Thermal Comfort Performance of Active Cooling T-Shirt in Agricultural Protective Clothing

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Keywords: Comfort, Thermal, Agriculture, Phase Change

Migrant agricultural workers endure harsh environmental conditions for extended periods of time while working in crop and livestock production. While the H2A program requirements mandate these workers be provided with access to basic needs such as shelter, food, and transportation, their clothing needs are often forgotten (U.S. Citizenship and Immigration Services, 2018; U.S. Department of Labor, 2010). The risk for occupational injuries increases when the ambient temperature increases. Accidents increase by 5.2%, 8.2%, and 30% when the maximum temperature is between 26.7-32.2˚C, 32.2-37.8˚C, and over 37.8 ˚C, respectively; all relative to a day with a maximum temperature between 15.6 and 21.1^{o}C (Page & Sheppard, 2016). Temperatures in the southeastern region of the United States, where migrant workers engage in crop production activities, can reach well above these temperature ranges; especially in the hot and humid summer months.

Therefore, the purpose of this research was to investigate if a t-shirt with proprietary printed cooling technology could significantly improve the physiological and subjective thermal comfort of agricultural workers. The following research objectives were established to accomplish the goal of this study:

1. To collect and analyze migrant agricultural worker end-user data regarding thermal comfort when wearing a traditional, short sleeve, synthetic t-shirt with and without novel printed cooling technology.
2. To determine if the addition of a printed cooling finish technology significantly improves the thermal comfort of agricultural workers.

The active cooling finish on the proprietary t-shirt assessed in this study is comprised of an encapsulated printed phase change material (PCM) applied to the back side of the fabric (McFarlin, Henning, Venable, Williams, & Best Sampson, 2016) (Figure 1). Phase change material has a unique chemical composition that allows it to change phase when a specific temperature is reached, providing a cooling sensation to the wearer.

A field trial was conducted by recruiting 20 migrant farmworkers who agreed to use the assigned clothing and measurement instrumentation as instructed for eight work days. An initial survey gathering demographics, farm work experience, laundering habits, and medical history was administered prior to the field trial. Wear trial instrumentation consisted of a heart rate monitor, data logger belt, and iButton

Figure 1. Printed vs. Control T-Shirts

Figure 2. Agricultural Worker Field Trial

lanyard. Chest skin temperature, chest microclimate humidity, and the heart rate of each participant was measured for the duration of their individual work days.

100% polyester t-shirts were randomly assigned to each participant throughout the field trial. On days 1-7, each interviewer equipped the instrumentation to the workers before beginning their work in crop production (Figure 2). Upon finishing work, instrumentation was immediately removed by the interviewers. Following the removal of the equipment, the workers completed a daily exit survey to assess perceived exertion (Borg, 1982), comfort, and temperature sensation (ISO 10551) along with recording the presence of heat illness symptoms. A final daily exit survey was given on the last day of the field trial (day 8) that consisted of additional user acceptance questions regarding overall perception of comfort and cost.

For the physiological thermal comfort data, there were no significant differences ($p<0.05$) for the overall average chest skin temperature, chest microclimate humidity, and heart rate for all participants for all work days by shirt type (control vs. printed) (Table 1). However, significant interactions were present in the quadratic models (run in SASS) between day, subject, and shirt for all three physiological parameters.

Table 1. Average Physiological Thermal Comfort Data by Shirt Type

Variable	Control T-Shirt		Printed PCM T-Shirt	
	Mean	Standard Deviation	Mean	Standard Deviation
Skin Temperature (°C)	30.50	3.60	30.99	3.14
Microclimate Humidity %	73.96	21.17	79.87	14.89
Heart Rate (bpm)	90	33.12	87	34.15

Figure 3 illustrates the average results of the daily exit survey. Overall comfort was perceived to be significantly better when wearing the printed t-shirt compared to a typical work shirt. In conclusion, results indicate important differences in the subjective and physiological thermal comfort of the agricultural workers.

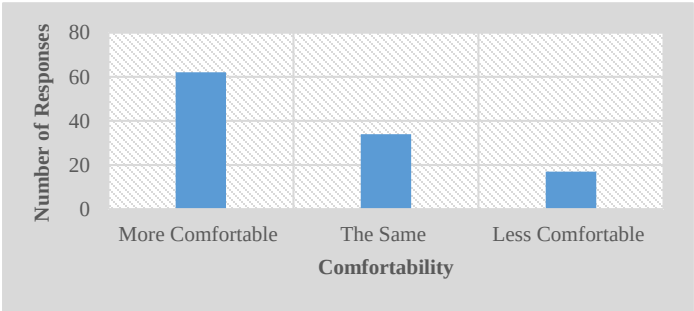

Figure 3. Perceived comfort of PCM T-shirt.

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