EFFECTS OF WEARING IMPERMEABLE AND PERMEABLE PROTECTIVE CLOTHING ON THERMOREGULATORY RESPONSES WHILE SEDENTARY

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INTRODUCTION

The use of protective clothing as a barrier against occupational and environmental hazards has increased dramatically in recent years. Certain types of protective overgarments are also being utilized in cleanroom manufacturing environments where contamination of the work site by personnel is a major concern. In the computer semiconductor manufacturing business, there is a reported industry-wide perception that the sedentary nature of the work does not justify the wearing of more costly, "breathable" protective clothing versus inexpensive, disposable, non-permeable garments. It is understandable that some managers of large-scale, industrial protective clothing and equipment programs would purchase specific garments based solely on a minimal cost per unit basis. Nevertheless, a recent study suggests that the use of higher-cost, vapor-permeable, and reusable protective clothing can actually be more economical when analyzed on a cost per use basis (1). The purpose of this present study was to investigate if protective overgarments manufactured from the same basic materials but with different levels of permeability would have an influence on thermoregulatory responses in volunteers who were sedentary and exposed to two typical indoor workplace environments.

MATERIALS AND METHODS

Eight healthy males (age = 21.0 ±1.9 years, height = 173.3 ± 5.6 cm, weight = 72.5 ± 6.3 kg, body surface area = 1.86 ± 0.10 m2) volunteered for the study. They were informed of the purpose, procedures and risks of the study. All volunteers expressed an understanding of the study by signing a statement of informed consent. All test overgarments were manufactured from material containing a waterproof/breathable, protective membrane. The material was made by W.L. Gore and Associates. The protective membrane was composed of a thin layer of microporous polytetrafluoroethylene (PTFE). The PTFE membrane can be manufactured with varying levels of permeability. The test overgarment materials were evaluated by the manufacturer for permeability according to ASTM Standard E96-80 (2), which is used to calculate a moisture vapor transmission rate (MVTR, $g \cdot m^{-2} \cdot 24\ h^{-1}$). All volunteers wore both an impermeable overgarment (IO, MVTR = 5) and a permeable overgarment (PO, MVTR = 864) during a 4-h sedentary exposure to two different environments: 18.3°C/50% relative humidity (RH) (COOL); 29.7°C/52% RH *(WARM).* There was a constant air velocity of 1.1 m·s-1 directed at the volunteers as they sat in the climatic chamber. All volunteers also wore lightweight 100% polyester underwear, gloves, socks and leather boots. Mean weighted skin temperature (Tsk, 8 sites, °C), rectal temperature (Tre, °C), skin wettedness (w, %) calculated from dew point sensors attached underneath the overgarment and heart rates (HR, bpm) were measured. Total body mass loss ($\dot{m}_b$, $g \cdot h^{-1}$) and moisture absorption (g) by the various garments were determined by pre- and post-experiment weights of all clothing items (Sauter balance, precision ± 0.01g). Subjects read or filled out various questionnaires during the time period. Repeated measures analysis of variance were applied to mean data for all variables and pair-wise comparisons were treated for significance using Tukey's test of critical differences.

RESULTS

Table 1 shows mean initial and final values of T_{sk} and T_{re} when wearing the IO and PO during COOL and WARM. During COOL, final values of T_{sk} and T_{re} were consistently lower than initial values in both the IO and PO. Some volunteers were observed to be shivering during their last hour of COOL exposure. This indicates that a complete protective clothing ensemble with insufficient thermal insulation could cause mild thermal discomfort in sedentary workers in cooler work environments. During WARM, final T_{sk} and T_{re} values were generally higher than initial values, especially when wearing the IO where the final T_{sk} value was elevated 7% above initial value.

Table 1. Initial and final values (Mean ± 1 SD) of T_{sk} and T_{re} of volunteers (n = 8) when wearing the IO and PO during COOL and WARM.

GARMENT		COOL	WARM
IO	Initial T_{sk}	29.5 ± 1.0	30.8 ± 1.6
	Final T_{sk}	27.8 ± 0.9	32.9 ± 1.5
	Initial T_{re}	36.9 ± 0.2	37.0 ± 0.3
	Final T_{re}	36.5 ± 0.5	37.2 ± 0.2
PO	Initial T_{sk}	29.2 ± 1.3	30.7 ± 1.3
	Final T_{sk}	27.7 ± 0.7	32.1 ± 1.3
	Initial T_{re}	36.9 ± 0.3	37.0 ± 0.3
	Final T_{re}	36.3 ± 0.7	36.9 ± 0.3

*Values shown are Means ± 1 SD

Fig. 1 shows w of the volunteers while wearing both overgarments during COOL and WARM. There were significant increases in w during both environmental conditions when wearing the IO ($P < 0.05$). At 4-h exposure, w approached **0.9** when wearing the IO during WARM. Excessive w has been shown to translate with warm discomfort **as** the respective skin site becomes wet with sweat. Translated to the whole body surface w has been shown to be a good-indicator of thermal strain **as** rate of body heat storage increases (3,4).

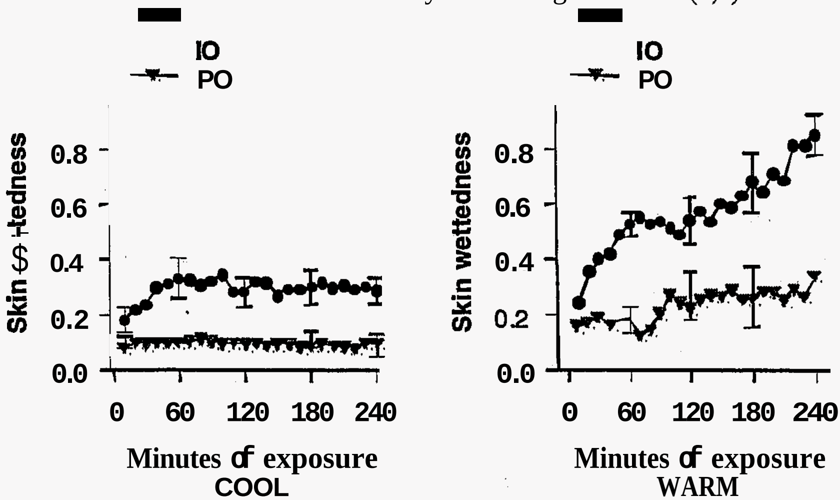

Figure 1. Local skin wettedness (Mean ± **1** SD) of volunteers (n = **8)** while wearing the IO and PO during COOL and **WARM** as a function of time of exposure.

Although there were no significant differences in HR when wearing either overgarment, HR during WARM was elevated an average of **24%** and **19%** above COOL values with the IO and PO, respectively. Mean $\dot{m}_b$ was lower (**$P < 0.05$**) during COOL runs (IO = **77.5,** PO = **78.5)** compared with the WARM runs **(IO = 92.3, PO = 103).** The **IO** had the highest mean weight increase (**$P < 0.01$**) (11 g, COOL and **44** g, WARM) due to absorption and/or condensation of nonevaporated moisture vapor within the overgarment during the 4-h test. Absorption of moisture vapor also caused higher mean underclothing/footwear weight increases **(22** g, **COOL** and **43** g, WARM) when worn with the IO. These weight increases were lower **(20 g,** COOL and **13** g, WARM) when wearing the PO.

CONCLUSIONS

These results showed that a moisture-vapor-permeable overgarment reduced overall thermal strain, reduced underclothing absorption **of** sweat and increased evaporation of moisture vapor when compared with a non-permeable overgarment during an extended sedentary exposure to simulated workplace environments. Cleanroom personnel can be required to wear completely encapsulating protective clothing ensembles for up to **12** h during an extended work shift. The use of protective clothing ensembles with sufficient thermal resistance and increased levels of moisture vapor transmission lowers the w built up underneath such garments and may improve overall thermal comfort that could lead to subsequent improvements in task performance and workforce morale.

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