert combat uniform (DCU), underwear briefs, belt, T-shirt, socks, and athletic shoes (size medium)	2.946	6.49
Army lightweight desert combat uniform (DCU), underwear briefs, belt, T-shirt, socks, and athletic shoes (size large)	3.109	6.85
Army lightweight desert combat uniform (DCU), underwear briefs, belt, T-shirt, socks, and athletic shoes (size extra large)	3.200	7.05
Kevlar® helmet with pads (size medium)	1.514	3.34
Kevlar® helmet with pads (size large)	1.562	3.44
Kevlar® helmet with pads (size extra large)	1.744	3.84
Body Armor interceptor body armor (IBA) – outer tactical vest (OTV) with enhanced small arm protective insert plates (ESAPI) (size medium)	8.664	19.10
Body Armor interceptor body armor (IBA) – outer tactical vest (OTV) with enhanced small arm protective insert plates (ESAPI) (size large)	9.798	21.60
Body Armor interceptor body armor (IBA) – outer tactical vest (OTV) with enhanced small arm protective insert plates (ESAPI) (size extra large	10.569	23.30
Deltoid auxiliary protection system (DAPS) (one size fits all)	1.179	2.60
Enhanced side ballistic inserts (ESBI) (one size fits all)	4.536	10.00
Heart rate chest strap	0.064	0.14
Hear rate watch	0.048	0.11
Velcro wrist strap for grounding	0.005	0.01
PCS #1 FAV (one size fits all)	1.920	4.23
PCS #2 BVS (size medium)	1.641	3.62
PCS #2 BVS (size large)	1.729	3.81
PCS #3 NACS (size medium)	0.470	1.04
PCS #3 NACS (size large)	0.490	1.08
PCS #3 NACS (size extra large)	0.510	1.12

Table 3. Characteristics of Subjects[a]

Subject Number	Age (years)	Race	Height	Weight	BMI
12	26	Hispanic	1.68 m 5 ft. 6 in.	78.5 kg 173 lbs.	27.8
13	20	White	1.85 m 6 ft. 1 in.	83.5 kg 184 lbs.	24.4
14	21	Hispanic	1.80 m 5 ft. 11 in.	82.6 kg 182 lbs.	25.5
15	19	White	1.80 m 5 ft. 11 in.	73.9 kg 163 lbs.	22.8
16	21	Black	1.91 m 6 ft. 3 in.	84.4 kg 186 lbs.	23.1
17	20	Black	1.68 m 5 ft. 6 in.	74.8 kg 165 lbs.	26.5
18	20	Asian	1.68 m 5 ft. 6 in.	73.3 kg 161.5 lbs.	26.0
19	20	White	1.85 m 6 ft. 1 in.	94.3 kg 208 lbs.	27.6
20	19	Black	1.78 m 5 ft. 10 in.	74.4 kg 164 lbs.	23.5
21	22	White	1.80 m 5 ft. 11 in.	74.4 kg 164 lbs.	23.0
22	20	White	1.78 m 5 ft. 10 in.	77.1 kg 170 lbs.	24.3

[a] Subject 11 had to quit the experiment due to an illness in his family. Therefore, his data are not reported.

Table 4. Separate Analyses of Variance for Determining the Effect of PCS on Different Dependent Variables

Source	Sums of Squares	Mean Square Error	Degrees of Freedom	F Ratio	Prob > F
Final Core (Rectal) Temperature (°C)					
PCS	0.02588	0.00863	3	0.3990	0.7548
Day	0.0277	0.00923	3	0.4271	0.7352
Subject (Random)	1.35227	0.13523	10	6.2555	<.0001
Change in Core (Rectal) Temperature (°C)					
PCS	0.02805	0.00935	3	0.3954	0.7573
Day	0.0175	0.00583	3	0.2467	0.8629
Subject (Random)	3.44482	0.34448	10	14.5691	<.0001
Final Metabolic Rate (W)					
PCS	1786.55	595.516	3	2.5505	0.0766
Day	527.275	175.758	3	0.7527	0.5304
Subject (Random)	15946.9	1594.69	10	6.8298	<.0001
Final Oxygen Consumption VO_2 (ml/kg/min)					
PCS	2.63405	0.87802	3	3.8468	0.0205
Day	0.53078	0.17693	3	0.7752	0.5181
Subject (Random)	35.8415	3.58415	10	15.7029	<.0001
Final Mean Skin Temperature (°C)					
PCS	1.66147	0.55382	3	4.9891	0.0070
Day	0.39965	0.13322	3	1.2001	0.3285
Subject (Random)	6.41409	0.64141	10	5.7781	0.0001
Final Average Back and Chest Temperature (°C)					
PCS	13.2164	4.40545	3	11.3662	<.0001
Day	2.69091	0.89697	3	2.3142	0.0984
Subject (Random)	6.21682	0.62168	10	1.6040	0.1588

Table 4 continued

Source	Sums of Squares	Mean Square Error	Degrees of Freedom	F Ratio	Prob > F
Final Heart Rate (bpm)					
PCS	489.43	163.143	3	5.5940	0.0041
Day	8.70303	2.90101	3	0.0995	0.9596
Subject (Random)	11160	1116	10	38.2663	<.0001
Whole Body Sweat Rate (g/hr)					
PCS	118798	39599.3	3	3.6646	0.0246
Day	87090.7	29030.2	3	2.6865	0.0664
Subject (Random)	605216	60521.6	10	5.6008	0.0002

Table 5. Means and Standard Errors for Statistically Insignificant Variables

Personal Cooling System	Mean	Standard Error
Final Core (Rectal) Temperature (°C)		
PCS0 Baseline DCU, IBA, Helmet	38.0	0.04
PCS1 Baseline + FAV	37.9	0.04
PCS2 Baseline + BVS	37.9	0.04
PCS3 Baseline + NACS	38.0	0.04
Change in Core (Rectal) Temperature (°C)		
PCS0 Baseline DCU, IBA, Helmet	0.57	0.05
PCS1 Baseline + FAV	0.52	0.05
PCS2 Baseline + BVS	0.50	0.05
PCS3 Baseline + NACS	0.54	0.05
Final Metabolic Rate (W)		
PCS0 Baseline DCU, IBA, Helmet	369.1	4.62
PCS1 Baseline + FAV	354.6	4.62
PCS2 Baseline + BVS	371.3	4.62
PCS3 Baseline + NACS	364.7	4.62

Table 6. Tukey Post Hoc Comparison Tests for Significant Variables

Clothing Ensemble	Mean	Tukey HSD*	Standard Error
Final Mean Skin Temperature (°C)			
PCS0 Baseline DCU, IBA, Helmet	37.1	A	0.10
PCS3 Baseline + NACS	36.9	A B	0.10
PCS2 Baseline + BVS	36.7	B	0.10
PCS1 Baseline + FAV	36.6	B	0.10
Whole Body Sweat Rate (g/hr)			
PCS0 Baseline DCU, IBA, Helmet	1082.9	A	31.44
PCS3 Baseline + NACS	970.3	A B	31.44
PCS2 Baseline + BVS	961.4	A B	31.44
PCS1 Baseline + FAV	957.0	B	31.44
Final Heart Rate (bpm)			
PCS0 Baseline DCU, IBA, Helmet	121.8	A	1.63
PCS3 Baseline + NACS	121.2	A	1.63
PCS2 Baseline + BVS	116.8	A B	1.63
PCS1 Baseline + FAV	113.6	B	1.63
Final Oxygen Consumption VO_2 (ml/kg/min)			
PCS0 Baseline DCU, IBA, Helmet	11.2	A	0.14
PCS3 Baseline + NACS	11.0	A B	0.14
PCS2 Baseline + BVS	11.1	A B	0.14
PCS1 Baseline + FAV	10.6	B	0.14
Final Average Back and Chest Temperature (°C)			
PCS0 Baseline DCU, IBA, Helmet	37.7	A	0.19
PCS3 Baseline + NACS	36.7	B	0.19
PCS2 Baseline + BVS	36.6	B	0.19
PCS1 Baseline + FAV	36.2	B	0.19

***** Means with the same letter designation are not statistically different from one another at the 0.05 level of significance.

Table 7. Soldier Preferences for PCS

Subject	Preference	Comments[a]
12	PCS1 ForcedAir Vest	PCS1 FAV: I felt the air moving, but I don't like the tubes—they restrict my body motion. PCS2 BVS: Added weight. PCS3 NACS: Did not work at all.
13	PCS1 ForcedAir Vest	PCS1 FAV: Kept me the coolest. Bulking in front where spacers are. Lightweight. PCS2 BVS: Weighed more than the others. Couldn't feel a cooling difference from not wearing it to wearing it. Needs more than one person to put it on. PCS3 NACS: Bulky all over. Couldn't feel a cooling difference. Good because it's lightweight. Might have worked better without DAP and ESBI pads.
14	PCS0 No cooling system; Basic DCU with IBA, DAP, ESBI, and helmet	PCS1 FAV: I had more mobility. Couldn't feel a cooling difference. Not very heavy. Not too bulky. Could be more durable; seemed flimsy—tubes moved around too much. PCS2 BVS: It was too heavy and too bulky. Restricted mobility. The small cooling effects felt were counterbalanced by the weight and restricted mobility. Least favorite. PCS3 NACS: Liked because it was lightweight, flexible—moved with me. Poor method of donning; needs a strap over shoulder or something. Blocked air flow by DAP pads.
15	PCS2 Body Ventilation System	PCS1 FAV: Did not move enough air around under vest. PCS2 BVS: Most comfortable, but needs more air flow. PCS3 NACS: Uncomfortable, bad system.
16	PCS2 Body Ventilation System	PCS1 FAV: It cooled the back well but not the front. After an hour I couldn't feel the cooling any more. PCS2 BVS: It was lightweight. Helped cool the front and back. It would be nice to cool the shoulder area. PCS3: Cooled front. Uncomfortable under the shoulder area of the body armor. Cooling outlet vent blocked by shoulder straps of armor.
17	PCS1 ForcedAir Vest	PCS1 FAV: Lightweight. Kept my lower back and lower stomach cool, but upper back and upper chest were hot. (Maybe this was because it was compressed by body armor. PCS2 BVS: Didn't work well because the air wasn't able to circulate through. Only my lower back stayed cool while wearing it. Was a little thick. May not be safe because if I fell back I might break the battery pack. No real discomfort while wearing in terms of weight. PCS3 NACS: It is too thick and uncomfortable under body armor; bulky. Didn't really do any cooling because it was compressed under body armor. Didn't fit my body well. Shaped well in terms of fitting into body armor, but was thick.

18	PCS1 ForcedAir Vest	PCS1 FAV: It is extremely lightweight and thin. The only problem was where the tubes were and I felt like the tubes were going to pop out. I felt cooler on my back when wearing this. PCS2 BVS: Only felt cool around the belt area. Not too heavy. Not restrictive in movement. PCS3 NACS: Didn't put in fresh air or take out heat. Put pressure on upper back. Limited my movement and the ability to add additional equipment to body armor. It was too bulky.
19	PCS0 No cooling system; Basic DCU with IBA, DAP, ESBI, and helmet	PCS3 NACS: Uncomfortable under body armor.
20	PCS2 Body Ventilation System	PCS2 BVS: Would be better if it had more air force; only cooled small of back. PCS3 NACS: Uncomfortable; did not feel cooler
21	PCS1 ForcedAir Vest	PCS1 FAV: Loose fitting and not uncomfortable. I could feel the air going through the system. Wasn't heavy. PCS2 BVS: I felt it cooling at first, but it couldn't keep up with cooling my body as I got hotter. It molded comfortably to my body; didn't slip around. PCS3 NACS: Uncomfortable, as it didn't fit my body and was too thick. The fans are too small and they were getting clogged by my clothes in front and weren't cooling me. Lightweight, but no comfort.
22	PCS1 ForcedAir Vest	PCS1 FAV: The pipes in the chest hurt and made it uncomfortable to breathe. I could feel it cooling by body. Lightest system. PCS2 BVS: Worked in the beginning cooling me, but it felt like it couldn't keep up with cooling as I got hotter. Didn't notice the weight. Fit snug and comfortably to my body. PCS3 NACS: It hurt my back. Didn't feel any cooling while wearing it. Not heavy.

[a] The subjects' comments were typed verbatim.

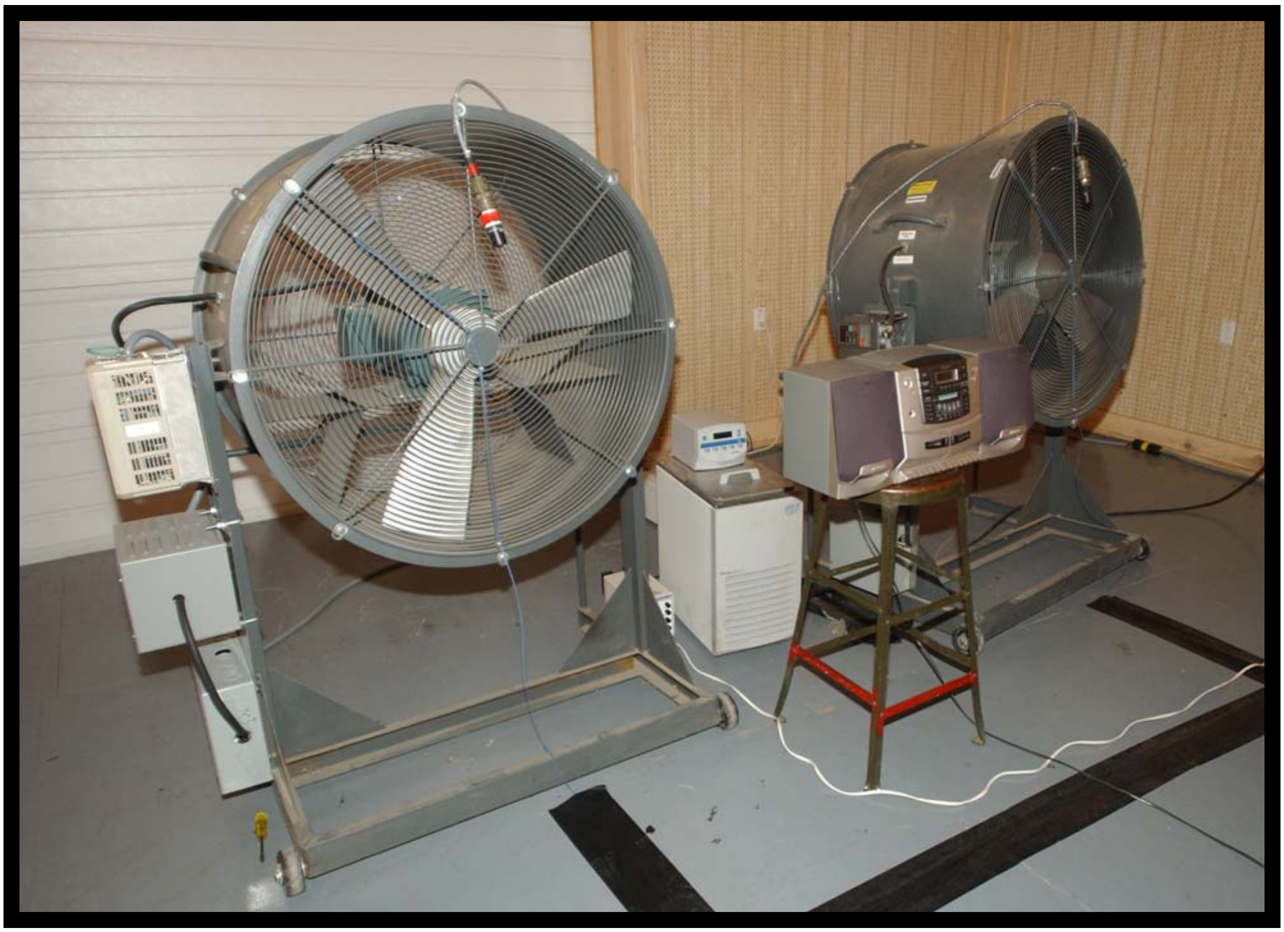

Figure 1. Fans in front of the treadmills; portable CD/tape player.

Figure 2. Lights generating the radiant load.

Figure 3. Subject stations in the preconditioning chamber.

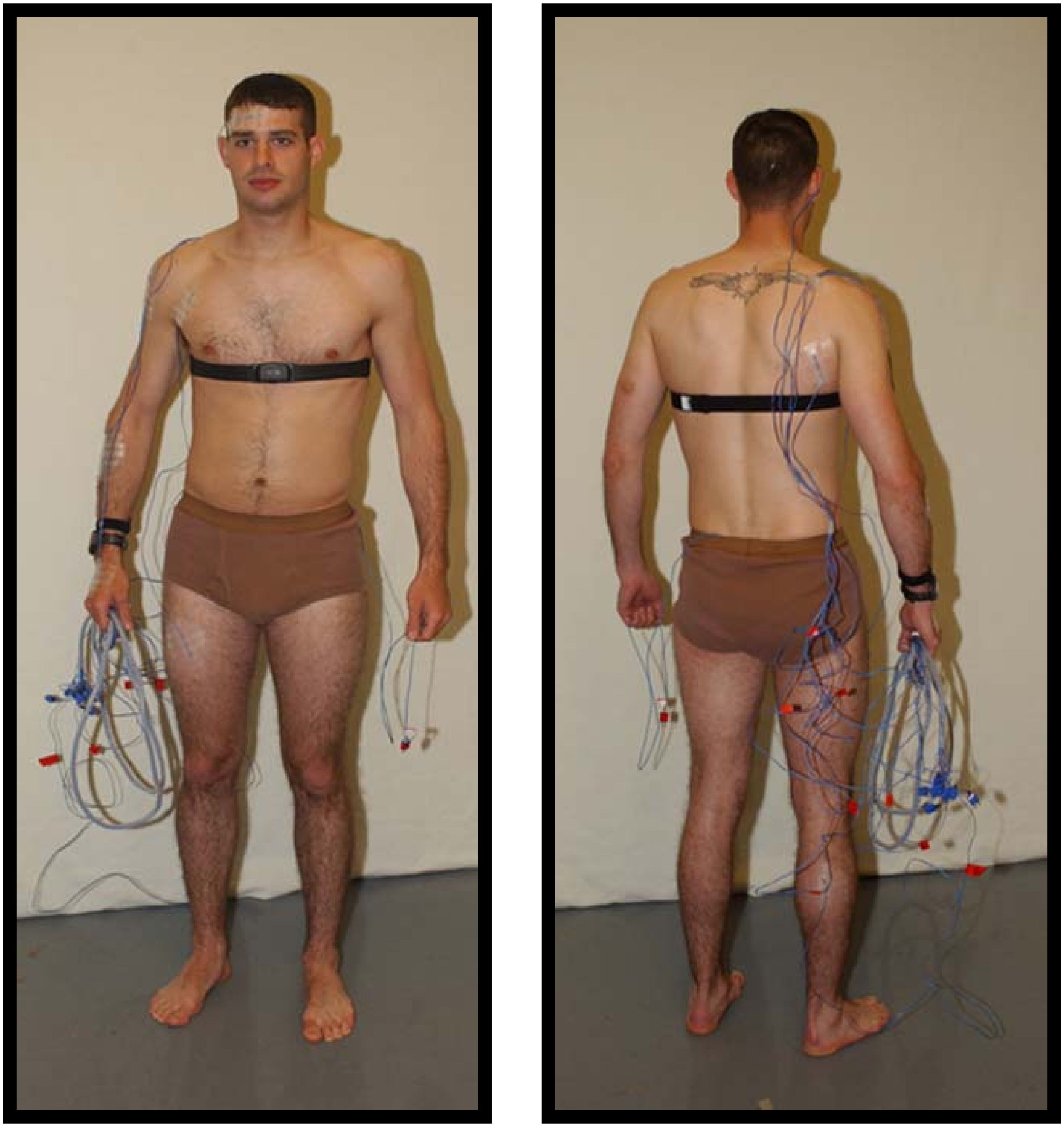

Figure 4. Front and back of instrumented subject.

Figure 5. Subject dressed in PCS #0 baseline desert ensemble with body armor.

Figure 6. Subject dressed in PCS #1 FAV.

Figure 7. Subject dressed in PCS #2 BVS.

Figure 8. Subject dressed in PCS #3 NACS.

Figure 9. Subject connected to the met cart.

Figure 10. Subjects walking on the treadmills during a test session.

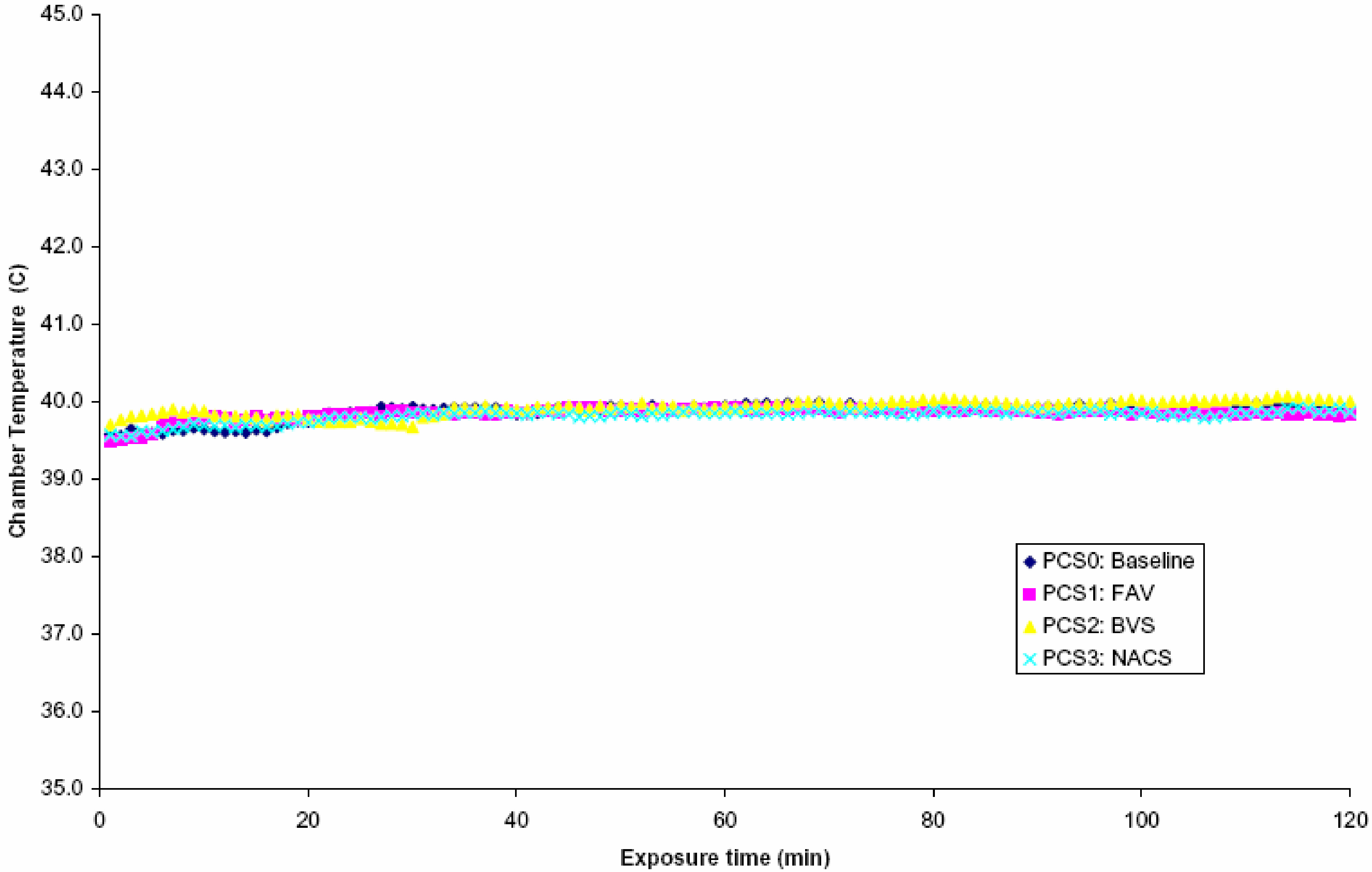

Figure 11. Average air temperature in the chamber during the test sessions – shown by PCS.

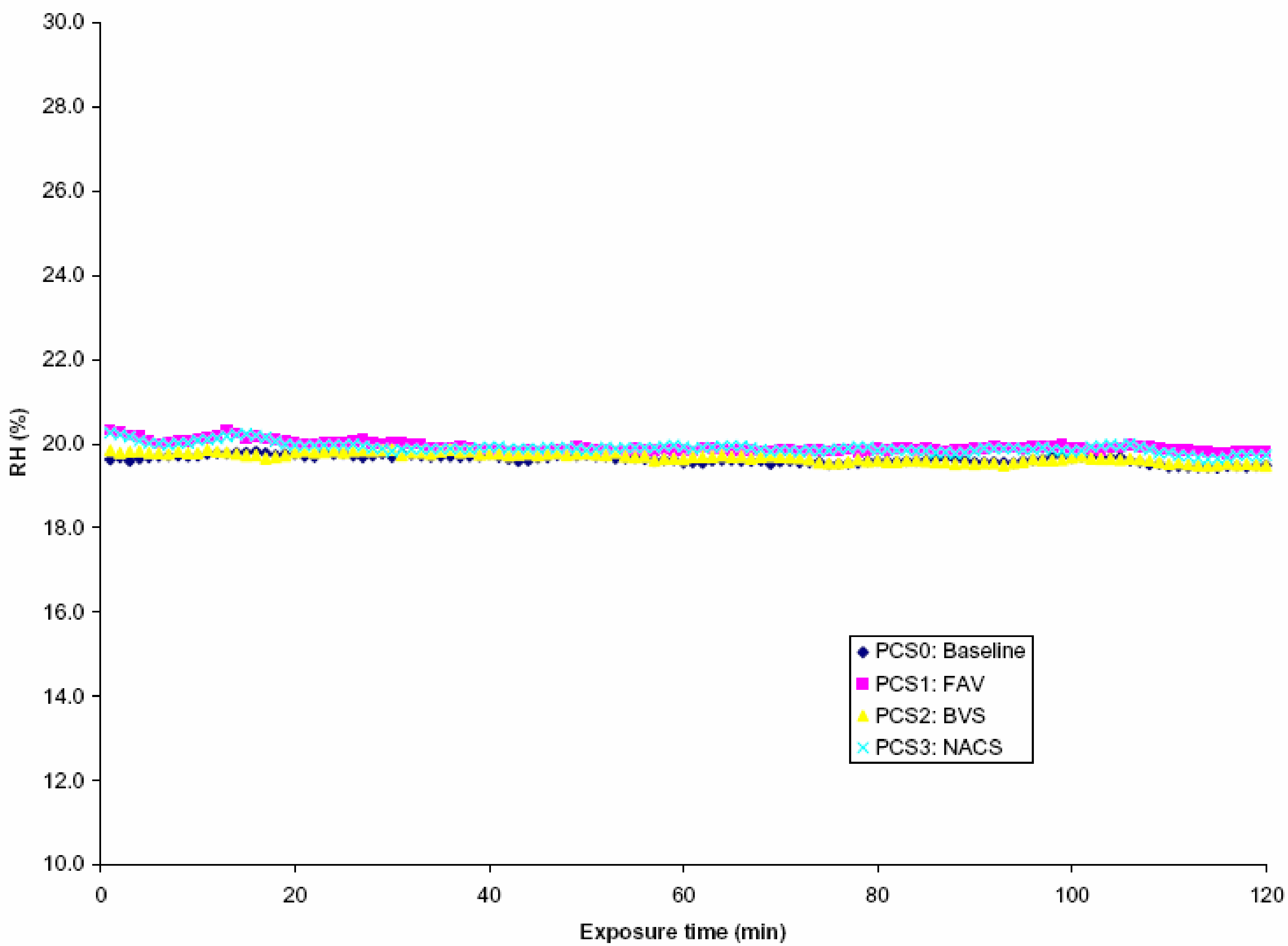

Figure 12. Average relative humidity in the chamber during the test sessions – shown by PCS.

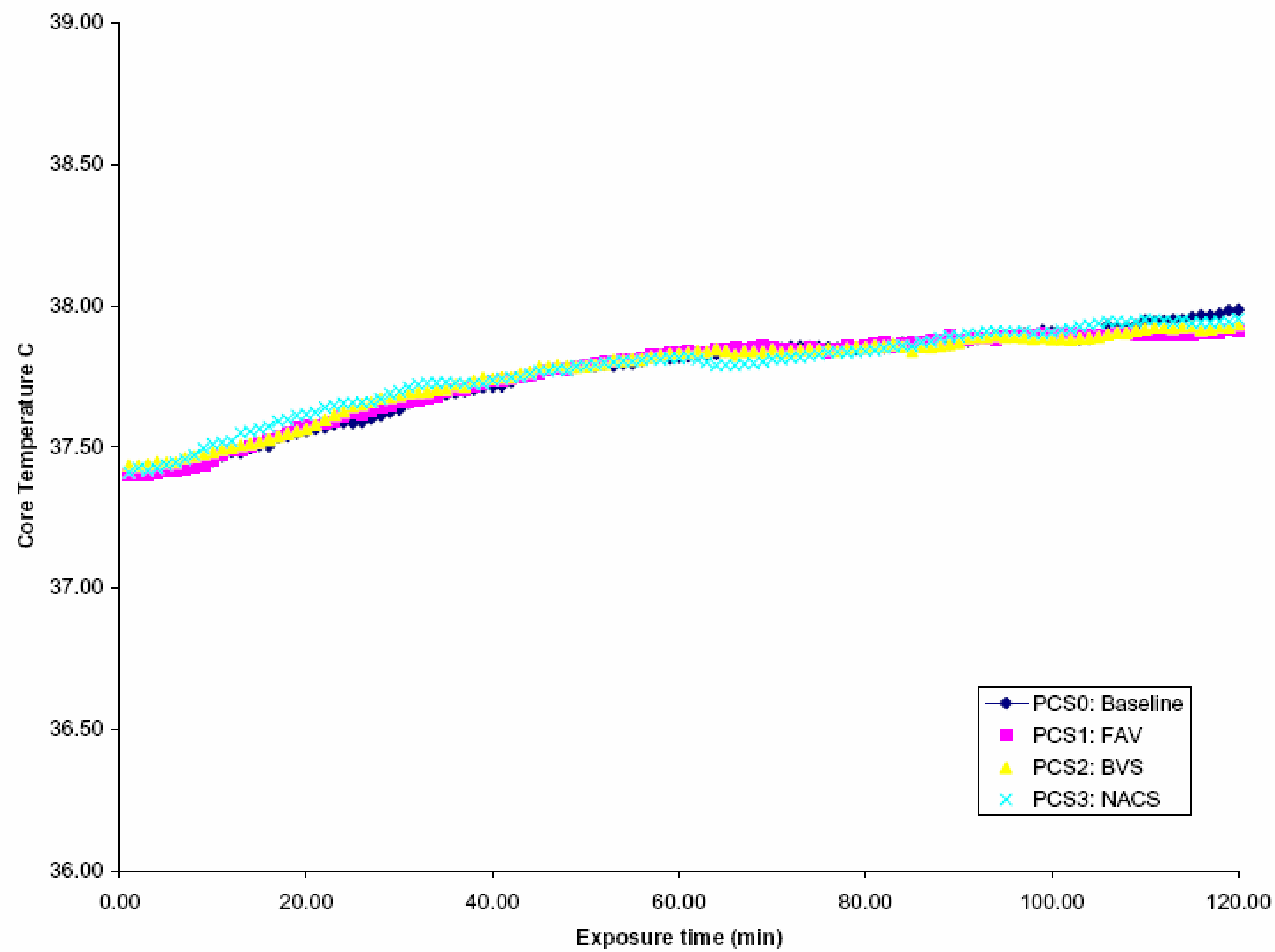

Figure 13. Average core temperatures of Soldiers while wearing different PCS.

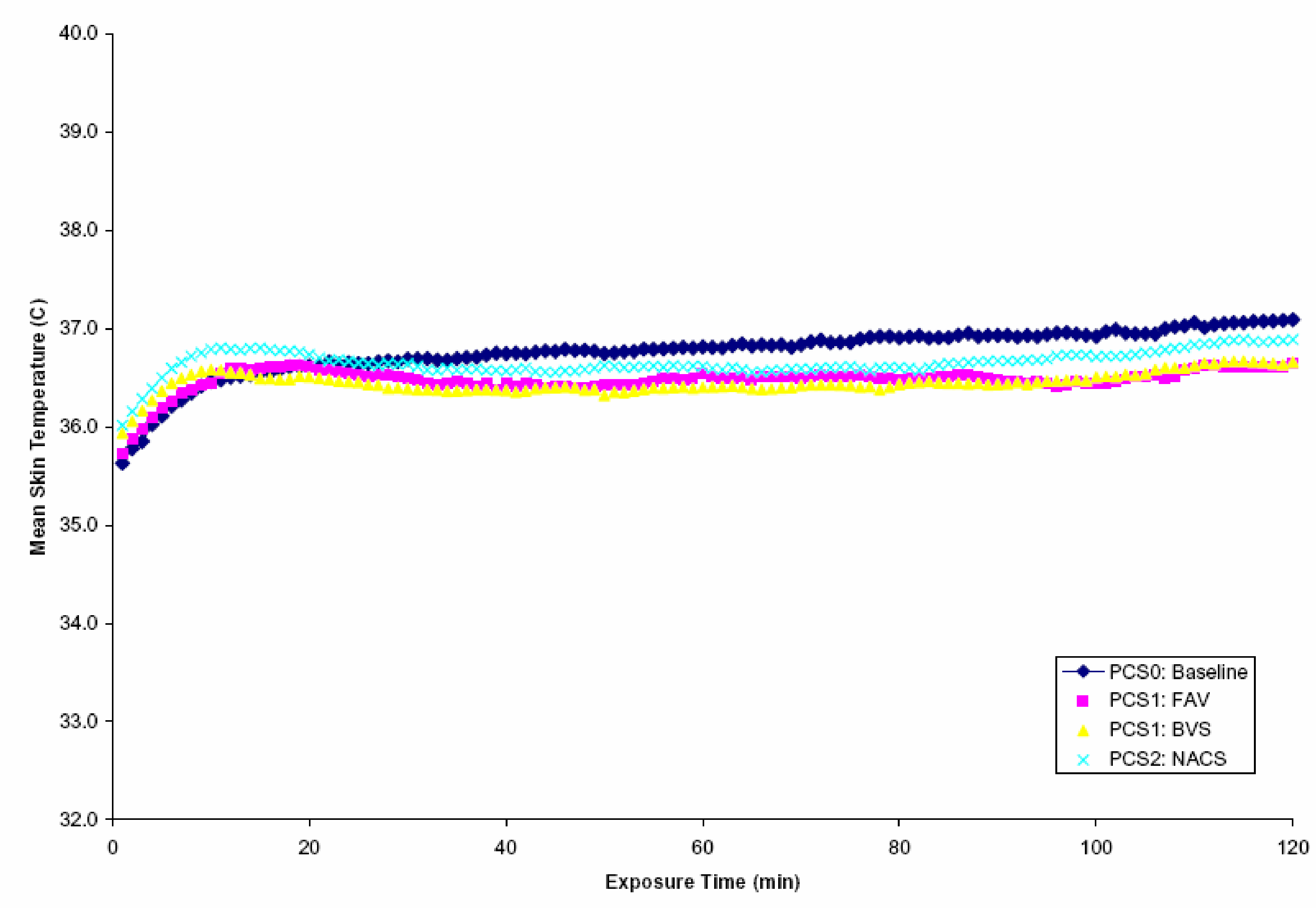

Figure 14. Mean skin temperatures of Soldiers while wearing different clothing systems.

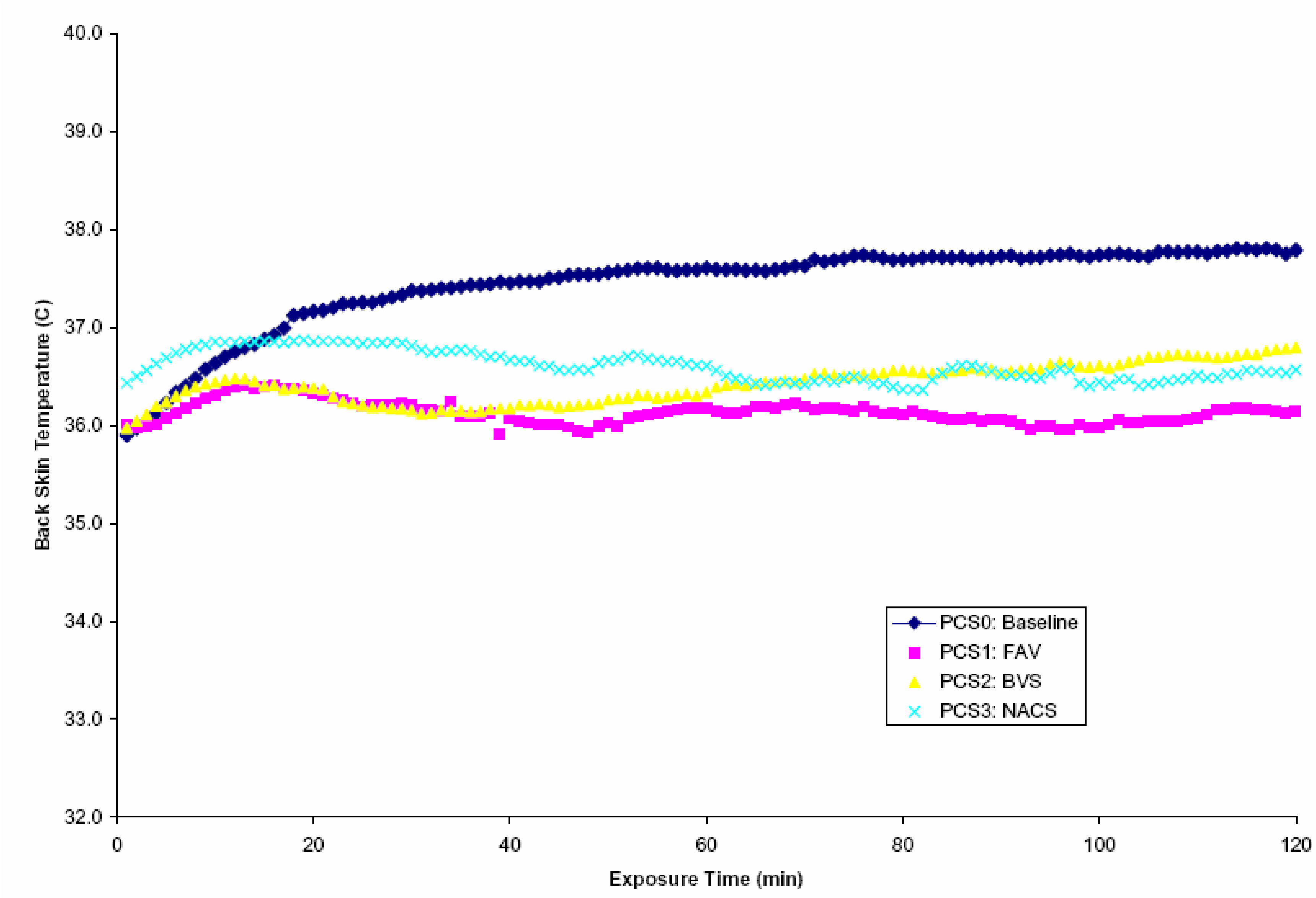

Figure 15. Average back skin temperatures of Soldiers while wearing different PCS.

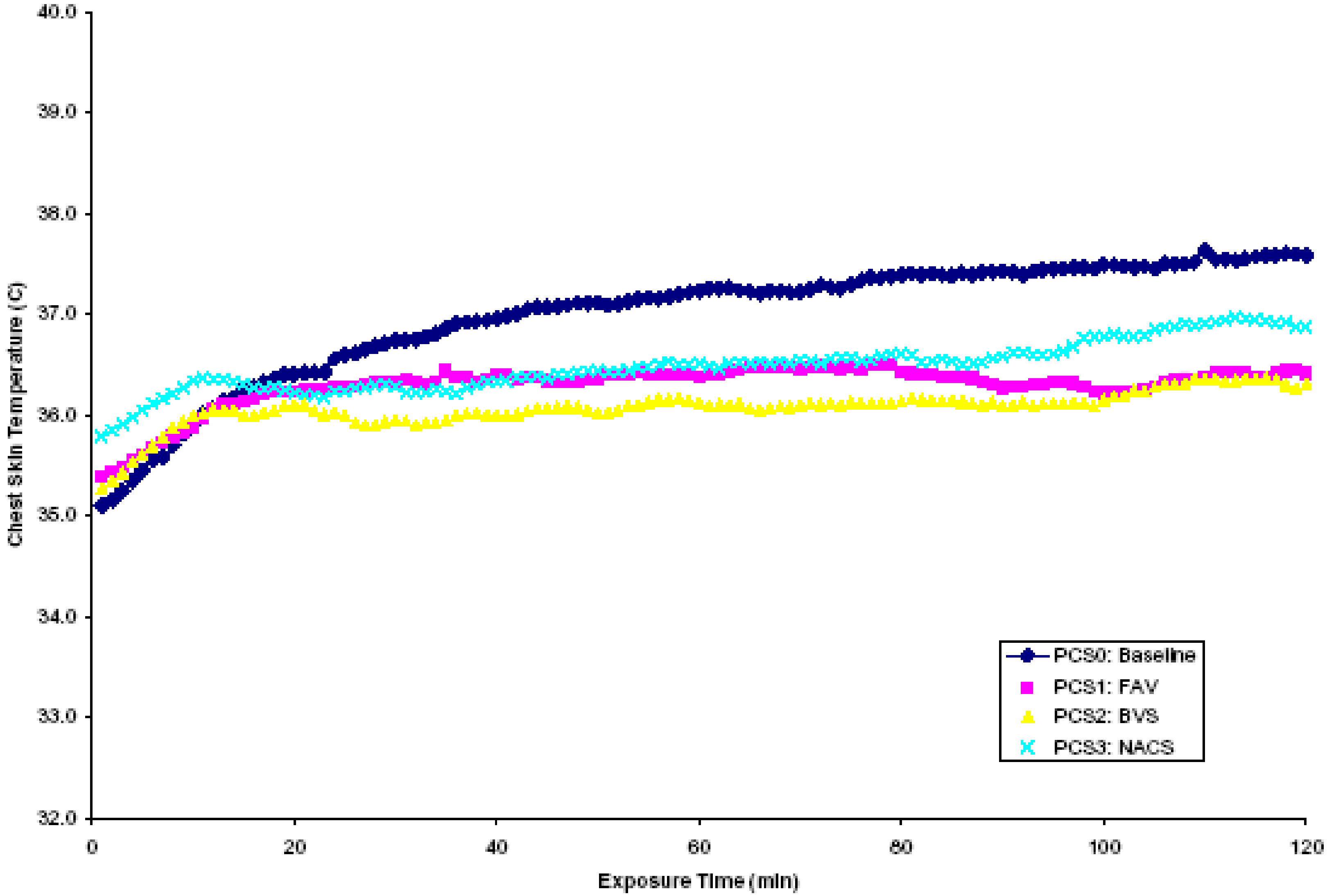

Figure 16. Average chest skin temperatures of Soldiers while wearing different PCS.

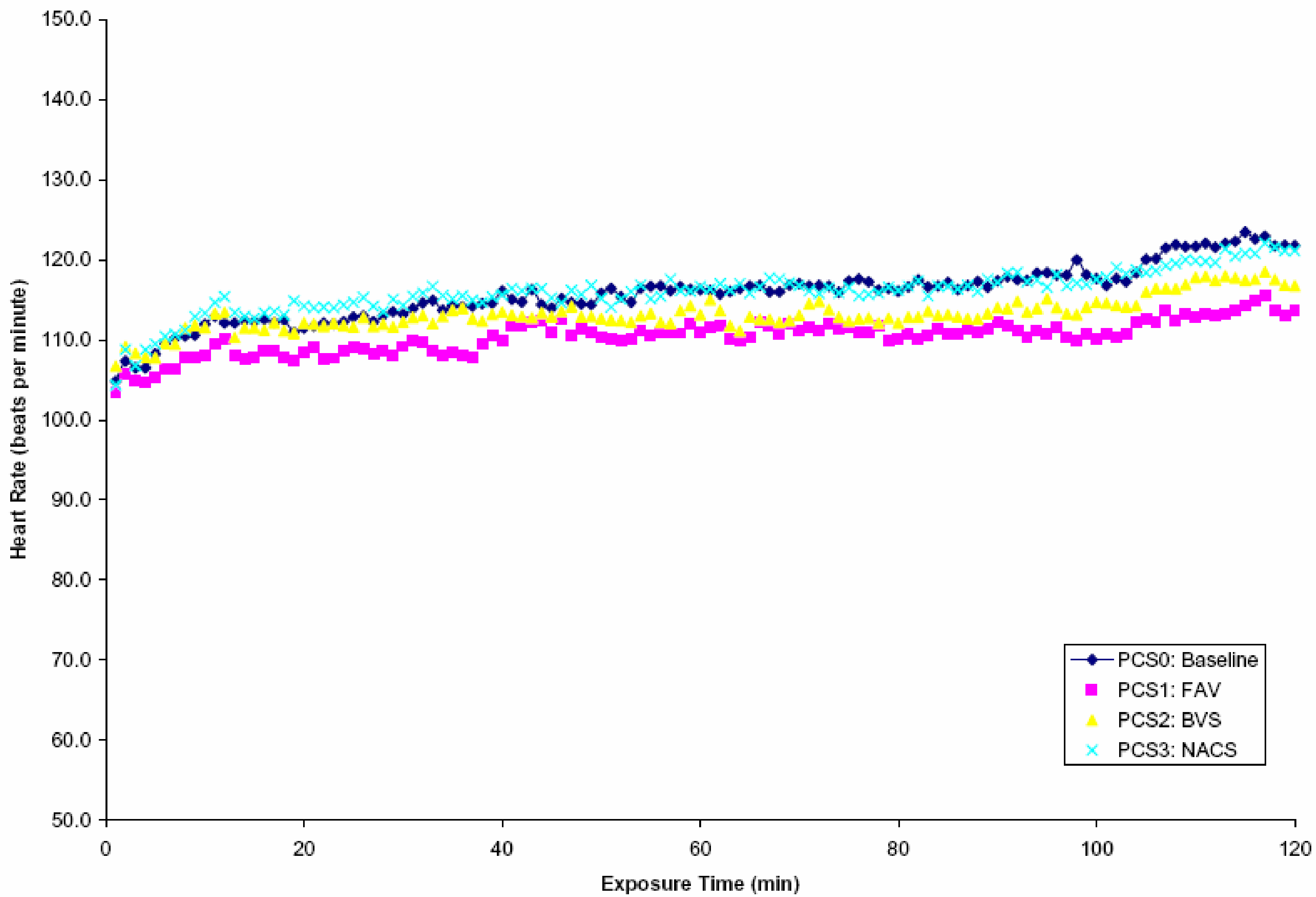

Figure 17. Average heart rates of Soldiers while wearing different PCS.

Appendix A – PCS #1

Product Name: ForcedAIR Vest

Company: Summitstone Corporation

Company Address: 1161 James Wharf Road
White Stone Va. 22578
(804) 435-0074

Company Contact: Steve Horn

Info Source: ClimaTech Safety website

Web Address: http://www.climatechsafety.com/Military.htm

Technology Classifications: Active Evaporation System

Short Technology Description: The Summitstone ForcedAIR Vest (FAV) is designed to circulate ambient air inside body armor. Twin blowers circulate ambient air at a rate of 15 cubic feet per minute through an airspace incorporated in the vest. Cooling occurs when sweat absorbed by the vest is evaporated by the air circulating through the airspace.

The FAV also has an auxiliary mode of operation where the vest is coupled to a compressed air source. This may be an important consideration as it will allow cooling for Soldiers while they ride in transports. A quick disconnect will allow the Soldier to rapidly dismount.

Physical Description: The Summitstone FAV is worn under body armor and over a shirt. The vest covers the torso and is secured in front by Velcro straps. The controls and battery pack are located in the front of the vest (see picture below).

Energy Removal: Summitstone does not provide cooling estimates for the FAV.

Size: The Summitstone FAV is designed to fit under any body armor. Adjustable straps are in place to ensure a snug fit.

System weight: The Summitstone FAV weighs 7.4 lbs, including the C alkaline battery pack. Lighter weights and extended life times can be achieved by utilizing advanced battery technology.

Power Requirements: The Summitstone FAV is designed to be compatible with Energizer alkaline 8350 mAh C cells. When powered with these batteries the expected operational life is 4 hrs. D cells can also be used to achieve an 8 hr operational life.

Support Systems Required: Additional batteries are needed for long missions.

Mobility Limitations: The Summitstone FAV does not appear to have any mobility limitations given sufficient battery supply.

Unit Price: Summitstone will loan a system for testing.

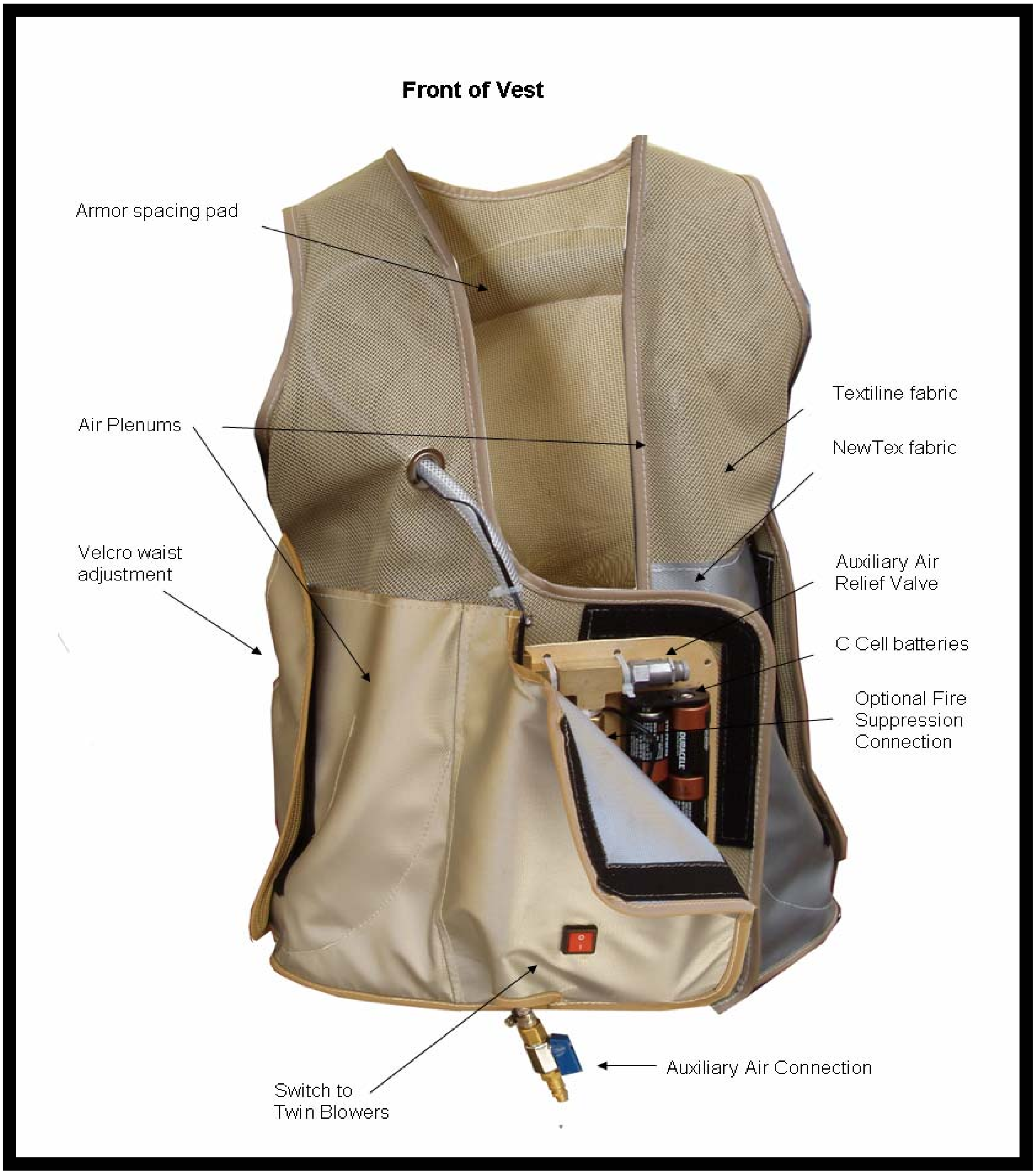

Figure A1. Summitstone ForcedAIR Vest.

Appendix B – PCS #2

Product Name: Global Secure Safety Body Ventilation System (BVS)

Company: Global Secure Safety Products, Inc.

Company Address: Global Secure Safety Products, Inc.
2020 Firedancer Lane
Bear, DE 19701
Local: 302.325.1190
Fax: 302.325.1198

Company Contact: Jack Sawicki
jsawicki@globalsecurecorp.com
(202) 333-8400 ext.224

Info Source: Prof. Steve Eckels e-mail

Web Address: http://www.globalsecurecorp.com/

Technology Classifications: Active Evaporation System

Short Technology Description: The Global Secure Safety Body Ventilation System (BVS) is designed to circulate ambient air inside standard issue Interceptor Body Armor. A small blower assembly mounted to the back of the Body Armor blows ambient air at a rate of 10 cubic feet per minute into a lining on the inside of the Body Armor. The lining absorbs sweat and the circulating air evaporates the sweat providing cooling to the Soldier. From the back section, the air wraps around the body into pockets covering the side and front of the body armor. The air leaves the lining from the front pockets through a mesh blowing air against the under shirt. This allows for additional sweat evaporation.

Physical Description: The Global Secure Safety BVS fits inside any standard issue Interceptor Body Armor. The BVS consists of two parts the lining and the blower compartment. The top of the vest is secured to the body armor with straps going through the preexisting loops. The bottom of the vest is secured to the waist through the blower compartment. The vest uses Velcro straps to close the front.

The blower compartment contains the batteries, blower, and controls enclosed in a protective casing. The blower compartment is mounted on a belt and positioned in the small of the back as well as strapped to the back of the body armor. The top of the compartment anchors to the vest.

Energy Removal: Global Secure Safety does not provide an amount of cooling for the BVS.

Size: The Global Secure Safety BVS vest fits inside standard issue Interceptor Body Armor. The blower compartment measures roughly 6 x 3 x 3 inches or 54 cubic inches.

System weight: The Global Secure Safety BVS weighs 5 lbs. including vest blower compartment and batteries.

Power Requirements: The required power for the Global Secure Safety BVS is the provided rechargeable Li-Ion battery pack.

Support Systems Required: Additional battery packs or a recharge station will be needed for long missions.

Mobility Limitations: The Global Secure Safety BVS does not appear to have any mobility limitations given enough batteries.

Unit Price: Global Secure Safety would loan a system for testing.

Figure B1. Global Secure Safety BVS mounted to Interceptor Body Armor.

Appendix C – PCS #3

Product Name and Code: Active Cooling System

Company: NASA

Company Address: EM40
Marshall Space Flight Center
MSFC, AL 35812
Aspen Thermal

Company Contact: N/A

Info Source: Nick Haynes
SYColeman
Engineer
PM Soldier Equipment
Technical Management Division

Web Address: N/A

Technology Classifications: Active Evaporation System

Short Technology Description: The NASA Active Cooling System (ACS) is designed to circulate ambient air inside moisture wicking cavity as shown in Figure 1. The fabric wicks sweat from the body into the cavity while two fans circulate air through the cavity. The resulting evaporation of sweat causes the ACS to cool thus removing energy from the body.

Physical Description: The NASA ACS is designed to be placed within the OTV or more preferably over the Soldier's t-shirt and under the Advance Combat Uniform (or Desert Combat Uniform). The ACS is flexible and can be held in place using hook and loop straps. One ACS is to be worn on the front of the torso and another on the back. The ACS is controlled by a control switch located between the fans on the bottom. The unit is 1 inch thick and provides sufficient space for air circulation. Two small exhaust fans are placed at the bottom of the unit as shown in Figure 2. The air is pulled through vents on the upper corners of the device and exhausted out the bottom of the vest. The exhaust air is cool and humid and poses no hazard to the Soldier.

Energy Removal: The energy removal has not yet been determined for the ACS.

Size: The NASA ACS is made to fit any OTV or under any Advance Combat Uniform and is 1 inch thick.

System weight: The NASA ACS weighs 0.6 pounds for the front and 0.6 pounds for the back or 1.2 lbs. total with batteries.

Power Requirements: The NASA ACS uses a 5 Volt battery for each fan for a total of 4 batteries for a full system.

Support Systems Required: Extra batteries will be needed for the ACS during extended missions.

Mobility Limitations: The NASA ACS has no mobility limitations if provided with enough extra batteries.

Unit Price: The price for an ACS has not yet been determined but will be made available for testing.

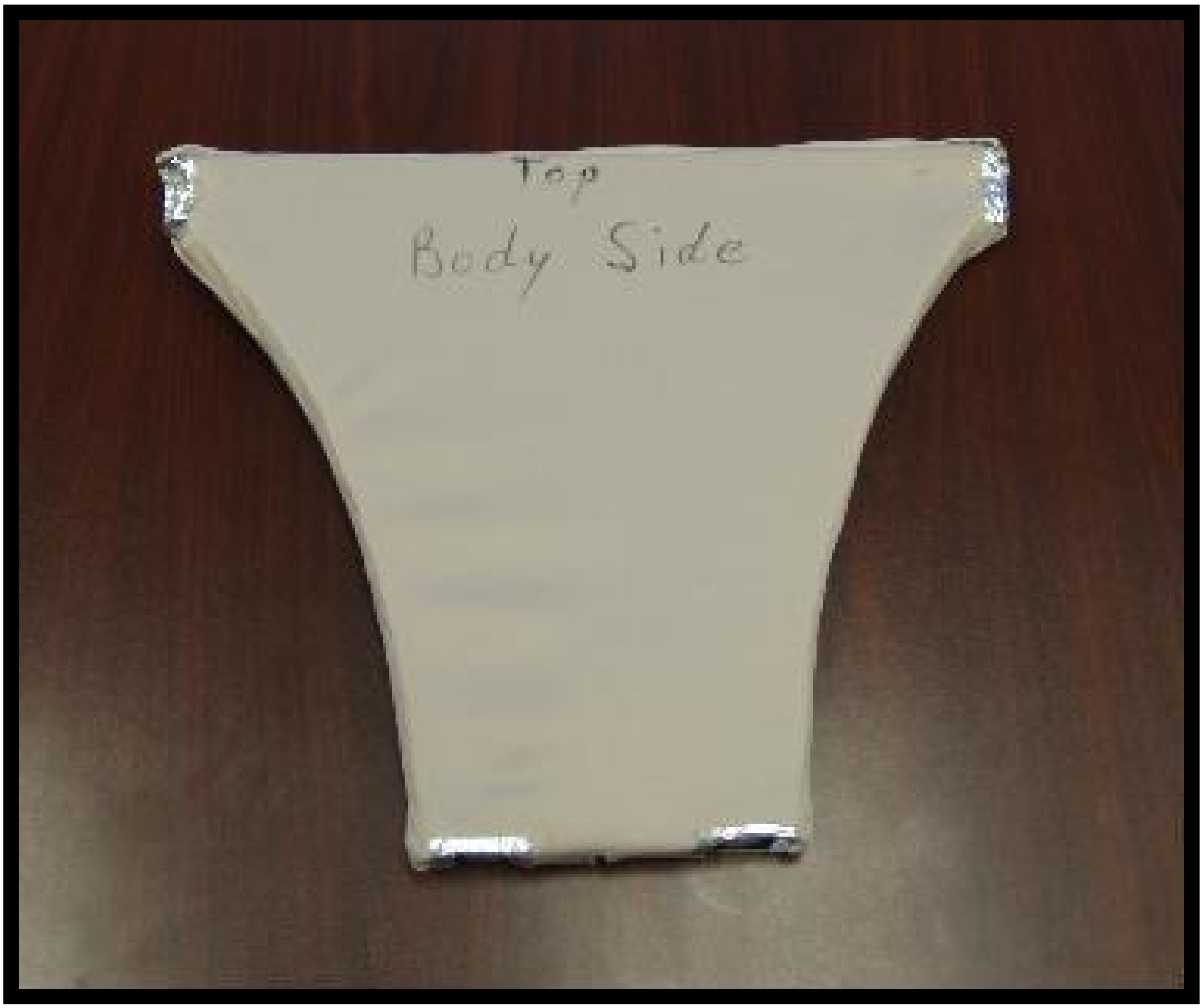

Figure C1. NASA ACS viewed from the body side.

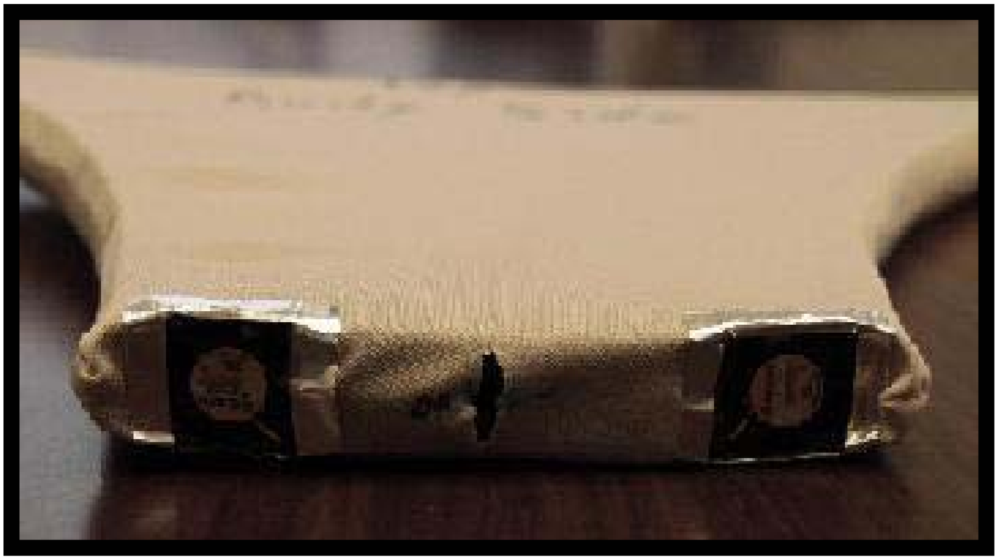

Figure C2. NASA ACS view of the fans.

Figure C3. NASA ACS view of the air outlet.

Appendix D

Army Requirements

Confidentiality

All data and medical information obtained was considered privileged and held in confidence. A unique subject ID number was assigned to each volunteer and used on all data collection instruments. A master list linking the subject's personal information with the subject ID number was kept in a separate file in the principal investigator's locked office. Access to the master list was restricted to the PI. Hard copy data records (e.g., perception scales) will be stored for a minimum of 3 years from the time the study is completed. Password protected electronic copies will be kept indefinitely.

Some of the confidential information described herein may be made available to the appropriate military and command authorities, and to the officials of the US Army Medical Research and Materiel Command.

Medical Precautions, Risks, and Safety

Registered nurses were present in the chamber during all test sessions. They completed an online training course on heat stress and read a copy of Chapter 4, in Section III of the ***OSHA Technical Manual*** on Heat Stress. This document was available during the experiments also.

No subjects were injured in this study. In the event of a medical emergency, the local Emergency Medical Services would have been contacted immediately. The area hospital is less than 1 mile from IER. All volunteers removed from testing would have been immediately escorted out of the test chamber, had their clothing and equipment removed, been made comfortable (by sitting or lying down on a cot, cooling them with a fan and/or cool wet towels), and given water to drink. The risks associated with participation in this study are those attributable to physical exercise in a hot environment, exercise in protective clothing, and insertion of rectal sensor.

Risks. Physical exercise can lead to overexertion and/or an accident. The possibility of cardio-pulmonary overexertion is slight and was minimized by recruiting only young (19-40 year olds), healthy individuals, and abiding by volunteer exclusion criteria. Exercise often carries a risk of injuries like strained and/or sprained muscles although this risk is low with walking. The subject could feel fatigued and fall off the treadmill. The nurse assisted the subjects in mounting and dismounting the treadmill, if they needed it. The treadmills were new and had a hand rail at the front and front sides. The nurse watched the subjects during their walk on the treadmill to make sure they maintained a steady pace.

Exercising in the heat may lead to dehydration, fluid/electrolyte imbalance, heat rash, and/or blisters on the feet. Exercise in the heat will increase body core temperature and can induce heat injury/illness, including heat stroke and death, but will more likely cause headache, dizziness, disorientation, and/or nausea. Dehydration can further increase the risk for heat illness. Volunteers were told to be aware of any unusually dark colored urine, and to report this to the Principal Investigator or the nurse immediately for further medical evaluation. Risk of dehydration was minimized by encouraging drinking before, during, and after all tests and monitoring the volunteer’s weight daily.

The insulation and evaporative resistance of the interceptor body armor and helmet in combination with the high ambient temperature during the tests created a situation that could potentially result in a significant level of heat strain during the tests – particularly when a PCS was not worn. The experimenter and nurse monitored the physiological responses and chamber conditions throughout the experiment and removed subjects who met the stop criteria listed earlier.

Insertion of a rectal sensor may cause injury to mucous membranes if it is not inserted carefully. There may be slight discomfort during the insertion of the rectal sensor. Volunteers inserted the rectal sensors by themselves after being instructed how to properly do so. The risk from electrical shock was considered to be remote – particularly since all of our equipment and sensors were new and grounded.

Unanticipated problems involving risk to volunteers or others, serious adverse events related to participation in the study, and all deaths of volunteers will be promptly reported by telephone (301-619-2165), by email (hsrrb@amedd.army.mil), or by facsimile (301-619-7803) to the Human Subjects Research Review Board. A complete written report will follow the initial notification. In addition to the methods above, the complete report can be sent to the U.S. Army Medical Research and Materiel Command, ATTN: MCMR-ZB-P, 504 Scott Street, Fort Detrick, Maryland 21702-5012. The same information will be sent to the KSU IRB Compliance Office (785-532-3224) at adassa@ksu.edu.

The Army's Medical Monitor Requirement

The medical monitor for the project was Dr. Robert Tackett, Medical Director of the KSU Lafene Student Health Center. The medical monitor is required to review all medical events involving risk to volunteers, serious adverse events and all subject deaths associated with the protocol, and provide an unbiased written report of the event. At a minimum, the medical monitor should comment on the outcomes of the event or problem, and in the case of a serious adverse event or death, comment on the relationship to participation in the study. The medical monitor should also indicate whether he concurs with the details of the report provided by the investigator. Reports for events determined by either the investigator or medical monitor to be possibly or definitely related to participation, and reports of events resulting in death should be promptly forwarded to the HSRRB.

Appendix E – Case Report Form

Subject Number_______________ Week 1 2 3 Morning 1 or Afternoon 2

Test Day 4 5 6 7 PCS# 0 1 2 3

Weight of subject in underwear briefs (lb):					
Weight of subject in underwear briefs after session (lb):					

Time (min)	√	Action	VO_2 ml/kg/min	REE (W) Met Rate (Goal 350)	HR Watch (bpm)
0		Start met test and treadmill; initial **speed**:			
5		Enter 5 min. data; adjusted **speed**:			
10		Enter 10 min. data; adjusted **speed**: Stop met test; prepare to switch to other subject.			
15					
20					
25					
30		Give both subjects 250 ml water			
60		Give both subjects 250 ml water			
90		Give both subjects 250 ml water			
105		Start met test			
110		Enter 5 min. data			
115		Enter 10 min. data Stop met test			
120		Stop treadmill; disconnect subject's wires; escort him out of chamber			

Time experiment was stopped (other than 120 min.): _________ min.

Comments:

Appendix F
Preference Ballot

Subject Number______________________

At the end of the last day of testing, please answer the following questions.

1. Did you think that any of the personal cooling systems improved your overall comfort in a hot environment as compared to the basic desert uniform?
_____1 = yes _____ 2 = no

2. Which personal cooling system did you prefer?

_____PCS0 = No cooling system. Basic DCU with ballistic vest and helmet.

_____PCS1 = FAV

_____PCS2 = BVS

_____PCS3 = NACS

(Note: Subjects were shown an example of each PCS as they answered the questions on this form.)

Please comment on each personal cooling system. What did you like about each system? What did you not like?
1.

2.

3.