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ASSESSMENT OF THERMAL RESPONSE OF SUBJECTS WEARING FUNCTIONALLY DESIGNED PROTECTIVE CLOTHING

By

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ABSTRACT

ASSESSMENT OF THERMAL RESPONSE OF SUBJECTS WEARING FUNCTIONALLY DESIGNED PROTECTIVE CLOTHING

By

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The objective of this research was to assess and compare the perception of thermal comfort and sensation and the accompanying physiological responses associated with selected fabrics and designs, under controlled environmental conditions, simulating Michigan summer weather conditions. This study, conducted at the Institute for Environmental Research, Kansas State University, was one component of a major research project aimed at developing functionally designed protective clothing for pesticide applicators that offered thermal comfort and social acceptability.

Three fabrics, whose resistance to pesticide penetration was known, were chosen. A spun-bonded olefin and a nylon three-layer laminate served as the protective fabrics. A cotton chambray was chosen to reflect what is commonly worn by applicators. Three designs were specified, two coverall variations and a shirt-and-jeans combination.

The dependent variables included: weighted skin temperature, rectal temperature, percentage of evaporated sweat, and thermal comfort and sensation votes.

A 3 x 3 complete factorial experimental design with six replications was used. Fifty-four male Kansas State University students served as test subjects. Each wore one test garment for one two-hour test session. An activity level of three mets was maintained.

Data analysis involved first an examination of the dependent measures by fabric and design over time and second, hypothesis testing. Since thermal-comfort assessment includes physical and perceptual measures as related aspects of a single response, multivariate statistical analysis was used to analyze the dependent measures as a whole.

Examination of the graphs for the three fabrics showed a consistent trend. Subjects wearing the spun-bonded olefin garments exhibited higher temperature readings and greater thermal dissatisfaction than subjects in the other two test fabrics. Thus, one of the protective fabrics offered a comfort level similar to chambray. The MANOVA analysis indicated a statistically significant difference for fabric at the .0001 level.

The graphs of the dependent measures for design showed an inconsistent pattern. There was a tendency for higher physical and perceptual measures for the coverall with the ventilating panel. The MANOVA results for design were not statistically significant.

Dedicated to

Michael,

Mike, Renée, and Kerry

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CHAPTER I

INTRODUCTION

U.S. farmers and foresters, in an effort to control detrimental insects, plant diseases, weeds, and crop infestations, have increased their usage of pesticides (Boraiko, 1980). The Mediterranean fruit fly infestation in California is a dramatic example of the serious problem of pest control, a problem which has commanded international attention. In addition to damaging crops, pests can carry serious diseases. In Michigan, health officials are weighing the risks and benefits of instituting a limited pesticide spray program to reduce the mosquito population in areas in which cases of Eastern Equine Encephalitis have been confirmed in horses (Lane, 1981). Although the risk of getting the disease is low for humans, a young Michigan boy who contracted the illness last summer and remains in a coma clearly shows the devastating results.

The detrimental effects of pesticide usage, including possible ecological consequences and pesticide-related illness and death, are a persistent concern for many. The contamination of rivers, ponds, and lakes by synthetic compounds continues to be a subject of inquiry for the scientific community and the general public. Also, the increased resistance of insects to pesticides has caused many to fear that we may be breeding "superbugs." Boraiko (1980) noted that over

400 species of insects and mites are now resistant to pesticides. Besides the negative environmental consequences, reports of adverse health effects associated with pesticides continue to proliferate. Viet Nam veterans exposed to Agent Orange, a controversial defoliant, are a particularly vocal group who have demanded recognition of the hazardous health side-effects of the chemical and compensation for the pain and suffering this exposure has cost them and their families. They hold Agent Orange responsible for causing a variety of health problems, ranging from skin diseases, hearing loss, and cancer to birth defects in their children.

Despite these negative consequences, the careful, prudent use of pesticides is considered by many scientists, not only beneficial to society (Kilgore & Akesson, 1980) but also necessary to provide sufficient food and fiber for the world's steadily expanding population. After researching the pesticide controversy for over a year, the editor of National Geographic (cited in Boraiko, 1980) concluded:

> With a steadily expanding population and a decrease in arable land, the world must use pesticides to maintain high crop yields and affordable food. At the moment there is simply no other way to farm on the scale required. Answers to questions of environmental danger, sensible regulation with diligent enforcement, proper application, and acceptable chemicals thus are a world necessity. (p. 145)

Assuming continued reliance on pesticides, then the potential adverse health effects of workers occupationally exposed to pesticides is one area of concern that should be addressed. Documentation of pesticide-related health effects, patterns of pesticide usage, population at risk, and mechanism of transference to the body are presented as a prelude to examining strategies for minimizing worker

exposure to pesticides. Further examination of one strategy concludes the chapter.

Adverse Health Effects

The adverse health effects can be either sudden and of relatively short duration, or they may be delayed long-term effects such as sterility, cancer, and neurological and renal disorders. Attention has centered on the dramatic sudden ill effects requiring medical attention of large numbers of field workers (Kahn, 1976a). For example, in September 1976, 118 workers from a 120-person grape-picking crew became ill after entering a field recently treated with dialifor. It was concluded that excessive skin exposure had resulted (Knaak, Peoples, Jackson, Fredrickson, Enos, Maddy, Bailey, Düsch, Gunther, & Winterlin, 1978). Recently, however, the long-term health significance of chronic exposure has become an increasing concern. Morgan (1980) warned that proving long-term effects such as increased prevalence rates of cancer is very difficult and may be impossible. Figure 1 illustrates both the spectrum of pesticide exposure and the related health effects.

Patterns of Use

Over the past decade, our pattern of use of pesticides has shifted away from the more persistent pesticides (DDT for example) to the shorter-acting but more toxic organophosphate and, to some extent, carbamate compounds (Freed, Davis, Peters, & Parveen, 1980). Because these compounds are less persistent in the environment, more frequent applications are required in order to maintain pest control, thus necessitating greater applicator exposure.

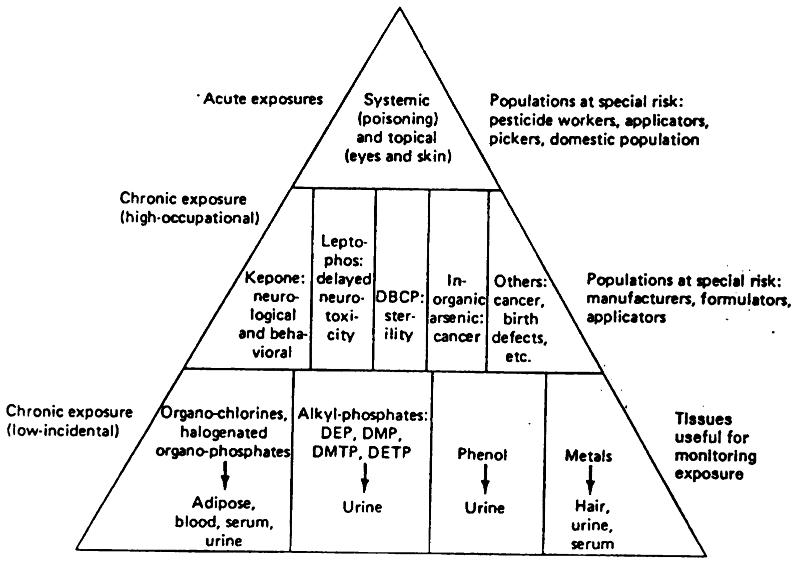


Figure 1.--Spectrum of pesticide exposure and some related health effects. (From Davis, Freed, Enos, Barquet, Morgade, & Danauskas, 1980, p. 10. Reprinted with permission of the editors of Residue Review.)

Population at Risk

The epidemiological history of authenticated episodes of pesticide poisonings has shown the population at risk to be those individuals involved in the manufacture (Kiraly, Szentesi, Ruzicska, & Czeize, 1979; Taylor, Selhorst, Houff, & Martinez, 1978), formulation (Glass, Lyness, Mengle, Powell, & Kahn, 1979; Young, Jung, & Ayer, 1979), mixing and loading (Bension, Richter, Weisenberg, Schoenberg, & Luria, 1979), and application (Bension et al., 1979; Hayes, Wise, & Seir, 1980) of pesticides as well as those involved in harvesting operations (Burns & Parker, 1975; Knaak et al., 1978; Wicker, Williams,

Bradley, & Guthrie, 1979; Wolfe, Armstrong, Staiff, Comer, & Durham, 1975). These categories should not be considered mutually exclusive. The California Department of Public Health has monitored the acute effects on California workers of pesticide exposure, and concluded that "occupational disease caused by pesticides and other agricultural chemicals is one of the most important occupational health problems in the State" (Kilgore & Akesson, 1980, p. 25). Figure 2 presents data gathered by this reporting service by category of worker for 1978.

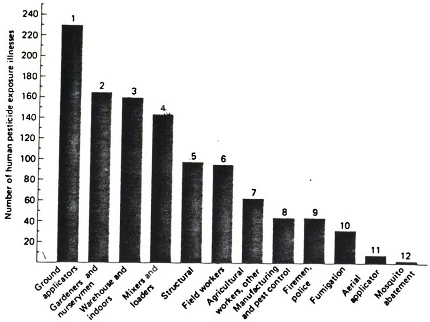


Figure 2.--Occupationally related pesticide-exposure illnesses in California during 1978. (From Kilgore & Akesson, 1980, p. 26. Reprinted with permission of the editors of Residue Review.)

Figure 2 clearly demonstrates that ground applicators, that is, those who apply pesticides using a variety of spray and dusting equipment, received medical treatment a greater number of instances than any other population at risk. It should be noted that even though California has an extensive medical reporting system, some investigators (Kahn, 1976a) believe that the number of reported cases represents only a small fraction of the true incidence of pesticide poisonings.

The concern that the number of documented cases may be grossly underestimating the true scope of the problem has been primarily focused on the population of field workers. California alone has more than 300,000 farm workers, including housewives and students, plus an unknown number of illegal aliens (Kahn, 1976a). Social and economic pressures, language barriers, and risk of deportation undoubtedly prevent many pesticide-related illnesses from being reported to physicians (Kahn, 1976a). Kahn (1976a) pointed out that "the agricultural work forces in Arizona and Texas share many of the same characteristics . . . , the ethnic make-up and sociological details may be different, but the net effect is very similar" (p. 694). Thus, Kahn (1976a) emphasized that this problem is not limited only to California.

A second factor that prompts researchers to suggest that the number of pesticide poisonings is greater than the number of documented cases is the nature of the early symptoms. Nausea, headaches, diarrhea, skin rash, and blurred vision can be symptomatic of other illnesses, making recognition of their occupational origin more difficult to ascertain for worker and physician.

The issue of the secondary exposure of the workers' family has received little attention, although documented cases have been reported in the literature. For example, in Virginia, an investigation of over-exposure of workers to chlordecone, an organochlorine insecticide, found detectable levels of chlordecone in the blood of all employees (Taylor et al., 1978). Over half of the workers had a history of tremor which interfered with ordinary manual tasks and daily activities. Despite detectable levels of chlordecone being found in 94% of the workers' family members, serious examination of the cause of secondary contamination of family members was not undertaken. The topic of secondary exposure of the family is beyond the scope of this research.

There have also been isolated efforts to assess the adverse health effects of pesticides on the general population. The interested reader is referred to Boraiko (1980) and to D'Ercole, Arthur, Cain, & Barrentine (1976) for discussion of this topic. Exposure of the general public to pesticide hazards is outside the scope of the present research.

Mechanisms of Pesticide Entry

There are three major routes of entry of pesticides into the human body: oral, respiratory, and dermal. Numerous investigators have established that dermal exposure is the major mechanism for pesticide entry (Hansen, Schneider, Olive, & Bates, 1978; Nigg, 1980; Taylor et al., 1978). Durham, Wolfe, & Elliot (1972) compared the dermal and respiratory routes and found that 87% of the total exposure was accounted for by dermal exposure.

Rate of dermal absorption is a function of the specific compound, use of various solvents ("Classification of Cutaneous Hazards and Their Effects," 1980), extent of exposed skin area and duration of contact, anatomic region (Maibach, Feldmann, Milby, & Serat, 1971), and ambient temperature (Hayes, Funchas, & Hartwell, 1964).

Strategies for Minimizing Occupational Exposure

The range of documented and suspected adverse health effects for an identified population at risk, as well as data on the primary routes of entry of pesticides into the body, suggest a basic mandate: minimize worker contact with toxic substances (Morgan, 1980). Although the wisdom of the mandate is obvious, the means to achieve it are neither simple nor acceptable to all parties involved (Morgan, 1980). Various strategies, some having limited applicability for certain classes of workers, have been suggested in an effort to support the basic mandate.

Elimination of Toxic Pesticides

The elimination or restricted use of toxic pesticides has been attempted through legislation and standard-setting. Created by President Nixon in December 1970, the Environmental Protection Agency (EPA) was given the administration of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA, transferred from the U.S. Department of Agriculture) and the responsibility for the registration of pesticides. The EPA was also given the duty of establishing pesticide residue tolerances on raw agricultural commodities. In 1972, FIFRA was amended, requiring the EPA to reregister all pesticide products

by 1976, over 40,000 products (Doutt, 1979). In order to register a pesticide, the EPA requires both acute and chronic toxicity tests be performed. Chemical industries spend years testing a product to ensure both its safety and its effectiveness. The RPAR process has been developed to investigate products thought to be possibly hazardous to the environment or humans and to assist in the regulatory decision-making process. Quantitation of risk of human pesticide exposure is part of the risk-benefit equation in the decision process (Davis et al., 1980). Doutt (1979), in tracing the history of pesticide regulation, noted that a new national pesticide law became effective in October 1978. Doutt (1978) charged that the law is very solicitous of the pesticide industry.

Data on the environmental persistence of a chemical and its full toxic potential must be gathered. Morgan (1980) stated that knowledge should not be limited to only active ingredients, but also to degradation products during storage and following application and to byproducts.

Despite a large organized mechanism for examining and registering a pesticide, toxic chemicals continue to find their way into the market place.

Maintenance of a Safe Work Environment

This basic strategy has been implemented in several diverse ways, including monitoring systems and established reentry intervals.

Development of a system to monitor the health of employees through preventive medical-supervision programs has been advocated (Culver, 1976). Yet, the mobile nature of the field workers precludes

the possibility of monitoring any delayed health effects for this population. Monitoring of the work environment for quantities of toxicants has also been suggested. This might involve the monitoring of residue levels in factory and field air, on skin and clothing, on soil, and on foliage in the field (Culver, 1976, p. 125). Both methodological and cost considerations limit the universal applicability of this strategy.

The establishment of "reentry intervals," set by the EPA, requires that field workers not enter a treated field for a designated time period, dependent on the specific compound. In addition, California has enacted state regulations more stringent than the federal standards. Both the established reentry periods and the methods used for hazard assessment have come under attack. Many feel that the intervals are unduly harsh (Culver, 1976). The extensive research devoted to the reentry problem (Burns & Parker, 1975; Iwata, Knaak, Spear, & Foster, 1977a, 1977b; Kahn, 1976b; Knaak et al., 1978; Serat, Mengle, Anderson, Kahn, & Bailey, 1975; Spenser, Cliath, Davis, Spear, & Popendorf, 1975) demonstrates the difficulty in establishing reentry intervals that are both safe (for a variety of compounds) and reasonable to agricultural interests. This strategy offers possible protection only to field workers.

Thus, maintenance of a safe work environment is not always a feasible alternative, but perhaps a micro-environmental strategy can ultimately provide increased safety and better health for workers occupationally exposed to pesticides.

Human-Constructed Environment

The rationale behind this strategy is that a micro-environment, a human-constructed environment, could be constructed to serve as a protective interface between the worker and the environment. Enclosed vehicles (i.e., tractors, planes, or helicopters) are frequently used as methods of application. There is evidence to suggest that enclosed vehicles do not offer the level of protection desired.

Cohen et al. (1979) studied Israeli pilots of an aerial spray company which sprays 50% of the pesticides in Israel. They learned that pilots are exposed to pesticides in two stages of their work: the loading phase and in flight, which resulted from flying back into clouds of pesticide aerosols and vapors (Cohen et al., 1979). They found the presence of pesticide concentrations in the cockpits and concluded that the level of concentration was a function of wind conditions. Pesticide concentrations have also been found inside enclosed tractor cabs.

Therefore, the quest for a more proximal human-constructed environment that could provide protection against a hazardous workplace has continued. Because of limitations of each of the strategies, protective clothing, which could be used as a barrier between the worker and the environmental hazard, has commanded increased attention from government, industry, public health officials, and researchers (Cohen et al., 1979; Davis et al., 1980; Morgan et al., 1980).

The recommendation of protective clothing has influenced the RPAR decision on several occasions. Davis et al. (1980, p. 8) cited the example of chlorobenzilate, which was found to be a weak carcinogen but was permitted on the market with the stipulation that worker protection be achieved through the wearing of protective clothing. There is a growing tendency to suggest protective clothing as an alternative to banning a "suspicious" compound for which an adequate substitute is unavailable. Protective clothing also offers the advantage of being applicable to all of the occupational categories given in Figure 2.

While consensus on the need for protective clothing is emerging, agreement on a definition of protective clothing is not so widespread. For example, the Federal Register has defined protective clothing at least three times. On March 11, 1974, protective clothing was defined as:

> at least a clean hat with a brim, a clean long sleeved shirt and long legged trousers or a coverall type garment, all of closely-woven fabric covering the body, including arms and legs, shoes to entirely cover both feet, clean socks, and clean fingerless gloves covering the back and front of hands and wrists.

Two months later, May 10, 1974, the Federal Register redefined protective clothing as "at least a hat or other suitable head covering, a long sleeved shirt and long legged trousers or a coverall type garment."

Kahn (1976b) took issue with the EPA as being "unaware that their prescribed 'protective clothing' was actually the usual attire of most workers engaged in foliar contact activities" (p. 39). Hats, long-sleeved shirts, and jeans are worn, Kahn noted, as protection against thorns, twigs, and sunlight.

Prior to the March 11, 1974, definitions, the EPA had suggested that protective clothing should be "impermeable." Cohen et al. (1979) had likewise specified "impermeable uniforms, boots and gloves" (p. 85) in their recommendations for Israeli ground crews and pilots.

The necessity of protective gear being impermeable to pesticide vapors, dusts, sprays, and even direct spills has dominated the development of available protective garments and equipment. Disposable nonwoven fabrics have been used in two-piece and coverall designs, aprons and gloves. The effectiveness of the fabrics as barriers to both particulates and liquids has been documented (Scheinberg, 1979).

Davis et al. (1980) undertook a study designed to compare the effectiveness of commonly worn clothing by the Florida pesticide applicators (Table 1) versus 100% treated and untreated cotton-denim coveralls. Their (Davis et al., 1980) results indicated that 100% cotton denim coveralls offered greater protection than the growers' own clothing. Davis et al. (1980) recommended the use of 100% cotton overalls for dermal protection. However, several studies (Ware, Morgan, Estesen, & Cahill, 1975; Wicker et al., 1975) have suggested that in the presence of moisture or high humidity, cotton jeans can be soaked by foliar contact, with a resultant increase in dermal absorption.

Rubber rain gear has also been suggested. At the other end of the spectrum, elaborate protective suits, boots, and head gear equipped with an independent air supply and constructed of various fabrics have been developed. Despite the considerable effort expended on the development of protective gear for the agricultural worker,

Table 1.--"Own" clothing characteristics of pesticide citrus grove applicators and mixers, Orange County, Florida, 1978.

Subject No.	Type of Clothing Worn
1	Synthetic, short-sleeve shirts (thin), frequently open. Work pants cotton and/or synthetic.
2	Cotton shirts, sweat shirts, and "T" shirts occasionally. Work pants. Low shoes.
3	Primarily a thin, synthetic shirt and trousers. Occasionally synthetic/cotton shirts. Rubber boots.
4	Combinations: "T" shirts and short-sleeve shirts. Variety of work pants, light-weight.
5	Combinations of synthetic short-sleeve shirts (light-weight) and work pants. Low work shoes.
6	Fresh, very clean and pressed long-sleeve cotton shirt daily. Trousers cotton and/or synthetic. Ankle leather boots.
7	Variety of short-sleeve shirts, "T" shirts, and sweat shirts. Work pants varied from cotton twill to cotton synthetic.
8	Short-sleeve, cotton/synthetic shirt worn open. Thin khaki trousers. Low shoes.
9	A varied assortment of shirts, sweat shirts (long and short sleeve), and athletic jerseys. Trousers varied including shorts; sandals.
10, 11, 12, 13	Wore heavy army "fatigue" coveralls of a heavier twill finish than the University of Miami protective clothing. These military green fatigues were from a surplus store (no labeling to determine type and weight of fabric; long sleeve).

(From Davis et al., 1980, p. 16. Reprinted with permission of the editors of Residue Review.)

what is now available has not been widely accepted by many of the workers at risk.

Protective clothing is seen as hot, uncomfortable, and expensive by California field workers and plane loaders (Boraiko, 1980). Data gathered by Henry (1980) indicated that independent farmers considered protective clothing valuable but unacceptably hot for Michigan summers. Culver (1976) concluded that protective garments "impose physiological stresses that in our work environment are largely unacceptable" (p. 42). Freed et al. (1980) noted that in temperatures between 28° and 40°C, current protective clothing "that encases a large part of the body would not only be extremely uncomfortable, but would be a hazard in itself due to hyperthermia or heat stroke" (p. 160). And the EPA backed down from its specification of "impermeable" clothing, saying that such clothing could be considered a greater risk, due to heat build-up leading to heat prostration, than not wearing any protective clothing (Federal Register, July 31, 1973).

Unfortunately, the currently available protective clothing has not been developed by studying the whole problem. Emphasis has been directed toward finding an impermeable fabric. Consideration for user acceptance has not been explored. Attention has not been focused on the problem of thermal comfort of a worker toiling in a hot environment while wearing an "impermeable" garment. The development of practical protective garments that satisfy the individual's needs of thermal comfort, acceptability, and protection is needed.

Functionally Designed Protective Clothing

In the fall of 1978, Jacquelyn Orlando De Jonge, Ph.D., then Associate Professor in the Department of Human Environment and Design, Michigan State University, currently Head and Professor of the Department of Textiles, Mechandising, and Design, University of Tennessee, undertook a research investigation aimed at limiting the dermal exposure of the independent farmer to pesticides, while maintaining acceptable thermal-comfort levels through the development of functionally designed protective garments. The total research effort has been supported by the Michigan State University Agricultural Experiment Station and the North Central and Southern Region Pesticide Impact Assessment Programs.

The investigation focused on independent farmers, specifically the fruit-grower population, who ordinarily perform the tasks of mixing, loading, and applying pesticides, as well as being involved in the harvesting of the crop. The method of pesticide application for fruit trees and the frequency of application further enhance the opportunity for deposition of pesticides on the applicator's skin and clothing. Thus, the data previously cited in Figure 2 suggest that the potential exposure to pesticides can be significant, yet the independent farmer has shunned protective clothing, citing the lack of thermal comfort as a primary reason. It is also likely that the independent grower perceives that protective clothing may become a future requirement and "thus another infringement upon their private lives" (Henry, 1980, p. 21). All of these concerns were systematically addressed in the conduct of each component comprising the total research effort.

The present research is one component of the overall research project, with the major thrust being the assessment of thermal comfort associated with selected fabrics and designs of known protective qualities under controlled environmental conditions. The ultimate purpose of this study was to contribute to the development of functionally designed protective garments for the fruit grower. Before proceeding with a formal statement of the problem, however, it is critical to view this research in the context of the larger project and to understand the methodology implicit in this design effort. An overview of first, the functional design process and second, the implementation of the process as it is being used to design protective garments is given to underscore the interrelatedness of the various components and how this quality impacted on the conduct of the thermal-analysis component.

Functional Design Methodology

The functional design methodology is a systems approach to design which seeks to explore the design situation in a holistic manner. The increasing complexity of design problems has stimulated the development and adoption of a wide variety of design methods, in response to world-wide dissatisfaction with traditional procedures (Jones, 1970). Alexander (1977) commented that today functional problems are becoming less simple all the time, with more design problems reaching insoluble levels of complexity. Accompanying this

growing complexity is a vast body of constantly changing information and specialist experience. Although all of this is available for the designer, the information and expertise are so widespread, diffuse, and unorganized and the designer so reticent to reach out for such input, that it is more comfortable to rely on traditional design methods.

The design process traditionally used for apparel is one based on the creative inward assimilation of inputs in the designer's head. The design solution emerged as a mysterious output of the designer's brain.

Traditional apparel designing emphasized creating an aesthetically pleasing, socially acceptable, and psychologically comforting garment. The physical needs of the body, while not ignored, were certainly not a primary concern. With the advent of space-age travel, increased usage of industrial clothing, and the burgeoning growth of participatory sports, there has been an increased demand for special-purpose clothing. Such clothing must be designed to accommodate all of the body's needs, and sometimes to protect the individual from harsh environmental conditions. Clearly, the traditional apparel-design process is inadequate for such design situations.

Jones (1970) has examined many of the new design methods and has shown them to be an extension of older methods. In all of the new design methods, the design process has been externalized, with an aim toward making designing more manageable. But the clear, concise elucidation of the design problem, as perceived, can also be readily

observed and critiqued by those who are not members of the design team, thus providing another benefit.

Figure 3 presents a schema for the functional apparel-design process, as given by Orlando (1979). Jones (1970) characterized the process as being one of divergence, transformation, and convergence. Once the design request has been received, it is treated as a starting point for the investigation. Exploring the design situation initiates the divergent search, a process aimed at expanding problem boundaries in many directions, with attention also directed at the consequences. It is a step back, in an attempt to examine the design problem from different perspectives, rather than a plunge ahead with preconceived solutions. This critical step identifies the general objectives and distinguishes user needs and other pertinent requirements, thus laying the groundwork for the designation of the critical factors. Once the critical factors have been identified, the necessary experiments or studies are planned, carried out, and the data are analyzed. This kind of pre-design work can be costly and time consuming. Therefore, asking the right questions and knowing when to terminate the search-acquisition phase is of the utmost importance.

Assessment of the findings of each critical factor results in the generation of design specifications. This begins the creative process of transformation. The main objective of this phase is to transform the results of the divergent search into a general pattern, into subsolutions that will later permit convergence to a prototype design. This is the stage where specific objectives, boundaries, constraints, and critical variables are identified. Frequently, the

OUTPUTS → INPUTS ↓	2 DESIGN SITUATION EXPLORED	3 PROBLEM STRUCTURE PERCEIVED	4 SPECIFICATIONS DESCRIBED	5 DESIGN CRITERIA ESTABLISHED	6 PROTOTYPE DEVELOPED	7 DESIGN EVALUATION
1 REQUEST MADE	state objectives literature search visual inconsistency user interview brainstorming					
2 DESIGN SITUATION EXPLORED		brainstorming observation analysis market analysis information search definition of problem				
3 PROBLEM STRUCTURE PERCEIVED			physiological assessment activity assessment movement assessment impact analysis thermal analysis social-psychological assessment			
4 SPECIFICATIONS DESCRIBED				charting ranking and weighting prioritizing		
5 DESIGN CRITERIA ESTABLISHED					materials testing technique evaluation brainstorming synectics creative integration solutions weighed against criteria	
6 PROTOTYPE DEVELOPED						specification testing user satisfaction

Figure 3.--Functional clothing design process and strategy selection. (From Orlando, 1979, p. 128. Reprinted with permission of the author.)

problem may be divided into subproblems, each being capable of alternative solutions.

Finally, the process of convergence, of gradually reducing the range of alternative solutions to a design prototype, is begun. Frequently, one or more critical factors may be deemed of greater importance in a given design situation, thus giving greater weight to the resultant specifications. Ranking and prioritizing design criteria are done in an effort to ensure the creation of a prototype that will satisfy as many of the essential design specifications as possible.

Evaluation of the prototype can be accomplished in a variety of ways, including validation against the design specifications. The ultimate test of evaluation is the wear testing of the design prototype by the user under typical use conditions. Such evaluation procedures may result in unanticipated problems with the design. This feedback can be utilized to make further modifications.

Operational Design Process

Figure 4 presents the model that this author developed to operationalize the functional design process for the development of protective garments for the agricultural worker. The work was specifically directed toward Michigan fruit growers who use air-blast spray methods to apply pesticides. The results, however, have applicability for a wider population.

Under the leadership of Jacquelyn Orlando De Jonge, Ph.D., an interdisciplinary team of researchers and graduate students from the

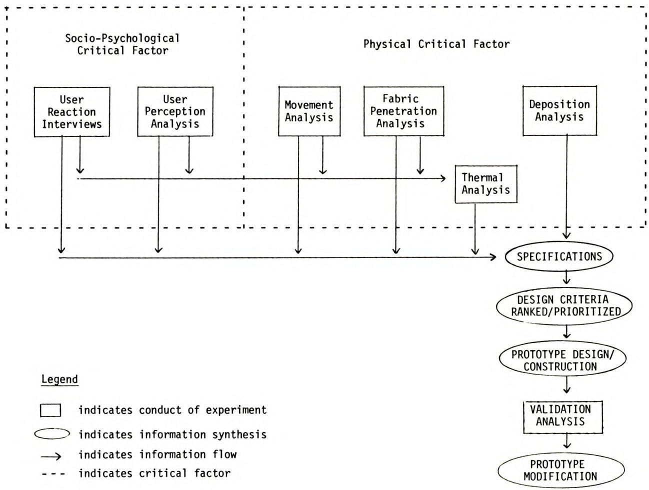


Figure 4.--Activity/information interaction flow process for the development of functionally designed protective clothing for the agricultural worker.

Departments of Human Environment and Design, Entomology, and the Pesticide Research Center at Michigan State University was formed to carry out this overall research project. The design and conduct of the various studies shown in Figure 4 were carried out by individual team members or some combination of team members. In addition to the thermal-analysis study completed for the doctoral research, the author participated in the design, conduct, and analysis of the fabric penetration and deposition studies, the formation and ranking of the design specifications, and the development of the prototypes. Following the departure of Jacquelyn Orlando De Jonge, Ph.D., from Michigan State University, the author assumed a leadership role in the field-exposure study (part of the validation analysis) and the subsequent design modifications. However, only the thermal-analysis study is reported in this work.

Initial exploration of the design situation resulted in the decision to examine two major critical factors, that is the socio-psychological and physical factors. This is not to say that other critical factors, such as economic and aesthetic, were ignored. Rather, due to resource constraints, experimental studies would only be planned for what were considered the two most critical factors requiring assessment.

Recognizing the importance of the socio-psychological functions of clothing, the pre-design divergence stage began by eliciting information from Michigan farmers (not necessarily fruit growers). Their preference and patterns of use for work clothing, their views on the potential health hazards of handling pesticides, and their perceptions

regarding protective work clothing were some of the topics that were investigated. This was accomplished in two ways. First, a purposive sample was used to explore user reaction to protective clothing regarding fabrics, color, and style preferences. The findings from these interviews provided insights into subsequent work. Henry (1980) then surveyed Michigan farmers to assess their perceptions of the attributes of the proposed protective clothing. Rogers and Shoemaker's theory (1971) of perceived attributes of innovation provided the conceptual framework for Henry's study.

Five hundred farmers responded to Henry's survey, providing data on characteristics of the Michigan agricultural worker and his perceptions of the innovation. A further result of the study was the derivation of design specifications. Three of the specifications that had particular import for the thermal-analysis study were:

1. The garment must be perceived by the users as more comfortable than the protective clothing presently available.

2. The garment must be perceived by the users as meeting their need to be covered and protected from the dangers of pesticides.

3. The garment must be perceived by the users as being comfortable as well as protective.

Simultaneously, the movement and protection needs of the farmer were being assessed in two different ways. The movement needs were being investigated through observational techniques. Agricultural work clothing must accommodate the movement needs of the farmer and should not contribute to farm-machinery accidents. A fabric-penetration study was also conducted to evaluate the protective qualities of selected fabrics under controlled laboratory conditions. A description of the methodology and the findings are reported in detail elsewhere (Orlando, Branson, Ayers, & Leavitt, 1981).

The results of all of these investigations were used as inputs into the planning of the thermal-analysis research. If protective clothing was to be adopted by the independent farmer, then clearly protection and thermal comfort had to be accommodated in the design prototype. The present study, as shown in Figure 5, was undertaken to investigate this issue.

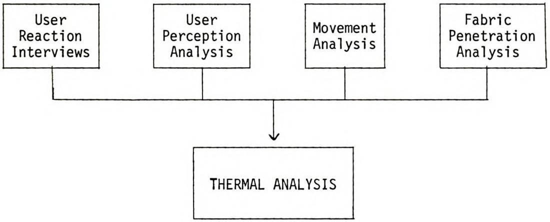


Figure 5.--Preparatory activity/information interaction flow process for the thermal analysis.

Conceptual Framework

The study of the influence of fabric and design on thermal comfort required an analytical framework which permitted the conceptualization of the wholeness, the complexity, and the interdependence between the individual and his/her environments.

The human body functions like a heat "engine" continuously transforming food, the body's fuel, into heat, as a furnace converts gas or oil into heat. The heat produced within the body is stored within the body, given up to the environment, or a combination due to a myriad of environmental and individual characteristics. Clothing can be viewed as a person's nearest environment. As such, clothing impacts on the body's ability to exchange heat with the natural environment, thereby influencing the thermal well-being of an individual. The maintenance of the internal body temperature within a narrow range is critical not only for comfort but also for the proper functioning of vital organs.

The complexity of the relationship between the total person, his/her total environment, and thermal well-being demanded a framework that could accommodate (1) the conceptualization of the problem, (2) the determination of the segment to be investigated, and (3) the subsequent interpretation of the findings within the broader contexts of the phenomenon. Hanlon (1969) noted that the human ecological perspective offered a framework whereby

> the needs of mankind--as individuals, in groups, and as communities--may be approached, not merely in a reductionist fashion . . . but rather in a holistic manner wherein the integrated responses of man to environmental forces find expression. (p. 57)

The human ecological approach, which focuses on human beings interacting with their environment, was used in this study. The organism, its environment, and their interaction are referred to as an ecosystem. Flows of matter, energy, and information continuously take place in the human ecosystem through biological, physical, and

social processes. These processes consist of (1) the input from the environment, (2) the transformation or utilization of the input by the organism, and (3) the output from the system which may or may not be recycled back into the system.

Figure 6 presents the human ecosystem model which served as the conceptual framework for this research. The model (Bubolz, Eicher, & Sontag, 1979) depicts the human environed unit (HEU) interacting with the three environments (NE, HCE, and HBE) that provide the resources necessary for life.

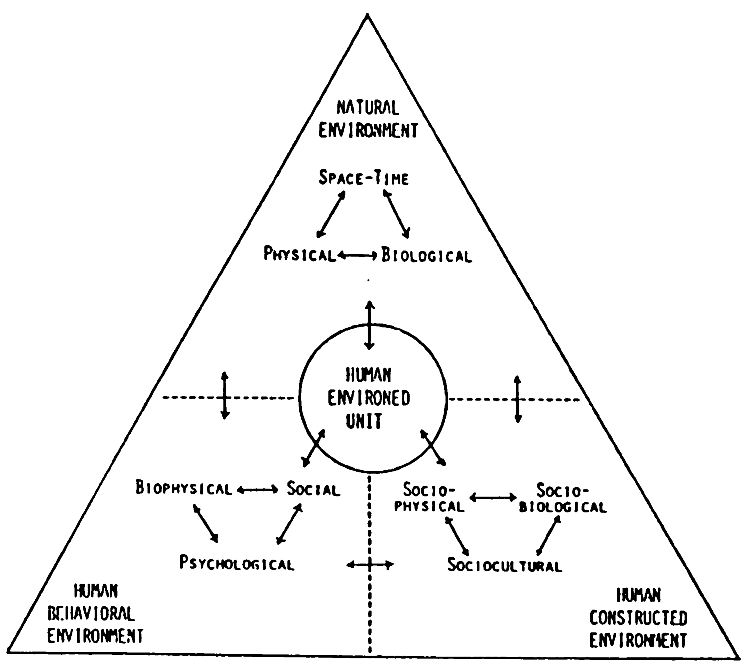


Figure 6.--The human ecosystem. (From Bubolz et al., 1979, p. 29. Reprinted with permission of the authors.)

Human Environed Unit

The HEU represents the population of Michigan independent farmers who share the common interests of fruit farming and therefore typically

apply various pesticides to their orchards. Based on information gathered by Henry (1980), it was learned that male members of the family are ordinarily responsible for pest control. In addition to this common attribute, the workers all possess biophysical, psychological, and social dimensions. The biophysical dimension includes the body's thermoregulatory system and other bodily systems necessary for life, as well as factors such as age and height and weight characteristics. The psychological dimension refers to all those factors, feelings, and sensations composing the psyche. The social dimensions include all those feelings, sensations, and characteristics that involve social interaction.

Human-Constructed Environment

The human-constructed environment (HCE) is the total environment created by human beings and includes sociocultural, sociophysical, and sociobiological components.

The sociocultural component encompasses technology, laws, values, and the formation of social institutions such as economic, political, health, and educational institutions. Thus, the sociocultural component includes the development of numerous pesticides as well as laws designed to regulate their use because of values placed on the importance of health and safety for the agricultural work force and the general population. The widespread use of pesticides also reflects the social values of ensuring sufficient food and fiber for the world's population. The formation of health systems for monitoring the health status of the agricultural work force on a continuing basis has received considerable attention (Culver, 1976). Education

programs to train pesticide applicators to meet safety standards set by the EPA are a result of Congressional Order. Since 1976, more than two million private and commercial pesticide applicators have been certified by Cooperative Extension Service state training programs (Sutherland, 1980).

The sociophysical component includes constructed objects such as the growers' clothing, the specific pesticides used, and the machinery that is designed for pesticide application. Fruit growers use pesticides that can be formulated in such a way that they can be applied as a spray. Wettable powders (WP), consisting of fine pesticide particles, surface-active agents, and inert fillers, and emulsifiable concentrates (EC), composed of an organic solvent and an emulsifier, are the most frequently used formulations for fruit trees. A wide variety of spray equipment can be used, although the air-blast sprayer, a tractor-driven large spray tank fitted with many nozzles, remains the most commonly used device in Michigan. The clothing that is normally worn in Michigan, based on discussions with Cooperative Extension personnel and informal interviews with farmers, appears to be similar to the clothing cited in Table 1. Jeans and long-sleeved chambray shirts are a favorite when the weather isn't too warm.

The sociophysical component also encompasses a vast array of personal and household artifacts, such as automobiles, furniture, washer and dryer, and carpeting. All of these represent potential mechanisms of pesticide transference from the worker to other family members. If the fruit grower's contaminated clothing and shoes are not removed at the work place, then contamination of the car, home

furnishings, and even the family pet can occur. Laundry procedures can also be a vehicle for contamination of family members. Finley (1979) showed that washing clean fabrics with those containing methyl parathion residues resulted in contamination of the clean fabrics.

The sociobiological component includes pets, plants, and the alteration of them and humans through exposure to pesticides.

Natural Environment

The natural environment (NE) includes climatological factors as well as everything else that makes up the natural habitat of Michigan fruit growers. The time dimension is the pesticide spray season, i.e., the spring through the early fall.

Human Behavioral Environment

The human behavioral environment (HBE) is composed of others, their thoughts, feelings, and actions. For example, the growers' families would be vital components of the HBE.

Interaction

Interaction can and does take place within the environed unit, between and within each of the environments, and between the environed unit and the three environments. For example, the use of protective clothing may be due to the grower's perception of the need for greater safety, or to the persuasive efforts of family members or friends, or to the effectiveness of educational programs, or to legislation requiring such clothing. The reasons for wearing the garment may impact on the way the garment is worn and cared for (for example, laundry procedures), and thus on the minimization of dermal contamination of the grower and his family. In addition to protective qualities, the garment itself will have characteristics, such that when it is worn under typical use conditions (i.e., temperature, relative humidity, and wind velocity), the thermal sensation and comfort of the grower will be affected. If the garment is perceived as being sufficiently hotter (a nebulous quality) than what is normally worn, then the grower will likely reevaluate his willingness to wear protective clothing.

Viewing the protective clothing issue from an ecological perspective permitted the conceptualization of the whole, the component parts, and their interactions. This conceptualization gave an overview of the larger problem, so that pieces of the problem could be isolated for investigation, and the findings subsequently interpreted within the context of the whole.

Thermal-Analysis Study

The present investigation focused on measuring thermal comfort and sensation of human subjects wearing garments of known protective qualities, under controlled environmental conditions in a laboratory that simulated Michigan summer weather conditions. In assessing thermal comfort and sensation, it is important to distinguish between the perception of comfort and sensation, and the underlying physiological dimensions that accompany the affective process. A controlled laboratory setting permitted monitoring vital physiological phenomena in addition to measuring subjective thermal sensations while maintaining constant environmental conditions. Recognizing that different kinds of settings impact on behavior (Bronfenbrenner, 1979), still,

the advantage of being able to control and monitor vital variables and parameters prompted the researcher to use a laboratory setting.

Statement of the Problem

Protective clothing has been shown to offer increased resistance to pesticide sprays and dusts and therefore is a viable means of reducing dermal exposure to pesticides. Yet, protective clothing has not been widely adopted by the population at risk, including the Michigan fruitgrower. Many indicate that protective clothing now available is simply too hot. They prefer to wear their normal work clothing.

In support of the total research effort to develop functionally designed protective clothing for the Michigan fruit grower while maintaining acceptable thermal comfort levels, this study was undertaken. The over-all purpose of this research was to investigate the perception of thermal comfort and sensation, as well as the underlying physiological phenomena, of fabrics of known protective qualities and designs under controlled environmental conditions, simulating a work environment.

Objectives

The following objectives motivated the conduct of the experiment:

1. To determine whether subjects who were wearing a specified fabric/design combination differed in their thermal response to a controlled heat stress environment. Thermal response was assessed by the physiological criterion measures of rectal temperature and

weighted skin temperature, and the affective criterion measures of thermal comfort and sensation.

2. To investigate if the total volume of sweat secreted by the test subjects and the percentage of sweat which evaporated differed by fabric and design.

3. To determine whether subjects' experienced comfort versus their anticipated comfort differed by fabric or design.

4. To determine whether subjects' willingness to wear protective clothing was influenced by fabric or design.

5. To formulate recommendations for the final protective garment prototype in the form of design specifications.

Hypotheses

In order to meet objective one, the data were treated in two distinct phases. First, the dependent measures, both physiological and affective measures, were plotted over time for fabric and design. The second phase focused on hypotheses testing. The null hypotheses for research objectives one through four are stated below.

Hypotheses for Research Objective 1

H_o^1 - H_o^3: There is no significant difference between fabrics for: (1) mean weighted skin temperature, (2) mean rectal temperature, and (3) mean thermal comfort.

H_o^4: Thermal sensation is independent of fabric.

H_o^5 - H_o^7: There is no significant difference between design for: (1) mean weighted skin temperature, (2) mean rectal temperature, and (3) mean thermal comfort.

H_o^8: Thermal sensation is independent of design.

H_o^9: There is no significant interaction between fabric and design.

Hypotheses for Research Objective 2

H_o^{10}, H_o^{11}: Percentage of sweat not absorbed or adsorbed in the test clothing is independent of (1) fabric and (2) design.

Hypotheses for Research Objective 3

H_o^{12}, H_o^{13}: Subjects' anticipated comfort is independent of (1) fabric and (2) design.

Hypotheses for Research Objective 4

H_o^{14}, H_o^{15} Subjects' willingness to wear protective clothing is independent of (1) fabric and (2) design.

Summary

Both acute and chronic adverse health effects have been shown to exist in agricultural workers, resulting from exposure to pesticides. Dermal absorption is considered the primary mode of entry into the body. The ineffectiveness of 100% cotton chambray (Orlando et al., 1982) and typical worker clothing ensembles (Davis et al., 1980) has been demonstrated. Thus, the use of protective clothing is considered vital for limiting dermal exposure of agricultural workers. Yet, the clothing which has been designed to provide protection is unacceptable to many of the individuals who have been shown to need it most, including Michigan fruit growers.

The present study was undertaken to evaluate the thermal comfort and sensation associated with selected fabrics and designs in an effort to develop a prototype garment that will insure worker safety while maintaining thermal comfort and acceptance levels. The prototype is being developed using the functional design process, a holistic approach to design that is research based. The findings from this study aided in the formulation of design specifications that have been used for continued development of the prototype design. An ecological framework served as the basis for the thermal-analysis study.

CHAPTER II

REVIEW OF LITERATURE

In order to effectively design and conduct a thermal comfort analysis, to interpret the findings, and to use the results as an aid in designing protective garments, it was necessary to review literature in diverse disciplines. This chapter has therefore been organized into six sections. First, the physics of heat exchange are briefly presented. Second, studies which sought to understand the complex problem of human thermoregulation are reviewed. The findings presented are limited to those that dealt with a heat stress environment. Third, definitions of thermal sensation and thermal comfort are given. The relevant factors implied in the definitions are discussed. The methods of assessment of thermal comfort and thermal sensation are reviewed in section four. Much of the work cited in the second, third, and fourth sections attempted to study phases of the thermal comfort issue without addressing the influence of clothing on thermal comfort. The subjects were often lightly clothed or nude in these studies. The remaining two sections of this chapter review research which focused on clothing properties as they impinge on thermal comfort. The fifth section examines research dealing with fabric properties, and the final section reviews investigations concerned with the interaction of clothing (either whole garment assemblies or specific design features) with the heat balance of the body.

Physics of Heat Exchange

There are four major avenues of thermal exchange possible between an individual and the environment: conduction, convection, radiation, and evaporation.

Conduction

Thermal transfer by conduction takes place at the skin surface, when the body is in physical contact with an object which is at a different temperature. Heat will flow to the cooler surface (skin or, for example, clothing) to create equilibrium.

Convection

Convection is a means of heat transfer which depends on the movement of a fluid (air) over a surface which is at a different temperature. Between an individual's body and each layer of clothing, there exists a layer of air. The thickness of each air layer, which is dependent on the fit and drape of the clothing, influences both body heat retention and dissipation. Air is a relatively good insulator, and as such a layer of still air can prevent body heat loss in a cold environment. In a warm environment, however, one would want to maximize air movement in order to transfer excess body heat to the environment.

There are two types of convection, i.e., natural and forced. Natural convection (chimney effect) refers to the movement of warm air after being heated at the skin surface, up along the body toward the head (Hollies & Goldman, 1977). Forced convection implies external influences which contribute to air movement, such as walking, wind, or a fan.

Radiation

Radiation, the third method of heat transfer, refers to the exchange of electromagnetic energies between facing surfaces that are at different temperatures. Radiant energy exchange is an important consideration in assessing thermal comfort in a hot environment. The absorption and emission of skin and textiles for the low-temperature infrared radiation range is above 0.9 (Fourt & Hollies, 1970). "Thus, for this radiation range, a textile fabric approximates a 'black body' emitting and absorbing energy to the maximum extent" (Fourt & Hollies, 1970, p. 160). The only materials with low emissivity or high reflectivity for this radiation range are the metals (Fourt & Hollies, 1970). Consequently, studies have been carried out to investigate the use of low-emission, high-reflection metallic surfaces to minimize radiant heat exchange (Fourt & Hollies, 1970). Such fabrics could be useful in both hot and cold environments.

Evaporation

Evaporation refers to the process in which a material is converted from a liquid to a gaseous state, due to thermal energy (Ruch & Parton, 1965). Evaporative heat loss via the skin can be accomplished in two ways. The first, passive cutaneous diffusion or insensible water loss, occurs by means of diffusion through the skin, and the rate of water loss from this way is small (Ruch & Parton, 1965). The second, regulatory sweating, is of paramount importance for heat dissipation. Without active sweating, the average person loses about 10 kcal $\cdot$ hr^{-1} $\cdot$ m^{-2} of body surface, half from his respiratory tract and half from insensible water loss which occurs at all temperatures and is the only evaporative heat loss below 82.4°F (28°C) (Whitlow, 1971).

The quantity of heat loss by evaporation from the skin surface depends on the rate of sweat secretion as well as the capacity of the environment to remove water vapor. The evaporative power of the environment is a function of: the water vapor pressure gradient from the skin surface to the ambient air, the resistance of clothing to the transfer of water vapor, and the ambient air movement (Winslow & Herrington, 1949). For example, if the air is moist and stagnant, heat loss is limited by the ability of the air to remove moisture from the skin (Ruch & Parton, 1965). When the body secretes more sweat than can be evaporated, there is little advantage for the individual, since sweat must be evaporated for body heat to be dissipated. Mecheels and Umbach (Hollies & Goldman, 1977) stated that "evaporation of one liter of sweat causes a heat loss of about 670 watt·hr" (p. 134).

Thermal Response to a Hot Environment

The human thermoregulatory system is capable of maintaining a fairly constant deep body temperature under a range of adverse environmental conditions. A better understanding of the nature of human regulation has been the impetus for numerous investigations. This extensive research has afforded opportunities for the testing of various theories, some of which were conflicting. It is agreed that human temperature regulation is mediated primarily through the activity of the central nervous system. The three essential elements of the system include: the receptors or sensors, which sense the temperature; the integrative structures, which have the ability to compare the sensed temperature to the "normal" temperature and then to activate appropriate responses; and the effectors, which, when activated, would be capable of altering the temperature. The following section briefly reviews the human thermal response to a hot environment.

Receptors

The first element of the system, the receptors, is located within the skin. Besides the cutaneous thermoreceptors, the hypothalmus, which is situated at the base of the brain, has been shown to be capable of responding directly to local changes in temperature. It has also been suggested that receptors may exist in other places within the body's core; however, support for this theory is not universal (Ruch & Parton, 1965).

The cutaneous thermoreceptors appear to be of two distinct types, cold receptors and warm receptors. Exploration of the skin, conducted in research experiments, has delineated very small areas that respond only to a sensation of cold, and other areas which respond only to warmth. The spaces between seem to be sensitive to neither. About thirteen to fifteen cold spots per square centimeter were found on the forearm, as compared with only one or two warm spots per square centimeter (Ruch & Parton, 1965). Newburgh (1968) and Ruch and Parton

(1965) found that both warm and cold spots show rapid adaptation and are particularly sensitive to rate of change of temperature. This implies that the thermal sensation can differ depending on whether the temperature change is effected gradually or rapidly.

Central Nervous System (CNS) Integration Sites

The second element of the system, the integrative structures, is capable of processing inputs from the receptors and then designating appropriate responses. The hypothalmus appears to be the major central nervous system integrative site, although the cortex and the spinal cord have subsidiary functions.

The major integrative site, the hypothalmus, is a small organ situated at the base of the brain. The hypothalmus appears to have two regions concerned with heat control, each having separate functions to some degree. The posterior section is the main center for protection against cold; its activity induces vasoconstriction and shivering, the purpose being to promote and control heat conservation. The anterior portion promotes and controls heat dissipation. This portion of the hypothalmus induces vasodilation and sweating in man and panting in animals. It appears that the centers operate in a manner such that the activity of one inhibits the activity of the other, thereby maintaining a balance. When environmental conditions are such that these mechanisms of control can no longer bring about the necessary adjustments, the situation becomes very serious. Below 80.6°F (27°C), shivering reactions may fail, respiration may be depressed, and cardiac output may become abnormal, presenting a serious threat. Newburgh (1968) gave 107.6°F (42°C) as the upper limit of temperature for the brain, for survival, although this temperature cannot be tolerated for long periods of time.

Effectors

The effectors are mechanisms of the body that respond to signals from the central integrative structures, and when activated have the capacity of helping return the system to a balanced state. The effector mechanisms include first of all changes in tissue insulation. If a change in tissue insulation is insufficient to maintain thermal neutrality, other effector mechanisms such as shivering or sweating are necessitated.

Metabolism

Basal metabolism refers to the "level of metabolic activity displayed by a subject at rest at an air temperature of about 70°F (21.1°C) and at a period long enough after a meal to avoid the specific dynamic action of food" (Winslow & Herrington, 1949, p. 16). The average value of basal metabolism varies by age, sex, and level of physical fitness.

Metabolic rate is equivalent to energy production of the human being. Energy is produced in two forms: mechanical work, which includes the movement of muscles against a weight and constitutes about 10 to 20% of the total energy, and heat energy, which makes up the remaining 80 to 90% of the total (Kuznetz, 1978). A change in activity brings about a corresponding change in metabolic rate, thus influencing the heat energy produced by the body. Table 2 gives an approximate energy cost for various activities. Metabolic rate is also sometimes given in mets. One met equals about 100 watts.

Table 2.--Energy costs for various activities.

Activity	Btu's/Hour	Calories/Hour	Watts
Sleeping	280	70	82
Sitting at lecture	730	183	214
Driving a car in heavy traffic	800	200	234
Slow walking	900	233	264
Washing clothes/ ironing	1000	250	293
Gardening	1380	345	404
Climbing stairs	2860	715	838
Running at a pace of 8 minutes/mile	4000	1000	1172
Swimming the breast stroke at 3 mph	23,100	5775	6768

(From Kuznetz, 1978, p. 50.)

Cardiovascular and Peripheral Vascular Control

The human body's response to heat stress involves cutaneous vascular dilation. This enlargement of the blood vessels results in an increased blood flow through the skin within a few minutes of sensory stimulation. Ordinarily this raises the skin temperature, making it closer to the air temperature, and thus reduces the body's heat gain from the environment. The circulation system plays a critical role in maintaining heat balance in the body in hot environments by being a vehicle for the conductance of heat from the tissues producing it to the skin and the respiratory system for dissipation.

Dilation of vascular areas is accomplished by changes in blood pressure, cardiac output, and blood volume. Upon exposure to a mild heat stress, blood pressure may drop. More intense heat exposure causes the systolic arterial pressure and possibly the diastolic to increase (Newburgh, 1968). Newburgh (1968) found that the volume of circulating blood increased as much as 10% with only "two to four hours of exposure to heat stress severe enough to produce general cutaneous vasodilation, the increase being due largely to increased plasma volume" (p. 207). Exposure to heat stress also results in increases in cardiac output of the order of 1.4 to 1.7 liters per minute, increases which vary little regardless of the resting or exercising state (Newburgh, 1968).

Sweat Gland Activity

Evaporation is the principal avenue for dissipation of excess body heat. There are two types of sweat glands: the apocrine glands and the eccrine glands. The secretion of sweat may be caused by muscular exercise, emotional or mental stress, and thermal stimuli. Sweat, secreted in response to heat stimuli, is produced chiefly by the eccrine glands which are distributed (not uniformly) over the entire skin.

The heat-regulatory function of sweating is controlled usually, thought not exclusively, by the hypothalmus. Various researchers have demonstrated this (Newburgh, 1968; Winslow & Herrington, 1949).

Yet it has also been shown that the sweat glands are able to respond to excessive local heat stimuli that raise the skin temperature. Sweating is usually not initiated immediately upon exposure to a hot thermal stress. It may take anywhere from five to forty minutes, depending on the heat stimulus, individual differences, whether or not the individuals are heat acclimatized, and the core temperature of the individual at the beginning of the experiment (Newburgh, 1968). For resting man, sweating is, on the average, initiated when skin temperature equals 94.1°F (34.5°C) (Winslow & Herrington, 1949).

The rate of sweating increases as the heat stress becomes more severe and as the metabolic rate in work increases. Acclimatization, fatigue, salt intake, and individual variation also affect rate of sweating.

Long-Term Response to Heat

Under the broad canopy of physiological adaptation to chronic thermal stress, two terms should be delineated:

1. Acclimatization--functional compensation in response to a number of environmental factors in an outdoor environment, over a period of time (several days to weeks).

2. Acclimation--functional compensation in response to a controlled laboratory environment, over a period of time (several days to weeks).

Acclimation or acclimatization to heat can be characterized by specified and measurable physiological changes as exposure continues. The majority of changes appear within the first four to six days and are complete in ten to fourteen days. The amount of time needed for daily exposure can be quite short--Lind (cited in Folk, 1966) has found that 100 continuous minutes per day was optimal. The changes included increased sweating capacity and blood volume, a fall in the threshold of skin temperature for the onset of sweating, a better distribution of sweat over the skin, increased peripheral conduction, and a drop in rectal temperature and pulse rates (Folinsbee, Wagner, Borgia, Drinkwater, Gliner, & Bedi, 1978; Folk, 1966; Newburgh, 1968; Yousef, Horvath, & Bullard, 1972).

Body Temperature

The human thermoregulatory system seeks to maintain a fairly constant deep body temperature, approximately 98.6°F (37°C), under a range of environmental conditions. However, skin temperature can vary widely, depending on the site of measurement and environmental conditions. This ability to vary skin temperature is one of the body's mechanisms to insure the maintenance of a constant deep body temperature.

Attempts to understand this phenomenon resulted in a theory whereby the body was divided into two concentric shells, each at a uniform temperature. This is where the term core temperature originated (Kuznetz, 1976). With the use of computers and the development of mathematical modeling of the human thermoregulatory system, it is now believed that the human body can be represented as three or more cylinders (head, trunk, and extremities), each divided into two or more concentric layers (Kuznetz, 1976). This supported the observed variability of skin temperature as a function of anatomic site and environmental condition.

Summary

In order to maintain a constant deep body temperature in a heat-exposure situation, the combined rates of heat gain must be balanced with the rates of heat loss. The human body's response to a warm environment is illustrated in Figure 7. Environmental heat and/or exercise set in motion a series of responses designed to maintain thermal equilibrium by increasing the body's heat loss to the environment. The anterior portion of the hypothalmus is the heat-dissipation center. It processes inputs from the receptors located in the skin, or it can act as a receptor itself. The hypothalmus designates appropriate responses, including vasodilation, which results in increased blood flow to the skin which ordinarily increases the skin temperature.

The body is thought to be composed of three cylinders, each of which contains a series of concentric shells, each exchanging heat with the adjacent shell via conduction. All of the layers exchange heat with the environment by all four routes of heat exchange. The deep body or core temperature can safely vary only within a narrow range about 98.6°F (37°C). Skin temperature varies by both anatomic site and environmental conditions.

Sweating is the body's chief means of dissipating excess body heat. The evaporative capacity of the environment (including clothing) impacts on the possible quantity of heat loss by evaporation.

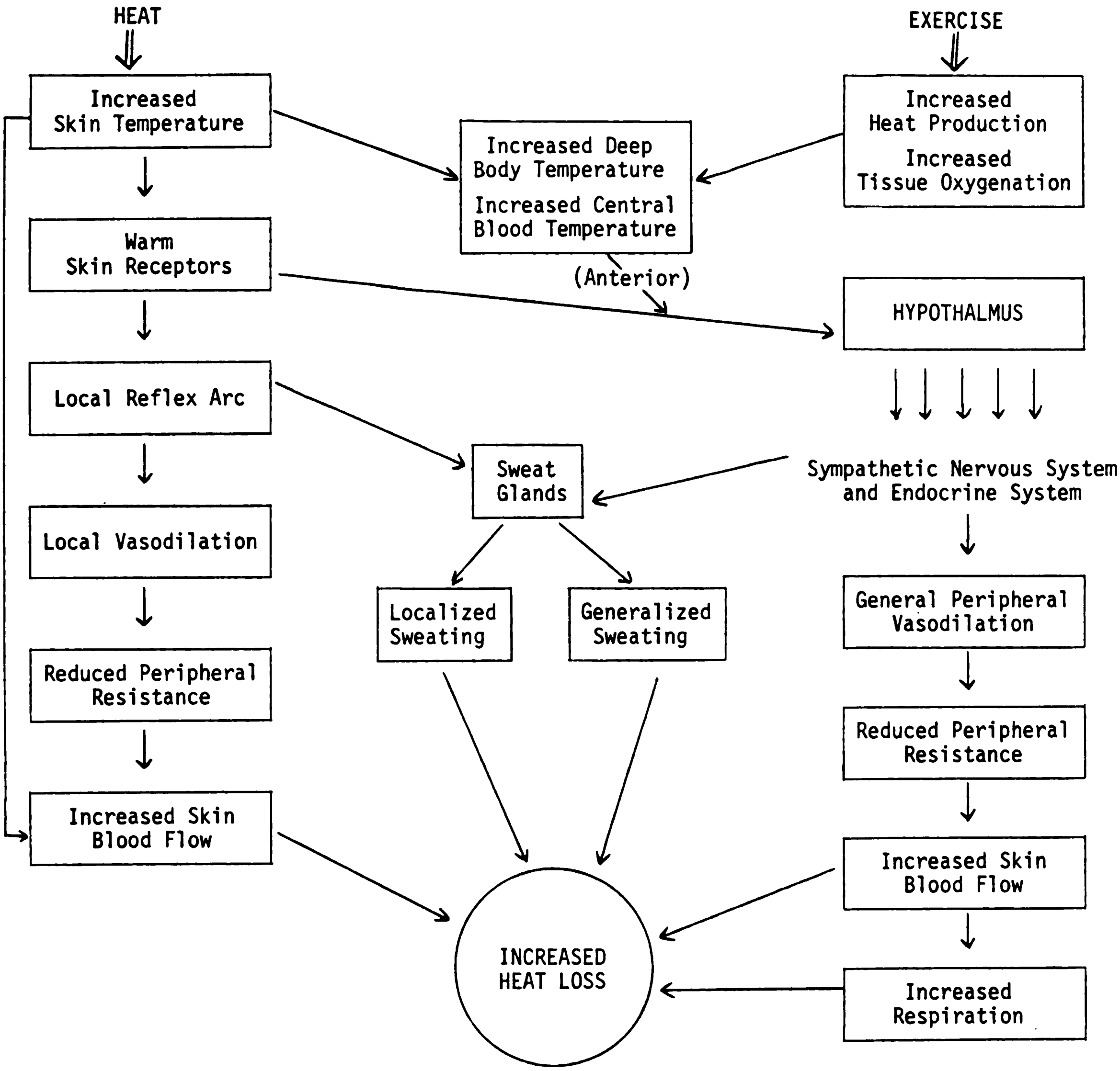


Figure 7.--Human thermoregulatory response to a warm environment. (Adapted from Kuznetz, 1976, p. 19.)

Thermal Sensation, Thermal Comfort

Thermal sensation refers to a conscious experience resulting from exposure to the thermal environment. The ASHRAE Handbook of Fundamentals (1977) specified a neutral thermal sensation as a "sensation that is neither slightly warm nor slightly cool" (p. 2). Numerous studies have used rating scales to assess thermal sensation, with a neutral point representing the midpoint of the symmetrical scale.

Thermal neutrality, however, is not always synonymous with thermal comfort, a distinction which is often not clearly elucidated. Thermal comfort was defined by ASHRAE Standard 55-74 (1974) as "that condition of mind which expresses satisfaction with the thermal environment" (p. 3). Although a neutral thermal sensation would seem to imply optimal thermal comfort, research findings have not always borne this out. McIntyre (1976) cited several studies in which test subjects expressed the most satisfaction with a temperature slightly above or below the neutral midpoint. The natural climatic conditions may impact on subjects' preferred temperature. Subjects in cold climates have indicated a preference for slightly warm temperatures, and the reverse situation has also been documented (McIntyre, 1976).

Because of these findings, Rohles, Hayter, and Milliken (1975) suggested assessment of both thermal comfort and thermal sensation when conducting environmental investigations.

Thermal Environment

There are two other points that should be emphasized regarding the definitions of thermal sensation and thermal comfort given above.

First, both definitions refer to the "thermal environment," an encompassing term which includes numerous variables requiring specification. Much effort in comfort research has been given to both the delineation of pertinent variables and to the combined effects of the specified variables on thermal satisfaction. Fourt and Hollies (1970, p. 9) identified four environmental quantities that should be specified: (a) air temperature or dry-bulb temperature, (b) relative humidity or moisture content of the air, (c) air movement, and (d) mean radiant temperature. These measurements are necessary in order to investigate the heat transfer between the body and the environment via all four routes of thermal exchange.

Fanger (1970) and Hollies and Goldman (1977) suggested the inclusion of ambient vapor pressure rather than relative humidity. This is because "water is evaporated across a vapor pressure difference" (Hollies & Goldman, 1977, p. 4). This is an important point because it emphasizes that even if the relative humidity were 100%, one could still evaporate sweat at the skin surface, since the vapor pressure at the skin temperature would be in the neighborhood of 42 mm Hg and the vapor pressure in the air would be considerably less (Hollies & Goldman, 1970).

Clothing, as one's nearest constructed environment, affects heat transfer by conduction, convection, radiation, and evaporation. Clearly, properties of clothing which impact on thermal comfort must therefore be identified or controlled (Fourt & Hollies, 1970). The _clo_ unit, a measure of thermal resistance for a single fabric layer or an assembly of layers, was proposed by Dr. Gagge and his colleagues at the Pierce Foundation over thirty years ago (Hollies & Goldman, 1977). The unit was intended to be readily understood by the nontechnical audience and was characterized as the intrinsic insulation of the typical business suit of the day, excluding the adhering exterior still-air layer.

The method of measuring clo values is given in section four. However, at this point, a limitation of the clo unit should be recognized. The clo unit essentially measures the dry heat loss through a material or assembly of materials by convection and radiation. For a resting individual in cold weather this is adequate, but for any other environmental condition in which evaporation of sweat is important, the clo unit alone is not adequate. Therefore, Hollies and Goldman (1977), Fourt and Hollies (1970), and Goldman (n.d.) suggested the inclusion of the permeability index, i_m, as a means of measuring the resistance of a material to evaporative heat loss. The permeability index was originally proposed by Woodcock (1962).

The weight, thickness, and surface area of clothing have also been used to specify clothing (Fourt & Hollies, 1970).

Affective Mental Process

The second point that should be emphasized regarding the definitions of thermal comfort and thermal sensation is that both refer to an affective mental process, i.e., "the conscious experience" and the "condition of mind." Although there are methodological difficulties in assessing variables associated with the thermal environment, assessment of a feeling of affective quality is even more difficult. This critical area is addressed in section four.

Characteristics of an individual also affect one's response (both psychologically and physiologically) to a thermal environment. Factors such as age, sex, body build, ethnic differences, circadian rhythm, and food intake have all been studied to determine their influence on thermal comfort.

Ecosystem Complex

Numerous environmental research studies have not or were not able to control the many variables now believed to impact on thermal sensation and comfort (Munson, 1980; Rohles, 1967). Recognizing this deficiency, Rohles (1971) used an ecological perspective for organizing and categorizing the variables that he felt required identification and control, if replicable results were to be achieved. Rohles termed his framework the Ecosystem Complex and depicted it as a three-dimensional solid consisting of three major components, corresponding to the three determinants of an ecosystem, i.e., the individual, the environment, and the interaction between them.

Table 3 summarizes the delineation and organization of variables that Rohles felt impacted on thermal sensation and comfort. The physical environment is specified by the physical factors, while the organismic factors identify characteristics of the organism itself which impinge on thermal response to the physical environment. The adaptive factors are those factors which permit the organism to interact with the environment in a way that can hinder or facilitate thermal comfort.

Table 3.--The ecosystem complex: An organization of variables for the study of thermal comfort, developed by Rohles (1971).

Physical Factors	Organismic Factors	Adaptive Factors
Sound	*Age	Ingesta
Light	*Sex	*Clothing
Area-volume	Body type	*Exposure time
*Air movement	*Psyche	Social
*Mean radiant temperature	Drive	Incentive
*Water vapor pressure	*Physical fitness	*Activity level
Force fields	Circadian rhythm	
*Temperature	*Genetics	
*Relative humidity		

*Rohles considered these variables particularly important.

Since it is frequently not possible to control all of the variables given in Table 3, Rohles (1978) identified the most critical variables that should be controlled. The physical factors specified are the same variables given by Fourt and Hollies (1970), Fanger (1970), and Hollies and Goldman (1977).

Assessment of Thermal Comfort and Thermal Sensation

Following a brief historical perspective of thermal-comfort research, methods of assessment are discussed.

Historical Development

The historical development of human-thermal-comfort research has been achieved through the efforts of researchers from various disciplines, including physiology, psychology, biology, engineering, the health professions, chemistry, and textile science. For the past sixty years, heating and ventilating engineers have been leaders in thermal-comfort research. The major thrust of this research has been directed toward understanding and assessing indoor thermal comfort. The underlying aim of this research effort was to create artificial indoor climates, such that the highest possible percentage of individuals would express satisfaction with the thermal environment (Fanger, 1970). One hundred percent satisfaction was not considered feasible (Fanger, 1970).

The classic study of F. C. Houghten and C. P. Yaglou (1923) for the American Society of Heating and Ventilating Engineers (ASHVE) resulted in the development of their "Effective Temperature," an index which combined dry-bulb temperature and humidity into a single temperature scale that described temperature sensation. Yaglou and Miller investigated the notion of effective temperature with industrial ventilation problems (1924) and with clothing (1925).

During the 1930s, physiologists emphasized formulating methods to quantify the energy exchange that takes place during vasodilation, vasoconstriction, shivering, and sweating. Winslow, Herrington, and Gagge (1936) and Hardy and DuBois (cited in Gagge, Gonzales, & Lishi, 1974) carried out studies now considered to be classics. DuBois developed height-weight formulae that could be used to calculate surface area of the human body (given in Newburgh, 1968). These formulae remain important today in order to quantify thermal transfer by all four methods.

During the 1940s, the orientation of much of the thermal-comfort research shifted toward a determination of the human tolerance limits for adverse thermal environments. The level of performance that subjects were capable of achieving under thermal stress conditions was also emphasized. Eichna, Ashe, Bean, and Shelley (1945) provided a summary of studies conducted (both chamber and field studies) to investigate thermal response to heat-stress environments. Eichna et al. (1945) carried out an experiment to determine the environmental limits at which disability begins under conditions of heat stress.

World War II also served as an impetus for this research effort. The limitations of human performance of the military in both hot and cold environments was clearly demonstrated during the war (Gagge et al., 1974). Increased attention was accordingly paid to designing arctic and tropical protective military clothing, which would facilitate improved human performance under environmental stress conditions. The interest of the military in thermal-comfort research has continued to the present time.

The comfort research during the 1950s continued to emphasize determination of tolerance and performance levels under severe thermal-stress conditions. However, the focus was directed toward developing standards for tolerable working conditions, primarily in mines and factories (Gagge et al., 1974). Belding and Hatch (1956) investigated the thermal comfort of steel workers, and Wyndham (1962) studied the thermal comfort of miners in the hot South African gold mines.

The past twenty years have witnessed the continued dual effort by scientists specializing in thermal comfort for military applications,

and scientists emphasizing thermal comfort for indoor conditions, most notably the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Assessment Techniques

Thermal comfort and sensation have traditionally been determined via an objective or a subjective approach or a combination of both. Rohles (1974) suggested that in order to study feelings about comfort or sensation, it was important to distinguish between the affective mental process and the "underlying physiological process that it parallels" (p. 98). Rohles referred to subjective approaches as methods of impression, and objective techniques as methods of expression.

Methods of impression. The objective of methods of impression is to obtain a subjective account of the test subjects' feelings about the thermal environment under investigation. This has been accomplished in three ways: (1) determination of preferred temperature, (2) use of various rating scales in environmental chambers, and (3) use of the same scales in field studies. The environmentally controlled chamber studies offer the researcher the advantage of being capable of monitoring and controlling many of the variables given in Table 3. Yet, as Bronfenbrenner (1979) succinctly pointed out, "the laboratory does have its special vulnerabilities, particularly when results are taken as applicable to everyday life" (p. 118). Goldman (n.d.) suggested that field evaluations "should never be carried out until the 'homework' in the laboratory has been completed and then only as a validation of the laboratory findings under field conditions" (p. 17).

The method of direct determination, pioneered by Fanger in the 1970s, produced more consistent results than either chamber or field tests. This method allowed a subject to find his/her preferred temperature by requesting changes in the chamber temperature until he/she was satisfied. This experimental procedure, which used only one test subject at a time, was very expensive and time consuming. Fanger has found that age, sex, previous thermal experience, and time of day did not affect his results (McIntyre, 1976).

The most commonly used technique for assessing thermal feelings involved the use of rating scales, one of the earliest being a five-point scale developed by Yaglou (1927). Although various investigators have used scales which ranged from three points to twenty-five, seven remains the most frequently used (McIntyre, 1976). The Bedford and ASHRAE scales, shown in Table 4, are two commonly used seven-point scales. Examination of the scales shows that the ASHRAE scale refers only to thermal sensation, whereas the Bedford scale combined sensation and comfort.

The choice of seven is supported by research evidence, which suggests that the number of separate estimates that a person can unambiguously assign to a one-dimensional stimulus is rather small (McIntyre, 1976). On this basis, many researchers have concluded that subjects will be unable to distinguish more than seven levels of thermal sensation (McIntyre, 1976).

Table 4.--The Bedford and ASHRAE thermal comfort rating scales.

Bedford Scale	ASHRAE Scale
Much too warm	Hot
Too warm	Warm
Comfortably warm	Slightly warm
Comfortable	Neutral
Comfortably cool	Slightly cool
Too cool	Cool
Much too cool	Cold

Recently, Winakor (1978) has been experimenting with a ninety-nine-point semantic-differential-type instrument which would assess both thermal comfort and thermal sensation. Pairs of words describing characteristics of the clothing worn and removed are also included in this instrument. At this time, it has not been administered to a sufficient number of subjects in different settings to establish its reliability.

Rohles (1974) has recommended the use of a nine-point scale to measure thermal sensation. The scale is identical to the ASHRAE scale except that the categories very hot and very cold have been added to the extremes of the ASHRAE scale. McIntyre (1976) cautioned that it should not be assumed that the ratings on the seven- and the nine-point scales will correspond; rather, this should be evaluated when sufficient comparative data are gathered. Rohles' (1978) rationale for extending the seven-point scale was to spread the variability of the overall distribution of responses. Rohles had found that there was a tendency for subjects not to use the end points, thus reducing a seven-point scale to effectively five.

McIntyre (1976) investigated the behavior of the Bedford and ASHRAE seven-point scales in detail, for both field studies and chamber experiments.

Methods of expression. Methods of expression are objective measures of physiological bodily changes. Depending on the given environmental conditions under study and the objectives of the researcher, various physiological criterion measures have been used, the most widely used being mean skin temperature, rectal temperature, metabolism, the rate of regulatory sweat secretion on the skin surface, and mechanical efficiency for doing external work (Gagge et al., 1974).

Eichna et al. (1945) varied the temperature/relative humidity conditions to identify the upper limits of heat-stress environments that men could tolerate and perform effectively in. The thirteen young male subjects were first trained to march with ease and then acclimated to simulated dry and humid heat. The men were required to march, carrying a twenty-pound pack a specified length of time under various heat-stress conditions (ranged between 90.7°-97.2° E.T. The "old" Effective Temperature, ET, was an arbitrary index combining temperature, humidity, air movement, and thermal sensation; Rohles et al., 1979). Neither clothing nor food and drink intake was controlled. Heart rate, rectal temperature, and respiratory rates were measured at hourly intervals. Skin temperatures for six body locations were determined with a radiometer at the end of the test. Three environmental zones were identified as (1) relatively easy, (2) undesirable, and (3) impossible. For the relatively easy zone, average internal temperatures remained under 101°F (38.3°C), between 101°F and 102°F (38.9°C) for the undesirable zone, and over 102°F for the impossible zone. Skin temperature for the individual varied little by anatomic site for all environmental conditions investigated. Skin temperature was influenced markedly by dry-bulb temperature, with an average of 100.3°F (37.9°C) for the impossible zone, 99.1°F (37.3°C) for the difficult, and 98.3°F (36.8°C) for the relatively easy zone. Sweat loss, determined by weighing the subjects, showed a similar pattern, with an average of 22.89 cc lost per hour for the impossible zone.

Stolwijk, Saltin, and Gagge (1968) studied four male subjects in a controlled-chamber experiment aimed at examining physiological factors and their relation to sweating during exercise. Skin temperature was computed as a weighted average of ten representative body-surface temperatures. Average evaporative heat loss was estimated by weighing the subjects before and after the experiment. Stolwijk (1968) found that rectal temperature was linearly proportional to metabolism but independent of ambient temperature, and that skin temperature was just the opposite, i.e., primarily dependent on ambient air temperature and independent of metabolic rate. They also concluded that both skin and rectal temperature played significant roles in the level of skin sweating. Distribution of sweating was studied qualitatively by observing regional changes in skin temperature with a thermograph, immediately after the subjects finished exercising. The trunk, which sweats abundantly, was found to be cool especially over fatty deposits, whereas the skin temperature of the head, neck, and arms was warmer. Stolwijk et al. (1968) suggested, therefore, that local skin temperature depends on "local level of sweating, local skin blood flow, and the temperature and thermal conductance of underlying tissues" (p. 1102).

Fourt and Hollies (1970) presented a discussion on methodology for determining onset of sweating, area involved, rate of sweating, local sweating rate, sweat collection, amount of evaporated sweat, and the efficiency of cooling by sweating. It was suggested that total sweat secreted be obtained by weighing the subject immediately prior to the test and at the conclusion of the test. Weighings of the clothing and towel (if used) provide data on secreted sweat that hasn't evaporated. Insensible evaporation can be approximated through the literature. Determining the amount evaporated can be quite difficult if sweat drips off of the skin. Onset of sweating and size of the area involved can be accomplished by using a dye that becomes visible when wet (Fourt & Hollies, 1970). Pontrelli (in Hollies & Goldman, 1977, chapter 6) used this approach to evaluate different fibers' ability to transfer sweat.

Rohles, Konz, Zuti, Smith, and Skipton (1979) conducted an experiment at Kansas State University to determine variability of the human behavioral and physiological responses to thermal stress (33°, 36°, 38°, and 40° CET*) for four hours. The reader is referred to Rohles et al. (1979) for a discussion of the CET* index. The sample of 262 semi-nude sedentary subjects varied by age and sex. Many of the heat-stress studies were conducted with only one or two subjects, throwing suspicion on the reported differences in the responses of different subjects as well as differences in the same subject over time. Of the twenty dependent measures collected, Rohles et al. (1979) felt the rectal temperature was the most critical. Females were found to be less tolerant of the environmental conditions than the males. Age difference was not found to be statistically significant. Skin-temperature thermisters were taped to fifteen body locations for determination of mean skin temperature.

Measuring clothing insulation. Clo units have been specified to define the thermal insulation of fabric or of a clothing ensemble. This term was originally intended to be thought of in familiar terms for easy understandability by nonspecialists, and as such, was described as the thermal insulation in a business suit worn in cool weather. The definition stated mathematically is:

$$\text{clo} = \frac{.18°\text{C}}{\text{kcal/m}^2\text{/hr}}$$

Burton and Edholm (1969) specified 1 clo unit as the insulation required to maintain a resting-sitting man, whose metabolism is 50 $\text{kcal}\cdot\text{m}^{-2}\cdot\text{hr}^{-1}$, comfortable in a 68°F (20°C) environment with r.h. less than 50% and air movement 20 ft/min.

Clo values have been experimentally measured and calculated by several methods. The flat-plate determinations (discussed by Goldman, n.d.) are primarily of use in selection of fabrics for a clothing ensemble. Heated, dry, and "sweating" cylinders have been used to imitate the shape of the body. While these devices are useful for studying factors such as wind penetration through a fabric, characteristics such as drape, fit, and shape cannot be examined on these devices.

Life-sized, heated copper manikins have been the solution. Seppanan (1972; cited in Munson, 1980, pp. 37-38) noted that determination of clo values on copper manikins employed the notion of thermal equilibrium "in that the electrical power supplied to the heated circuits equaled the rate at which thermal energy left the manikin via conduction, convection, and radiation." There are only four copper manikins in existence. They are located at the Institute for Environmental Research, Manhattan, Kansas; the U.S. Army Research Institute for Environmental Medicine at Natick, Massachusetts; the Bekleidungsphysiologisches Institut in Hohenstein, Germany; and the Technical University of Denmark in Copenhagen.

Goldman (n.d.) emphasized that although the copper man predictions are useful, they should be supplemented by chamber studies and ultimately by field studies.

Fabric Properties

Andreen, Gibson, and Wetmore (1953) used both objective physiological data and subjective opinion to compare coverall garments constructed from six fabrics: a 80/20 wool/acrylic blend, cotton shirting, filament nylon shirting, cotton denim, spun nylon denim, and neoprene-coated nylon. Skin temperature, degree of skin wetness, rate of sweating, total sweat cost, and heart rate were measured. The results indicated that under warm, humid conditions, differences between fabrics were small and sometimes nonexistent. Inconsistent subjective responses were obtained under hot, humid conditions. The authors concluded that comfort depends upon "the geometry of the fabric construction and the manner in which the fabric is worn on the body" (p. 22).

Pontrelli (in Hollies & Goldman, 1977, chapter 6) studied the comfort associated with athletic socks. Three fabric variations, cotton, wool, and acrylic, were used. Basketball team members served as test subjects and wore two different athletic socks. Thirty-three out of forty preferred acrylic over cotton, and twenty-six out of twenty-nine preferred acrylic over wool. Preference was defined in terms of subjective evaluation of which felt drier. Pontrelli concluded that either the foot with the acrylic sock was sweating less or the fabric was transporting the sweat from the foot to the shoe and environment at a faster rate. Another experiment was conducted to investigate this. It was found that the acrylic sock was transporting sweat to the athletic-shoe surface at a rate about 2.5 times faster than the natural fibers.

The transport (moisture and air) properties of fabrics have been found to be important in determining thermal comfort in warm environments. A good summary of the physical properties pertaining to moisture transport, i.e., wettability, wicking, moisture regain, moisture content, water-vapor permeability, and drying rate, was presented by Hollies and Goldman (1977, pp. 45-48).

Bruce Latta (in Hollies & Goldman, 1977, chapter 4) found comfort differences between hydrophobic and hydrophilic finishes applied to polyesters. Eighteen women wore the test garments under different environmental conditions. It was learned that under moderate environmental conditions, differences between the garments were most pronounced.

Fourt and Hollies (1970) emphasized that the nature of the contact of fabric with the skin plays a major role in determining subjective comfort in moderate-thermal-stress environments. Fiber fineness has been shown to impact type of contact fabric makes with the skin (Fourt & Hollies, 1970). Work has also been done to study the sensation of warmness or coolness as a function of contact with the skin. Rees (1941) determined that smooth fabrics which tend to have high surface contact are subjectively evaluated as having a cool feel. Hock, Sookne, and Harris (1944; cited in Fourt & Hollies, 1970) found that cool sensations of smooth fabrics were accentuated in the presence of moisture. Leach (1957) concluded that for warm-weather clothing, filament structures had a potential advantage of ridding the body of perspiration, but spun-yarn fabrics are more comfortable. Hollies (cited in Fourt & Hollies, 1970) found that comfort can be maintained in warm environments if moist fabrics do not make substantial contact with the skin.

Garment Properties

A study by Reischl and Stransky (1980) examined the present fire fighter's protective system relative to a development design. This design was constructed of two different fabric assemblies and could be worn either in an open or closed configuration. The purpose of the study was to assess the ventilation characteristics of the garments. Only two subjects (male and female) were used as test subjects. All five garment variations showed increasing temperature (air temperature inside clothing) over time. The authors concluded that prototype number one offered no advantage over the standard turn-out gear; however, prototype number two (different fabric assemblies) was more comfortable as assessed by air temperature within the clothing. However, the authors didn't address if the fabric differences caused the observed difference, most likely because they couldn't since their experimental design confounded fabric and design.

Breckenridge (in Hollies & Goldman, 1977, chapter 11) studied the effects of body motion on convective and evaporative heat exchange. He cited an example in which clo and i_m values were determined using the copper manikin for various raincoats and a poncho. The garments were subsequently worn in a human-subject chamber study. The study is noteworthy for it demonstrated that differences in design characteristics were not correctly assessed by the manikin. The rate of body-heat storage for the poncho was less than anticipated due to the movement of air which increased evaporative cooling. The vents did not promote the expected level of ventilation.

Belding, Russell, Darling, and Folk (1947) found that the intrinsic value of an arctic uniform decreased from 2.7 clo (while the subjects were standing still) to 1.3 clo (while working). This 50-percent reduction in clo value was due to a reduction in insulation of dead-air spaces.

Goldman (n.d.) examined raincoats worn as full-length or cut-down versions (1/4, 1/2, or 3/4 of the total length). The chamber-study results were as expected: The average sweat production increased as a function of increased impermeable coverage. Goldman concluded that the extra sweat a man will produce as his body temperature rises can be evaporated if sufficient unimpeded body surface area is available (p. 14). The greater average sweat production of the individuals wearing the 3/4 and full-length garments couldn't be evaporated in sufficient quantities to compensate.

Yaglou and Rao (1947) examined sweat secretion and evaporation in a two-hour controlled-chamber study to evaluate closeness of fit as a determinant of comfort. They found that tight-fitting and sealed closures contributed to an increased physiological burden for the test subjects.

Summary

In order to maintain a constant deep-body temperature in a heat-stress environment, the combined rates of heat gain must be balanced with the rates of heat loss, which is most notably due to evaporation.

Thermal comfort and sensation are two distinct concepts, although both refer to a conscious sensation. In assessing thermal comfort and sensation, it is vitally important to recognize and assess both the affective sensation and the physiological phenomenon it parallels. The subjective assessment has been carried out by the method of preferred determination (a very costly and time-consuming technique) and the use of rating scales for controlled-chamber and field studies. Objective criterion measures usually include rectal and skin temperature, rate of sweating, skin wettedness, heart rate, and heat storage. Determination of values for clothing insulation requires a copper manikin, only four of which are available in the world. Clo values do not measure heat transfer by evaporation. The permeability index, also determined on the copper man, can give an indication of evaporative potential of a garment.

Both of these measures are subject to variation depending on body movement. This supports the importance of carrying out controlled-chamber studies, particularly in heat-stress environments.

Moisture and air-transport properties of fabrics and the geometry of the fabric construction are particularly important to comfort in a hot environment. The nature of the contact between the fabric and the skin influences subjective thermal comfort.

Body motion is critical for promoting convective and evaporative cooling. When wearing impermeable clothing, Goodman (n.d.) suggested that a sufficient unimpeded body surface area must be available for the evaporation of the extra sweat. Tight-fitting garments that restrict air movement within the garment do not facilitate body-heat loss.

CHAPTER III

METHODOLOGY

The present study was undertaken to evaluate the thermal comfort and sensation associated with selected fabrics and designs. This research is in support of an overall effort to develop a prototype garment that will provide the grower both safety and adequate thermal comfort. Recognizing the ultimate goal that the thermal-analysis study was contributing toward, the choice of a context for the conduct of the experiment was given serious consideration.

Laboratory and field settings each offer unique advantages and disadvantages that were carefully weighed. Bronfenbrenner (1979, p. 109) cautioned that a basic tenet of the ecological approach holds that: "Different kinds of settings give rise to distinctive patterns of role, activity, and relation for persons who become participants in these settings." The validity of research findings, their subsequent interpretation and implications can be suspect, unless attention has been directed toward the contextual variables and their influence on observed behavior (Bronfenbrenner, 1979; Brookhart & Hack, 1976). Bronfenbrenner (1979) suggested that seeking universal processes of behavior that are invariant across different settings is inappropriate because of the adaptive capacity of human beings. He concluded that processes at or near the physiological level are most likely the only processes that are invariant across different contexts (Bronfenbrenner, 1979, p. 128). Yet, the validity of both settings as means of eliciting different contributions was acknowledged by Bronfenbrenner (1979).

An important focus of the present study was on the assessment of subjects' physiological responses to a hot environment, while wearing selected test clothing. A field study would not have permitted the monitoring of physiological responses. Because some protective clothing now available has been characterized as being potentially more hazardous due to heat build-up than the pesticide exposure, it was considered vital to assess the physiological responses as well as the perceptual responses of the subjects to a hot environment. These motivations prompted the researcher to choose a laboratory setting as the context for this study.

The Institute for Environmental Research at Kansas State University was used as the site for the conduct of the thermal-analysis study. This facility offered the advantage of permitting the monitoring of physiological responses while controlling environmental variables at prescribed levels. Figure 8 illustrates the experimental model for this study. The human environed unit (HEU) was each individual test subject. The nearest human constructed environment (HCE_1) was the test garment that the subject was wearing. The human behavioral environment (HBE) contained the researcher and all other test subjects that were present in the test chamber. The second level of the HCE (HCE_2) was the structure of the test chamber and the climatological conditions present in the chamber.

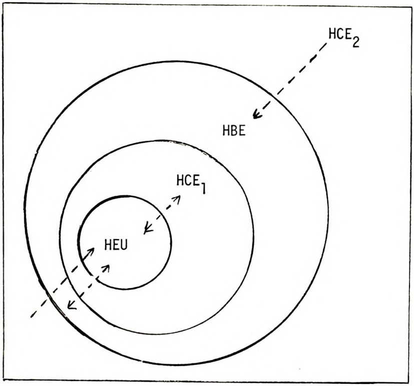


Figure 8.--Experimental model for the thermal-analysis study.

Controlled Variables

Because the focus of the study was on evaluating the sensation of thermal comfort and the accompanying physiological measures associated with wearing selected garments, numerous variables which impact on thermal comfort had to be controlled. These variables were organized into those relative to the HEU, the HBE, and the HCE_2.

Human Environed Unit

Characteristics of the test subjects known to affect thermal comfort include age, sex, body type, psyche, and physical condition. It is also known that food and drink intake, level of physical activity and the length of exposure time also impact on one's physiological response to heat. For this study, these variables were controlled as specified in Table 5. None of the subjects was acclimated to a hot environment prior to the experiment.

Table 5.--Controlled variables for the human environed unit.

Variable	Control Specification
Age	18-25 years
Sex	Male
Psyche	Random Assignment
Body Type	All Wore Same Size Garment
Physical Condition	Physical Examination Required
Food/Drink Intake	Standard Breakfast Provided
Physical Activity	3 mets
Exposure Time	30 min. preconditioning, 2 hr. exposure

Human Constructed Environment--Level 2

Within the test chamber air movement, relative humidity, mean radiant temperatures, and dry-bulb air temperature were controlled as given in Table 6. The rationale for the choice of air temperature and relative humidity was to simulate the natural environment that a grower typically would be working in during the spring and summer pesticide-application season in Michigan.

Table 6.--Controlled environmental variables.

Variable	Control Specification
Dry-Bulb Air Temperature	85°F
Mean Radiant Temperature	85°F
Relative Humidity	60%
Air Movement	Still Air (.15 m/s)

The process of specification of the controlled environmental variables began by investigating first, where Michigan's fruit growing industry was located in the state; second, selecting a representative location; and third, studying the weather conditions of the representative site. Figure 9 delineates the four districts given in the 1978 Michigan Fruit Tree--Vineyard Survey (Department of Agriculture, 1978). The shaded portion of the map, i.e. the northwest, west central and southwest districts, contains the greatest concentration of various types of fruit trees (Dept. of Agriculture, 1978), with tart cherries and apples representing the leading crops.

Dry-Bulb Air Temperature

Preliminary examination of the climatological data collected by the National Oceanic and Atmospheric Administration (NOAA) for Michigan's western fruit-growing districts showed considerable variability between sites. Therefore, it was decided to establish the laboratory environmental conditions based on an analysis of the climatological data for a specified representative location.

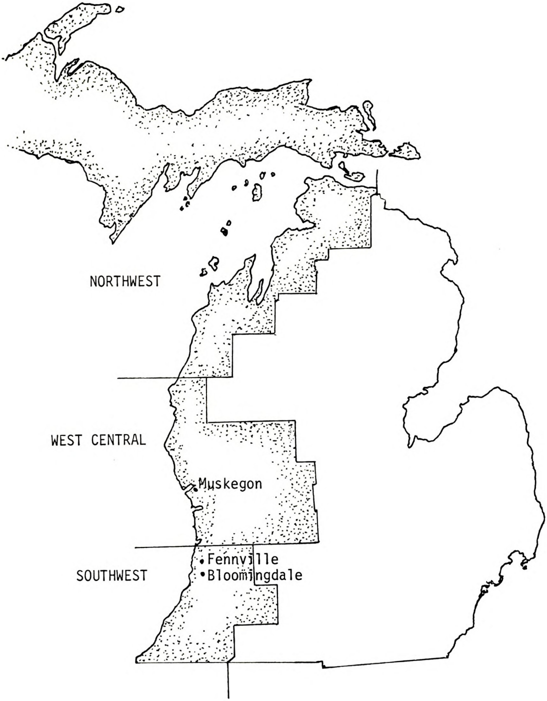


Figure 9.--District definition map of Michigan's fruit industry. (Adapted from Department of Agriculture, 1978, p. 9.)

Since two of the planned experiments, the deposition and the field exposure studies, were to be conducted at the Trevor Nickols Experiment Station in Fennville, Michigan, a location close to the station would facilitate future comparisons between data gathered in the field and in the laboratory. Therefore, Bloomingdale, Michigan, was chosen as the representative site. The Daily Temperature NOAA data for the months of July and August, 1970 through 1979, were examined. Analysis of these data indicated that the maximum daily temperature did not exceed 85°F more than 70% of the time.

Maintenance of the temperature within the test chamber was consequently specified at 85°F. Although designation of this temperature did not permit evaluation of a "worst case" situation, it did enable evaluation under conditions which are not exceeded the majority of the time. Also, temperature ranges which were characteristic of Bloomingdale were warmer than the majority of the northern section of the state.

Mean Radiant Temperature

All surface temperatures (mean radiant temperatures) were maintained equal to the air temperature.

Relative Humidity

The process of selecting a level for relative humidity was similar to the process employed for designation of air temperature, although the number of sites for which data were available was less. Muskegon was chosen as a representative site due to its proximity to Fennville and Bloomingdale. NOAA climatological data, for the years

1975 through 1979, were studied for the months of July and August. The average relative humidity for that time period was approximately 61.8%. Thus, 60% relative humidity was chosen for the environmental test condition.

Air Movement

Air movement was controlled in the chamber at the level of still air. This decision, which made the chamber conditions more thermally burdensome, was made to permit comparison of data from the present study with anticipated future research data.

Human Behavioral Environment

It was recognized that the presence of other subjects and the researcher in the environmental chamber could impact on an individual's subjective evaluation of his thermal comfort and sensation. Therefore, subjects were instructed during the orientation that discussion of the test garments and the test conditions was not permitted. However, visual observation among test subjects could not be restricted.

Research Design

Independent Variables

The independent variables for the study included two factors, design and fabric, each having three levels. The overall rationale for the choice of levels was to enable a comparison of the thermal comfort associated with clothing commonly worn by the grower for pesticide application, and alternative prototypes that offered greater protection against pesticide penetration. As indicated in Figure 10, data from four preceding components of the total project and information obtained through the pesticide-exposure and thermal-comfort literature were used as inputs into the specification of the levels of the independent variables.

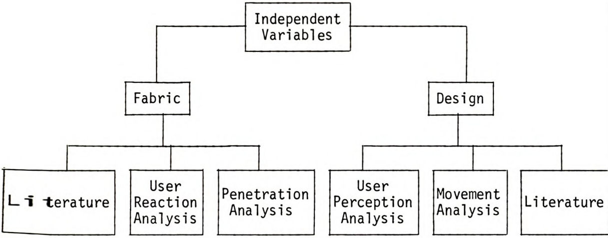


Figure 10.--Inputs to the choice of levels for fabric and design.

Design. The first level of the factor design was chosen to meet two objectives: (1) to reflect what was commonly worn by the grower for pesticide application and (2) to enable examination of the thermal comfort associated with a protective garment that was a partial body covering. It was important to meet the first objective so that an evaluation and a comparison of the relative thermal comfort afforded by protective garments versus commonly worn clothing could be achieved. The second objective was a serious concern since data reported in the literature on which areas of the body receive pesticide deposition during actual field spray operations were limited and fragmentary. Although the present overall project included a "deposition study," this component was planned for the summer following the thermal analysis. It was therefore important to anticipate what the pattern of deposition of pesticide spray during application might be. It seemed reasonable to consider that pesticide deposition might be primarily localized on the upper portion of the body, thus suggesting the necessity of a partial protective body covering.

Both of the objectives were met in the two-piece design shown in Figure 11. The design consisted of denim jeans and a long-sleeved traditional-styled shirt, constructed in each of the test fabrics. Thus, only the shirt fabric was varied, and the fabric for the jeans was held constant.

The second and third levels of the independent variable design were two variations of a one-piece coverall. Henry's study (1980) indicated that growers were divided in their preference for one- or two-piece work clothing designs; thus it was considered important to include one-piece variations.

As indicated in Figure 10, the movement analysis and the thermal comfort literature provided inputs into the development of the prototype designs. The thermal comfort literature suggested that loose, flowing designs with wide openings at the neck, wrist, and lower leg would maximize internal air flow throughout the garment and facilitate the exchange of internal air with outside air. However, these general principles were in contradiction for the need to maintain closed openings to minimize dermal pesticide exposure. Also,

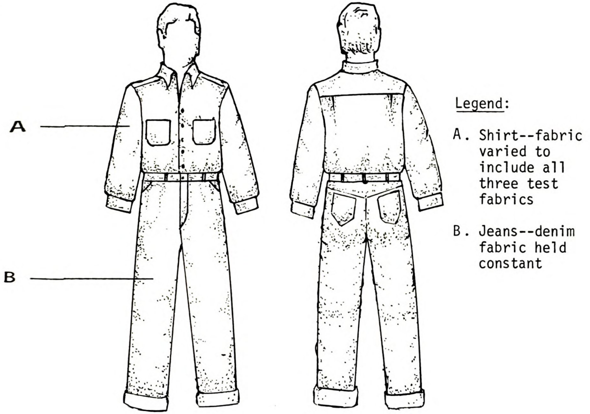
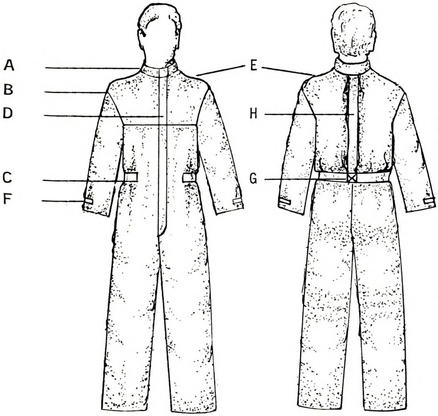


Figure 11.--Two-piece design, Design 1.

loose-fitting clothing posed a serious hazard to the grower. Based on data obtained from surveys in the states of Ohio, Michigan, New York, Wisconsin, Louisiana, Nebraska, Minnesota, Indiana, Illinois, Oregon, West Virginia, Alabama, California, Missouri, and Maryland, over 200,000 injuries occur annually to farm residents, their help, and visitors (Pfister, 1976). Farm machinery was involved in 22% of these injuries, and almost one-third of the tractor injuries resulted from the victim being caught in or between the tractor and another object (Pfister, 1976). Clothing that is loose or clothing with something hanging from it can be and has been a contributing factor to injuries resulting from these accidents.

Figure 12 illustrates design 2, a one-piece coverall design that was developed to cover the body in areas that were anticipated to be areas of pesticide deposition under actual use conditions. The back torso and shoulder area were kept free of seams, and the armscye seamline was lowered, since the upper back and shoulder area were considered likely high-deposition areas. Seam leakage remains a problem that has not been fully solved for protective clothing now available.



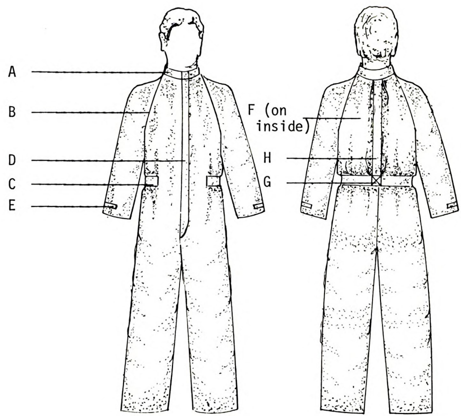
DESIGN FEATURES

A. High secured collar
B. Dropped armscye
C. Velcro half-belt adjustment
D. Concealed zipper
E. Shoulder seam removed, back cut in one with front yoke
F. Velcro-tabbed wrist adjustment
G. Half-belt, secured at center back
H. Action pleat

Figure 12.--One-piece coverall design, Design 2.

Additional design features of note included the concealed zipper extending to the collar and adjustable wrist and neck openings. The lower edge of the sleeve included a velcro tab that can be left completely open for maximal outside air exchange when the grower is not spraying or can be readily closed with a gloved hand during resumption of spraying. The narrow stand-up band collar fits the neck closely for dermal protection, but the zipper can be easily lowered to improve comfort when the grower has stopped applying pesticide. The back action pleat was designed to help facilitate movement and to add looseness to the back torso area for improved thermal comfort. The half-belt, which was secured at the center back, can be adjusted not only to improve fit but also to promote thermal comfort when fully extended. This position could give a loose fit through the waist, increasing the possibility of internal air flow.

The second coverall variation, design 3, was very similar to design 2; however, it featured raglan sleeves rather than the dropped armscye and the back-front-yoke construction of design 2 (see Figure 13). This variation also included a ventilating panel on the inside of the garment as illustrated in Figure 14. The purpose of the panel was to facilitate wicking of perspiration away from the body to the outer fabric layer to promote thermal comfort. The ventilating panel consisted of two trapezoidal-sahped pieces of outer fabric positioned under the back raglan seamlines, sewn to a center 100% cotton mesh panel. The reasoning that prompted the use of the outer fabric was concern for seam leakage in the back torso area.



DESIGN FEATURES

A. High secured collar

B. Raglan sleeve

C. Velcro half-belt adjustment

D. Concealed zipper

E. Velcro-tabbed wrist adjustment

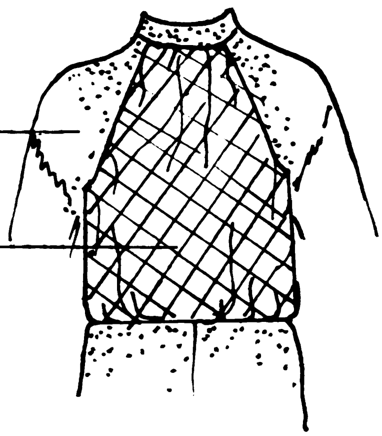
F. Interior ventilating panel

G. Half-belt, secured at center back

H. Action pleat

Figure 13.--One-piece coverall design, Design 3.

INSIDE BACK



DESIGN FEATURES

A. Outer fabric--designed to cover raglan seamline

B. 100% cotton mesh, used for ventilating panel

Figure 14.--Inside ventilating panel for Design 3.

Other design possibilities for improving the convective and evaporative capacity of the garment were considered and finally rejected. Design features such as air vents, zippered air vents, bellows, and the use of multiple outer fabrics (for example, a less protective but more comfortable fabric used in combination with a fabric offering superior resistance to pesticides) were not included in designs 2 and 3 for several reasons. First, the deposition study had not been completed before the thermal-analysis study. Thus, it was not known if and where it would be safe to locate air vents or less protective fabrics. It was felt that following the deposition study, such features could readily be added if the deposition findings supported their inclusion. Second, bellows were rejected because of concern for pesticide deposition and the subsequent problem of pesticide removal.

Fabric. The underlying rationale for the specification of the test fabrics was to permit a comparison between a commonly worn fabric and fabrics with demonstrated improved resistance to pesticide spray penetration. If a fabric could be shown to offer greater dermal protection and a level of thermal comfort similar to what is now worn, then the feasibility of meeting the ultimate objective of the overall project would be enhanced.

Three levels of fabric were specified to include two fabrics that offered superior resistance to pesticide penetration and one fabric that was commonly selected by the grower for its comfort. The literature on occupational exposure to pesticides and information obtained from extension agents were used to specify chambray as the shirt fabric considered representative of what was commonly worn by growers. The effectiveness of $chambray_1$ and five other fabrics as barriers to penetration of pesticide spray had been evaluated in a study conducted before the thermal-analysis study. The results of this study (Orlando et al., 1981) are given in Table 7.

Examination of Table 7 clearly shows that four fabrics offered significantly better resistance to pesticide penetration than $chambray_1$. Two of the superior fabrics, fabrics 1 and 2, as well as $chambray_1$, were selected for further examination in the thermal-analysis study.

Fabric 1 was a disposable polyethylene-coated 100% spun-bonded olefin fabric. The fabric consisted of very fine polyethylene fibers interconnected in a network structure that was self-bonded under heat and pressure. The physical properties of fabric 1 are

mostly unaffected by organic and inorganic chemicals, including acids, bases, and salts. This fabric has been and is now being used for chemical-protective clothing.

Table 7.--Summary of results of Guthion Penetration Study, conducted by Orlando, Branson, Ayers, and Leavitt (1981).

Fabric	Guthion® μg/cm²			
	Inner Gauze Layers μg/cm²	Outer Fabric μg/cm²	Totals	Duncan's Multiple Range[a]
1	.014	3.30	3.31	A
2	.018	3.35	3.37	A
3	.018	3.35	3.37	A
4	.023	3.16	3.18	A
5	.460	2.95	3.41	B
$Chambray_1$	.564	2.83	3.39	C

[a]Values followed by unlike letters are different at .01 level.

Fabric 2 was a thin microporous polymeric film of polytetrafluoroethylene (PTFE). The combination of pore size and pore volume produced about nine billion pores per square inch (Tanner, 1977). The large number of pores and the thinness of the film facilitate the diffusion of perspiration in the vapor phase through the fabric. Yet, the small pore size and the hydrophobic nature of the film retard the penetration of liquids.

The fabric 2 film has been bonded to a variety of fabrics in either a two- or a three-layer construction, thus resulting in a family of laminates. The fabric tested for the penetration and subsequently for the thermal analysis was a three-layer structure consisting of an outer layer of rip-stop nylon and an inner layer of 1.3 oz/yd^2 nylon knit laminated to the film. This fabric has been developed for application in the area of camping and backpacking and has not been used for pesticide protective gear.

Chambray, a 100% cotton woven shirting fabric, was considered representative of what is now often worn by the grower. Table 7 provided data indicating that this fabric was not as effective as fabrics 1 and 2 in preventing pesticide penetration. The description of the three levels of both independent variables is summarized in Table 8.

Fabrics 1, 2, and chambray$_1$ were procured as yard goods. Designs 2 and 3 (both coverall designs) were constructed in these three fabrics. Design 1 (the two-piece design) test garments were obtained by purchasing four pairs of prewashed denim jeans (size 36 x 32) and two 100% cotton chambray$_2$ shirts (size 15½). Shirts were also constructed in fabrics 1 and 2 to resemble the purchased shirts. Thus, two chambray variations were used. Data for both chambray fabrics have been combined and are referred to as fabric 3 throughout the remainder of this work.

Table 9 summarizes the physical characteristics of the test fabrics. The physical characteristics of both chambray fabrics were very similar. Unfortunately, due to limitations of the laboratory, information on moisture regain was not obtained for the test fabrics. Air permeability was determined at a pressure of 0.5 inches of water with a Gurley Tester. The considerable difference in the rate of air flow through the various fabrics should be noted. This test

Table 8.--Summary of the independent variables, fabric and design.

Independent Variable	Level	Description
Fabric	Fabric 1	Disposable polyethylene-coated 100% spun-bonded olefin fabric; shown to offer excellent resistance to pesticide spray
	Fabric 2	Three-layer laminate structure consisting of an outer rip-stop nylon layer, a thin microporous polymeric film of polytetrafluoroethylene, and an inner layer of nylon tricot; shown to offer excellent resistance to pesticide spray
	Fabric 3	100% cotton woven chambray shirting fabric; representative of commonly worn work shirt fabric; shown to be less effective as a barrier to pesticide spray than fabrics 1 and 2
Design	Design 1	Two-piece design, consisting of denim jeans and a traditional-style shirt; only the shirt fabric was varied in the test fabrics to provide comfort data on a partial protective covering
	Design 2	Coverall with dropped armscye, front yoke cut-in-one with back torso, high collar, back action pleat, and adjustable velcro closures at the waist and lower arms
	Design 3	Coverall with raglan sleeve, ventilating 100% cotton mesh panel on back inside torso, high collar, back action pleat, and adjustable velcro closures at the waist and lower arms

method is suggested as an indicator of the "breathability" of a fabric. Thickness was determined with a Custom Scientific Instrument with pressure equal to 8.654 g/cm^2 for denim and 4.385 g/cm^2 for the remaining fabrics.

Table 9.--Physical characteristics of test fabrics.

Test Fabrics	Fabric Weight[a] (oz/yd^2)	Fabric Thickness[b] (Inches)	Thread Count[a] (Warp, Filling)	Air Permeability[c] (ft^3/min/ft^2)
Fabric 1	2.52	.011	NA	0.0
Fabric 2	2.96	.015	136,114[d]	0.0
Fabric 3				
$Cham_1$	4.95	.017	74,54	173.83
$Cham_2$	3.65	.019	70,47	213.33
Denim	14.76	.044	65,47	4.33

[a]Testing done according to the ASTM D1910-64 method.

[b]Testing done according to the ASTM D1777-64 method.

[c]Testing done according to the ASTM D737-75 method.

[d]Surface fabric only.

Because the outer garment was an independent variable in the study, it was important to insure that all subjects wore identical undergarments. Therefore, fifteen sets of white 70/30 cotton/polyester blend undershirts (size medium) and briefs (size 36) were purchased for the study. White cotton crewsocks, available through the Institute for Environmental Research, were also provided for each test subject.

All test garments were pre-washed and hung to dry before conducting the study. This was done since washing softens fabric 2 and therefore might influence the thermal comfort perceived by the subjects who would wear this fabric. Order in which garments were to be tested was by random selection.

Dependent Measures

The dependent variables which were measured included subjects' rectal temperature, weighted mean skin temperature, percent of sweat that evaporated, and the affective measures of thermal sensation and thermal comfort.

Weighted mean skin temperature was measured with skin thermistors located as shown in Figure 15, and computed using formula (1), as given in Rohles, Milliken and Krstic (1979, p. 12):

$$T_{wmsk} = 0.50\ t_{skc} + 0.36\ t_{skl} + 0.14\ t_{ska} \qquad (1)$$

where:

T_{wmsk} = weighted mean skin temperature

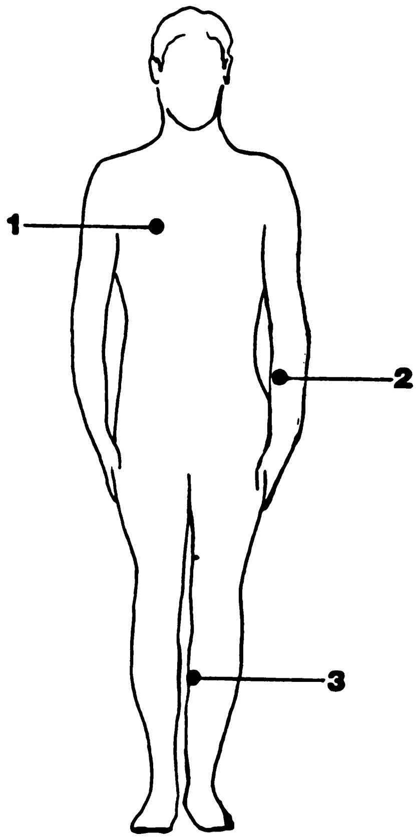
t_{skc} = skin temperature measured at the chest

t_{skl} = skin temperature measured at the lower leg

t_{ska} = skin temperature measured at the lower arm

The thermal sensation response was assessed by the 9-point thermal sensation scale (see Figure 16) developed by Rohles et al. (1979).

The thermal comfort rating was the summed value of ratings that subjects assigned to each of six pairs of polar adjectives on the thermal comfort ballot illustrated in Figure 17. This comfort ballot was developed by Rohles et al. (1979).



Location

1. Right pectoral region of the chest
2. Radial surface of left arm (or right arm if subject was left-handed)
3. Fibular surface of the left leg

Figure 15.--Location of three skin temperature thermistors.

It was hypothesized that the fabric and/or design which facilitated evaporation of sweat would improve the subjects' perceived thermal comfort and the accompanying physiological responses. The assessment of sweat production and evaporation in previous studies has been determined by weight change (Fourt & Hollies, 1970). To estimate total sweat production, ordinarily the weight of the subject

Name ______________________________ Test No. ________

Vote No. ________

comfortable	__:__:__:__:__:__:__:__:__	uncomfortable
bad temperature	__:__:__:__:__:__:__:__:__	good temperature
pleasant	__:__:__:__:__:__:__:__:__	unpleasant
good ventilation	__:__:__:__:__:__:__:__:__	poor ventilation
unacceptable	__:__:__:__:__:__:__:__:__	acceptable
uncomfortable temperature	__:__:__:__:__:__:__:__:__	uncomfortable temperature
satisfied	__:__:__:__:__:__:__:__:__	dissatisfied

Figure 16.--Thermal comfort ballot.

Vote No. _____ Test No. _____

Name & No. ______________________________

Circle the number beside the adjective that describes how you feel.

9	Very hot
8	Hot
7	Warm
6	Slightly warm
5	Neutral
4	Slightly cool
3	Cool
2	Cold
1	Very cold

Figure 17.--Thermal sensation ballot.

without clothing is taken before and after the test. If no water has been consumed, then the difference in weights gives the total sweat secretion. If the subjects were allowed to drink, then the quantity would need to be added to the original pre-test weight. However, while total sweat can be measured by weight change, the researcher was primarily interested in the percentage sweat evaporated.

In order to investigate this issue, three sets of pre- and post-test weights were taken. The dressed subjects were weighed immediately before and after the two-hour chamber test. Therefore, post-test subject weight change reflected a change in the subject's body weight as well as a change in the weight of the clothing. This departure from the usual procedure was considered acceptable because actual body weight was not the variable of interest. Concern was focused instead on weight change, and this could be obtained.

The second set of pre- and post-test weights was taken of the test clothing in sealed plastic bags. Again, the emphasis was placed on the weight difference. Therefore, the additional weight of the bag (same coded bag was used for before and after weights) was not seen as objectionable. Thermos jugs of ice water constituted the third set of weights obtained.

No attempt was made to account for sweat run-off that occurred during the test or during the undressing process. While sweat run-off was a very minor problem during the test, the severity of it during the undressing process is unknown. Second, sweat that adhered to the body after the test clothing was removed was not accounted for. Third, sweat picked up by the subject's towel during the experiment was not determined. These limitations contributed to measurement error for this variable.

In order to compute total sweat secretion, all three sets of weights were used in the following manner. Taking the difference in weight of the thermos yielded how much water was consumed and therefore the weight gain of the subject had no evaporation occurred. Consider the following hypothetical situation. Assume an individual is within a sealed micro-environment and that the person drank two pounds of water. This two pounds of water should therefore be contained within the person, his clothing, or the sealed environment. If the clothed person gained one pound, then the other pound must be in the environment (sweat evaporated). Determining the change in clothing weight, for example 1/3 lb, yields the amount in the clothing (sweat adsorbed and/or absorbed in the clothing). Thus, a total of 1-1/3 lbs of sweat has been produced, 1 lb of which evaporated. This example illustrates the manner in which the three sets of weights were used to estimate percentage evaporated sweat. This quantity included respiratory evaporation and insensible evaporation. These could have been estimated from the literature and subtracted. However, the amount would have been constant for all subjects and therefore would not have altered the results relative to fabric/design comparisons. With measurement error already a problem with these data, it was considered appropriate to refrain from using approximations from the literature. The findings instead could be examined relative to the levels of independent variables.

The amount of evaporated sweat was calculated by the following equation:

$$S_e = (W_1 - W_2) - (S_2 - S_1) \quad (2)$$

where: W_1 = pre-test thermos weight

W_2 = post-test thermos weight

S_1 = pre-test clothed subject weight

S_2 = post-test clothed subject weight

S_e = total sweat evaporated

The amount of sweat not evaporated could be determined by the change in weight of the test clothing, as shown in equation (3).

$$S_a = C_2 - C_1 \quad (3)$$

where: C_1 = pre-test clothing weight

C_2 = post-test clothing weight

S_a = sweat absorbed or adsorbed by the clothing

The total amount of sweat secreted was computed as given in equation (4).

$$S_s = S_a + S_e \quad (4)$$

Percentage sweat evaporated was then calculated.

Experimental Design

A 3 x 3 complete factorial experimental design with six replications was used. The research design for this study is illustrated in Figure 18, where F = fabric, D = design, and C = controlled climatological conditions.

		C				
	F_1	S_1	.	.	.	. S_6
D_1	F_2	S_7	.	.	.	. S_{12}
	F_3	S_{13}	.	.	.	. S_{18}
	F_1	S_{19}	.	.	.	. S_{24}
D_2	F_2	S_{25}	.	.	.	. S_{30}
	F_3	S_{31}	.	.	.	. S_{36}
	F_1	S_{37}	.	.	.	. S_{42}
D_3	F_2	S_{43}	.	.	.	. S_{48}
	F_3	S_{49}	.	.	.	. S_{54}

Figure 18.--Research design of thermal-analysis study.

Twelve test sessions of two hour duration were held in a six-day period in the spring of 1980. The number of test subjects in the test sessions varied from two to six subjects, as shown in Table 10. The variability was due to either an insufficient number of subjects that had successfully passed the physical examination or to failure of test subjects to report for their assigned test session. To alleviate the second problem, one alternate test subject was scheduled for sessions nine through twelve.

Sample

Fifty-four male students, between the ages of 18 and 25, attending Kansas State University, served as test subjects. The students were recruited through newspaper advertisements and were

Table 10.--Number of test subjects per test session.

Session	Number of Subjects
1	3
2	3
3	5
4	2
5	6
6	6
7	4
8	2
9	6
10	6
11	6
12	5

required to pass a physical examination before being accepted as a test subject. Each qualified test subject was expected to complete one testing session and was paid $20 for his participation. Test subjects were randomly assigned to wear one test garment for the entire test session.

Facilities and Equipment

The study was conducted in a Sherer Environmental chamber located in the Institute for Environmental Research at Kansas State University. The chamber was a 12 ft x 24 ft (2.5 m x 7.3 m) room with an 8 ft (2.4 m) ceiling. The floor was carpeted, the walls were painted white, and white acoustical tiles covered the ceiling. The room was furnished with six vinyl-cushioned straight-backed chairs and six sets of two nine-inch wooden steps that were positioned next to the chairs (see Figure 19). The test subjects used these chairs and steps in the experiment. In the center of the room, a rectangular table held the junction boxes to which the skin thermistors and the probes were connected. The dry-bulb temperature and the relative humidity within the chamber were maintained at 85±2°F and 60% relative humidity throughout each testing session. One small table, which was used to hold necessary supplies including magazines, newspapers, metronome, clock radio, ballots, pencils, paper, extra surgical tape, and the test protocol, was positioned against one wall. One straight-backed chair, for the researcher, was placed next to the table, facing the test subjects. Fluorescent lighting was held constant throughout the experiment.

The pre-conditioning room was located outside but immediately adjacent to the environmental chamber. This area was carpeted, the walls were panelled, and six wooden tablet-arm chairs were arranged in a semi-circular fashion along three walls. The tablet-arm chairs held each subject's equipment for the test, including three Yellow Spring Instrument Company thermistors for measuring skin temperature, one Yellow Spring Instrument Probe 701 for measuring rectal temperature, a canvas harness and a digital heart-rate device for monitoring heart rate, and a clipboard containing data-acquisition forms. A large desk and chair, for the researcher, were placed on the fourth wall. A Digital Automatic Temperature Acquisition System was used

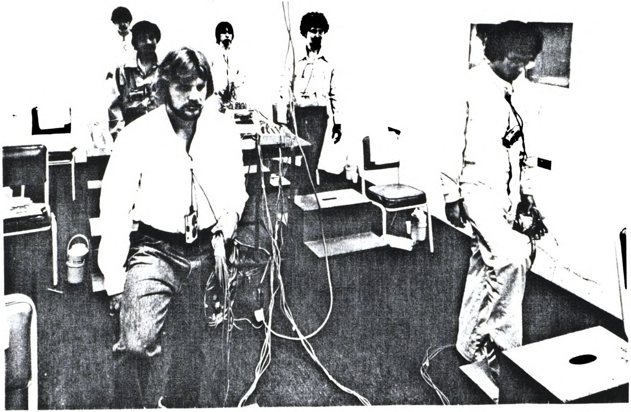


Figure 19.--Test subjects and equipment in the Sheror Environmental Chamber.

for measuring and recording every five minutes skin and rectal temperatures of the test subjects as well as the air temperature of the test chamber. The system was housed in a control room outside the chamber. A Holmes clinical balance scale was housed in a room adjacent to the pre-conditioning room.

Procedure for Obtaining Subjects

Two weeks prior to the scheduled testing, announcements recruiting male volunteers for the study were made in the Kansas State University school newspaper. Those interested in participating were directed to the Institute for Environmental Research to register for the study. At registration, volunteers were asked to read an orientation statement describing the general purpose and protocol of the study, risks that might be incurred, and the subjects' obligations, rights, and remuneration. (See Appendix A1.) Having read this statement, if they were still interested in participating, they were asked to complete a Medical History Questionnaire (see Appendix A2) and to schedule their physical examination.

The physical examination (see Appendix A2, p. 6), which was conducted by a registered nurse, was patterned after the class II Flight Physical Examination as specified in the Army Regulation AR40-501C29, dated January 29, 1974. Additional measures included: electrocardiogram, exercise habits, and cardiovascular fitness as estimated by the Astrand Method using a Schwinn Bicycle Ergometer. Their responses to the Medical History Questionnaire and the results of the physical examination were reviewed by a physician. Those judged to be physically qualified were subsequently scheduled for the experiment. They were given instructions not to take drugs, medication, or alcohol twelve hours before the test and not to eat or drink anything except water after 11 p.m. the evening before their scheduled test. (See Appendix A3.) The instructions also included information on clothing to be worn, the standard breakfast provided, and a reminder of the importance of reporting for the scheduled test. A specific breakfast instruction sheet (see Appendix A4) was also given to each test subject at this time.

Test Protocol

Pilot Study

A pilot study, consisting of one complete test session, was conducted to determine and correct any problems in the planned testing procedure. The environmental chamber was maintained at 73°±2°F and 50% relative humidity. Six male subjects participated in the pilot study. No major changes were made as a result of the pilot study. However, potential problems such as walking up and down stairs with the rectal probe and skin thermistors were recognized. Precautionary actions were decided upon to minimize these problems.

Pre-test Protocol

Test subjects were called the evening before their scheduled test to encourage adherence to the instructions and to serve as a reminder of the scheduled test date. On the morning of the scheduled test, subjects reported to the Kansas State University Student Union building at their assigned time (either 7:00 a.m. or 9:30 a.m.). A

male research assistant (Kansas State graduate student) met each group of subjects at the Union. This procedure assured that subjects received and ate the high-protein 600-calorie breakfast as directed. The standard breakfast consisted of: 120 ml (4 oz) of orange juice, 120 ml (4 oz) of skim milk, scrambled eggs, a 50 g broiled lean beef patty, and one slice of dry toast. Students were instructed to eat all of this, plus all of the water they desired. No substitutions were permitted.

During this time, the researcher and an assistant (Kansas State undergraduate student) were completing final preparations at the Institute for Environmental Research. The test garment, one pair of socks, and one set of underwear which had been placed in coded plastic bags, weighed, and the data recorded by the researcher earlier that morning, were placed on the rung beneath each tablet-arm chair in the pre-conditioning room. Coded water jugs, which had been filled with ice water, weighed, and the data recorded, were positioned next to each chair. (See Appendix B1 for the data sheet used to record these weights.) The rectal probe, three skin thermistors, and the harness for the heart-monitoring device were hung on the back of each chair. A pencil and the data-acquisition forms (Appendices B1, B2, B3, B4, B5), which were secured to a clipboard, were placed on the surface of the tablet-arm chair. Examination of the environmental chamber was also performed to ensure that all chairs and steps were correctly positioned, that necessary supplies were available, and that the cords required for measuring skin and rectal temperature were properly fastened and that coding was legible.

Orientation

Following breakfast, the test subjects and the male research assistant reported to the pre-conditioning room for the orientation. Test subjects were assigned a tablet-arm chair, which contained all of the supplies previously prepared by the researcher. At this time the researcher introduced herself and explained that she was conducting a study to determine how man responds to his thermal environment. The importance of following the directions they would be given was stressed, and appreciation for their participation was expressed. Their attention was then directed to the clipboard with materials placed before them on their chairs. They were asked to read and if still willing to participate, sign an Agreement of Release Form (see Appendix B2). Other materials that identified the test subject, their rectal and skin thermistors numbers (see Appendix B3), and a short health questionnaire (see Appendix B4) were subsequently read and completed by the subjects, as directed by the researcher. Each set of forms, upon completion, was picked up by the investigator and reviewed. The researcher read the following orientation statement to the subjects concerning the test in which they were to participate. Throughout the reading of the statement, the investigator paused at appropriate places to hold up equipment to familiarize the subjects with the various monitoring devices.

> The purpose of the study in which you are participating is to determine how man, wearing a specific clothing ensemble, responds to his thermal environment. You will be wearing three skin temperature thermistors to measure your skin temperature. Your rectal temperature, which will be monitored throughout the study, will not only provide valuable data for the research project but will also allow

us to monitor your body's core temperature to ensure your safety. You will monitor your heart beat periodically throughout the test.

The test will proceed in the following manner: in about five minutes you will be given a coded plastic bag containing an outer garment, socks and underwear. You will take your plastic bag, the rectal probe and the heart monitoring harness with you to the men's room. There, you will change your clothing, insert the rectal probe about 6 inches and put on the harness in this manner (demonstration stressing the need for the harness to fit snugly).

Once you have completed dressing, you will return to the pre-test room, so that the investigator or the assistants can put on the skin thermistors. After you have been weighed, you will be ready to begin the test.

The test will be a two-hour test. While you are there, you will be asked to walk up and down the steps provided to a specified cadence. Although this activity may seem contrived, it is essential that each of you walk as directed to ensure that you are all doing an equal amount of work. You will also have time to sit and rest. You may feel free to read or talk if you desire. However, you may not discuss the experiment, the garment you will be given or any other aspect of the test while you are dressing, during the test itself nor for two weeks after the test.

While you will be seated, you will be asked to complete two ballots. You have examples of these ballots on your clipboard.

[Directions for completing the ballots were given. In order to assure that the subjects understood the directives, the test subjects were asked to immediately complete two examples. The investigator picked up the ballots (Figures 16 and 17) and reviewed them to minimize problems of misunderstanding of the scales.]

You will be asked to respond to one of these ballots immediately after entering the test chamber. I shall collect this ballot, then you will respond to the second ballot which will be collected immediately. This pattern of rest and ballot completion, followed by walking will be continued throughout the two hour test. Ice water has been provided for you. You may drink as much as you choose, but you must exercise care not to spill any.

You may leave the experiment at any time. Any change that suggests danger to your physical well-being will cause you to be removed from the test. A registered nurse will monitor your vital signs.

At the end of two hours, you will leave the test chamber, your weight will be taken, and monitoring devices will be removed. You will then return to the men's room, change your clothing, carefully putting all of the test clothing into the coded plastic bag that it originally came in, and return to this room. At that time, you will be asked to complete several summary questions. You will then be paid twenty dollars for your participation.

Are there any questions?

Dressing of Test Subjects

Upon completion of the orientation, the test subjects with their equipment and clothing, and the male graduate student proceeded to the men's room where the subjects changed their clothing. The presence of the male graduate student minimized potential problems associated with insertion of the rectal probe, handling the coded plastic bags, coded clothing, and the harnesses for the heart-monitoring devices.

Skin Temperature Thermistors

Having completed the dressing process, the test subjects returned to the pre-conditioning room, where the investigator and her two assistants taped skin thermistors to the subjects' skin. The thermistors were attached with micropore surgical tape to the right pectoral region of the chest (see Figure 20), the radial surface of the left arm (or the radial surface of the right arm if the subject was left-handed), and to the fibular surface of the left leg. The heart-monitoring device was secured to the harness. Care was taken that each person was dressed uniformly with sleeves, collars, closures, Velcro tabs, and shirts all positioned and secured similarly. The dressed subjects were weighed, and the weight was entered on the data sheet. (See Appendix B1.)

Figure 20.--Placement of skin thermistor on the right pectoral region of the chest.

Test Chamber

The subjects, carrying their clipboards and ice water, entered the test chamber, seated themselves on an assigned chair, and waited to have their coded chest, arm, leg, and rectal sensors plugged into the appropriately coded extension cords and numbered positions in the junction box. The table in the center of the room held all of the junction boxes. As soon as all of the subjects' sensors were attached to the junction boxes, the test began.

In order to simulate the amount of work performed in applying pesticides by the air-blast spray method, an activity pattern was established such that the metabolic cost of the activity was about three mets. This moderate level of activity corresponded to the estimated metabolic cost of driving a tractor. A pattern consisting of a nine-minute rest period followed by six minutes of walking up and down the steps to a specified cadence (maintained with a metronome) was established.

During the first eight rest periods, the subjects recorded their heart rate (as indicated on their digital heart-rate device) on their thermal sensation ballot (Figure 21) which was then completed and collected by the investigator. Immediately thereafter, they recorded their thermal comfort responses, which were collected. During the first rest period after ballots were collected, the investigator demonstrated the manner in which the subjects were to walk up and down the steps to the cadence of the metronome. This was done to ensure uniformity among the subjects and also to demonstrate how to hold the numerous lengthy cords while walking. Having

Figure 21.--Subject recording heart rate on the thermal sensation ballot.

done this, the investigator seated herself in the chair facing the subjects for the duration of the test. She requested the subjects' thermal sensation and thermal comfort responses again every 15 minutes for a total of eight times. Skin and rectal temperature readouts and chamber temperature were being taken automatically every five minutes and checked by the technician. If any thermistor was malfunctioning the technician informed the researcher, and the deficiency (such as a loose connection or an improperly inserted rectal probe) was corrected.

The rectal temperature readings were also carefully monitored to ensure the safety of the test subjects. An individual whose rectal temperature increased 2°F was removed from the test. In such instances where the data indicated the possibility that a subject might have to be removed, the registered nurse remained in the test chamber as a precaution. Typically, however, one of the two registered nurses in attendance would periodically check on the subjects, rather than stay throughout the test.

Procedure Following the Chamber Test

At the end of the two-hour exposure, the subjects' sensors were disconnected, their post-test weight was taken by the investigator on the Holmes clinical scale in an adjacent room, and recorded on the appropriate data sheet. (See Appendix B1.) Skin-temperature thermistors and the heart-monitoring devices were removed by the investigator and her assistants. The male assistant took the subjects to the men's room, where they changed their

clothing, depositing all of the test clothing in their original coded bag and the rectal probe in a container provided. During this time, the investigator weighed the subjects' coded water jugs and entered the post-weight on the appropriate data sheet. (See Appendix B1.)

When the subjects returned to the pre-conditioning room, they were asked to answer the two summary questions below. They were instructed to choose only one answer. (See Appendix B5 for the summary data sheet.)

> I found the clothing that I wore for the study to be . . .
>
> _____ cooler _____ warmer _____ about the same
>
> . . . as I expected.
>
> The test you have just completed was conducted to measure thermal comfort of protective garments at 85°F. Knowing that this clothing would provide protection against harmful chemicals in your work, indicate your willingness to wear this garment:
>
> _____ I would be willing to wear it under these temperature conditions.
> _____ I would wear it if the temperature was less than 85°F.
> _____ I would wear it only if required to do so.
> _____ I would not wear it.

After completing the summary questions, the subjects were paid $20.00 for their participation and were asked to sign a receipt form (see Appendix B7) acknowledging that they had been paid. The subjects were given a post-test information sheet (see Appendix B6) which outlined possible symptoms of heat stress, and they were dismissed. The coded plastic bags, each containing all of the clothing worn by a subject for the test, were then weighed and the post-weight was recorded on the appropriate data sheet. (See Appendix B1.) The soiled clothing was stored until laundered later

the same afternoon. The entire test procedure was repeated with two tests being completed per day.

Laundry Procedures

A Kansas State University undergraduate student in the Department of Textiles and Clothing was hired to assist in the daily laundering of the test clothing. The laundry was done using the Textile and Clothing Department's research laboratory located in Justin Hall. The laundry was transported in large plastic bags from the Institute for Environmental Research to Justin Hall by the researcher and her assistant at the end of each test day. Because the fabrics varied greatly relative to fiber content, fabric structure, color, and recommended laundering procedures, it was not possible to follow the same procedure for all of the clothing. Instead, the clothing was separated into three groups with a uniform procedure established for each group.

The equipment used to conduct the laundering included a Kenmore heavy-duty washing machine and electric dryer, both model 600. A United Systems Corporation (CTID 312422) digital Thermocouple Thermometer was used to measure the temperature of the wash and rinse water for each washing procedure. Ivory Snow was used as the detergent since it was recommended by the manufacturer of one test fabric in order to maintain the fabric's breathability. Table 11 lists the specification of the laundry variables for each of the clothing groups. After the cleaning procedures were completed, all of the laundry was folded and transported back to the Institute. The garments in groups two and three were hung, and those in group one were placed as folded in a closet provided. Socks were commercially laundered.

Table 11.--Specification of laundry variables for three clothing groups.

Laundry Variables	Clothing Groups		
	Group 1: Undergarments	Group 2: Fabrics 1 & 2	Group 3: Fabric 3 & Jeans
Wash water temperature	160.2°F	150.4°F	150.4°F
Rinse water temperature	150.4°F	83.4°F	83.4°F
Wash cycle setting	Normal	Knit, Delicate	Normal
Length of time of wash cycle	10 min	6 min	10 min
Amount of detergent	250 ml	250 ml	250 ml
Dryer temperature setting	High	Low	Almost High
Length of time of drying cycle	50 min	20 min	50 min
Dryer cycle setting	Normal	Delicate	Normal

Data Treatment

The statistical treatment of the data was accomplished in two integral phases. The first phase focused on a graphical representation of each of the dependent measures over time by fabric and design. The second phase was concerned with statistical-significance testing of the various hypotheses (cited in Chapter I), which were developed to meet the objectives of the study.

Phase 1

In order to graph mean rectal temperature; weighted mean skin temperature; mean skin temperature for the leg, arm, and chest; mean thermal comfort responses and mean thermal snesation responses by fabric and design over time, a number of preliminary steps were required. First, the data had to be examined for a common truncation point. In the event that a subject had to be removed before the test was completed, an incomplete data set would result for that subject. It was decided to graph the dependent measures by fabric and design to the last time period for which complete data were available on all subjects.

Second, all temperature data for each subject were examined for deviations from an expected temperature range. It was anticipated that skin temperature would vary between 90°F and 98°F and that rectal temperature would be between 97°F and 101°F. This preliminary scrutiny of the temperature data was essential to distinguish out-of-expected-range data points due to data-recording irregularities from those due to individual differences of subjects. Initially, the computer software package Mini-Tab was used to plot each set of temperature data over time for each level of fabric and design. (See Appendix C1.) Because the researcher desired greater precision in examining these data, a computer listing of all temperature data per subject was examined. (See Appendix C2.) In this way, any suspected deviation could be evaluated relative to the rest of a subject's temperature data.

Out-of-range data points determined to be caused by recording irregularities comprised about 1% of approximately 5,400 temperature data points. Missing data were therefore not a serious problem in this study. Such data resulted ordinarily from a skin thermistor becoming detached from the surface of the skin due to perspiration. There were also two instances in which rectal probes gave out-of-range values due to improper insertion. Once a bad value had been determined, cell means were calculated from the remaining clean values and substituted for the appropriate bad values.

Following the determination of the common truncation point and the examination of the temperature data to ensure clean data, the computer software system, Statistical Plotting On-Line Command System (SPOCS), was used to graphically display the data over time. This system, which was designed for the Control Data Corporation (CDC) 6500 mainframe at Michigan State University, was available through the Department of Entomology.

The truncation point determined for the temperature data was used also for graphing the thermal comfort and thermal sensation responses by fabric and design over time. There were no missing data for these two perceptual measures to the truncation point. However, the following preliminary steps were necessary for the thermal comfort measure before graphing could be initiated: first, coding the data and second, computing the thermal comfort response from the semantic differential scale.

The thermal comfort ballot, shown in Figure 16, was coded by assigning a scale of one to nine for each of the available spaces from right to left on the ballot. Thus, a value between one and nine would constitute a subject's response to one pair of polar adjectives. The responses for each of the seven pairs were coded as indicated above and summed for a total thermal comfort vote of between 7 and 63. Lower scores indicated feelings of comfort and satisfaction with the thermal environment.

Thermal comfort and thermal sensation responses were subsequently graphed by fabric and design over time.

Phase 2

The second phase of the data analyses focused primarily on the statistical-significance testing of the hypotheses cited in Chapter I. The present study was planned to examine the effects of two independent variables, fabric and design, each with three levels, on five major dependent variables. Data on two physiological measures, weighted mean skin temperature and rectal temperature, and two perceptual measures, thermal comfort and thermal sensation, were gathered over time. The fifth major dependent variable, percentage of sweat production that evaporated, was obtained as a single response to the environmental conditions.

Recognizing that the assessment of man's thermal response should include both physiological and perceptual measures as related aspects of a single response, multivariate statistical analysis was used to analyze the dependent measures as a whole. The advantage of multivariate models was that with conceptually related measures that are intercorrelated and have different variances, the statistical analysis was not invalidated. Rectal temperature, weighted mean skin temperature, and the perception of thermal comfort were used as the set of dependent measures. All of the analyses were executed using the MULTIVARIANCE computer program developed by Finn (1974).

Since the three dependent variables were measured over time, it was necessary to specify a distinct point in time for which the data would be analyzed. The truncation point for the temperature data, which had been set at time equal to 90 minutes for Phase 1 of the analyses, was chosen as the appropriate point in time. The responses to the sixth thermal comfort ballot (Figure 17) were chosen for analyses with the temperature responses since the sixth ballot was administered approximately at time equal to 90 minutes.

The remaining two major dependent measures, percentage of evaporated sweat and thermal sensation, were each analyzed separately. Volume of total sweat produced by subjects for fabric and design was computed from pre- and post-test weights of subjects and the quantity of water that they consumed. The change in weight (pre- and post-test) of all of the subjects' clothing was calculated to give an indication of the volume of sweat adsorbed or absorbed by the test clothing. The volume of sweat evaporated was taken as the difference between the volume produced and the volume absorbed or adsorbed. Percentage of evaporated sweat was computed so that a comparison and analyses could be completed by fabric and design. The presence of measurement error was a concern for this dependent measure. Thus, it was not included in the multivariate analysis. Because thermal sensation votes were clustered at the upper end of the scale, this variable was not included in the set of dependent measures. Instead, thermal sensation responses were analyzed by chi-square analysis for design and fabric.

In addition, information on two other minor variables of interest was sought. The investigator recognized that the test subjects for this study were college students, not growers. It was anticipated that the physiological responses and, to a lesser degree, the perceptual responses of the student test subjects would be somewhat invariant if the experiment were repeated with growers, while maintaining the same environmental conditions. However, student responses to the two summary variables, anticipated comfort and willingness to wear protective clothing, could well differ from responses that growers would give. This was considered particularly so for willingness to wear protective clothing. Response to this variable would likely be influenced by one's perception of the potential danger, working familiarity with chemicals, past physical effects of handling chemicals, and feelings, attitudes, and practices of family members regarding chemicals. Recognizing the lack of generalizability of these data to other populations, this information was sought anticipating comparison of these data with data from a user-satisfaction study planned for the future. Chi-square analyses were used to analyze these two measures by fabric and design.

Summary

The study was designed to evaluate the thermal response of male college students in a hot environment while wearing selected designs and fabrics with known chemical protective characteristics.

Approval was obtained from Michigan State University and Kansas State University Committees on Research Involving Human Subjects to conduct this study.

The experimental design of the study, a 3 x 3 complete factorial, permitted the main effects and the interactions of the independent variables to be investigated. The laboratory study was conducted in an environmental-controlled chamber, located in the Institute for Environmental Research at Kansas State University. All of the environmental variables relative to the human environed unit, the human-constructed $environment_2$, and the human-behavioral environment were maintained as specified. The determination of controlled HCE_2 variables was made in order to simulate typical Michigan summer climatological conditions and to facilitate future research plans.

Five dependent measures were investigated: weighted skin temperature, rectal temperature, sweat production and evaporation, thermal comfort, and thermal sensation response. Anticipated comfort and willingness to wear protective clothing were also explored. Subjects were tested in a two-hour test session in groups of two to six during the spring of 1980.

Subjects were recruited through newspaper advertisements and required to pass a physical examination prior to being accepted as a test subject. Healthy subjects wore one test garment for one test session and were paid $20 for their participation.

The analysis of the data involved first a graphical presentation of the dependent measures by fabric and design over time. The second component of the analyses was concerned with hypotheses testing. Univariate, analysis of variance, chi-square analyses, and multivariate statistical techniques were used to test the hypotheses of interest.

CHAPTER IV

FINDINGS AND DISCUSSION

This study investigated the influence of selected protective garment designs and fabrics on subjects' conscious feelings of thermal comfort and sensation and their accompanying physiological responses in a hot environment. The controlled environmental conditions of 85° ± 2°F, 60% relative humidity were specified to simulate typical summer weather conditions in the fruit-growing sector of southwestern Michigan. The investigation involved testing the thermal response of 54 male subjects who each wore one test garment for one two-hour test session. The findings from the testing of these subjects are reported in this chapter.

Thermal response was evaluated in terms of: thermal comfort ratings, thermal sensation ratings, weighted mean skin temperature (and skin temperatures at the arm, leg, and chest, which were used to compute mean skin temperature), and rectal temperature. In addition, the total volume of sweat secreted by the subjects during the test, the volume of sweat contained in the test clothing, and the volume of evaporated sweat were estimated from pre- and post-test weights. Two summary questions administered to the subjects immediately after their test provided retrospective data on the subjects' anticipated comfort when they were first given the clothing and

their willingness to wear the garment after learning of its protective qualities.

The analyses of the data consisted of two integral components. The thrust of the first phase was directed toward a graphical representation of each of the dependent measures over time by fabric and design. This phase was particularly useful to the investigator from a design perspective. The second phase of the analyses focused on statistical-significance testing of the various hypotheses of interest. Univariate analysis of variance, chi-square analyses, and multivariate statistical techniques were used.

This chapter has been organized into two major sections. The summary plots of the dependent measures are presented in the first section, Phase 1. Results of the inferential statistics are given in the second section, Phase 2.

Phase 1

The graphical representation of the dependent temperature measures by fabric and design have been plotted for the first 90 minutes of the experiment. This truncation point was specified since two subjects had to be removed from the experiment prior to the completion of the test because their rectal temperatures increased 2°F.

The presentation of the findings from Phase 1 has been partitioned into, first, summary plots of the temperature data for fabric followed by a display of the thermal comfort response. Second, the same dependent measures are presented for design. Last, the major insights gained through examination of the summary graphs are discussed.

Fabric

In a heat stress environment, as the human body attempts to maintain a fairly constant deep body temperature, certain physiological responses are activated within a short period of time following sensory stimulation. The test subjects in this experiment were also asked to sustain a moderate level of physical activity corresponding to a metabolic rate of approximately three mets. Figure 7 (shown in Chapter II, p. 48) shows the dual effect of heat and exercise on the human thermoregulatory system.

One of the initial physiological responses is that of vascular dilation. This enlargement of the blood vessels permits an increased blood flow through the skin and ordinarily elevates the skin temperature. Thus, the circulation system plays a critical role in maintaining the body's heat balance during exercise in a hot environment by being a vehicle for conducting heat produced in the tissues to the skin and the respiratory system for dissipation.

The ability of the body to tolerate a wide skin temperature range is evidenced in the following graphs. Thermal comfort has been frequently associated with a mean skin temperature of 91°F to 93°F without sweating. Fanger (1970), however, found that this was true only for sedentary individuals. For higher activities, Fanger's results suggest that comfort is achieved with lower skin temperatures and moderate sweating.

Weighted mean skin temperature. Weighted mean skin temperature was computed as given in equation (1), Chapter III. All of the following skin temperature graphs show a similar alternating pattern over time. This reflects the activity pattern developed for the experiment, which included a nine-minute rest period followed by a six-minute period of walking up and down the steps provided.

Figure 22 presents the mean weighted skin temperature of subjects wearing fabric 3, chambray. Chambray fabric was chosen for investigation because it is frequently chosen by the agricultural worker for its social acceptability, durability, and comfort. Notice that a clear over-all slight downward trend from an initial mean skin temperature of less than 94°F is apparent. This indicates that evaporative and/or convective cooling was taking place during the 90 minutes of exposure to the test conditions.

Close examination of Figure 22 indicates a slight pattern regarding design emerging. The ventsuit design seems to be fairly consistently reporting the highest temperatures, with jeans (two-piece design) mostly indicating the lowest temperatures. However, the pattern is not clearcut, particularly from time equal to 40 minutes on.

Figure 23 presents very similar data for fabric 2, although the initial temperatures are slightly higher than temperatures of subjects wearing fabric 3. Both fabrics indicate low temperatures approximating 92°F.

Design for fabric 2 is not showing a clear pattern, although the coverall seems to be frequently reporting the lowest temperatures.

The two-piece design of jeans and shirt of fabric 2 is above the coverall for most of the temperature readings.

The data given in Figure 24 for fabric 1 are quite different from the temperature data for fabrics 2 and 3. Notice that the temperature of the subjects wearing farbic 1 is initially greater than the initial temperatures reported for subjects wearing the other two test fabrics. The over-all trend is also clearly upward, and this appears true for all three designs. The subjects wearing the ventsuit design seem consistently to have the highest mean skin temperatures, and those wearing the coverall usually have the lowest temperatures.

Comparison of the three graphs (Figures 22, 23, and 24) clearly indicates that subjects wearing fabric 1, regardless of the design variation, experienced higher mean weighted skin temperatures than the rest of the test subjects, up to a 3°F difference. Weighted mean skin temperature, being a weighted computed value, can mask individual body site temperature data. Therefore, summary plots of skin temperature for the arm, leg, and chest are presented to explore further differences in skin temperature as a function of fabric.

Lower arm mean skin temperature. Figures 25, 26, and 27 present the mean skin temperatures at the lower arm for the three test fabrics. The initial arm skin temperatures of all of the subjects were between 94°F and 95°F, regardless of fabric or design. The pattern of alternation which characterized the graphs of weighted mean skin temperature is similarly present here.

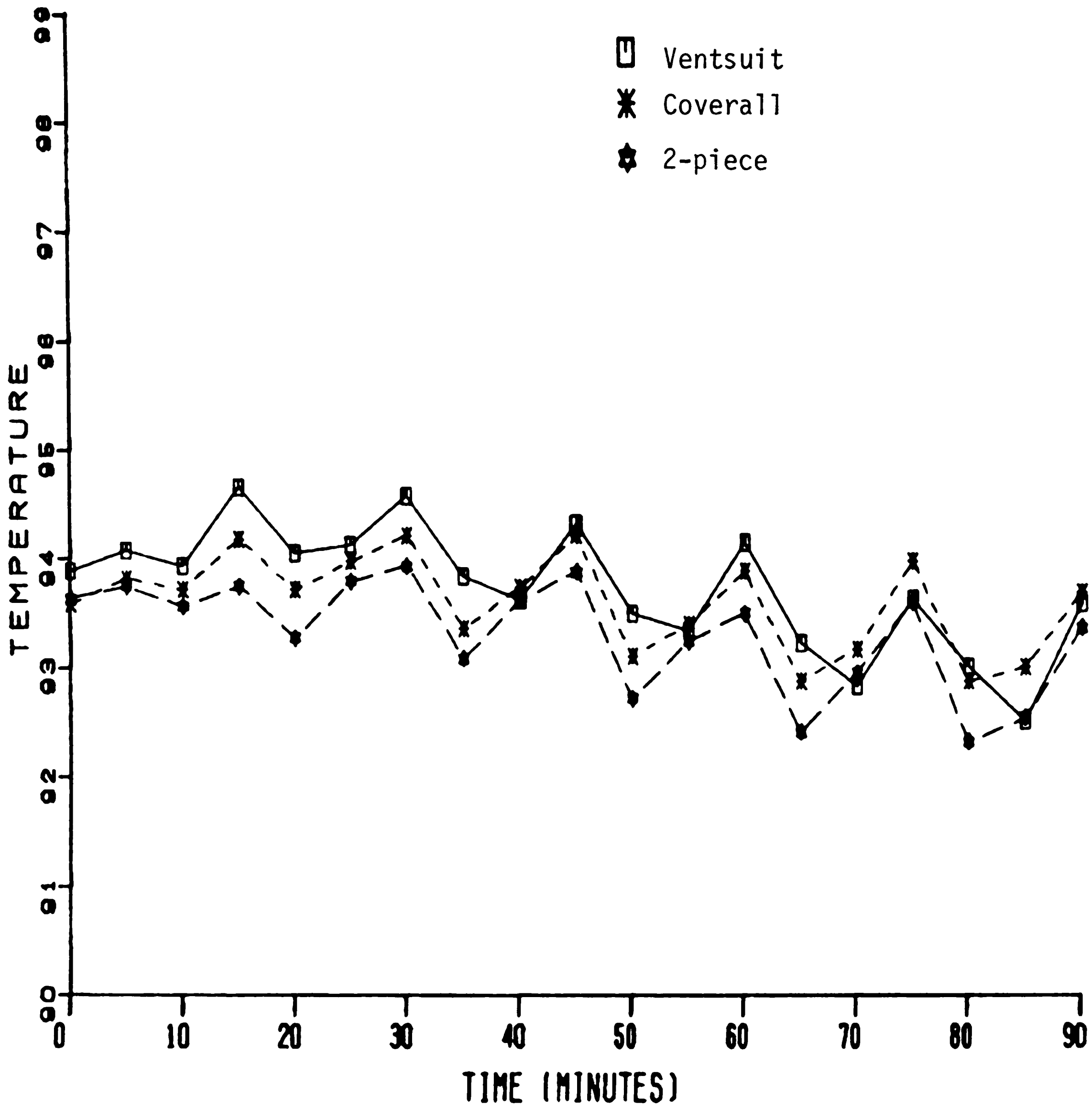


Figure 22.--Weighted mean skin temperature for fabric 3.

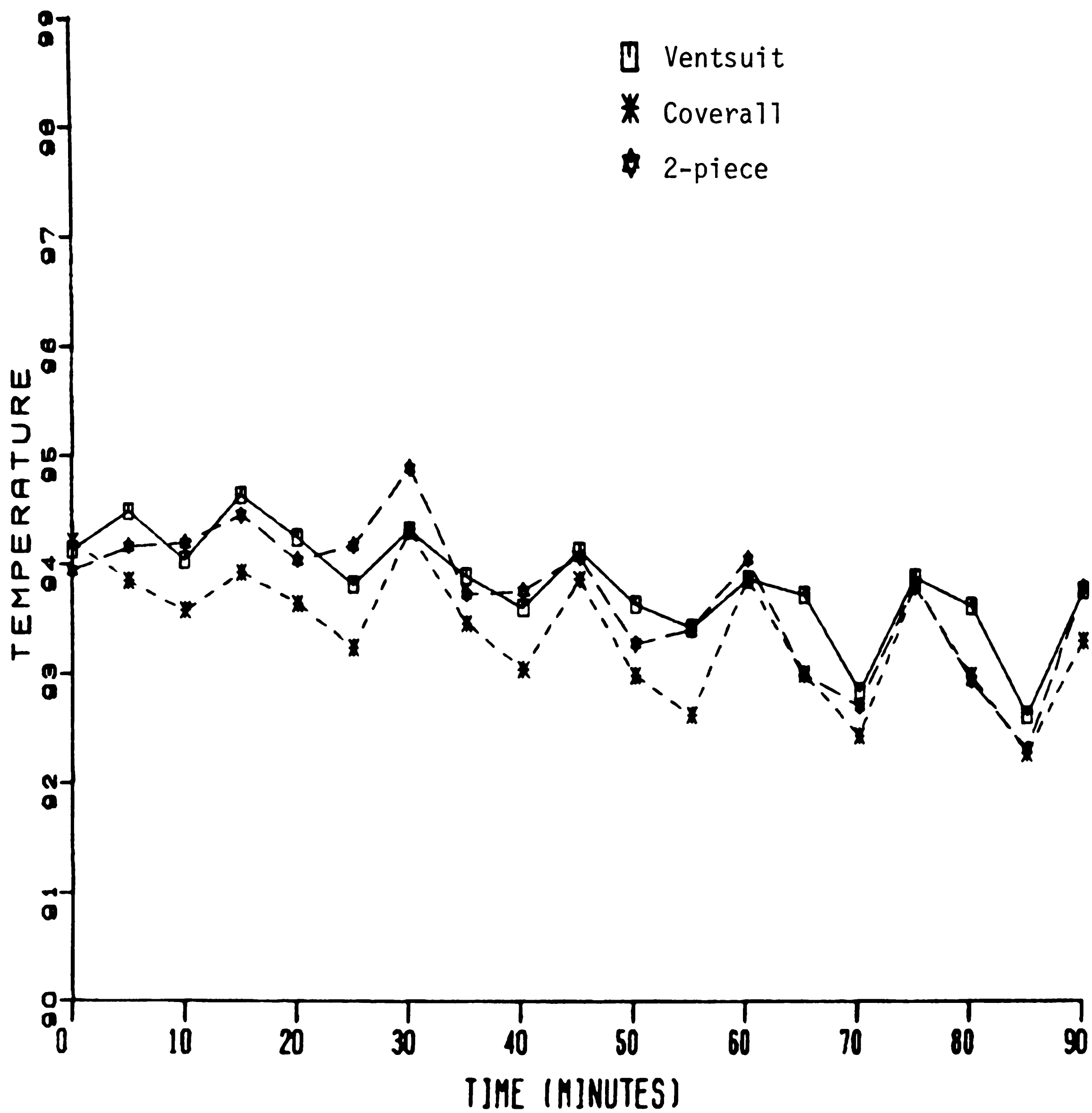


Figure 23.--Weighted mean skin temperature for fabric 2.

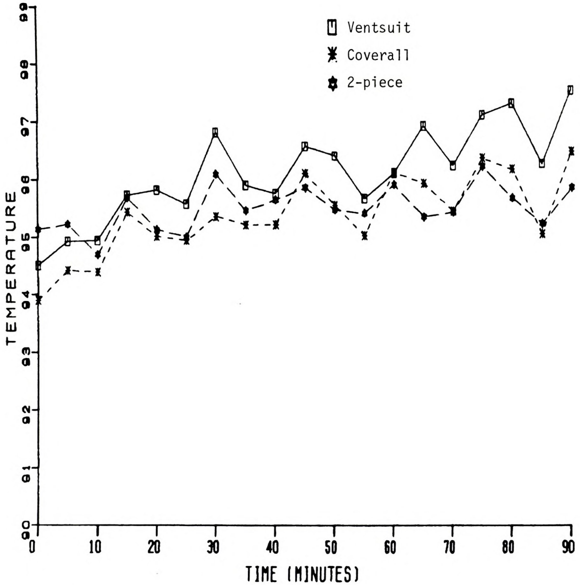


Figure 24.--Weighted mean skin temperature for fabric 1.

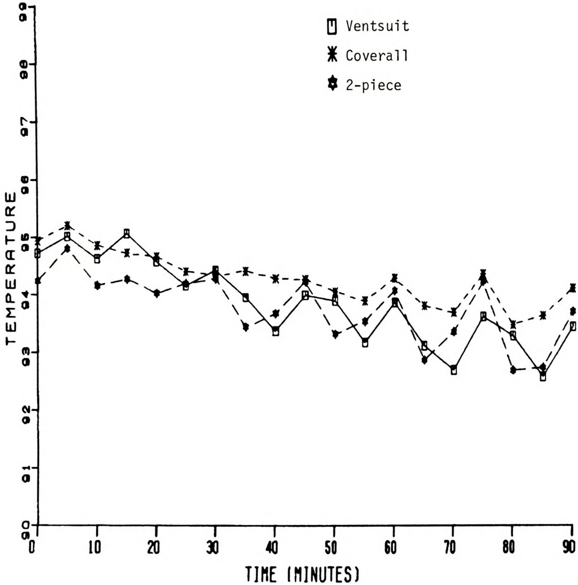


Figure 25.--Lower arm mean skin temperature for fabric 3.

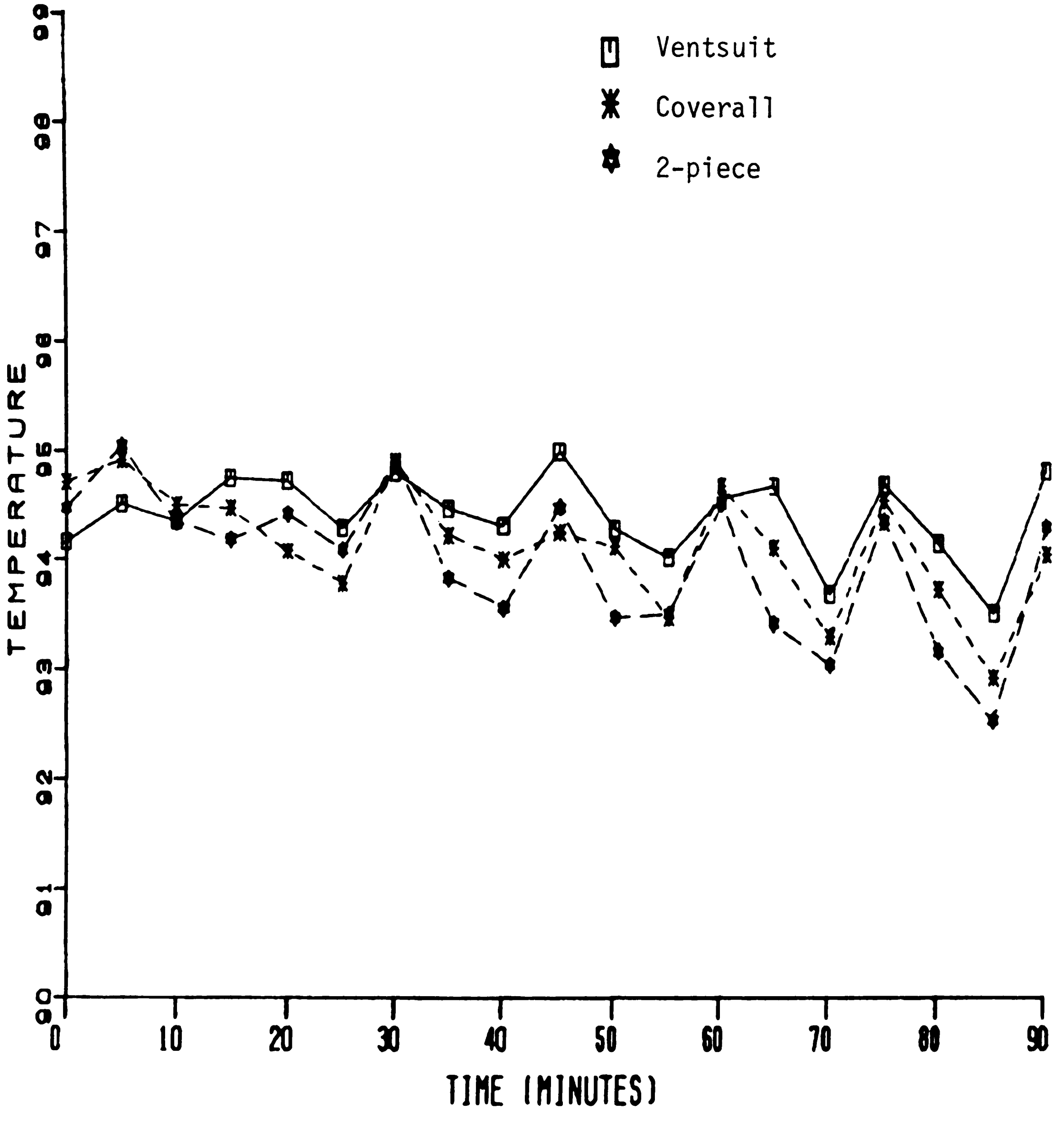


Figure 26.--Lower arm mean skin temperature for fabric 2.

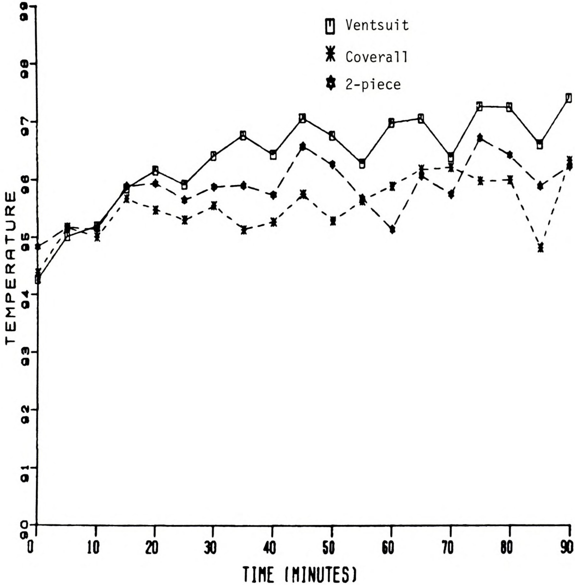


Figure 27.--Lower arm mean skin temperature for fabric 1.

Examination of Figures 25 and 26 shows a similar over-all slight downward trend over time. Note that there are differences, however, regarding the influence of design. Subjects wearing the fabric 3 ventsuit tend to experience the lowest arm skin temperature, whereas those subjects wearing the same design in fabric 2 show higher temperatures, particularly after 20 minutes. At the end of the test there was about a 1°F difference between subjects wearing fabric 2 and those wearing the fabric 3 ventsuit. The coverall and the two-piece jeans assembly are indicating the lowest arm temperatures for fabric 2, yet the coverall appears to be showing the highest temperatures for fabric 3.

Figure 27 reiterates the over-all upward trend depicted for weighted mean skin temperature for fabric 1. The influence of design is more clear-cut, however. Subjects wearing fabric 1 in the ventsuit design experienced higher temperatures than those wearing the other designs, with those in the coverall indicating lowest temperatures. Notice that the influence of design is more pronounced for fabric 1.

<u>Lower leg mean skin temperature</u>. The graphs for leg temperature (Figures 28, 29, and 30) are distinguished from the previous plots for several reasons. First, the initial temperatures, although not uniform across fabric or design, are lower than those reported previously. Second, the over-all pattern for all three fabrics is a slight increasing trend over time. And third, the pattern of alternation is amplified particularly for fabric 1, shown in Figure 30.

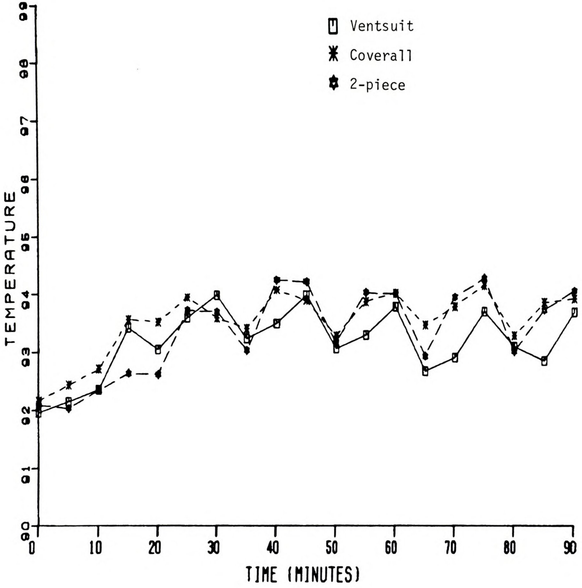


Figure 28.--Lower leg mean skin temperature for fabric 3.

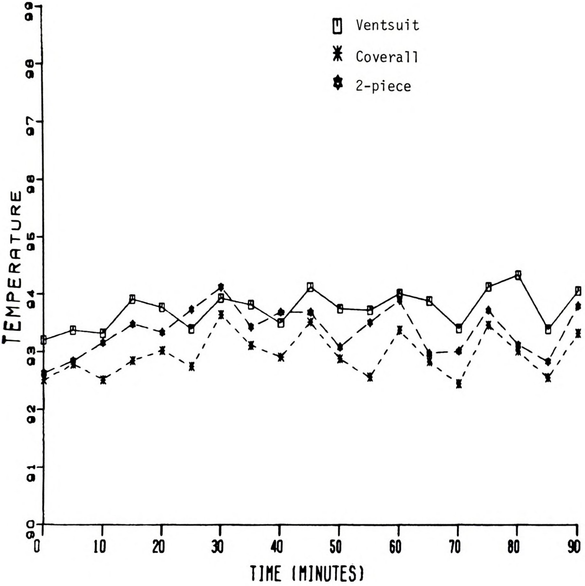


Figure 29.--Lower leg mean skin temperature for fabric 2.

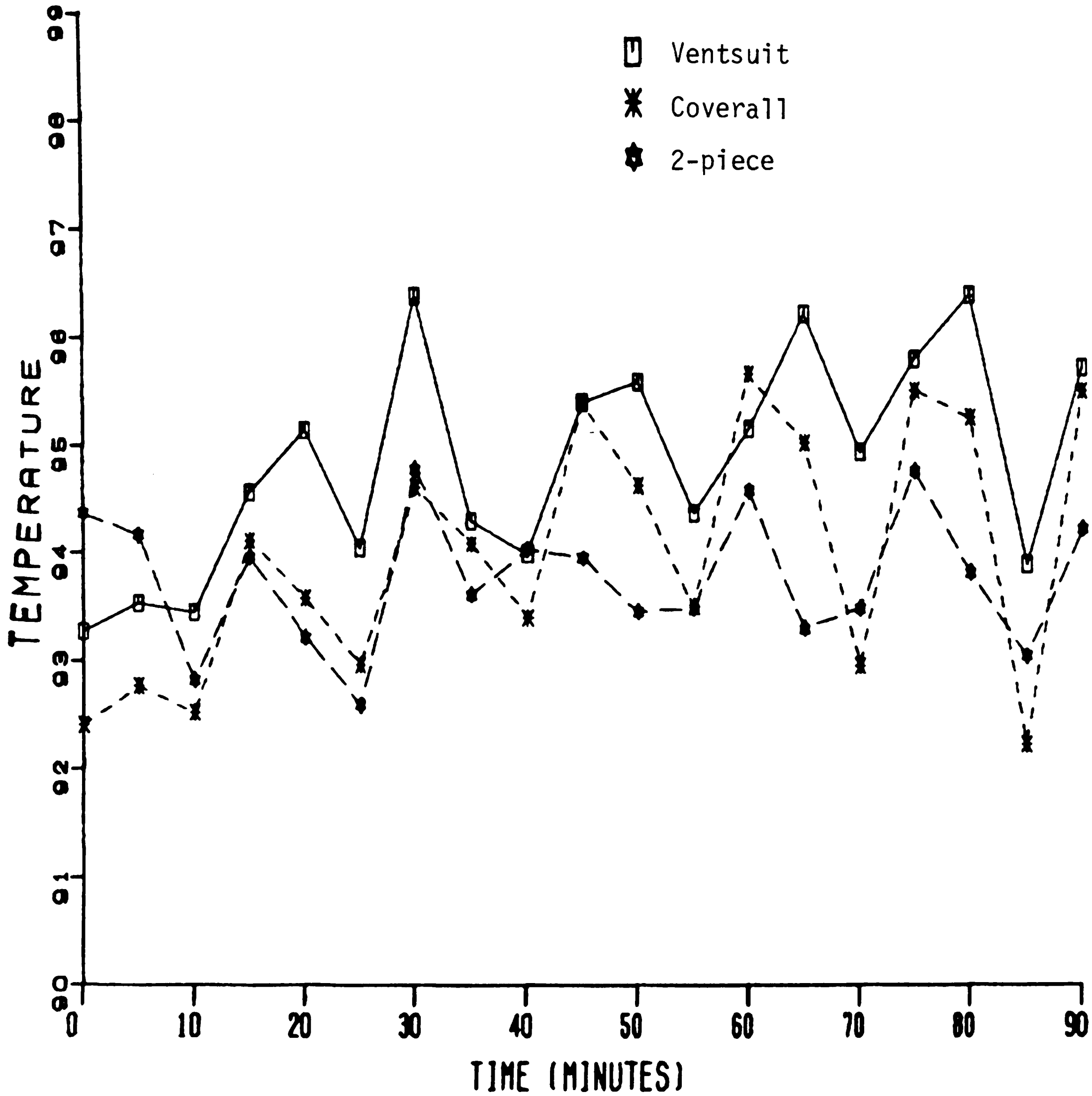


Figure 30.--Lower leg mean skin temperature for fabric 1.

Persons wearing fabric 3, regardless of design, showed a consistent tight mean leg skin temperature, suggesting that design had little influence on leg temperature. This was true even though subjects wearing the design 1 variation had bottom weight denim jeans on.

Figure 29 for fabric 2 showed a similar pattern, although it was not as tight. There seemed to be a trend for those wearing the ventsuit to have the highest temperatures and those in the cover-all the lowest. The arm temperature data alluded to a similar notion.

The marked amplitude of the graphs in Figure 30 is characteristic primarily of the coverall and ventsuit designs. Also, this pattern appears more obvious as the exposure time increases. These two designs are also indicating the highest skin temperatures, not only for fabric 1 but for all of the test fabrics. The data suggest that the heat energy produced in walking is not being dissipated well for those subjects in fabric 1, designs 2 and 3.

Mean chest skin temperature. Chest temperature factors heavily in the formula that is used to compute weighted mean skin temperature. Thus, the data displayed in Figures 31, 32, and 33 are of significant import to the determination of this dependent measure. A rapid appraisal of these three figures reveals dramatic differences.

The data for subjects wearing fabric 3, exhibited in Figure 31, illustrate an over-all downward theme over time. The impact of design is more visible for this fabric than in previous plots. The ventsuit design showed higher temperatures initially. However, the coverall design after 75 minutes showed equally high temperatures. Subjects

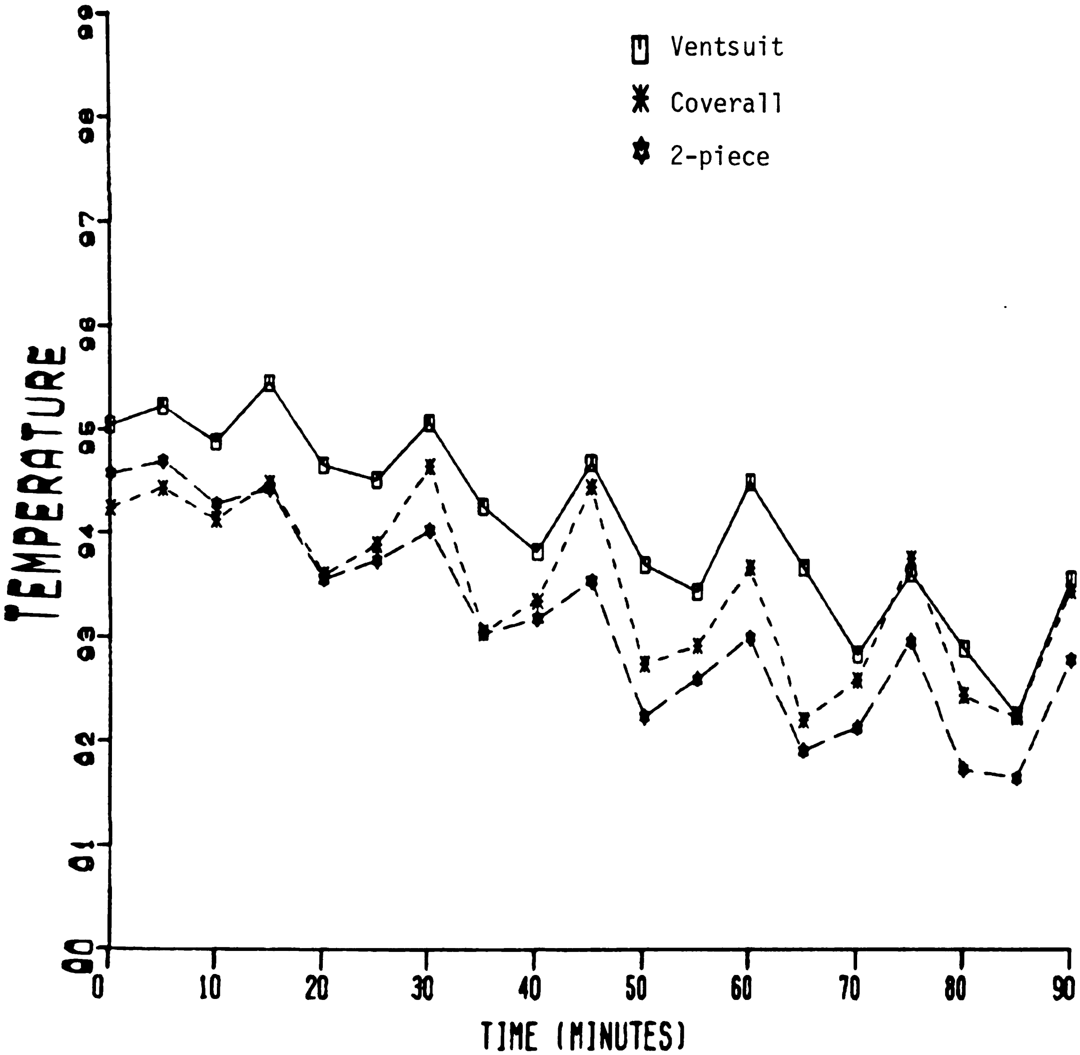


Figure 31.--Mean chest skin temperature for fabric 3.

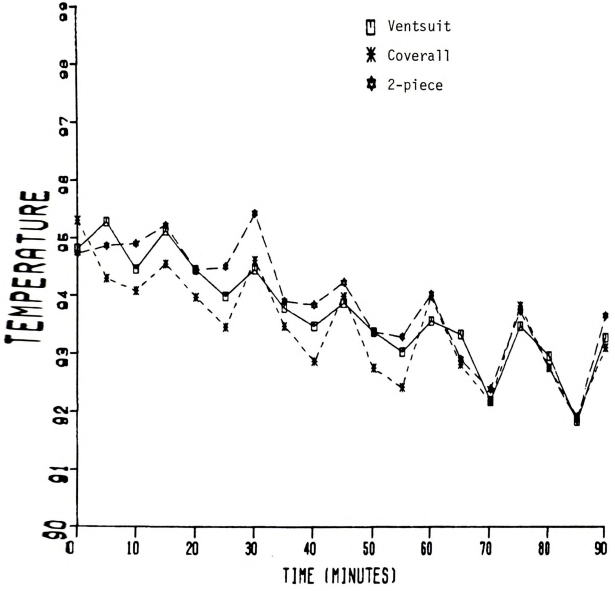


Figure 32.--Mean chest skin temperature for fabric 2.

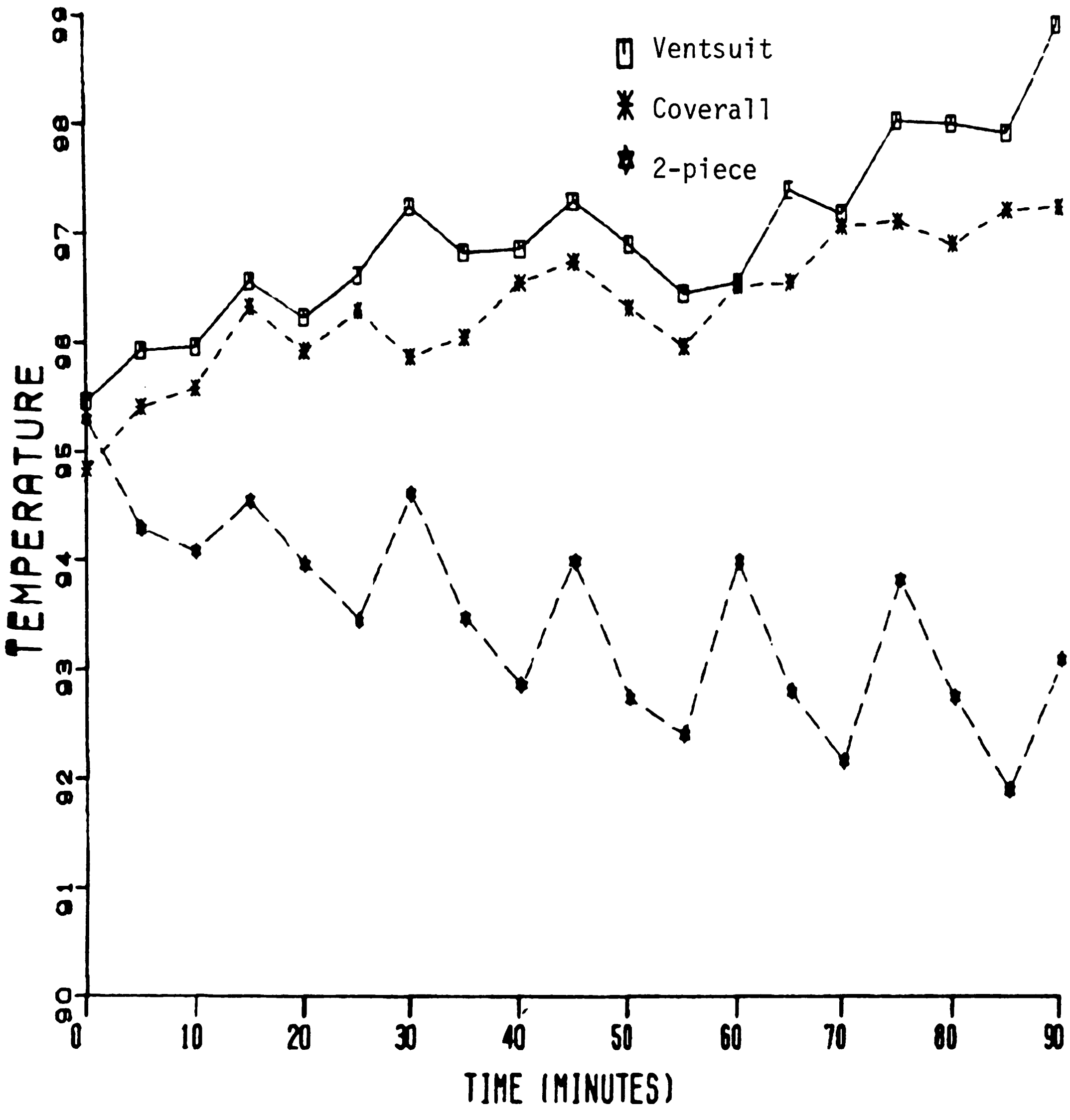


Figure 33.--Mean chest skin temperature for fabric 1.

wearing the two-piece design experienced the lowest skin temperatures after the first 20 minutes.

A similar downward pattern is evident in the data given in Figure 32 for fabric 2. However, the impact of design, if any, cannot be discerned. Those in the coverall design show the lowest chest temperatures.

The influence of design is readily observable in the dramatic graph for fabric 1 (Figure 33). Two designs, the ventsuit and the coverall, show a distinct upward trend with the ventsuit design exhibiting the highest chest temperatures. Yet, design 1, the two-piece design, surprisingly has shown a downward trend. Thus, the presence of jeans on the lower portion of the body appears to have helped these subjects achieve a reduced chest skin temperature. This downward trend is in clear contrast to all of the preceding skin temperature plots for fabric 1.

Rectal temperature. While skin temperature can safely vary within a wide range, rectal temperature cannot do so. A subject whose rectal temperature increased 2°F above his/her temperature taken at the beginning of the experiment was removed from the test. A registered nurse who was in attendance at the Institute routinely checked on the subjects throughout the experiment. There were two subjects whose increased rectal temperature necessitated their removal from the experiment prior to its completion. In these two instances, the nurse remained in the test chamber to ensure the health and safety of the subjects.

In general, Figures 34, 35, and 36 show an increasing trend over time. The rate of increase for fabric 3, as seen in Figure 34, is less than the other two fabrics. Also, this graph indicated that design 1, the two-piece jeans variation, after 20 minutes exhibited the highest rectal temperature, with no distinction between designs 2 and 3.

Figure 35 does not suggest any distinct pattern other than its over-all increasing trend. The data displayed in Figure 36, however, clearly indicate a higher rectal temperature for design 3, the ventsuit. Both subjects who were removed from the test were wearing fabric 1; one wore the ventsuit and the other wore design 2, the coverall.

Mean thermal comfort votes. The perceptual measure of thermal comfort was assessed by a semantic differential scale. The ballot was administered eight times at 15-minute intervals during the two-hour experiment. However, complete data were not available for the seventh and eighth votes due to the removal of two subjects. The method of determination of the total thermal comfort vote from the semantic differential scale denoted that higher thermal comfort votes represented greater perceived discomfort with the thermal environment.

The data presented in Figure 37 document a pattern exhibited repeatedly with the temperature data, particularly the various skin temperature measures. Subjects wearing fabric 1, regardless of the design variation, perceived greater discomfort than those wearing the other test fabrics. Note also how proximate the graphs are

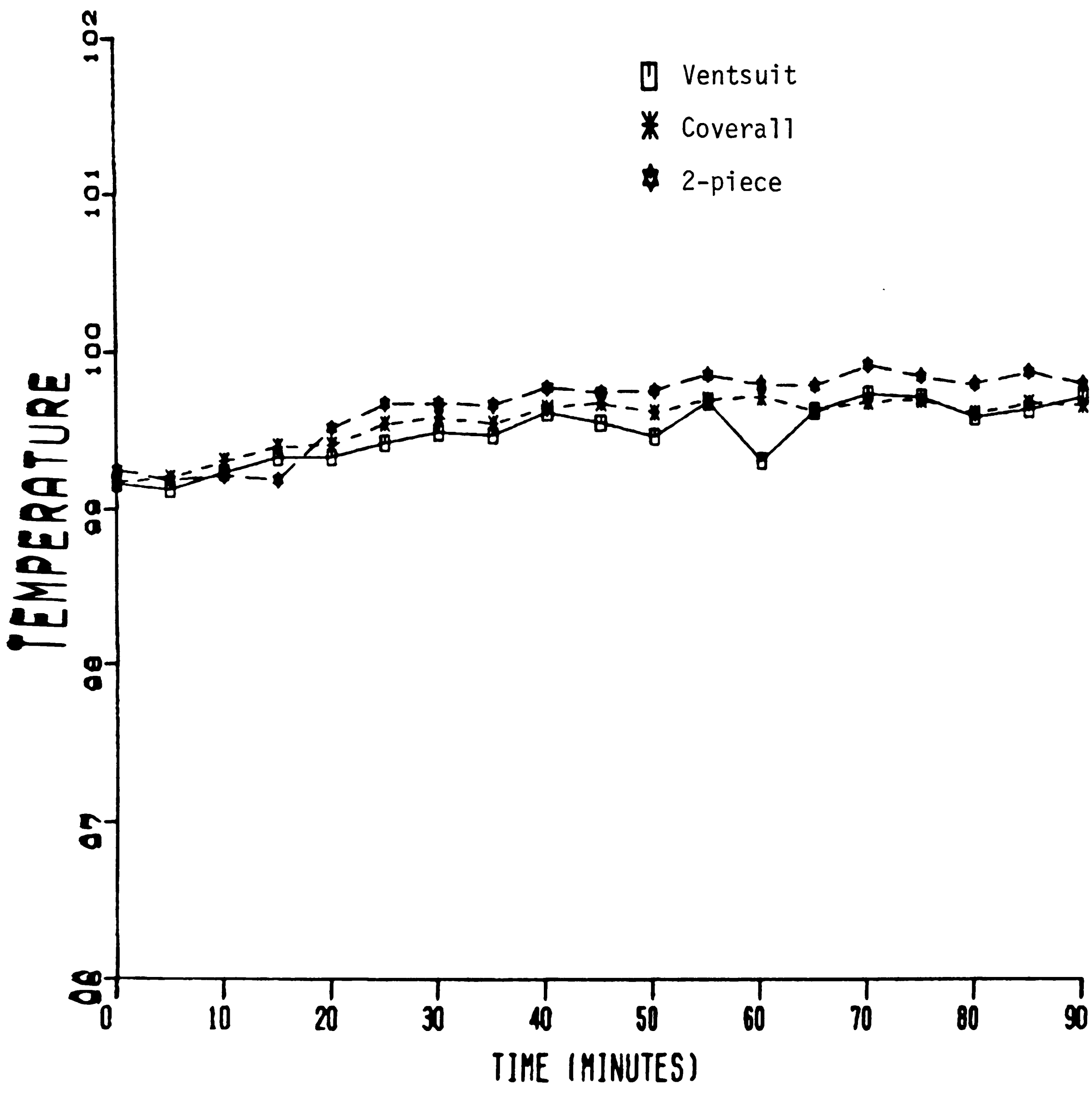


Figure 34.--Mean rectal temperature for fabric 3.

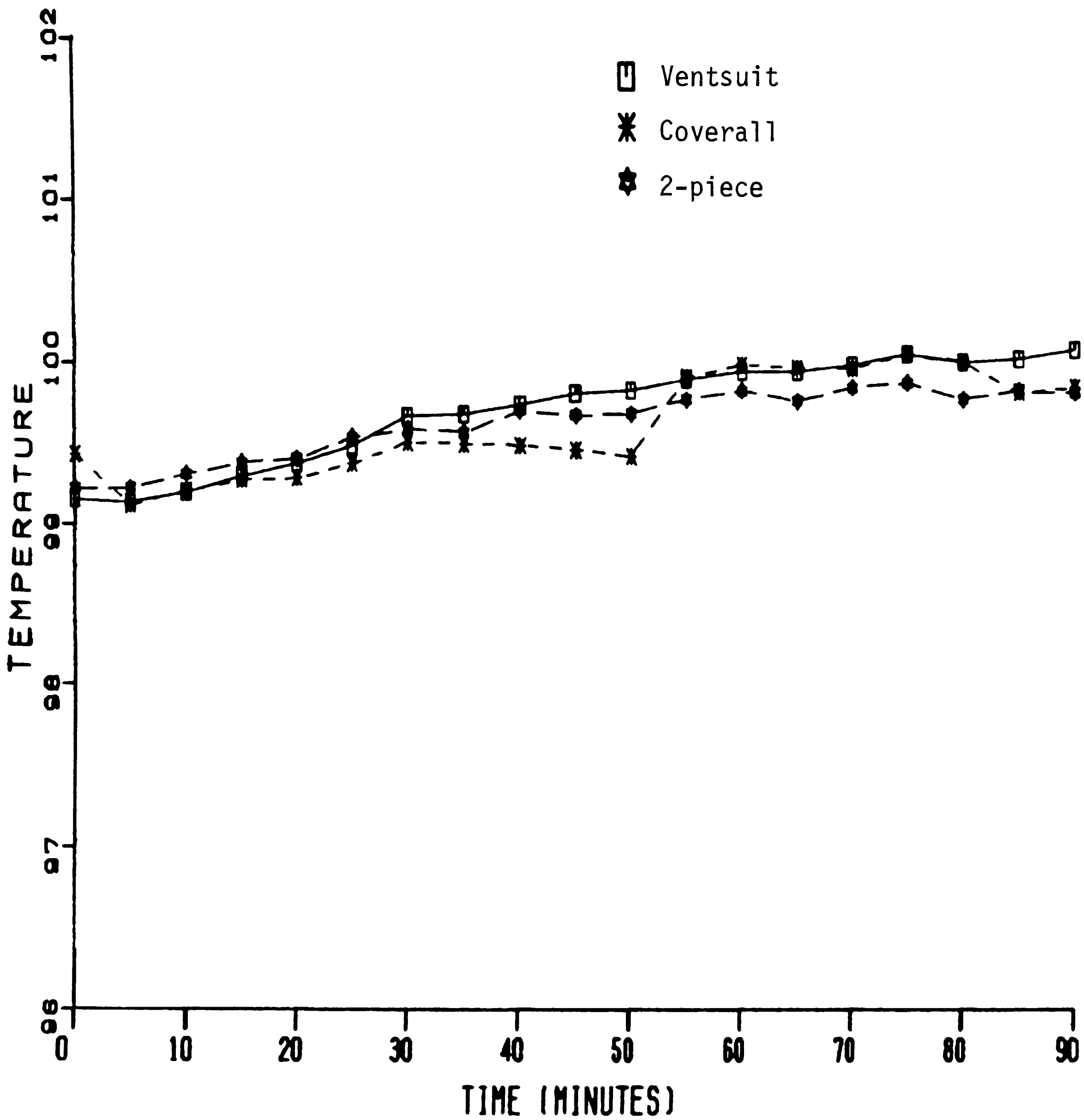


Figure 35.--Mean rectal temperature for fabric 2.

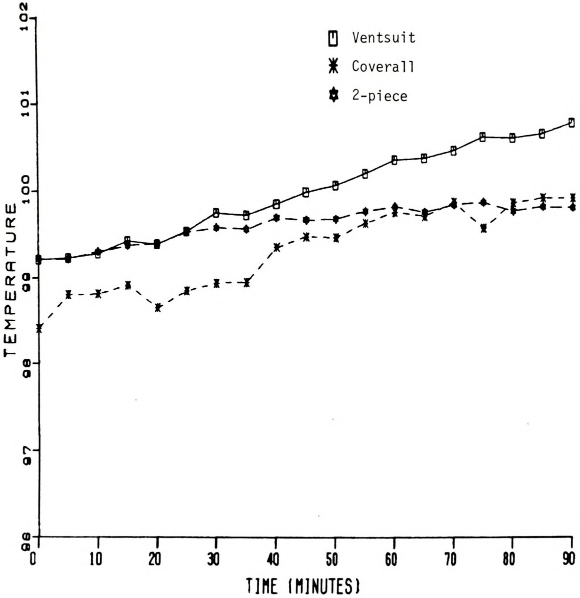


Figure 36.--Mean rectal temperature for fabric 1.

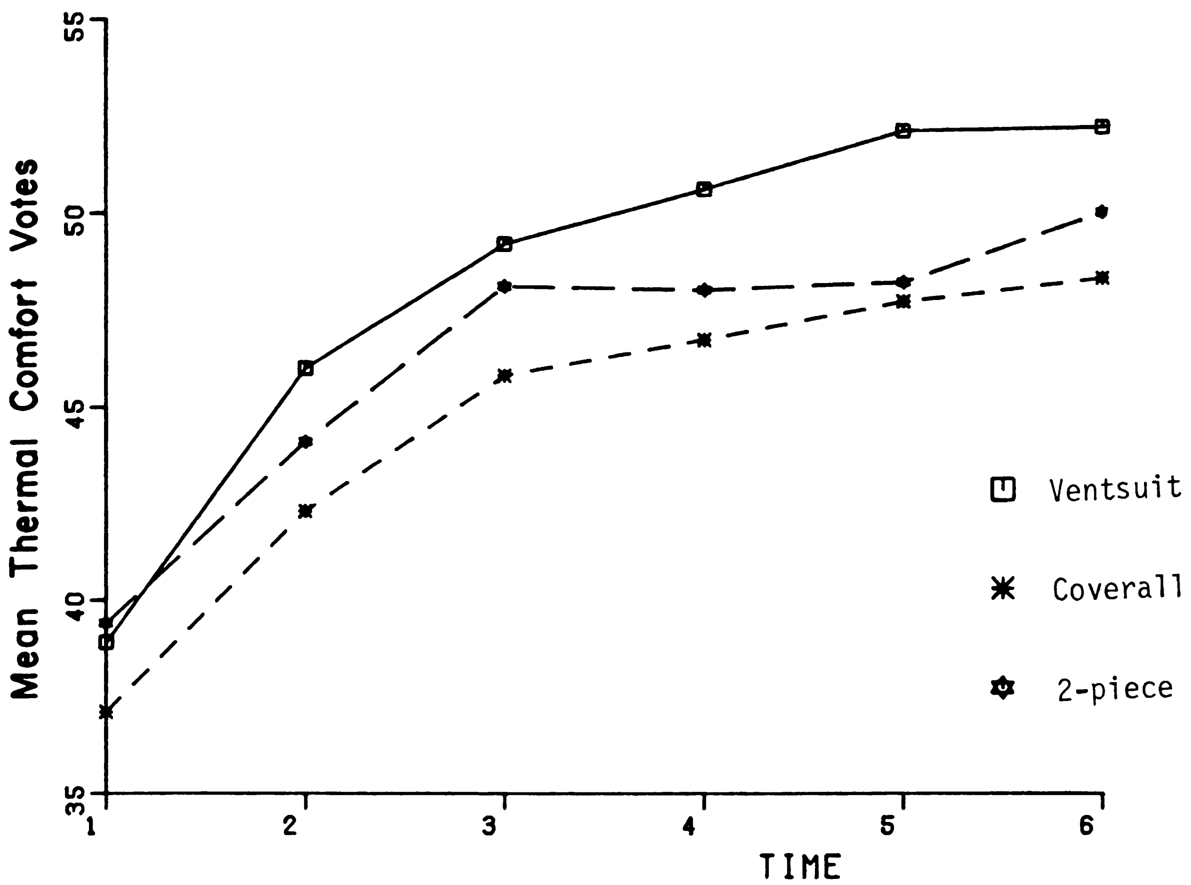


Figure 37.--Mean thermal comfort response for fabric.

for fabrics 2 and 3. Thus, the data show a clear distinction in perceived comfort.

Design

The graphical representation of the physiological temperature measures and the thermal comfort responses for design are presented to parallel the data previously shown for fabric.

Mean weighted skin temperature. Examination of Figures 38, 39, and 40 shows a clear consistent pattern by fabric that is present for all three designs. Subjects wearing fabric 1, regardless of which design variation they had been assigned to, exhibited higher mean skin temperatures than subjects wearing the other two test fabrics. Elevated skin temperatures were particularly characteristic of subjects wearing fabric 1 and design 3, the ventsuit, as shown in Figure 40. The mean weighted skin temperature for these subjects reached almost 98°F after 90 minutes of exposure to the test condition.

Note also that the data (particularly Figures 38 and 39) for fabric 2 closely parallel the data for fabric 3. Figure 38 suggests that for design 1, fabric 3 is showing slightly cooler weighted mean skin temperatures over fabric 2. The overall patterns illustrated in Figures 38 and 39 are similar.

Mean arm skin temperature. The over-all pattern exhibited by the data presented in Figures 41, 42, and 43 reiterates the theme that subjects wearing fabric 1 experienced higher arm skin temperatures than those wearing the other two test fabrics. An upward trend

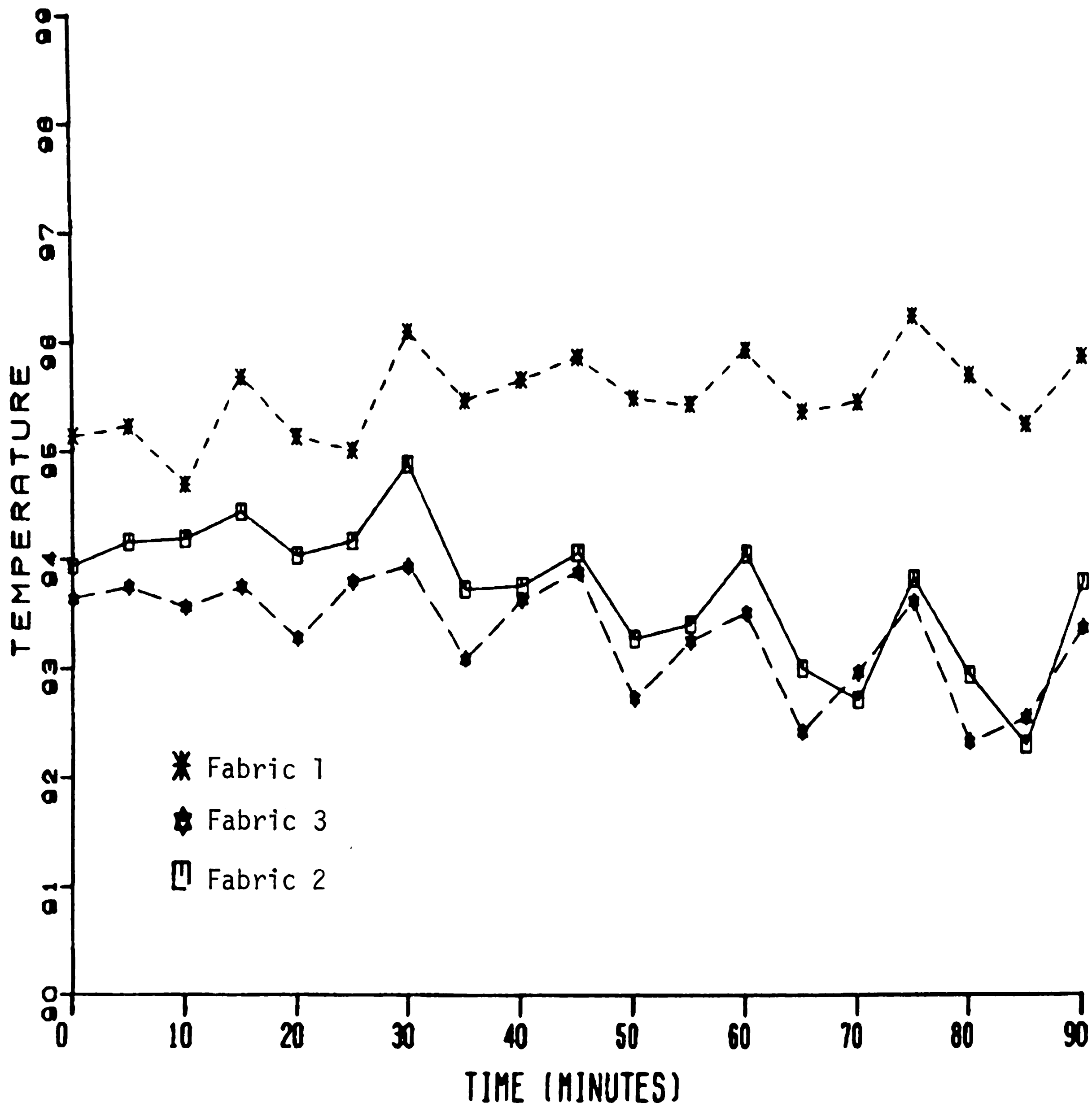


Figure 38.--Mean weighted skin temperature for design 1, the two-piece jeans assembly.

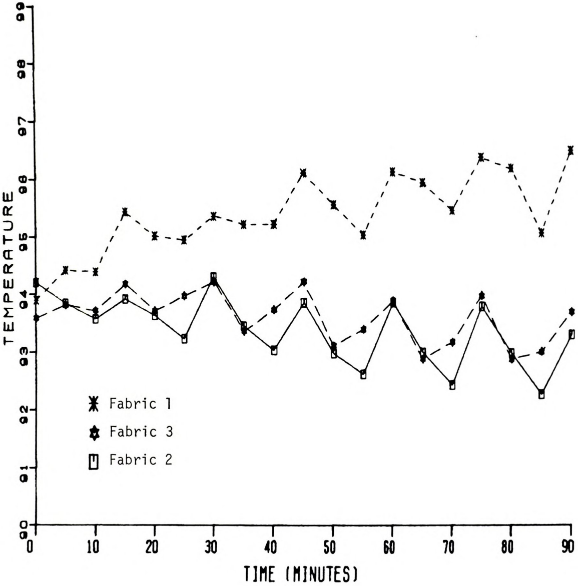


Figure 39.--Mean weighted skin temperature for design 2, the coverall.

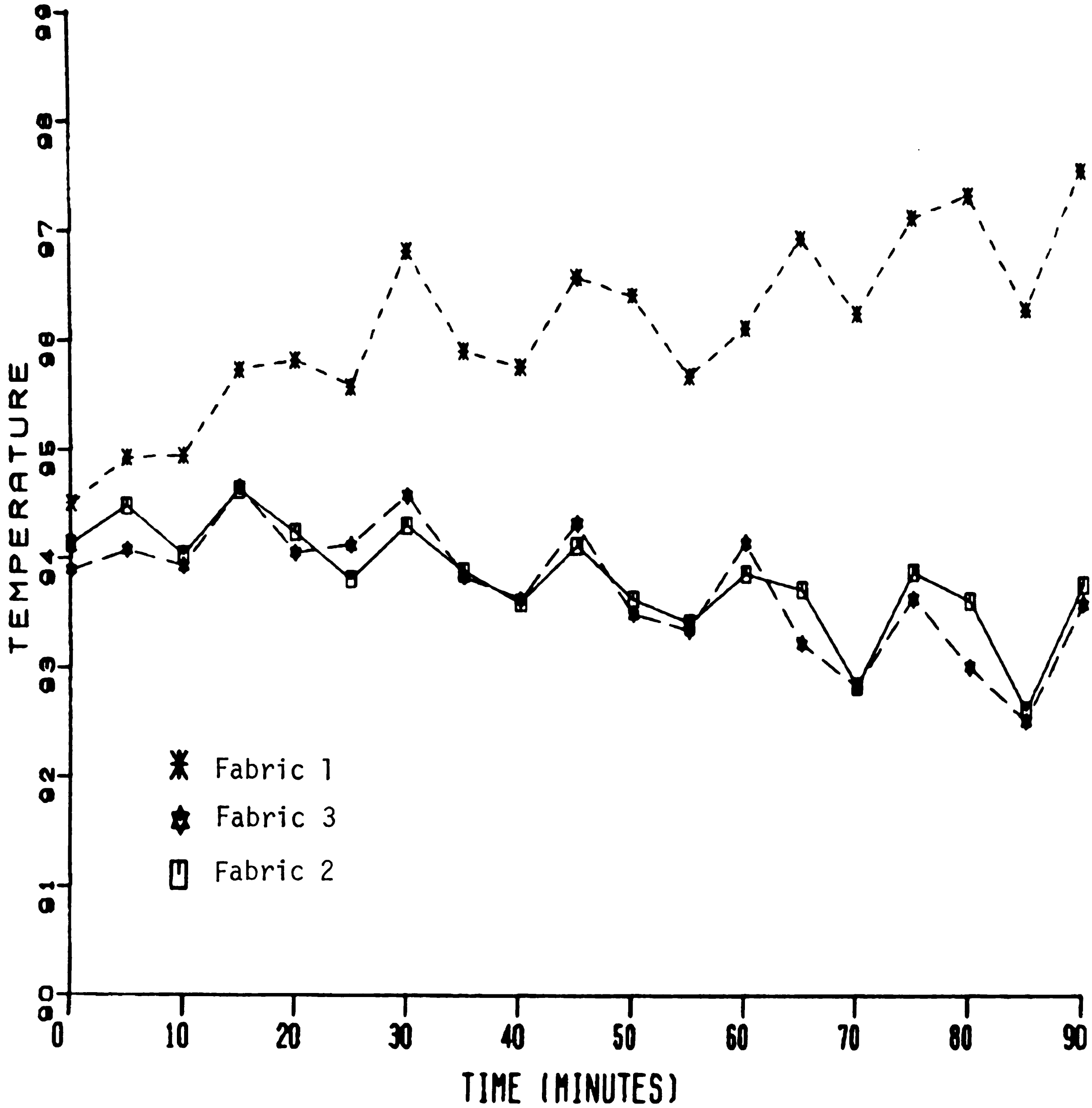


Figure 40.--Mean weighted skin temperature for design 3, the ventsuit.

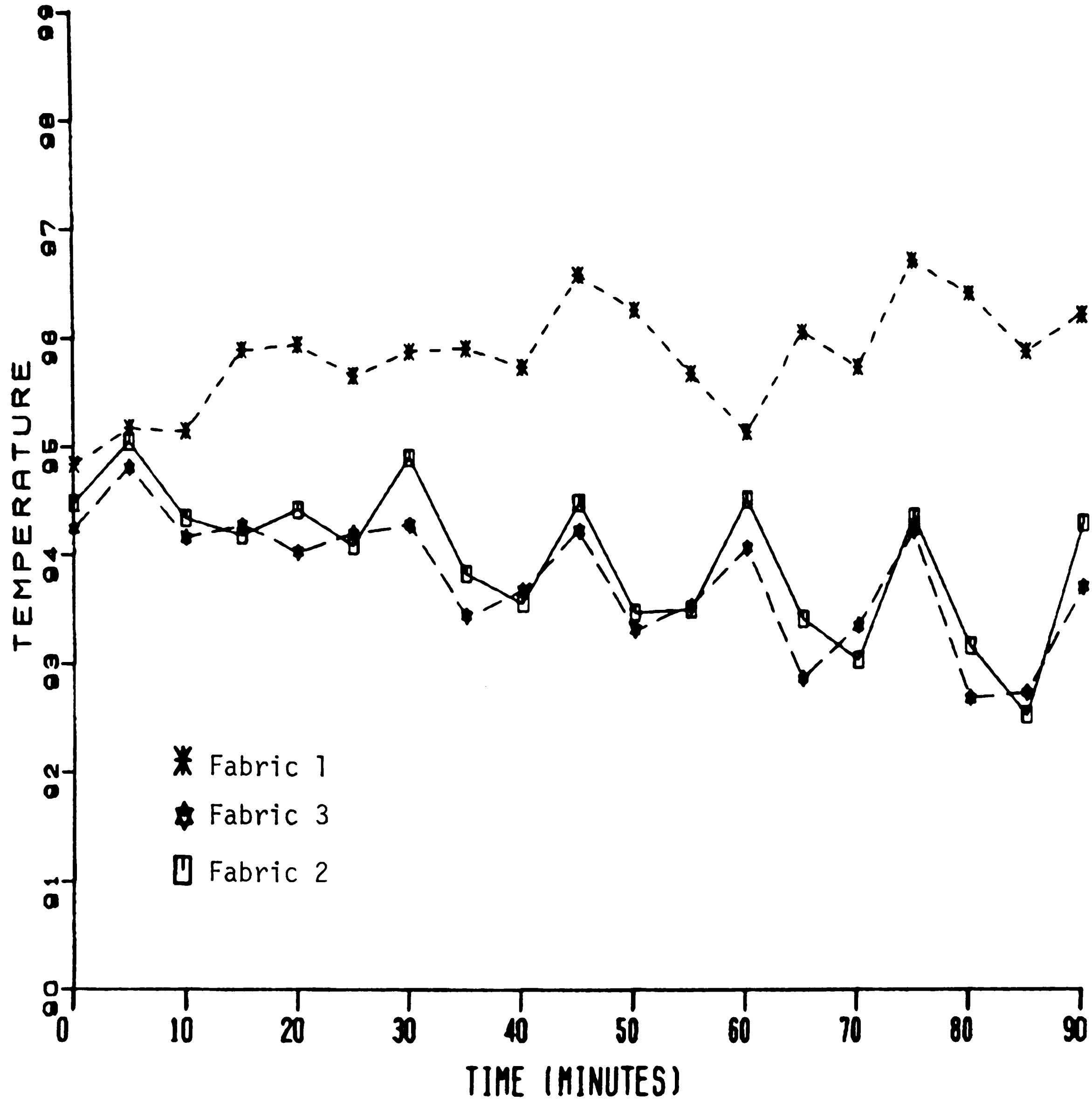


Figure 41.--Mean arm skin temperature for design 1, the two-piece jeans assembly.

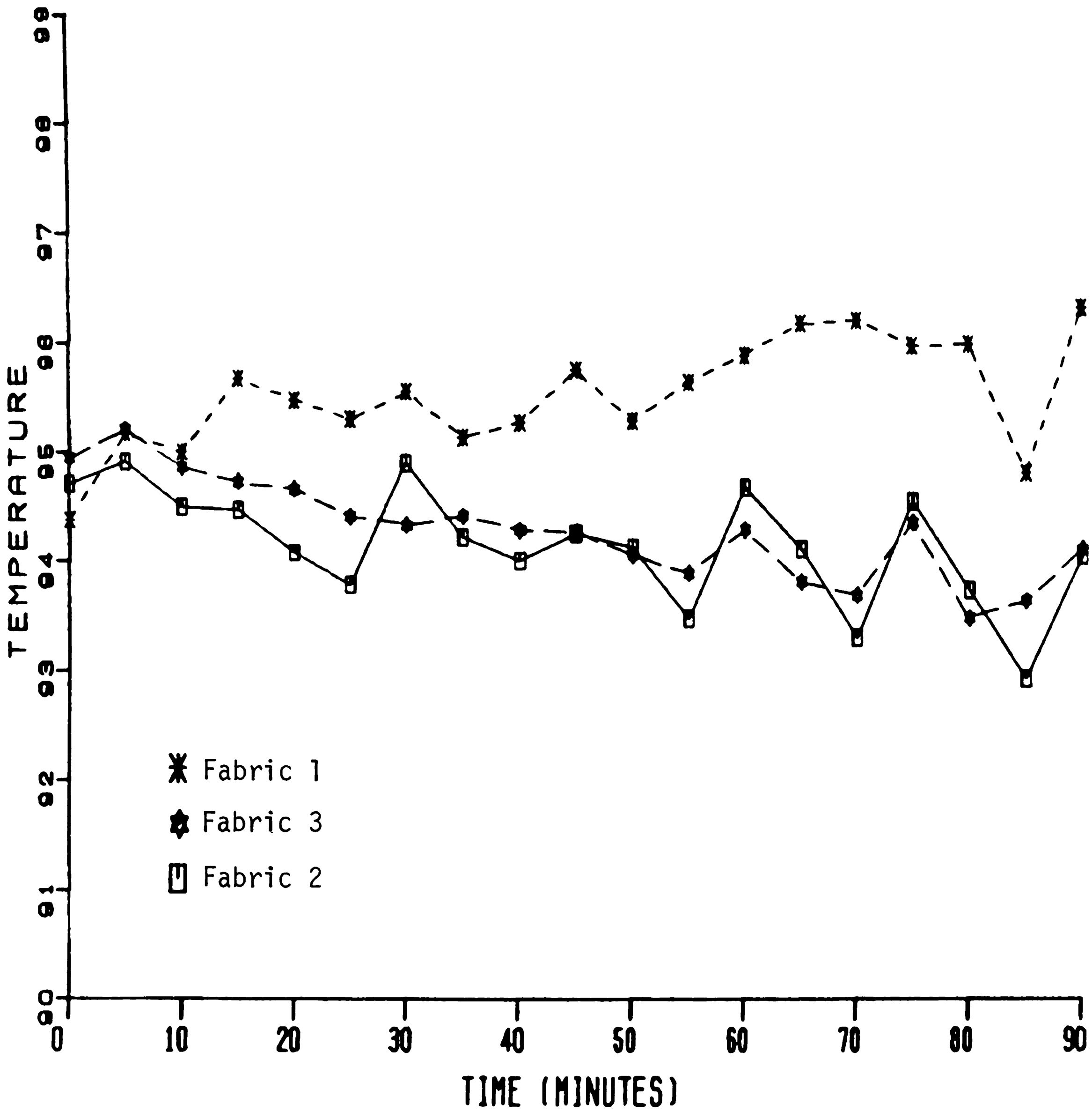


Figure 42.--Mean arm skin temperature for design 2, the coverall.

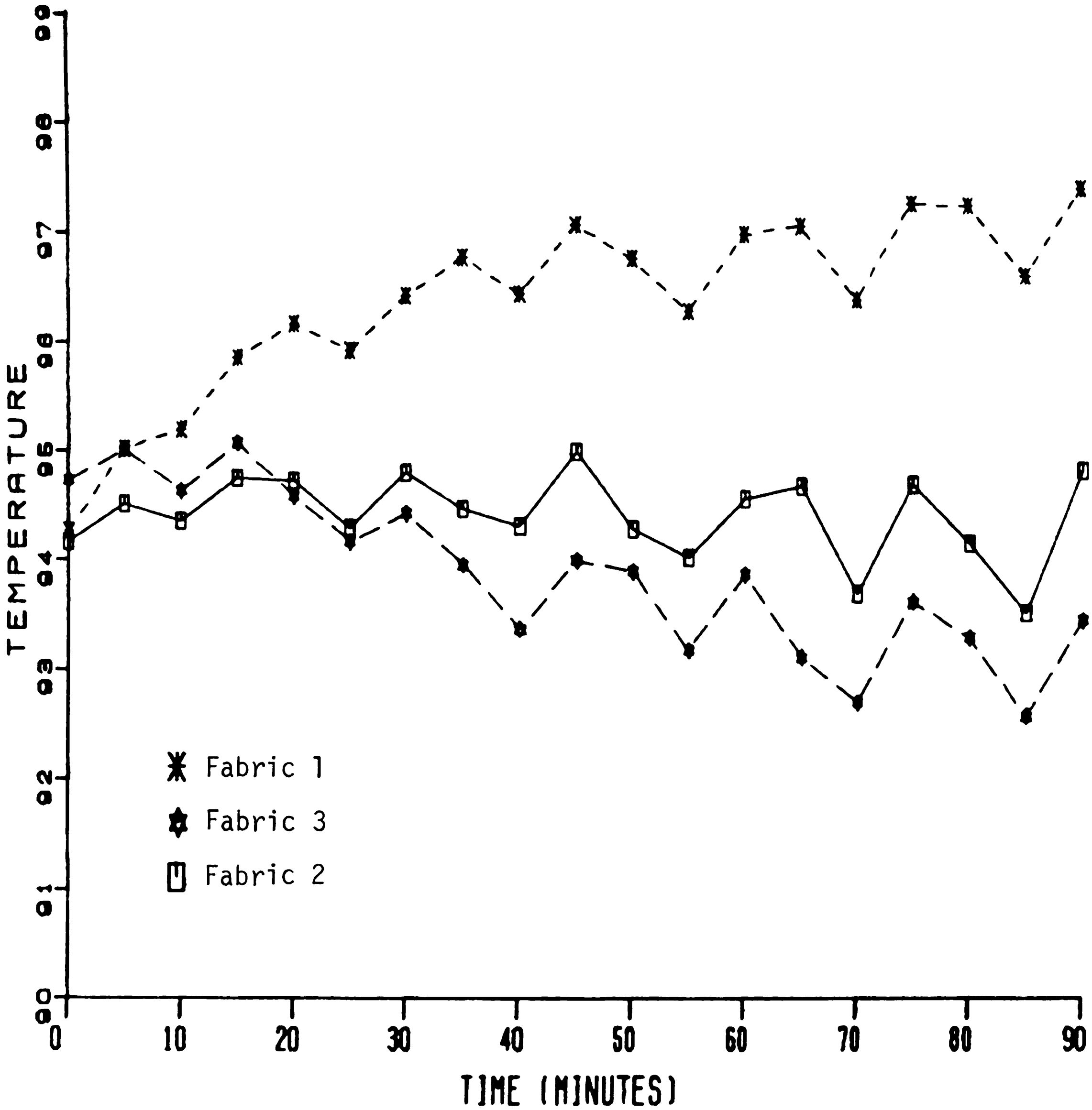


Figure 43.--Mean arm skin temperature for design 3, the ventsuit.

over time is apparent for all three designs in fabric 1. This trend is contrary to that shown by fabrics 2 and 3 for all three designs. The downward trend suggests that evaporative and/or convective cooling was taking place over time with these fabrics.

Figure 43 is particularly noteworthy for three reasons. First, the mean temperature of subjects wearing fabric 1 was clearly higher in the ventsuit relative to the two other designs. Also, the temperature difference between the test fabrics indicated greater disparity than the other designs. And third, the temperature data for those wearing fabric 2 are above the data for those in fabric 3. Figures 41 and 42 indicated very similar temperature data for fabrics 2 and 3.

Mean leg skin temperature. As expected, the data presented in Figure 44 are very similar. Recall that all of the subjects assigned design 1 wore denim jeans, only the shirt fabric was varied. Therefore, the leg temperature data in Figure 44 are for subjects all wearing denim jeans.

Data for subjects wearing design 2, the coverall, are given in Figure 45. Data for those wearing design 3, the ventsuit, are illustrated in Figure 46. Note that Figures 45 and 46 display similar results. The strong influence of fabric 1 is again apparent but in a different way. Subjects wearing fabric 1 again exhibited the highest leg skin temperature readings, particularly in design 3, the ventsuit. However, the clear upward trends demonstrated in Figures 38, 39, 40, 41, 42, and 43 are not found in these data. Rather, an initial increase followed by an alternating pattern of notable

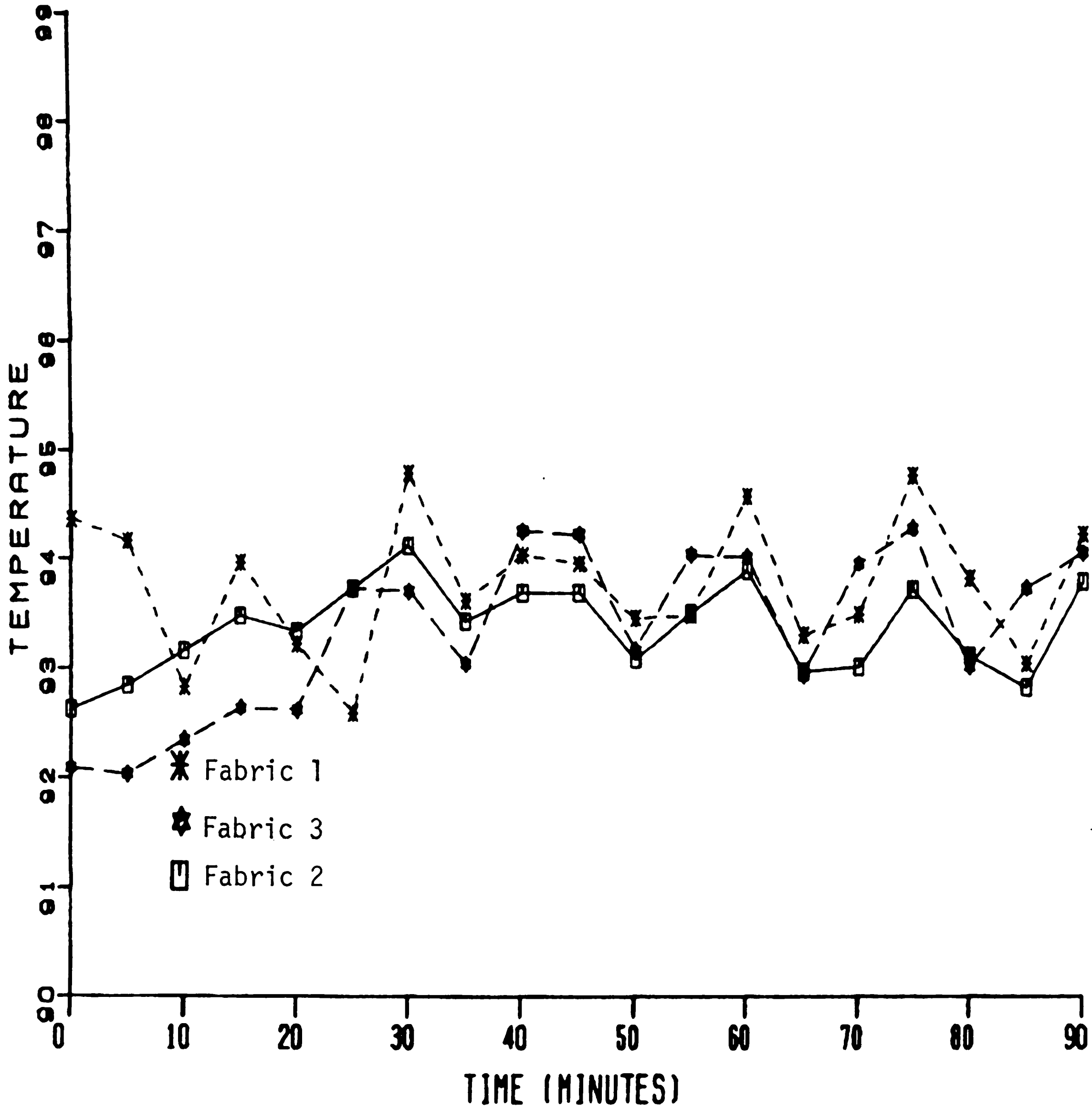


Figure 44.--Mean leg skin temperature for design 1, the two-piece jeans assembly.

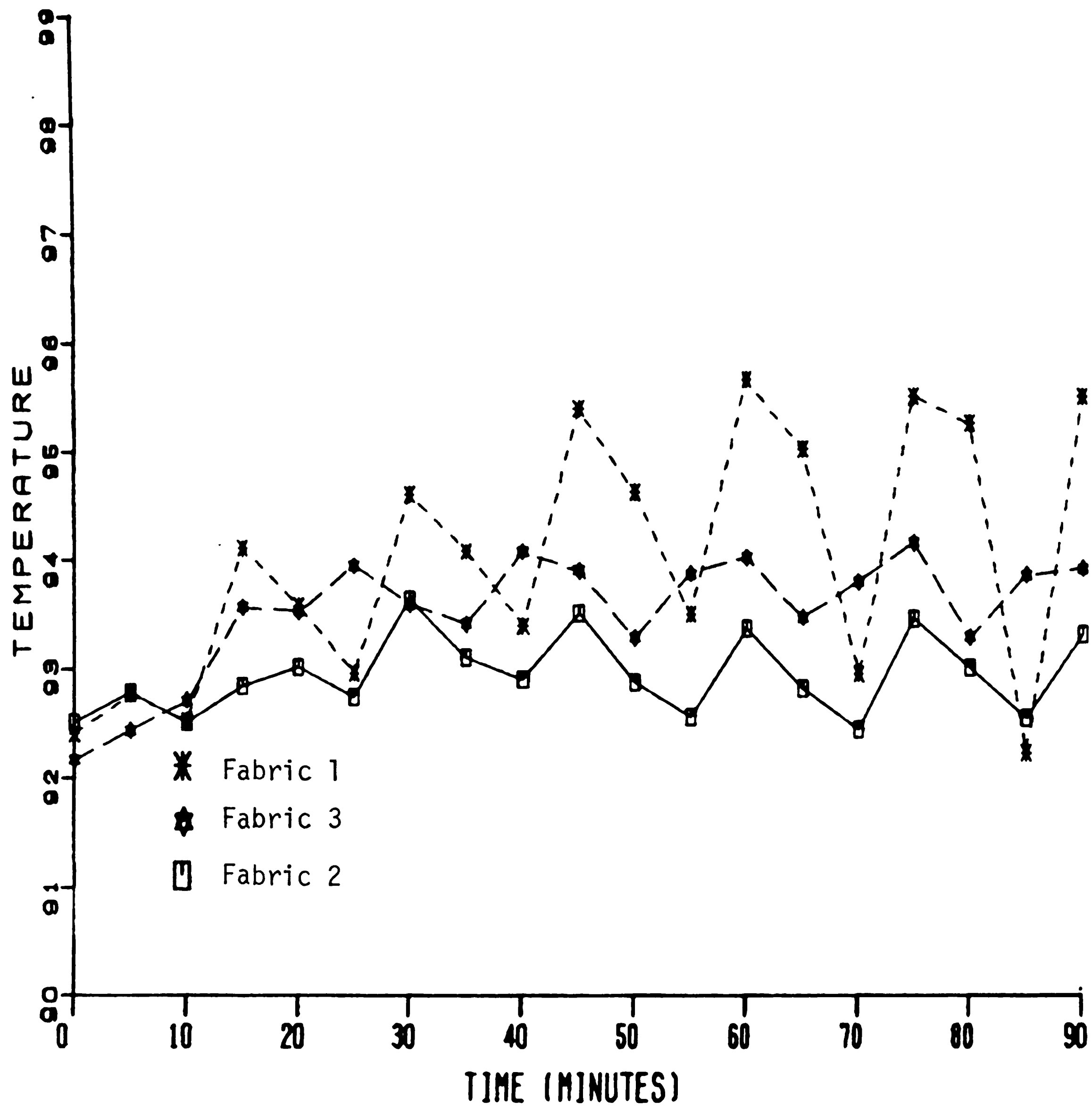


Figure 45.--Mean leg skin temperature for design 2, the coverall.

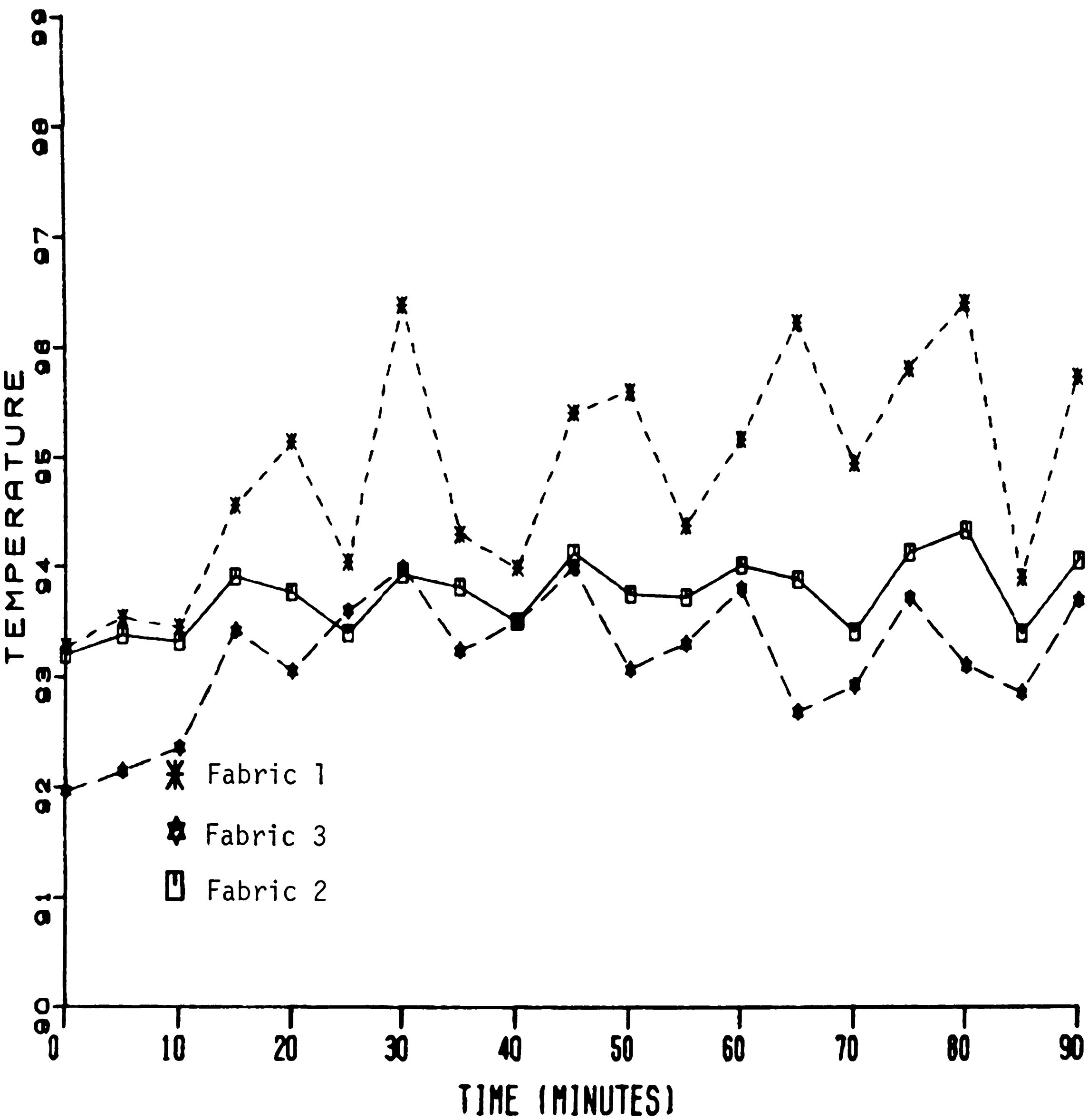


Figure 46.--Mean leg skin temperature for design 3, the ventsuit.

amplitude can be seen in Figures 45 and 46. Also, the data clearly demonstrated that no downward trend was taking place for any of the test fabrics.

Further examination of Figures 45 and 46 points out another distinction. For the coverall design, fabric 2 was consistently showing the lowest temperatures, whereas with the ventsuit, fabric 2 was indicating higher temperatures than fabric 3.

Mean chest skin temperature. The dominant theme that subjects wearing fabric 1 regardless of the design variation experienced higher skin temperature readings, so pronounced for weighted mean skin temperature and mean arm skin temperature, was again reiterated with the mean chest skin temperature data.

Figure 47 shows a clear downward temperature trend for subjects wearing either fabric 2 or fabric 3. Although lower temperatures characterized fabric 3 during the beginning of the test, temperatures for fabrics 2 and 3 are very similar after the first 45 minutes.

Data displayed in Figures 48 and 49 are very similar. However, note that in design 3, the ventsuit, subjects wearing fabric 1 experienced particularly elevated skin temperature readings, almost to 99°F. That represented approximately a 5.5°F difference between subjects wearing fabric 1 versus fabric 2 after a 90-minute exposure to the environmental conditions. This temperature differential for design 3 was greater than with either design 1 or 2.

Rectal temperature. The distinctive pattern that most of the skin temperature data have demonstrated was not as clearly

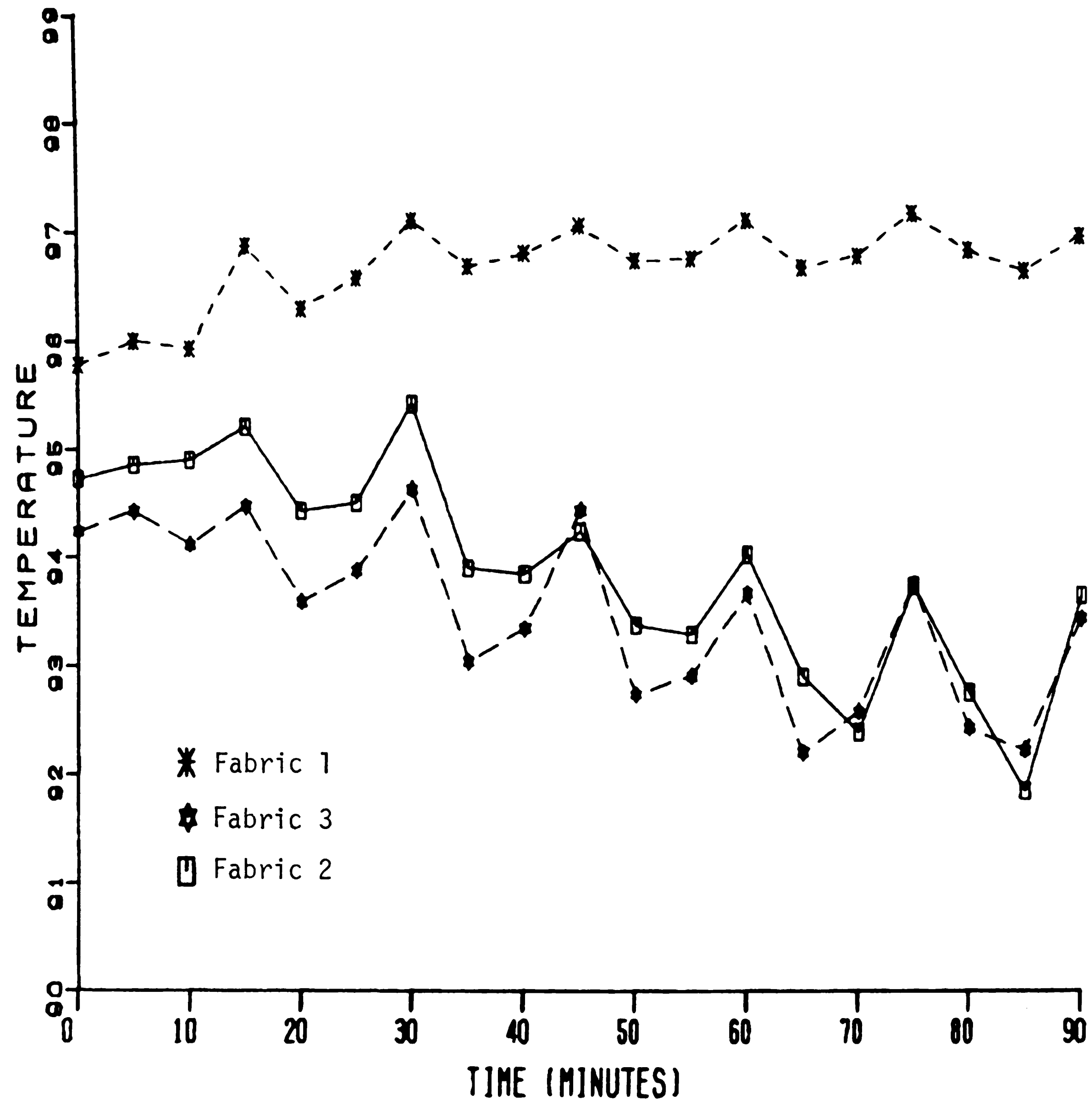


Figure 47.--Mean chest skin temperature for design 1, the two-piece jeans assembly.

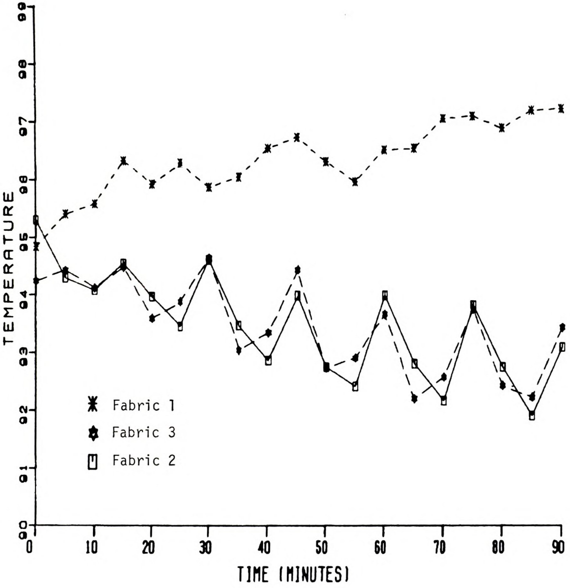


Figure 48.--Mean chest skin temperature for design 2, the coverall.

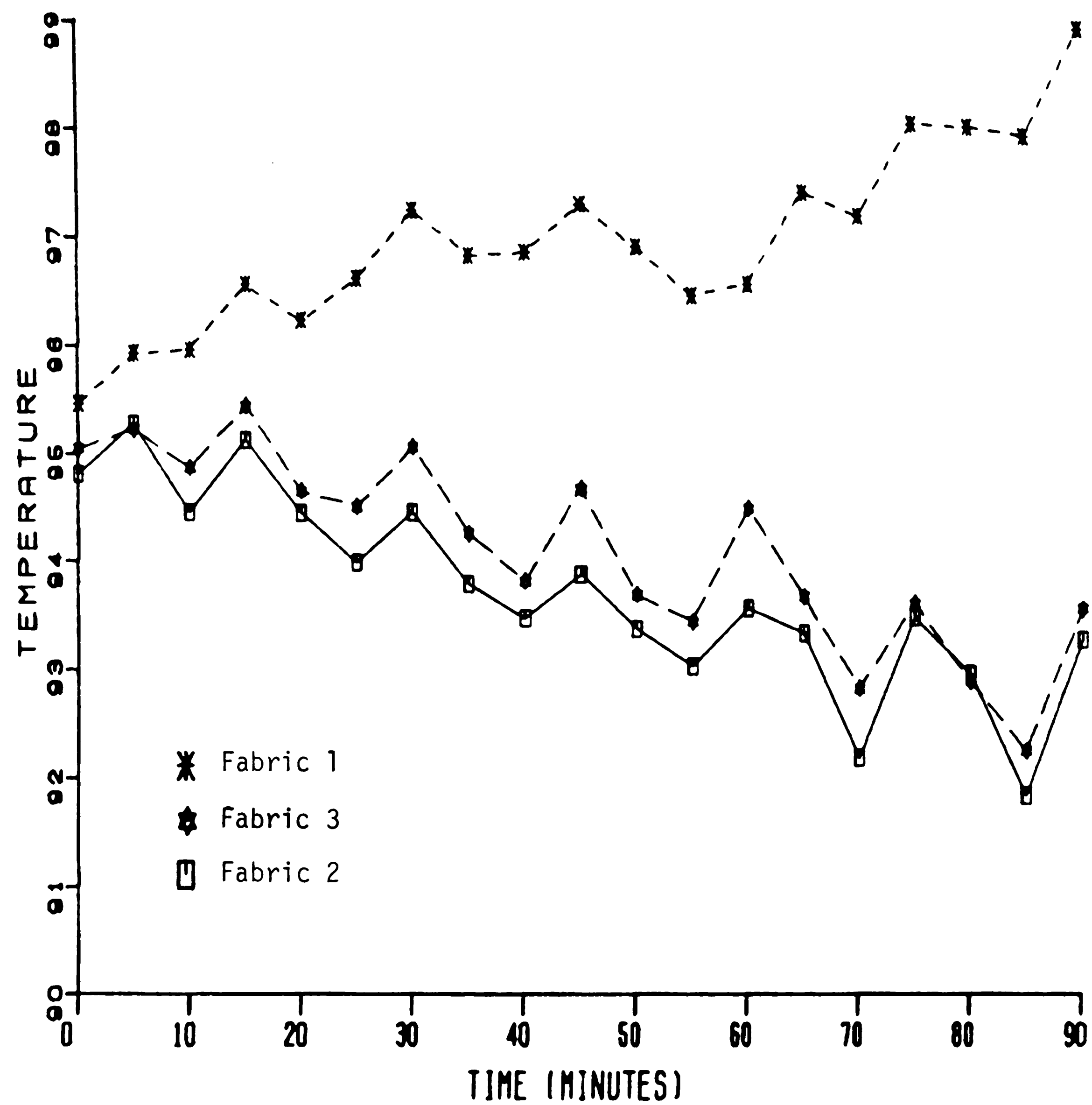


Figure 49.--Mean chest skin temperature for design 3, the ventsuit.

elucidated by the mean rectal temperature data. Figures 50, 51, and 52 document an increasing temperature trend over time.

Surprisingly, fabric 1 for the two-piece jeans ensemble seems to be indicating lower mean rectal temperatures than the other two test fabrics (see Figure 50). As the time in the chamber continued, the temperature data for the three fabrics merged to a similar level.

No clear pattern was discerned from scrutinizing Figure 51. However, the data acquired for design 3, the ventsuit (shown in Figure 52), were in accord with the skin temperature data previously presented. Those wearing fabric 1 experience higher rectal temperatures than those wearing fabric 2 or those assigned to fabric 3. A 1°F difference is apparent for fabric 3 and fabric 1 after completing 90 minutes of the test.

<u>Mean thermal comfort vote</u>. The perceptual thermal comfort response for design was not as pronounced as this measure was for fabric. Yet, Figure 53 suggests that subjects wearing design 3, the ventsuit, perceived greater discomfort than the subjects wearing the other two design variations. Also, those wearing the coverall design indicated the least dissatisfaction with the thermal environment, and those in the jeans assembly expressed feelings of discomfort between the other two designs.

<u>Thermal sensation</u>. Figures 54 and 55 show subjects' responses to the thermal sensation ballot for the two highest categories, 8 (hot) and 9 (very hot). Notice in Figure 54 (for fabric) the clear increasing number of individuals wearing fabric 1 who felt that they were "very hot." Few subjects wearing either fabric 2 or fabric 3

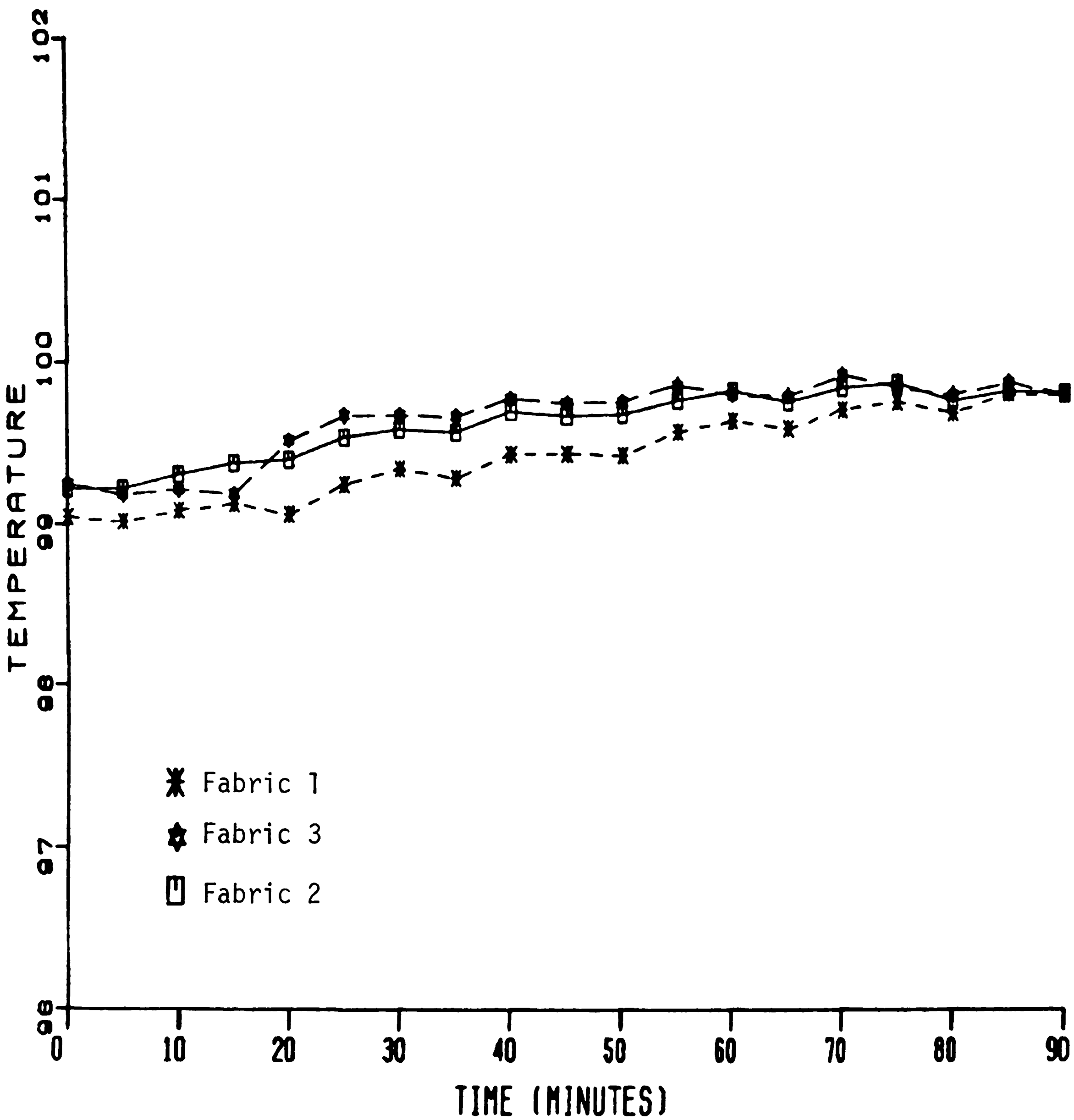


Figure 50.--Mean rectal temperature for design 1, the two-piece jeans assembly.

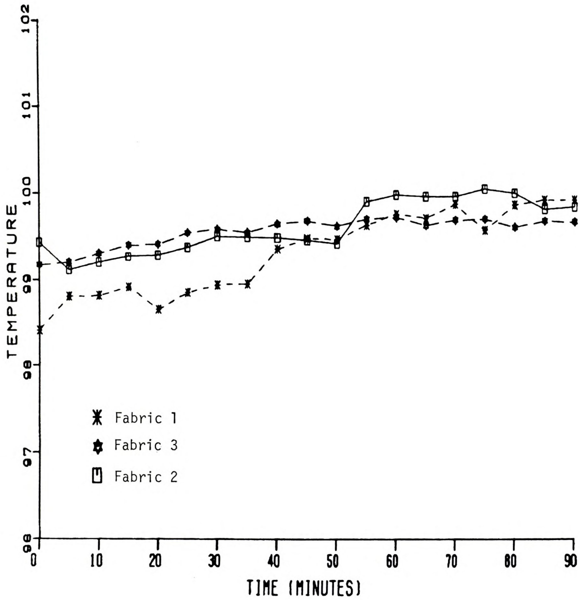


Figure 51.--Mean rectal temperature for design 2, the coverall.

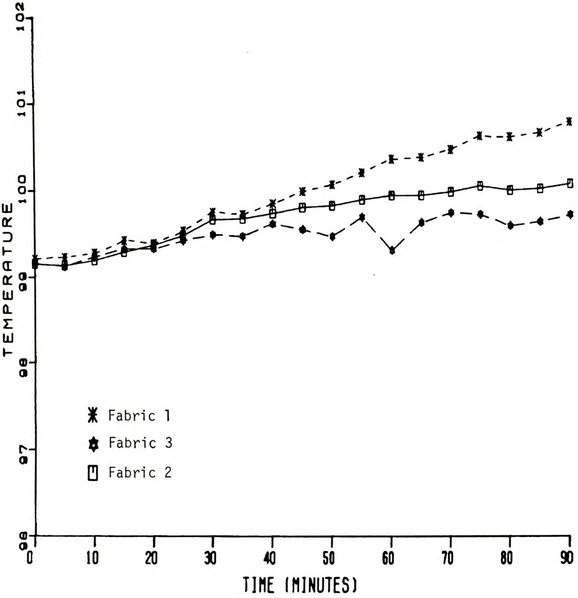


Figure 52.--Mean rectal temperature for design 3, the ventsuit.

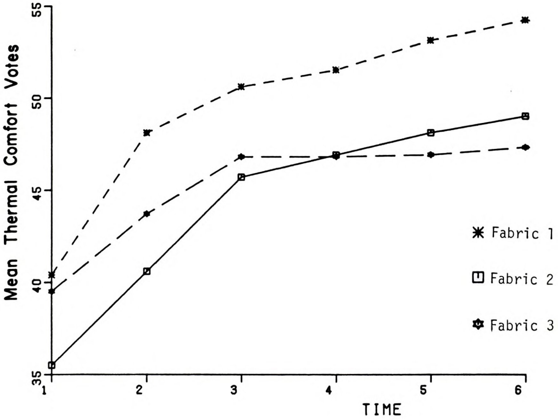


Figure 53.--Mean thermal comfort vote by design.

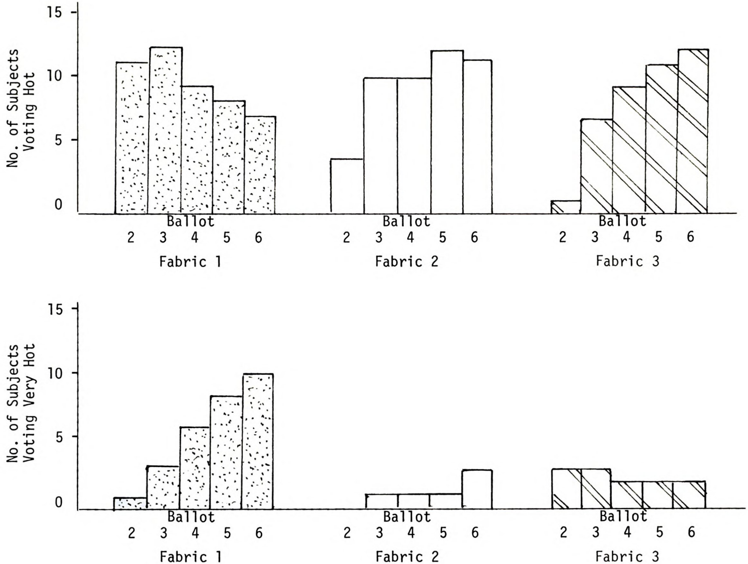


Figure 54.--Number of subjects voting hot or very hot by fabric over time.

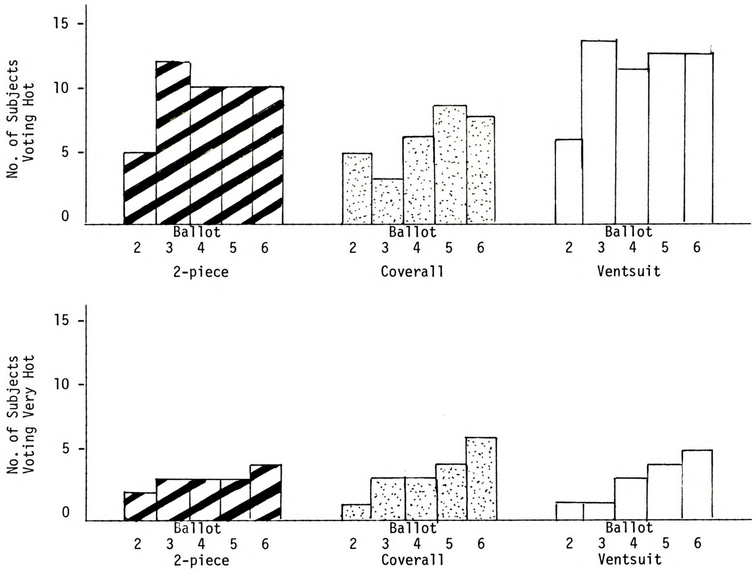


Figure 55.--Number of subjects voting hot or very hot by design over time.

specified the "very hot" category as describing their thermal sensation. Many of them chose category 8 instead.

The results presented for design, shown in Figure 55, do not show any definite pattern.

Summary

The dependent measures graphed over time strongly suggested that those subjects wearing fabric 1 experienced elevated mean temperatures (especially skin temperatures) and also perceived themselves to be hotter and in greater discomfort. The temperature and the perceptual data for fabrics 2 and 3 demonstrated a similar consistent pattern. Lower temperature data and lower thermal comfort (lower value indicated greater comfort) and sensation data were observed for subjects wearing fabrics 2 and 3. In some cases, a decreasing trend over time was readily apparent for these two fabrics, indicating evaporative and/or convective cooling taking place. Clearly, the physiological and perceptual data presented documented that subjects wearing protective fabric 2 experienced similar comfort levels as those given fabric 3, while those assigned protective fabric 1 exhibited greater discomfort.

A clear, consistent pattern was not observable for the dependent measures by design. The temperature data showed a trend toward the highest temperatures being reported for design 3, the ventsuit. This was especially true with fabric 1. It was theorized that a panel of synthetic fabric would promote evaporative and convective cooling of the back. However, only 100% cotton mesh was available at the time of the experiment. The cotton mesh absorbed perspiration (data to be presented in the next section), causing the panel to cling to the back, most likely increasing perceived discomfort. The panel, laden with sweat, may also have added to the metabolic cost of the planned physical activity.

Recalling that jeans and a chambray shirt were specified to represent what was commonly worn by the grower, graphs of the dependent measures for this fabric/design combination were prepared on acetate sheets. This was done to visually compare the results for this cell with the results for the two protective fabrics and the various design variations. This visual examination demonstrated similar data for the control and fabric 2 and considerable differences between the control and fabric 1. To determine if these observed effects were statistically significant, analyses were performed and the results are given in Phase 2 of this chapter.

Phase 2

This section of the findings was partitioned into five subsections. The first three subsections cover the statistical treatment of the major dependent variables for fabric and design. Subsection 1 addresses the thermal sensation votes, subsection 2 explores the data gathered for percentage of sweat that evaporated, and subsection 3 presents the MANOVA results for the set of three dependent measures treated as related aspects of a single response. The results of the chi-square analyses for the two summary variables, anticipated comfort and willingness to wear protective clothing, are given in the fourth

subsection. The final subsection summarizes the results of the data analyses.

Thermal Sensation Votes

As indicated by Figures 54 and 55, which depicted the frequency of thermal sensation votes by fabric-design over time, a definite clustering of votes at the upper end of the scale was apparent. For ballot six, four categories were selected by the subjects to describe their perception of the warmness of their environment, with over half of the subjects choosing category 8 (hot). Thus, categorical analysis of the data was deemed appropriate rather than analytical procedures which relied on the dependent measure being interval data. The categories 6 and 7 were combined, and two 3 x 3 chi-square analyses were performed to determine if thermal sensation response was independent of fabric and design. Two separate analyses were carried out because if the data were broken down for a three-way cross-tabulation, such as is used in log-linear models (see Everitt, 1977), the data would be too sparse.

The frequency of the sixth thermal sensation vote by fabric, given in Table 12, indicated that subjects wearing fabric 1 responded higher on the scale than subjects wearing the other two fabrics. Note that similar responses were given by subjects wearing fabrics 2 and 3. The observed data do not suggest independence, and this was borne out by the chi-square analysis. With 4 degrees of freedom, χ^2 = 11.00, which was statistically significant at the .05 level.

Table 12.--Frequency of the sixth thermal sensation votes by fabric.

Fabric	Thermal Sensation Votes: Warm and Slightly Warm	Hot	Very Hot	Column Total
Fabric 1	1	7	10	18
Fabric 2	4	11	3	18
Fabric 3	4	12	2	18
Row total	9	30	15	54

$\chi^2 = 11.0$ with 4 df, $p < .05$.

The frequency of thermal sensation votes for design (Table 13) do not indicate a clear-cut pattern, although these data do support the trend that those wearing design 3, the ventsuit, considered themselves hot and perceived thermal discomfort. With 4 degrees of freedom, $\chi^2 = 6.866$, which was not statistically significant at the .05 level.

Table 13.--Frequency of the sixth thermal sensation votes by design.

Design	Thermal Sensation Votes: Warm and Slightly Warm	Hot	Very Hot	Column Total
2-piece assembly	4	10	4	18
Coverall	5	7	6	18
Ventsuit	0	13	5	18
Row total	9	30	15	54

$\chi^2 = 6.866$ with 4 df, $p < .05$.

Percentage of Evaporated Sweat

During exercise in a warm environment there is the danger of heat build-up. Vasodilation and the usual increased skin temperature is one of the body's responses as it seeks to maintain thermal equilibrium. This response has been illustrated in a preceding section. However, sweating is another primary mechanism of the body to dissipate heat. In order to be effective as a means of ridding the body of excess heat, evaporation of the sweat must take place. Therefore, the volume of sweat secreted and the percentage of that which is evaporated are important determinants of a person's thermal well-being in a heat-stress environment.

The presence of clothing can seriously impede evaporation. As Fourt and Hollies (1970) pointed out, clothing is not merely a passive skin covering; rather, it interacts with and modifies the heat-regulating function of the skin. Body movement further impacts on the effects of clothing. Figure 56 diagrams the clothing assembly and air layers that formed level one of the human-constructed environment for each test subject.

Typically, a thin air space, the size dependent on the design and fit of the clothing plus air and body movement, separates the various garment layers. These layers of air and fabric add to the resistance of heat and moisture transfer from the body which was at a higher temperature than the environmental chamber (the arrow in Figure 56 indicates the direction of heat and moisture flow from the body through air and fabric to the environment).

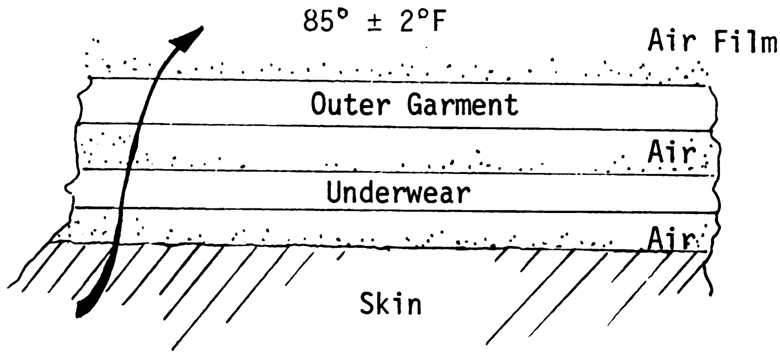


Figure 56.--Diagram of the skin, the HCE_1, and the direction of heat and moisture transfer.

The physical properties of fabrics strongly impact on heat and moisture transfer. But the literature suggests that the effect of design on heat and moisture transfer is less conclusive. The advantage of wetting out of a garment to facilitate evaporative cooling has been documented.

Recognizing the vital role that sweat production and evaporation play in fostering thermal well-being, data on this phenomenon were sought. Unfortunately, due to measurement imprecision, these data should be considered as crude approximations of the phenomenon under investigation, and as such should be viewed as exploratory in nature.

The test clothing varied in its ability to hold and transfer moisture. Table 14 presents the clothing weight change in grams. The change reflects moisture either absorbed (into the fiber, yarn, or fabric structure) or adsorbed (retained on the surface area of

fibers, yarns, or fabric structure) in all of the test clothing provided. A subject's underwear, socks, and test garment were weighed together and the data separated by fabric and design of the outer garment. Table 14 clearly shows a dramatic difference for clothing weight change. Fabric 1 showed a greater weight gain than fabrics 2 or 3. This moisture collected on the inside of the garment to the point of run-off. This problem contributed to the measurement error.

Table 14.--Mean clothing weight change in grams for fabric and design.

Fabric	Design			Fabric Mean Total
	2-Piece Assembly	Coverall	Ventsuit	
Fabric 1	291.467	335.917	488.867	372.083
Fabric 2	118.217	39.183	43.617	67.006
Fabric 3	273.500	159.717	232.100	221.772
Design mean totals	227.728	178.272	254.861	

Design 1, which included denim jeans, showed substantial weight gain as would be expected due to cotton's ability to absorb moisture. Fabric 2 showed relatively little weight gain compared to the other fabrics. Subjects wearing fabric 2 either didn't sweat as much as the other test subjects or they were able to evaporate a greater quantity or a combination of the two. The presence of the 100% cotton panel in the ventsuit likely contributed to the elevated weight changes shown by this variation.

The method of determining volume of evaporated sweat yielded over-estimates; it more accurately reflected sweat that wasn't absorbed or adsorbed in the clothing. Thus, these data should be studied only relative to each other for fabric and design. Table 15 reports the data computed for mean percentage of evaporated sweat by fabric and design. Looking at these data by fabric, one notes that those wearing fabric 2 experienced the highest percentage evaporated sweat and those in fabric 1 showed the lowest percentage. The presence of the two-piece jeans assembly improved the over-all fabric 1 mean. It was interesting that fabric 2 showed greater evaporative power than fabric 3. Interpretation of these data demands caution, yet, despite the over-estimate, a consistent pattern was apparent. This trend suggested that evaporation was enhanced with use of fabric 2, and perhaps more so than fabric 3 (chambray). If indeed this was occurring as the data seem to suggest, this evaporation would have had a cooling effect on these subjects. The skin temperature data for fabric 2 do indicate cooling taking place. No trend was observed for design.

Table 15.--Mean percentage evaporated sweat by fabric and design.

Fabric	Design			Fabric Mean Total
	2-Piece Assembly	Coverall	Ventsuit	
Fabric 1	69.56%	59.15%	52.86%	60.52%
Fabric 2	86.51%	93.52%	93.69%	91.23%
Fabric 3	74.49%	85.16%	76.52%	78.72%
Design mean totals	76.85%	79.28%	74.35%	

Rectal and Weighted Skin Temperatures, Thermal Comfort Responses

The thermal comfort literature repeatedly echoes a theme that an individual's thermal response to the environment has multiple facets. Therefore, the assessment of a person's thermal response should include both physiological and perceptual assessments if the researcher is to tap that multidimensional aspect of thermal comfort. The present experiment was planned and conducted to enable evaluation and comparison of physiological and affective criterion measures of rectal temperature, weighted skin temperature, volume of sweat secreted and percentage evaporated, thermal sensation, and thermal comfort. Two of the dependent measures, as previously noted, required a separate statistical treatment even though they were logically part of the same response. Unfortunately, due to a problem in measurement precision, only crude approximations of percentage of evaporated sweat could be obtained. Recognizing the deficiency of these data, the investigator chose to statistically analyze this variable by itself. The clustering of the second measure, thermal comfort responses, suggested that a statistical technique for categorical data might be more appropriate than a technique which required that the dependent measures have at least ordinal properties. Thus, even though all five dependent measures were related logically and theoretically, only three were selected as the set of dependent measures to be tested as a single response for fabric and design using multivariate statistical analysis.

The use of multivariate techniques is predicated on the notion of "multiple causes" or "multiple outcome variables" that are conceptually meaningful to describe and analyze a phenomenon of interest. Finn (1974) stressed that "in every case, it is critical that the variables of any set share a common conceptual meaning, in order for the multivariate results to be valid" (p. 4). Positive intercorrelation between dependent measures is not in itself a sufficient criterion to designate dependent measures as a "meaningful set" (Finn & Mattsson, 1978).

Multivariate models offer the advantage that if conceptually related measures are intercorrelated (often moderately to highly intercorrelated) or have different variances, the analysis is not invalidated (Finn et al., 1978). Instead, a set of arbitrary variances and intercorrelations is assumed in the model, estimated from the data, and can be used for interpretation and inference.

For this study, a multivariate two-way analysis of variance with three levels of each independent variable was used to test group means on three intercorrelated variables simultaneously. The purpose of the analysis was to investigate mean differences among fabrics and designs on rectal temperature, weighted skin temperature, and perceived thermal comfort. The two-way fixed-effects analysis-of-variance model was:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{jk} + \varepsilon_{ijk} \qquad (5)$$

where: $i = 1,2,3$
$j = 1,2,3$
$k = 1,2,\ldots,6$

In equation (5), μ represents the grand mean, the α's and β's represent fabric and design effects, respectively, while the $(\alpha\beta)$'s connote the interaction effects of fabric and design. The model assumes that ε_{ijk} are independent and identically distributed normal random variables with a mean of 0 and a common variance of σ^2. Therefore, each observed cell variance (s_{ij}^2) is an independent estimate of σ^2 with degrees of freedom equal to 5, i.e., (6-1). The pooled variance estimator, s^2, is used to estimate σ^2 with 45 degrees of freedom (i.e., 9 cells x 5).

Tables 16, 17, and 18 give the observed cell means for the nine cells for each of the dependent measures. Examination of the three tables by fabric showed a consistent trend. Higher temperatures and greater perceived thermal discomfort were characteristic of fabric 1. Fabrics 2 and 3 showed similar mean values for the three dependent measures. However, for design a distinct pattern could not be discerned. Little variation is apparent for weighted skin temperature. Tables 17 and 18 suggested that higher rectal temperatures and greater perceived thermal discomfort were associated with the ventsuit design.

Before proceeding with the MANOVA analysis, the cell standard deviations (Table 19) were examined. Recall that MANOVA does not assume homogeneity of variance across dependent measures. However, the variances for a <u>given dependent measure</u> are assumed to be homogeneous. Thus, for example, the variances for rectal temperature should not vary significantly from one cell to another, but they can be quite different from the variances for thermal comfort. Since

Table 16.--Observed cell means and combined means for weighted skin temperature.

Fabric	Design			Fabric Combined Means
	2-Piece Jeans Assembly	Coverall	Ventsuit	
Fabric 1	95.8367	96.4517	97.5133	96.601
Fabric 2	93.7667	93.2883	93.7400	93.598
Fabric 3	93.3383	83.6800	93.5583	93.526
Design combined means	94.314	94.473	94.937	94.575 = grand mean

Table 17.--Observed cell means and combined means for rectal temperature.

Fabric	Design			Fabric Combined Means
	2-Piece Jeans Assembly	Coverall	Ventsuit	
Fabric 1	99.7700	99.8900	100.7583	100.139
Fabric 2	99.7867	99.8117	100.0467	99.882
Fabric 3	99.7717	99.6433	99.7000	99.705
Design combined means	99.776	99.782	100.168	99.909 = grand mean

there were equal cell sizes, the Hartley test (Neter & Wasserman, 1974) was used to test for homogeneity of variance. Since this assumption was met, a multivariate extension of the usual F-test was used to test Hypotheses 1-3, 5-7, and 9 listed in Chapter I.

Table 18.--Observed cell means and combined means for thermal comfort responses.

Fabric	Design: 2-Piece Jeans Assembly	Design: Coverall	Design: Ventsuit	Fabric Combined Means
Fabric 1	51.1667	54.8333	56.5000	54.17
Fabric 2	51.8333	46.1667	49.0000	49.00
Fabric 3	47.0000	44.0000	51.0000	47.33
Design combined means	50.0000	48.3333	52.1700	50.17 = grand mean

Table 19.--Cell standard deviations for rectal temperature, mean skin temperature, and thermal comfort.

Fabric	Design	Std. Dev. for Rectal Temperature	Std. Dev. for Weighted Skin Temperature	Std. Dev. for Thermal Comfort
1	2-piece	.361	.543	9.988
1	coverall	.653	1.173	8.931
1	ventsuit	.348	.187	7.556
2	2-piece	.242	1.190	6.940
2	coverall	1.015	.970	9.538
2	ventsuit	.526	1.145	5.692
3	2-piece	.692	.972	7.563
3	coverall	.354	1.343	11.645
3	ventsuit	.406	.910	6.164

A summary of the results of the MANOVA analysis is presented in Table 20. Examination of the multivariate F for fabric and design interaction indicated no statistical significance. Therefore, we were able to proceed with the test of significant differences among means for the three levels of design. The multivariate F of equality of mean vectors for design was 1.44 with degrees of freedom of 2 and 45, which was not significant. The multivariate F for fabric equalled 14.07, which was highly significant at the .0001 level, with 2 and 45 degrees of freedom. Thus, there was a significant effect of fabric on the set of dependent measures.

Table 20.--Summary of analysis of variance for thermal-analysis study.

Source of Variation	df	Tests of Significance: Multivariate F-Values: F	p***	Univariate F-Values: Rectal Temp.	Weighted Skin Temp.	Thermal Comfort Response
Constant	1	--	--			
Fabric	2	14.07	.0001	2.75*	55.74**	3.22**
Design	2	1.44	.2098	2.91*	1.90	.94
Fabric & design interaction	4	1.07	.3942	1.57	1.53	.71
Mean sq. error	45			.312	.994	71.00
Pooled std. dev.				.559	.997	8.43
Total	54					

*Significant at p < .10.

**Significant at p < .05.

***These are exact alpha levels.

The multivariate test statistic is used for an initial decision about the null hypothesis. Once this test statistic has been found significant, then it is appropriate to examine the set of univariate results computed by the Multivariance program. These F-ratios are the results that would have been obtained if each dependent measure had been considered in isolation in a simple one-variable analysis. Since the dependent measures are intercorrelated, the univariate F-statistics are not independent of one another. However, they do have interpretive value. Clearly, weighted mean skin temperature, which was most affected by fabric, was primarily responsible for the significant effect. Rectal temperature and thermal comfort also contributed to the significant effect.

It is important to note that because the multivariate F for design was not significant, the univariate results were not discussed. Without the protection of a significant multivariate F-test, separate univariate decisions are suspect since statistical error rates are likely inflated (Finn et al., 1978).

From Table 16, which presents the observed cell means for weighted skin temperature, the data clearly suggest that fabric 1 was significantly different from the second protective fabric and from fabric 3, thus being the contributor for the significant MANOVA fabric effect. Since the weighted skin temperature data for fabrics 2 and 3 were so similar, and because fabric 3 was originally chosen as a control, univariate confidence intervals were constructed to estimate the magnitude of the difference between fabric 1 and fabric 3 for the three dependent measures. Table 21 presents the

results of this post-hoc procedure. The interpretation would be that the difference between fabrics 1 and 3 for weighted mean skin temperature, for example, would be in the range from 2.4 to 3.75.

Table 21.--Confidence intervals for the difference in effect of fabric 1 and fabric 3.

Dependent Variable	Estimated Effect of Differences $\alpha_1 - \alpha_3$	Standard Error of $\alpha_1 - \alpha_3$	95% Confidence Interval for True Difference in Effects, $\alpha_1 - \alpha_3$
Rectal temperature	.4344	.186	.06 to .81
Weighted skin temperature	3.075	.332	2.40 to 3.75
Thermal comfort	6.833	2.809	1.16 to 12.51

df = 45

Summary Questions

At the completion of the experiment, the subjects were asked to respond to two summary questions. The first requested that the subjects evaluate their experienced comfort versus their anticipated comfort for the test garment that they had been assigned. The findings for this variable by fabric are given in Table 22. Although very few subjects found the test clothing cooler than what they had anticipated, it was interesting that almost all who did were wearing fabric 2. Of the 24 students who found their assigned clothing warmer than they had expected, over 70% had worn fabric 1.

Table 22.--Cross-tabulation for anticipated comfort by fabric.

Fabric	Anticipated Comfort			Row Total
	Cooler	About the Same	Warmer	
Fabric 1	0[a] 0%[b] (0%)[c]	5 29.4% (22.7%)	12 70.6% (50.0%)	17
Fabric 2	6 33.3% (85.7%)	7 38.9% (31.8%)	5 27.8% (20.8%)	18
Fabric 3	1 5.6% (14.3%)	10 55.6% (45.5%)	7 38.9% (29.2%)	18
Column total	(7)	(22)	(24)	53

χ^2 = 6.911 with 2 df, $p < .05$.

[a]Indicates number of subjects.

[b]Indicates row percentage.

[c]Indicates column percentage.

Since the expected cell size was less than five in the column labelled "cooler," this column was combined with the column "about the same" before chi-square analysis was performed. Analysis yielded χ^2 = 6.911 with 2 degrees of freedom, which was significant at the .05 level.

As Table 23 indicates, the data for anticipated comfort by design did not suggest a meaningful pattern. When anticipated comfort was analyzed by design, the null hypothesis of independence could not be rejected. With 4 degrees of freedom, χ^2 = 2.197, which was not significant at the .05 level.

Table 23.--Cross-tabulation for anticipated comfort by design.

Design	Anticipated Comfort			Row Total
	Cooler	About the Same	Warmer	
Ventsuit	3[a] 16.7%[b] (42.9%)[c]	7 38.9% (31.8%)	8 44.4% (33.3%)	18
Coverall	3 17.6% (42.9%)	8 47.1% (36.4%)	6 35.3% (25.0%)	17
2-piece jeans assembly	1 5.6% (14.3%)	7 38.9% (31.8%)	10 55.6% (41.7%)	18
Column total	7	22	24	53

$\chi^2 = 2.197$ with 2 df, $p > .05$.

[a]Indicates number of subjects.

[b]Indicates row percentage.

[c]Indicates column percentage.

Willingness to wear the test garments was assessed after informing the subjects that the clothing provided protection against harmful chemicals in the workplace. The frequency of responses for this variable by fabric is shown in Table 24. Of the 54 subjects responding, only two would be unwilling to wear the protective clothing. Examination of the remainder of the responses indicated a modest trend. Almost 56% of the subjects wearing fabric 1 were either unwilling to wear the garment or willing, only if required to do so. A modest 16.7% indicated that they would be willing to wear fabric 1 under environmental conditions similar to the test. This percentage willing to wear the test clothing under similar climatological

conditions increased to almost 39% for those wearing fabric 2 and 50% for those given fabric 3. A reverse trend was apparent for those subjects who responded that they would only wear the clothing if required, as shown in Table 24.

It is important to emphasize that these findings are not generalizable to a larger population. At the planning stages of the experiment, the investigator recognized that a myriad of factors impact on an individual's willingness to wear protective clothing. These data were collected to gain possible insights and to facilitate comparison with future field data.

Before chi-square analysis was used to test for independence, column 4 (not willing to wear) was combined with column 3 (willing to wear only if required). Results of the analysis indicated $\chi^2 = 4.83$ with 4 degrees of freedom, which was not significant at the .05 level.

The data for willingness to wear the test garment by design are displayed in Table 25. Of the subjects wearing the ventsuit, almost 39% indicated that they would be willing to wear the garment under environmental conditions similar to the test. Recall that although a consistent pattern did not emerge for design in the data presented in the Phase 1 findings, yet there was a tendency for those wearing the ventsuit to exhibit higher temperatures and to perceive greater discomfort. This was most apparent for those in fabric 1. Recognizing this, further information regarding the fabric worn by these subjects was sought. Of the seven subjects willing to wear the ventsuit under similar conditions, one wore fabric 1, three

Table 24.--Cross-tabulation for willingness to wear protective clothing by fabric.

Fabric	Willingness to Wear Test Clothing				Row Total
	Willing to Wear Under Temp. Conditions Equal to Test	Willing to Wear if Temp. Was Less Than 85°F	Willing to Wear if Required to Do So	Not Willing to Wear	
Fabric 1	3[a] 16.7%[b] (15.8%)[c]	5 27.8% (38.5%)	9 50.0% (45.0%)	1 5.6% (50.0%)	18
Fabric 2	7 38.9% (36.8%)	4 22.2% (30.8%)	6 33.3% (30.0%)	1 5.6% (50.0%)	18
Fabric 3	9 50.0% (47.4%)	4 22.2% (30.8%)	5 27.8% (25.0%)	0 0 0	18
Column total	19	13	20	2	54

$\chi^2 = 4.83$ with 4 df, $p > .05$.

[a]Indicates number of subjects.

[b]Indicates row percentage.

[c]Indicates column percentage.

Table 25.--Cross-tabulation for willingness to wear protective clothing by design.

Fabric	Willingness to Wear Test Clothing: Willing to Wear Under Temp. Conditions Equal to Test	Willing to Wear if Temp. Was Less Than 85°F	Willing to Wear if Required to Do So	Not Willing to Wear	Row Total
Ventsuit	7[a] 38.9%[b] (36.8%)	1 5.6% (7.7%)	10 55.6% (50.0%)	0 0 0	18
Coverall	4 22.2% (21.1%)	7 38.9% (53.8%)	6 33.3% (30.0%)	1 5.6% (50.0%)	18
2-piece jeans assembly	8 44.4% (42.1%)	5 27.8% (38.5%)	4 22.2% (20.0%)	1 5.6% (50.0%)	18
Column total	19	13	20	2	54

$\chi^2 = 7.4$ with 4 df, $p > .05$.

[a]Indicates number of subjects.

[b]Indicates row percentage.

[c]Indicates column percentage.

wore fabric 2 and three wore fabric 3. Evidently one subject who wore the fabric 2 ventsuit either did not find the situation thermally burdensome or he perceived the dangers from hazardous chemicals to outweigh the discomfort. There were two other subjects who wore fabric 1 and yet were willing to adopt the garment for use under similar conditions. Both of these subjects, however, wore design 3, that is, the fabric 1 shirt and the denim jeans.

Further examination of Table 25 did not suggest any over-all trends. Chi-square analysis with columns 3 and 4 combined gave $\chi^2 = 7.4$ with 4 degrees of freedom, which was not statistically significant at the .05 level.

Summary

The phase 1 graphical representation of the dependent measures over time clearly indicated that elevated temperatures and greater perceived thermal discomfort were associated with fabric 1, the spunbonded olefin fabric. Similar data, both physiological temperature data and perceived thermal comfort and sensation, were observed for fabric 2 (the three-layer laminate) and fabric 3 (chambray). Many of the temperature graphs for fabrics 2 and 3 indicated an over-all decreasing trend over time. This was in marked contrast to fabric 1.

No clear-cut patterns were apparent for design, although the data suggested that higher temperatures and greater thermal discomfort were characteristic of design 3 (the ventsuit), especially when constructed in fabric 1.

The second phase of the data treatment focused on hypotheses testing. The hypotheses tested, the methods of analyses, and the results are summarized in Table 26. Examination of the table shows that none of the hypotheses for design was rejected, whereas all of the hypotheses for fabric except willingness to wear were rejected.

Mean rectal temperature, mean weighted skin temperature (time = 90 minutes), and the thermal comfort votes (sixth ballot) were treated as a set of conceptually related dependent measures that represented different facets of a single response. As such, multivariate statistical techniques were used to test Hypotheses 1-3, 5-7, and 9. The MANOVA results indicated that mean differences in the dependent measures for fabric were significant at the .0001 level. Mean weighted skin temperature strongly contributed to this statistically significant finding. There were no significant differences detected for design at the .05 level. Confidence intervals indicated that the three dependent measures for fabric 1 were significantly different from those measures for fabric 3.

Thermal sensation votes, which were in general clustered at the upper end of the nine-point scale, were highest for subjects wearing fabric 1. As Table 26 indicates, results of the chi-square test of independence for thermal sensation and fabric (H_0^4) did not support independence. The null hypothesis for design (H_0^8) could not be rejected, however.

Unfortunately, measurement error was a problem for data gathered to investigate the percentage of evaporated sweat. Therefore, means and standard deviations were computed solely for

Table 26.--Summary table of results of inferential statistics.

Null Hypothesis Tested	Statistical Procedure Employed	Value of the Test Statistic	Signif. Level	Decision
1. No significant fabric difference by mean weighted skin temperature	MANOVA	Mult. F=14.07 Univ. F=55.74	<.01 <.05	Reject
2. No significant fabric difference by mean rectal temperature	MANOVA	Mult. F=14.07 Univ. F= 2.75	<.01 <.10	Reject
3. No significant fabric difference by mean thermal comfort votes	MANOVA	Mult. F=14.07 Univ. F= 3.22	<.01 <.05	Reject
4. Mean thermal sensation votes are independent of fabric	Chi-square test of independence	χ^2=11.0	<.05	Reject
5. No significant design difference by mean weighted skin temperature	MANOVA	Mult. F=1.44* Univ. F=1.9	>.20 >.05	Failed to reject
6. No signficant design difference by mean rectal temperature.	MANOVA	Mult. F=1.44* Univ. F=2.91	>.20 >.05	Failed to reject
7. No significant design difference by mean thermal comfort votes.	MANOVA	Mult. F=1.44* Univ. F= .94	>.20 >.05	Failed to reject
8. Mean thermal sensation votes are independent of design	Chi-square test of independence	χ^2=6.87	>.05	Failed to reject

Table 26.--Continued.

Null Hypothesis Tested	Statistical Procedure Employed	Value of the Test Statistic	Signif. Level	Decision
9. No significant interaction between fabric and design	MANOVA	F=1.07	>.30	Failed to reject
10. No significant fabric difference by percent of evaporated sweat	Not tested due to measurement error			
11. No significant design difference by percent of evaporated sweat	Not tested due to measurement error			
12. Anticipated comfort was independent of fabric	Chi-square test of independence	χ^2=6.91	<.05	Reject
13. Anticipated comfort was independent of design	Chi-square test of independence	χ^2=2.2	>.05	Failed to reject
14. Willingness to wear protective clothing was independent of fabric	Chi-square test of independence	χ^2=4.83	>.05	Failed to reject
15. Willingness to wear protective clothing was independent of design	Chi-square test of independence	χ^2=7.4	>.05	Failed to reject

*Without a significant multivariate F, the separate univariate results are viewed as "suspect" since statistical error rates may be inflated (Finn et al., 1978).

exploratory purposes. The null hypotheses H_0^{10} and H_0^{11} were not, therefore, tested. Despite the deficiencies of these data, a trend was apparent. Subjects wearing fabric 2 exhibited the highest percentage of evaporated sweat, and those in fabric 1 the lowest percentage. Investigation of the moisture adsorbed or absorbed by the test clothing indicated that the greatest increase in weight was associated with fabric 1 and the least with fabric 2. This concurred with on-site observation of the investigator at the end of the test sessions. Moisture had collected to the point of run-off on the inside of garments constructed of fabric 1.

Anticipated comfort and willingness to wear protective clothing were analyzed using chi-square analyses by fabric and design. The null hypothesis of independence for anticipated comfort and fabric (H_0^{12}) was rejected at the .05 level. Willingness to wear protective clothing and fabric (H_0^{14}) and the null hypotheses H_0^{13} and H_0^{15} for design could not be rejected at $p < .05$.

Thus, both phases of the data treatment yielded a consistent, unmistakable pattern for fabric. Subjects wearing fabric 2 (three-layer laminate) and fabric 3 (100% cotton chambray) experienced a similar level of thermal comfort, as indicated by both physiological and perceptual measures. Subjects wearing fabric 1 (the spun-bonded olefin) experienced higher temperatures, lower percentage of evaporated sweat, greater perceived discomfort, and higher perceived thermal sensation. Clearly, evaporative and/or convective cooling was taking place for subjects wearing fabrics 2 and 3. When these results are examined in conjunction with the physical characteristics of the test

fabrics given in Table 9, implications for the ASTM test methods emerged. Air permeability is frequently used as an indication of the "breathability" of a fabric. Results of the air-permeability testing indicated no air flow through fabric 2 and approximately 190 $ft^3/min/ft^2$ through fabric 3, an appreciable difference. Yet, the present study found the thermal response to both fabrics during wear-testing very similar. The data suggest that either air permeability was not a good indicator of "breathability" or that the Gurley Tester did not adequately determine the air permeability of fabric 2, or both.

Design clearly did not influence thermal response as fabric did. The ventilating panel not only did not improve thermal well-being, but the data suggested that it might have added to the thermal burden. Ventsuits constructed of fabric 1 showed an increased post-test weight that was markedly higher than any other combination. Most likely as the panel became saturated with sweat, the panel clung to the undershirt and both probably hugged the back, thus eliminating air spaces between the clothing layers. This could well have contributed to the perceived increased discomfort recorded by subjects wearing this test garment.

CHAPTER V

SUMMARY AND CONCLUSIONS

This chapter has been organized to cover four topics. First, a summary of the thermal-analysis study and the context within which this study was conducted is presented. Second, the limitations of the study are identified. The enumeration of the limitations offers a prelude to the two concluding sections of the chapter, implications of the study and recommendations for future research.

Summary

Agricultural pesticide usage has continued to increase. California alone doubled its usage of pesticides to more than 111 million pounds, between 1974 and 1977 (Doutt, 1979). The Environmental Protection Agency has been charged with a variety of monitoring, standard-setting, and enforcement activities related to the usage of pesticides. Both acute and chronic adverse health effects continue to be documented for agricultural workers occupationally exposed to pesticides, despite efforts to reduce the hazard through elimination of toxic pesticides, the establishment of "safe" reentry periods, and the installation of various health and workplace monitoring systems. Pesticide poisoning incidence data are difficult to obtain, and various approaches have been tried by different countries. However, the World Health Organization estimates that approximately 500,000

cases occur annually worldwide, with about a 1% fatality rate (Davies & Enos, 1980).

The use of protective clothing has been recommended to reduce workers' dermal exposure to pesticides. Of the three routes of pesticide entry into the human body (i.e., respiratory, dermal, and ingestion), dermal exposure is considered the primary mechanism (Hanset et al., 1980; Taylor et al., 1978). Protective clothing is one strategy for reducing dermal exposure that is applicable for all of the major categories of workers occupationally exposed to pesticides. However, the clothing which has been designed to provide protection is unacceptable to many of the individuals who have been shown to need it most. Emphasis has been directed toward finding an impermeable fabric, rather than an examination of the whole problem. Attention has not been focused on the issue of thermal comfort of agricultural workers toiling in a hot environment, a problem which contributes toward lack of user acceptance.

In the fall of 1978, Jacquelyn Orlando De Jonge, Ph.D., then Associate Professor in the Department of Human Environment and Design, Michigan State University, currently Head and Professor of the Department of Textiles, Merchandising and Design, University of Tennessee, initiated a major research investigation aimed at limiting the dermal exposure of the independent fruit grower to pesticides, while maintaining acceptable thermal-comfort levels through the development of functionally designed protective garments. Although the major focus of the study was directed toward Michigan fruit growers who apply pesticides by air-blast spray methods, the protective clothing being

developed would be appropriate for a much larger population as well. This research has been supported by the Michigan State University Agricultural Experiment Station and the North Central and Southern Pesticide Impact Assessment Programs.

The present study, one component of this over-all research project, was undertaken to evaluate the thermal response of subjects wearing selected protective fabric/design combinations under controlled environmental conditions simulating Michigan summer weather conditions. This study was conducted at the Institute for Environmental Research at Kansas State University, a facility that permitted the monitoring of the subjects' physiological responses while controlling environmental variables at prescribed levels. An ecological perspective served as the framework for this study.

Dependent Variables

Thermal response was assessed by weighted mean skin temperature, rectal temperature, percent of evaporated sweat, and perceived thermal comfort and thermal sensation. Data on willingness to wear protective clothing and anticipated comfort were also obtained.

Independent Variables

Three fabrics whose characteristics as barriers to pesticide penetration were known were selected for evaluation. Fabrics 1 and 2 had been shown to offer excellent resistance to pesticide penetration in an earlier phase of the total research project (Orlando et al., 1981). Fabric 3 had shown poor resistance to pesticide penetration in the same study cited above, but was selected since it is frequently

now worn by the grower for pesticide application. Fabric 1 was a disposable polyethylene-coated 100% spun-bonded olefin fabric. Fabric 2 was a three-layer laminate construction consisting of an outer woven ripstop 100% nylon/a thin microporous polymeric film of polytetrafluoroethylene/and an inner 100% nylon tricot. Fabric 3 was a woven 100% cotton chambray shirting fabric. The physical characteristics of the test fabrics are given in Table 9, Chapter III.

Three design variations were specified. Design 1 included a long-sleeved traditional-styled shirt and denim jeans. Only the shirt fabric was varied in the three test fabrics. This procedure enabled examination of the thermal response associated with a protective garment that was a partial body covering. This was a serious concern since only limited data were available on which areas of the body received pesticide deposition during actual field spray operations. The combination of denim jeans and fabric 3 represented what was commonly worn by the grower for pesticide application.

Designs 2 and 3 were both coverall designs, developed to cover areas of the body anticipated to be areas of high pesticide deposition. In addition to pesticide protection, other needs of the growers, including movement, thermal comfort, and safety from farm accidents, influenced the development of designs 2 and 3. Figures 11, 12, and 13, Chapter III, illustrate the three design variations.

Controlled Variables

Because the focus of the study was on evaluating the sensation of thermal comfort and the accompanying physiological measures

associated with wearing selected garments, numerous variables which impact on thermal comfort had to be controlled. In using an ecological framework, these variables were organized into those relative to the human environed unit (each test subject), the human behavioral environment (the researcher and other test subjects present in the chamber with the HEU), and the human constructed environment--level 2 (climatological conditions within the test chamber). The controlled variables are given in Table 27.

Table 27.--Summary of controlled environmental variables.

	Variable	Control Specification
Human Environed Unit	Age	18-25 years
	Sex	Male
	Psyche	Random assignment
	Body type	All wore same size garment
	Physical condition	Physical examination required
	Food/drink intake	Standard breakfast provided
	Physical activity	3 mets
	Exposure time	30 min preconditioning, 2 hr exposure
Human Constructed $Environment_2$	Dry-bulb air temp.	85°F
	Mean radiant temp.	85°F
	Relative humidity	60°
	Air movement	Still air (.15 m/s)
Human Behavioral Environment	Verbal interaction between subjects	Discussing test clothing and test conditions not permitted

Experimental Design and Sample

A 3 x 3 complete factorial experimental design with six replications was used. Fifty-four male students, attending Kansas State University, served as test subjects. The students were recruited through newspaper advertisements and were required to pass a physical examination before being accepted as a test subject. Each qualified test subject was expected to wear one test garment for one test session and was paid for his participation. Twelve test sessions of two-hour duration were held in a six-day period in the spring of 1980. Between two and six persons constituted a test group. All testing was done in the morning.

Test Protocol

All test subjects were fed a 600-calorie (20-25 g protein) breakfast the morning of their scheduled test. Following breakfast, the subjects reported to the pre-conditioning room at the Institute for a 30-minute orientation. After the procedures were outlined to the students, test clothing, consisting of the experimental garment, white socks, jockey shorts, and undershirt, was issued to each subject. They were instructed to change their clothing, insert the rectal probe, put on the heart-monitoring harness, and then to return to the pre-test room. When they returned, skin thermistors were taped to each subject with micropore surgical tape in three locations: the right pectoral region of the chest, the radial surface of the left arm (or right arm if the individual was left-handed), and the fibular surface of the left leg. A pre-test weight of each subject was taken.

The subjects then entered the test chamber. In order to simulate the work accomplished in applying pesticides using a tractor, an activity pattern was established. A nine-minute rest period was followed by six minutes of walking up and down steps to a specified cadence. This pattern was continued for the two-hour duration of the test. The students were free to read or to speak to each other throughout the test, with the restriction that they not discuss the experiment. A thermos jug of water was provided for each student, and they could drink if they chose to.

During the eight rest periods, the subjects completed two ballots, a nine-category thermal sensation scale, and a nine-category semantic differential comfort scale. Both ballots were collected after each vote. Skin temperature and rectal temperature were monitored in a control room located near the test chamber throughout the test. A subject whose rectal temperature rose 2°F was removed from the test. Heart rate was monitored by the test subjects for safety reasons and not for analysis. A registered nurse was present throughout the experiment.

Upon completion of the test, subjects were disconnected, taken to the pre-conditioning room, and weighed. Monitoring devices were removed, subjects changed their clothing, and they returned to the pre-conditioning room to complete two summary questions. Students, after being informed of the protective characteristics of the clothing that they had been wearing, were asked to indicate their willingness to wear such clothing. Information on their anticipated comfort versus their experienced comfort was also requested.

Findings

Data were treated in two distinct phases. The dependent measures were first graphed over time for fabric and design. The second phase was devoted to inferential statistics.

Examination of the graphs of the dependent measures over time demonstrated a consistent trend. Subjects wearing fabrics 2 and 3 showed similar temperature data and perceptual responses over time. Besides exhibiting similar temperature, a number of the plots showed an over-all decreasing trend over time for these two fabrics, indicating that convective and/or evaporative cooling was taking place. In contrast to this pattern, subjects wearing fabric 1 were found to have higher temperature readings. These subjects also perceived themselves to be hotter and in greater discomfort than subjects wearing fabrics 2 and 3.

Thus fabric 2, the three-layer laminate fabric which had previously been shown to be an effective barrier to pesticide spray, was found to offer a similar level of thermal comfort as fabric 3, the 100% woven cotton chambray. Fabric 3 was selected for inclusion in this study, not because of its protective qualities, but rather due to its comfort characteristics. Fabric 3 is frequently now worn by the grower for pesticide application. Therefore, fabric 2 elicited similar thermal comfort responses (assessed by both physiological and perceptual measures) as fabric 3 did, yet this three-layer laminate offered significantly better protection against pesticide penetration than fabric 3.

Examination of the same data for design did not yield any evidence of a clear trend. There was a tendency, however, for the ventsuit design to be more thermally burdensome than the other two designs. Clothing that is worn while performing activities adds to the metabolic costs for the body, the percentage dependent on various factors including clothing weight, number of layers, and thickness (Fourt & Hollies, 1970). The ventsuit design featured an additional inner fabric layer (a 100% cotton mesh) in the back torso region. During the experiment, this mesh panel became saturated with sweat, providing both thermal advantages and disadvantages. As illustrated in Figure 57, as the panel became wetted out with sweat, the skin surface was brought closer to the fabric surface and therefore had less resistance to evaporation. This condition offered an advantage for increased cooling. Yet, clothing wet with sweat has disadvandates also, for example, clinging to the body and to other clothing. This, as noted previously, places greater burden on motion, a drag effect.

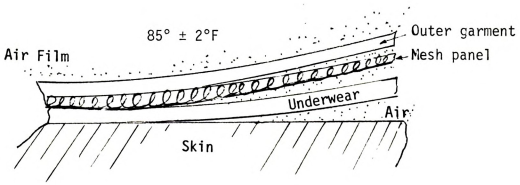


Figure 57.--Diagram of moist panel clinging to skin.

There are still other factors that likely impacted on perceived thermal comfort and sensation, namely the extent of specific contact area and the transient contact effects. As indicated in Figure 57, the contact area increased with sweating as the panel tended to cling to the undershirt and back. Subjects consistently rated their sensation of thermal comfort as dissatisfied or uncomfortable. Last, the multiple layers could also have contributed to the thermal burden.

Mean rectal temperature, mean weighted skin temperature (time = 90 minutes), and mean thermal sensation votes (sixth ballot) were treated as a set of conceptually related dependent measures that represented different facets of a single response. As such, multivariate statistical techniques were used to test the hypotheses identified in Chapter I. The advantage of multivariate models was that with conceptually related measures that are intercorrelated or have different variances, the statistical analysis was not invalidated. The MANOVA results indicated that mean differences in the dependent measures for fabric were significant at the .0001 level. Mean weighted skin temperature strongly contributed to this statistically significant finding. There were no significant differences detected for design at the .05 level. Confidence intervals indicated that the three dependent measures for fabric 1 were significantly different from those measures for fabric 3.

Thermal sensation votes, which were clustered at the upper end of the nine-point scale, were not included in the MANOVA analysis. Results of the chi-square analysis showed that the null hypothesis of

independence for fabric was rejected at the .05 level. However, the null hypothesis for design was not rejected.

Although measurement error was a problem for determination of percent of evaporated sweat, a clear trend was apparent. Subjects wearing fabric 2 (three-layer laminate structure) exhibited the highest percentage of evaporated sweat, and those in fabric 1 (spunbonded olefin fabric) the lowest percentage. Investigation of the moisture adsorbed or absorbed by the test clothing indicated that the greatest increase in weight was associated with fabric 1 and the least with fabric 2. The data indicated that evaporation was taking place for fabric 2, the fabric that showed similar physiological and perceptual data as fabric 3, the 100% cotton chambray.

Anticipated comfort and willingness to wear protective clothing were analyzed using chi-square analyses by fabric and design. Information on these two variables was obtained even though the ability to generalize from the data was limited. The null hypothesis of independence for anticipated comfort and fabric was rejected at the .05 level. The data suggested that the majority of students who had found their test clothing cooler than they expected were wearing fabric 2, and 70% of those who rated the clothing warmer than they anticipated were wearing fabric 1. The null hypothesis of independence for this variable and design could not be rejected at the .05 level.

The data for willingness to wear protective clothing did not suggest any meaningful pattern for either design or fabric. Neither null hypothesis of independence could be rejected. The majority of

the subjects were willing to wear the clothing either voluntarily or if required to do so.

Thus, both phases of the data treatment yielded a consistent, unmistakable pattern for fabric, but not design. These analyses confirmed that one protective fabric, the three-layer laminate (fabric 2), offered similar thermal-comfort levels as the 100% cotton chambray (fabric 3). The coverall design appeared to be as comfortable as the two-piece jeans and shirt. There was a slight trend for the ventsuit coverall to offer less thermal comfort than the other two designs.

Limitations of the Study

1. This study was limited to male college students, aged 18 to 25, at Kansas State University, in the spring of 1980. It was felt that the physiological measures, and to a lesser extent the perceptual measures, would likely be somewhat invariant across different male populations at similar levels of physical fitness. The conclusions for the two summary measures should be restricted to the population under study.

2. Students were recruited through newspaper advertisements and were paid $20 for their participation. This "encouragement" to participate and the method of acquiring a sample could have influenced their responses to the perceptual and summary measures.

3. The study was conducted in an environmentally controlled laboratory that was maintained at a temperature/humidity level to simulate Michigan summers. Yet, air movement was only that of still air. In the natural environment, the myriad combinations of

temperature, humidity, air movement, and presence of trees, etc., could significantly impact on man's thermal response. Because of the air-movement specification, the test condition was probably more thermally burdensome than 85°F, 60% r.h. would be under normal conditions.

4. Methods used for gathering evaporated-sweat data were not sufficiently precise to tap this variable as desired. A standard towel-drying procedure would have to be carefully planned, rigidly carried out with no exceptions, and the towel would need to be placed in a plastic bag to minimize evaporation for immediate weighing. Some provision would need to be made for the problem of run-off. Suggestions by Fourt and Hollies (1970) would be impractical to implement.

5. This study evaluated and compared the thermal response of subjects wearing selected fabrics. The results cannot be generalized to other nonwoven and laminate fabrics. The designs tested should not be considered inclusive for what is possible for protective clothing.

6. Two different chambray fabrics were used in this study. Purchased chambray yard goods were used to construct the two coverall designs, and ready-to-wear chambray shirts were purchased for the two-piece design variations.

Implications

The findings of this study had immediate implications for the ultimate objective of the over-all research project--that is, the development of protective apparel for pesticide users that offered

acceptable thermal-comfort levels. Henry's work (1980) indicated that the likelihood of eventual adoption of protective clothing by the independent growers would be enhanced if the protective garment's appearance was similar to their present work clothing. Thus, no serious consideration was given to designing garments requiring a power source for cooling. It was felt that the growers would find such clothing incompatible with their work activities and their values. Emphasis, rather, was directed toward finding a suitable fabric and an effective design that offered increased dermal protection from pesticides and a similar level of thermal comfort as commonly worn work clothing. The findings of this study offered encouragement that the ultimate goal was feasible.

However, only a limited number of fabrics and designs could be evaluated in this study. Using human subjects in a climatically controlled chamber was an expensive mode of studying thermal response. And while the literature frequently recommended human-subject testing to fully evaluate thermal response to garments and climatological conditions, nevertheless a less costly means of assessing the potential thermal comfort of fabrics and designs yet to be developed would be very beneficial to the over-all research effort.

There are also methodological implications from this study. Measurement error was a problem with the determination of percentage of sweat that evaporated. Refinement of techniques to tap this vital variable is needed. The data suggest that if it is not feasible to monitor all of the dependent variables used in this study, mean skin temperature is a good predictor of thermal comfort. Also, the

nine-point thermal-sensation ballot needs further refinement. The deficiency of the scale was apparent in this heat-stress situation where many votes were clustered at the upper end of the scale.

In addition, the conduct of the thermal-analysis study and the review of the thermal-comfort literature resulted in the generation of design specifications. This enabled meeting objective 4. These specifications are in support of the total over-all project objective to develop functionally designed work clothing that is protective for pesticide application, while being thermally and socially acceptable. Therefore, several of the design specifications enumerated below were derived from previous components of the total project. They are listed here to permit a complete listing of the thermal design specifications.

Design Specifications

The following design specifications were generated from previous components of the over-all research project:

1. The garment should be perceived by the users as providing thermal comfort.

2. The design should be capable of being worn over other clothing.

3. The garment should be such that users will be willing to wear the protective garments for a range of environmental conditions.

The following specifications for design and for fabric were generated as an outcome of the review of the thermal-comfort literature and the findings of the thermal-analysis study:

4. The garment design should promote evaporative and convective cooling through the use of any of the following:

- fabric combinations
- wide openings at the neckline, sleeve, and pants edges
- vents or air holes in areas of low deposition
- means for increasing air flow within garment sections

5. The design should promote conductive cooling, particularly in the upper torso areas.

6. The design should be capable of being adjusted to promote thermal comfort for a range of environmental conditions.

7. The design should promote thermal comfort when the grower isn't spraying by being easily adjustable with a gloved hand.

8. The design should promote air exchange between the environment and the body.

9. The fit and design of the garment should minimize physical contact between the skin and the garment, particularly in the upper torso area.

10. The garment should provide a similar level of thermal comfort as that shown for denim jeans and a long-sleeved chambray shirt. (Level of comfort--as assessed by weighted skin temperature, rectal temperature, percentage of evaporated sweat, and perceived comfort.)

11. The fabric should promote evaporative cooling by allowing body perspiration to be dissipated through the garment to the environment, at a level equivalent to denim jeans and a long-sleeved shirt.

12. The fabric should promote convective cooling of the body.

13. The color of the fabric should be specified so as to minimize heat gain from the environment by radiation.

But the implications of the study also go beyond the overall research project, whose scope was depicted in Figure 4 (Chapter I). The findings strongly suggest that fabric 2 offers both protection and thermal comfort. However, fabric 2 is an expensive reusable fabric that, if finally adopted for this end-use, would be repeatedly used. Thus, there are implications for the issue of laundry and decontamination. Stepping into this arena demands consideration of additional implications pertaining to the possible secondary exposure of family members to pesticides. These implications will be briefly considered.

Laundering and Decontamination

Referring back to the flow chart given in Figure 4 to operationalize the design process, we notice that the implications of this study suggest that an essential "new" piece of the problem must be included. Before recommendations could be made advocating use of fabric 2, considerable effort is needed to examine the critical issue of decontamination. The limited research done in this area has shown inconsistent results, and none of the studies has examined pesticide removal from the specific fabric used for the thermal-analysis study. Percentage removal of pesticide has varied, and some residues have been shown to be biologically active (Easley, Laughlin, Gold, & Tupy, 1981). Southwick, Mecham, Cannon, and Gortatowski (1974) reported a dramatic example of a 70-year-old male who was admitted to a hospital for pesticide poisoning after spraying parathion on his backyard garden and fruit trees. Following the hospitalization, the

man showed improvement until he put on the laundered bib overalls which he had worn previously while spraying. He immediately became ill with flu-like symptoms and died the following day. Laboratory analysis of the bib overalls showed a large residue of parathion remaining, despite the laundering.

Familial Exposure

Recognition of occupational exposure to harmful chemicals has recently grown. But recognition that this exposure can affect not only the worker, but also his/her family, is a relatively new concept. Bellin (1981) presented data for familial exposure to beryllium and asbestos. Almost every case of household contamination presented by Bellin cited the laundering of clothing and/or linens as the contaminant source. Hardy (cited in Bellin, 1981) noted that 40 out of 60 neighborhood cases of berylliosis were due to beryllium dust which contaminated clothing, skin, shoes, car, and furniture. Consequently, since 1960, beryllium workers in this plant have been required to change their clothing and to shower before leaving work. The soiled clothing is sent to a commercial laundry facility. The effectiveness of these measures remains to be documented.

Thus, if the health and safety of the agricultural worker is to be enhanced through the adoption of protective clothing, concern must also be focused on the implications of the use and care of this clothing for the worker's family. Those making recommendations on the frequency of laundering and the methods for laundering and storage must be cognizant of the real danger of the secondary exposure of the

worker's family. There is a need to know what is currently being done by the growers and their families. There is a need to consider attitudes and values that motivate the families regarding this issue. And there is a need for creative problem solving for the serious problem of pesticide transference during laundering.

Recommendations for Future Research

1. It is recommended that further work be directed toward the development and refinement of laboratory test methods to assess air, heat, and moisture transport properties that would correlate well with known human-subject data on thermal response. If laboratory test methods on the test fabrics and designs used in this study could be shown to correlate with the thermal-response data obtained with human subjects, this would facilitate the development of predictive models to assess thermal response of new fabrics and designs without human subjects.

2. It is recommended that further work be directed toward refinement of a thermal-sensation scale. Such clustering at one end of the scale diminishes the discriminating function of the instrument.

3. It is recommended that an investigation be conducted to examine the influence of age and sex on thermal response of subjects wearing protective clothing. This study might be conducted in an environmentally controlled chamber or in the field. A chamber study offers the advantage of permitting assessment of physiological variables of interest as well as control of environmental variables at prescribed levels. The perceptual data on thermal comfort from a

field test, however, would offer an interesting comparison with these measures from a controlled chamber study. If the population for the field test consisted of growers, then their perceptual responses would be even more valuable to the designer.

4. It is recommended that a study be undertaken to determine the efficiency of laundering and/or other decontamination procedures to remove pesticide from contaminated clothing. Also, the question of whether the remaining pesticide residue is biologically active should be addressed.

5. It is recommended that current laundry and storage practices of growers' families be investigated. Data on where the work clothing is stored, length of time stored, where the clothing is laundered, with what other clothing, with what kind of equipment and methods, by whom, and how frequently should be gathered in order to assess the potential for secondary familial exposure.

6. It is recommended that attitudes and the perceived risk of handling pesticides or pesticide-contaminated clothing be investigated for families who have a member involved in handling pesticides. It is thought that the grower who perceives himself to be at risk while spraying pesticides will be more likely to adopt protective clothing. Similarly, the family members responsible for the laundry will likely be more willing to follow recommended decontamination procedures of the work clothing if a risk is perceived.

7. It is recommended that future studies consider using multivariate statistical techniques when investigating a phenomenon

requiring a set of dependent measures that are conceptually meaningful for adequate assessment.

8. It is recommended that an ecological approach be used for experimental studies when appropriate.

APPENDICES

APPENDIX A

FORMS USED IN THE PROCEDURE FOLLOWED

FOR OBTAINING SUBJECTS

APPENDIX A_1

ORIENTATION STATEMENT

The purpose of the study in which you are participating is to determine how man responds to his thermal environment. At the outset, you should be fully aware that the conditions to which you will be exposed may entail some physical risks including physical discomfort and mental stress. Second, you have volunteered to act as a subject and are participating on your own volition. Third, you may leave the experiment anytime you wish. Fourth, your identity as a subject will not be disclosed and anonymity will be maintained.

Your participation will include completing a physical examination, eating a standardized meal at the K-State Union, experiencing one-half hour of preconditioning and a two-hour environmental test exposure. During the test exposure you will be performing the physical task of walking up and down steps. You may not leave the room during the test without forfeiting your participation in this experiment. At certain intervals you will be asked to complete ballots evaluating the temperature of the environment and your comfort. You will also be wearing skin temperature sensors to measure your skin temperature. Your rectal temperature and heart beat will be monitored throughout the study. A registered nurse will monitor your vital signs. Any change that suggests danger to your physical well being will cause you to be removed from the test. For your participation you will receive $20.00 remittance.

Do you have any questions?

APPENDIX A_2

MEDICAL HISTORY QUESTIONNAIRE

1. Last Name, First Name, Middle Name ______________________ 2. Social Security No. ______________

3. Home Address ______________________ 4. Home Phone ______________

5. School Address ______________________ 6. School Phone ______________

7. Date __________ 8. I.D. No. __________ 9. Birth __________ 10. Age __________

Citizen of ______________ Ancestral Background __________

Have you ever (please check each item)

yes	no	
		lived with anyone who had TB (tuberculosis)
		coughed up blood
		bled excessively after injury or tooth extraction
		attempted suicide
		been a sleep walker

Immunizations (please check)

	Yes	No	Date (Month and year are sufficient)
Tetanus			
Diphtheria			
Smallpox			
Measles			
Mumps			
BCG			
Influenza			
Typhoid fever			
Polio			

Do you (please check)

yes	no	
		wear glasses or contact lenses
		have vision in both eyes
		wear a hearing aid
		stutter or stammer habitually
		wear a brace or support

Do you smoke? yes_____ no_____

How many cigarettes do you smoke per day? ______

How long have you smoked? __________

Do you take drugs regularly? yes_____ no_____

Name of drug(s) and how often? ____________________________________

____

(Please include any over-the-counter drugs as well as marijuana, etc.)

Do you take any of the following medications?

Medication e.g.	yes	no
Cantil		
Prednisone		
Blood-pressure medication		
Cardiac medication		
Ulcer medication		
Thyroid medication		
Antibiotics (except those prescribed for cosmetic medication)		
Dilantin		
Allergy injections		

Has any relative (parent, sibling, or grandparent) had any of the below?

	yes	no	relationship
Tuberculosis			
Heart disease			
Chronic kidney disease			
Cancer			
Thyroid disease (goiter)			
Diabetes			
Epilepsy			
Asthma			
Hay fever			
Mental disorder			
Abnormal bleeding			
Arthritis			
High blood pressure			
Migraine headaches			

Have you ever had or now have (Please check)

yes	no		yes	no	
		Scarlet fever			VD (gonorrhea, syphilis, etc.)
		Rheumatic fever			Typhoid fever
		Hepatitis			Kidney stones or blood in urine
		Poliomyelitis			Sugar or albumin in urine
		Infectious mononucleosis			Nephritis or nephrosis
		Recurrent painful & draining ear			Bed wetting since age of 12
		Recurrent "strep throat"			Frequent or painful urination
		Pneumonia			Diabetes
		Urinary tract infection			Heart trouble

Have you ever had or now have (Please check)

	yes	no
Hearing loss		
Chronic or frequent colds		
Severe tooth or gum trouble (2 wks)		
Head injury		
Skin diseases		
Thyroid trouble		
Tumor, growth, cyst or cancer		
Rupture or hernia		
Piles or rectal trouble		
Adverse reaction to serum, drugs or medicine		
Car, air, train, or sea sickness		
Neuritis		
Paralysis		
Epilepsy		
Convulsions or seizures		
Frequent trouble sleeping		
Depression		
Excessive worry		
Loss of memory, amnesia		
Nervous trouble of any kind		
Periods of unconsciousness, fainting		
Measles (regular, hard, red)		
Measles (German, 3-day)		
Mumps		
Chicken pox		
Diphtheria		
Whooping cough		

List continues on next page. Please fill out in the same manner. Thank you!

	yes	no
High or low blood pressure		
Palpitations or pounding heart		
Pain or pressure in chest		
Shortness of breath		
Chronic cough		
Asthma		
Hay fever		
Sinusitis		
Frequent indigestion		
Stomach, liver or intestinal trouble		
Gallbladder trouble or gallstones		
Jaundice		
Ulcer		
Swollen or painful joints		
Cramps in your legs		
Broken bones		
Arthritis, rheumatism or bursitis		
Bone or joint deformity		
Lameness		
Loss of finger, toe or extremity		
Painful or "trick" elbow or shoulder		
Foot trouble		
Anemia		
Frequent headaches		
Dizziness or fainting spells		
Eye trouble		
Ear, nose or throat trouble		

Comments: (Do not write in this space)

I certify that the above information is true and correct to the best of my knowledge. ______________ Signature ______________ Date

Please do not write on this page! TO BE COMPLETED BY NURSE

Physical Exam Form

Name________________ Date____________ Test Date_________

Wt. ______ Ht. ________ TPR ____________

Sex (Male)_______ (Female) ______ Blood Pressure ___/____

Pulse________ Heart Sounds______

EKG Strip:

Rhythm______ Comments: ______________________________

____

Urinalysis: Sp. Gr. __________ pH__________ Protein_________

Glucose________ Ketones________ Bilirubin_______

Occult Blood_________ Urobilinogen_______________

Blood Test: Hb_________ Hct________ SMA 12 results attached___

Skin Fold: Tri_________ Eye Color_______________

Pect________ College yr._____________

ABD_________

ILL_________ Years at present job

% Fat_______ __________________

TBF_________

LBM_________ Race_______________

C.V. Fitness

1st Load KPM_________ Min(S)_______________ Hr_________

2nd Load KPM_________ Min(S)_______________ Hr_________

3rd Load KPM_________ Min(S)_______________ Hr_________

4th Load KPM_________ Min(S)_______________ Hr_________

Dominant Grip Strength_____________ Trunk Flex____________ Inches

Do you exercise regularly? Yes____ No____ If so, what and how often? ____

____

APPENDIX A_3

Your test will be ____

INSTRUCTIONS

Unless notifying the nurse, take no drugs, medication or alcoholic beverages 12 hours before the test. Do not eat or drink anything except water after 11 p.m. the evening before your test. Be sure to bathe or shower before reporting for the test.

Wear tennis shoes and socks the day of your test. Report to the student union at ___ a.m. for breakfast. Tell the cafeteria personnel that you are a test subject and they will give you the high protein breakfast free. You must eat all of this and drink a glass of water. Do not add or substitute to this meal.

Immediately after eating breakfast report to the pre-test room of the Institute for Environmental Research. If the outside door is locked please wait on the benches outside E 63 until we unlock the door.

Unless you notify us by 3 p.m. on the day before your test is scheduled, it will be assumed that you will keep this appointment. If you do not or do not meet this appointment, you will not be scheduled at a later date. The tests are too expensive to run with less than the required six subjects who are scheduled.

Any questions please call IER 532-5620.

APPENDIX A_4

BREAKFAST INSTRUCTIONS

You should receive from the grill scrambled eggs, breakfast patty, and dry toast.

You will get a small glass of white skim milk and a small glass of juice (orange or grape for yourself).

You may have all the water you wish but no other liquids.

You may have no butter, jelly, salt, pepper, mustard, catsup, or seasoning of any type.

APPENDIX B

FORMS USED DURING THE CONDUCT OF THE EXPERIMENT

APPENDIX B_1

Subject Name______________________________ Subject #_____________________

Garment #_________________________________ Test # _____________________

1. Subject Weight Pre-Test__________

2. Subject Weight Post-Test_________

1. Clothing Wt. Pre-Test_______

2. Clothing Wt. Post-Test______

3. Thermos Wt. Pre-Test________

4. Thermos Wt. Post-Test_______

APPENDIX B_2

AGREEMENT AND RELEASE

1. I, ________________________________, volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I realize that participation may impose physical and/or mental stresses upon me and/or the other subjects. I believe that I am physically and mentally fit to withstand any such stresses.

3. I understand that I will be observed during my participation and that my conduct and/or voice may be recorded by photographic and/or recording devices. I may have attached to my person sensors to measure temperature, pulse, blood pressure, etc. I also realize that public reports and articles may be made of the experiments and all of the observations and I consent to publication of such, including the use of photographs.

4. I hereby authorize the Kansas State University to remove me from the evaluation exercise at any time and for any reason. I agree to leave said exercise willingly when asked to do so.

5. I understand that I will be permitted to leave the evaluation exercise at any time that I find that I am unable to withstand the conditions and request to be relieved.

6. As compensation for my voluntary services as a participant in the aforesaid studies, Kansas State University will pay me. It is clearly understood and agreed, however, that in no event am I to be considered an employee of Kansas State University during such participation. Therefore, no Social Security, income tax, retirement, or other benefits of employment will be deducted or accrue.

7. I hereby agree, under penalty of forfeiture of all compensation due me, not to give information regarding these studies to any public news media nor to publicize any articles or other accounts thereof without prior written approval by Kansas State University.

I have signed the herein Agreement and Release, this _____ day of _________________, 19_____.

____

Signature

APPENDIX B_3

Subject Name and No. ______________________________ Test No. ________

Thermister No.

Chest_______________

Arm________________

Leg________________

Rectal______________

APPENDIX B_4

HEALTH QUESTIONNAIRE

Subject Name and No.______________________________ Test No.__________

Have you consumed alcohol within 12 hours? Yes____ No____
If yes, what? _______________
How much?___________________
How long ago?________________

Have you taken any drugs within 12 hours? Yes____ No____
If yes, what? _______________
How much? ___________________
How long ago? _______________

How many hours sleep did you have last night? ________________

APPENDIX B_5

SUMMARY QUESTIONS

Name and Subject No.________________________________ Test No. ________

Please answer the following questions by checking the appropriate blank.

1. I found the clothing that I wore for the study to be . . .

    ____ cooler ____ warmer ____ about the same

    . . . as I expected.

2. The test you have just completed was conducted to measure thermal comfort of protective garments at 85°F. Knowing that this clothing would provide protection against harmful chemicals in your work, indicate your willingness to wear this garment:

    ____ I would be willing to wear it under these temperature conditions.

    ____ I would wear it if the temperature was less than 85°F.

    ____ I would wear it only if required to do so.

    ____ I would not wear it.

APPENDIX B_6

POST-TEST INFORMATION SHEET

The primary effect of your heat exposure is a loss of fluid and of salt; therefore, you may experience some transient light-headedness, headaches, nausea, or muscle cramps.

You should treat these temporary problems by rest, fluid, and salt intake. Example: Gatorade, sodas, and salted popcorn, potato chips, etc.

If any symptoms are severe or persist despite fluid and salt intake, call Environmental Research nurse at 532-5620 or your own family physician.

APPENDIX B_7

KANSAS STATE UNIVERSITY
Manhattan, Kansas

Receipt Form for Cash Payments to Research Subjects

Fund Name Institute for Environ. Res. Account Name Mich. State Univ. Study

K.S.U. Account No. 52442-2757 P.P.O. No. ______

I certify that I have served as a subject for the research project entitled Thermal component of Reduction of Dermal Exposure of the Operator in Pesticide Application and that I have received the amount set opposite my name for this service.

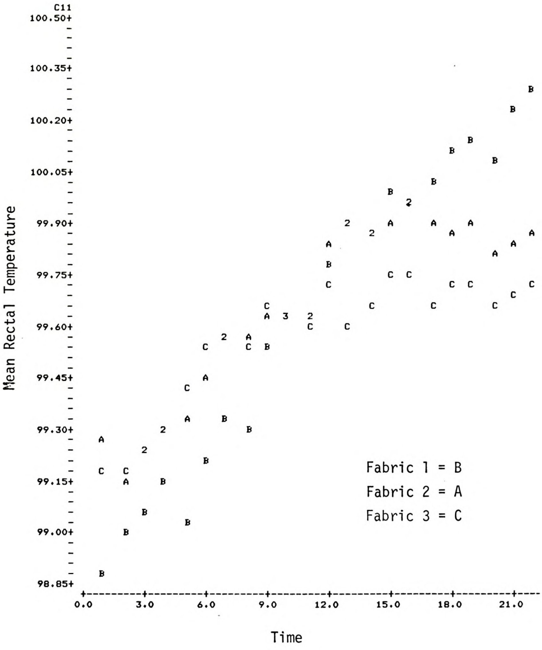
	NAME (1st line) & COMPLETE ADDRESS	SOC. SEC. NUMBER	SIGNATURE	DATE	AMOUNT
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					

APPENDIX C

EXAMINATION OF TEMPERATURE DATA

APPENDIX C_1

SAMPLE MINI-TAB COMPUTER GRAPH OF TEMPERATURE DATA FOR DESIGN 3



APPENDIX C_2

SAMPLE COMPUTER PRINTOUT OF LISTING OF SUBJECTS' TEMPERATURE DATA

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      13 I1 0422 06 06 4A 159.8158.3 0564.0 0582.2 1380.5 1380.5
      13 B1 527228926456667547555764576467645753576457545854575467446854686548645844513

ROOM      8436 8471 8559 8562 8550 8513 8501 8505 8484 8492 8498 8466 8490 8486 8484 84
CHEST     9507 9519 9392 9559 9465 9298 9538 9366 9321 9498 9407 9294 9457 9376 9261 94
ARM       9466 9525 9361 9501 9463 9266 9513 9394 9315 9548 9492 9303 9446 9436 9260 94
LEG       9269 9253 9251 9326 9232 9265 9346 9361 9346 9369 9368 9357 9405 9396 9353 94
RECTAL    9934 9932 9928 9928 9921 9932 9928 9919 9928 9926 9917 9932 9926 9926 9936 99


      14 I1 0512 07 01 5B 197.0197.0 0515.6 0788.7 1450.7 0914.8
      14 B1 519129917646833889199119891991198919911999199119981891199919911999199119 22

ROOM      8461 8511 8526 8592 8605 8607 8571 8500 8471 8417 8405 8421 8386 8463 8613 86
CHEST     9413 9476 9501 9582 9513 9638 9503 9367 9605 9601 9507 9609 9573 9409 9603 95
ARM       9546 9626 9617 9648 9613 9671 9575 9478 9632 9607 9542 9611 9613 9515 9655 95
LEG       9073 9148 9025 9115 9007 9228 9175 9119 9301 9403 9188 9298 9411 9248 9353 91
RECTAL    9707 9653 9648 9692 9728 9761 9767 9775 9600 9946 9944 9961 9973 9969 9984 97


      15 I1 0522 09 06 8B 154.5154.5 1151.1 1361.9 1377.1 0596.3
      15 B1 537227737545465699197118992981199919811999199119991991199919911999199119 32

ROOM      8461 8511 8526 8592 8605 8607 8571 8500 8471 8417 8405 8421 8386 8463 8613 86
CHEST     9363 9436 9455 9523 9530 9646 9521 9573 9642 9636 9592 9667 9632 9615 9707 96
ARM       9415 9423 9469 9521 9540 9559 9592 9409 9425 9578 9488 9475 9507 9448 9440 95
LEG       9421 9428 9423 9350 9396 9569 9523 9386 9548 9469 9375 9561 9571 9436 9548 95
RECTAL    9919 9921 9919 9903 9892 9928 9932 9926 9953 9940 9938 9967 9959 9948 9963 99


      16 I1 0522 05 11 3A 150.5151.8 0721.9 0750.7 1557.2 0491.5
      16 B1 537347738737542697287228991972189919321298196217991954389929432799195427 33

ROOM      8461 8511 8526 8592 8605 8607 8571 8500 8471 8417 8405 8421 8386 8463 8613 86
CHEST     9559 9619 9623 9615 9555 9640 9553 9528 9619 9578 9511 9588 9532 9476 9596 95
ARM       9407 9515 9536 9569 9525 9488 9438 9536 9501 9442 9415 9513 9436 9396 9521 94
LEG       9159 9205 9198 9198 9246 9476 9421 9400 9511 9438 9386 9496 9419 9384 9540 94
RECTAL    9948 9938 9938 9932 9926 9923 9919 9921 9938 9923 9934 9975 9963 9967 9990 99


      17 I1 0522 07 16 4B 172.5175.5 0572.9 0633.2 1387.6 0674.3
      17 B1 428219816636743677377337773773377837833878288237782782288828822889298229 33

ROOM      8461 8511 8526 8592 8605 8607 8571 8500 8471 8417 8405 8421 8386 8463 8613 86
CHEST     9521 9505 9507 9484 9459 9492 9515 9432 9494 9384 9376 9469 9417 9444 9519 94
ARM       9470 9338 9388 9459 9430 9405 9351 9432 9407 9294 9376 9361 9290 9369 9359 91
LEG       9234 9182 9155 9138 9238 9446 9417 9359 9515 9453 9340 9463 9388 9346 9476 93
RECTAL    9875 9876 9876 9871 9867 9871 9882 9886 9892 9900 9903 9907 9919 9911 9909 99
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