Analysis of Cooling Mechanisms to Combat Heat Stress in the Construction Industry

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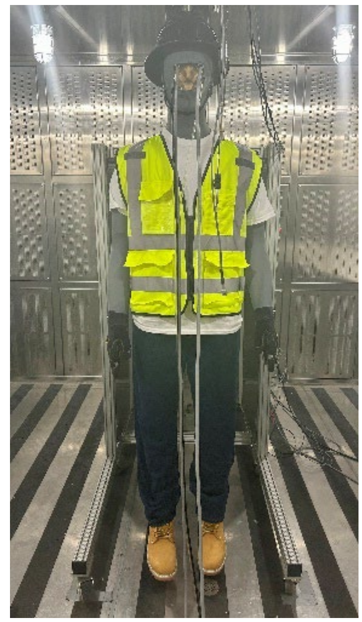

Figure 1. Control construction ensemble

Background: Heat stress poses a substantial threat to construction workers due to the strenuous nature of the job performed under hot/humid conditions for long duration work shifts. The construction industry was responsible for 33.1% of all HRI worker's compensation claims between 1995-2005, the highest heat related illness (HRI) claim rate of all occupations (Acharya, P. et al., 2018). Despite the clear prevalence of HRIs in the construction industry, little to no regulations are implemented to protect workers, especially regarding PPE (OSHA 29 CFR 1926). Along with the strenuous activity and environmental exposures of construction work, PPE can be a compounding heat-related hazard. Wearing protective clothing can inhibit the body's ability to dissipate heat and may increase the energy cost for an activity when an individual is working in a hot environment (Poulianiti, K., 2019). With advanced innovations in functional clothing design, incorporating thermal comfort apparel could be a potential measure for reducing the prevalence of heat stress in construction workers (Guo, Y. et al., 2019). With the global cooling fabrics market expected to reach USD 2.6 billion by 2025, more affordable cooling garments and accessories are becoming readily available for the average consumer, making these cooling devices a cost feasible prevention method for reducing HRIs in the construction workplace (NASDAQ OMX, 2020).

Multiple studies have evaluated the thermal insulation of various cooling garments on a sweating thermal manikin (Bendkowska, W. et al., 2010; Gao, C. et al., 2010; Jetté, F. et al., 2004; Lu, Y. et al., 2015). Fewer studies have evaluated these cooling fabrics and garments' effectiveness in the context of a construction worker's ensemble, and scarcely any research has been conducted to determine the effectiveness of these cooling garments while replicating the metabolic work rate of construction employees during simulated working conditions. (Miura, K. et al., 2017; Guo, Y., et al., 2017; Yi, Wen, et al., 2017; Zhao, Y. et al., 2018). Therefore, the purpose of this research was to determine the efficacy of various cooling technology garments based on a representative construction worker's ensemble, replicating a typical workday. To the researchers' knowledge, this work is the first of its kind to combine optimal cooling fabric technologies for assessment during a simulated construction workday in high-temperature conditions.

Methods: A state-of-the-art dynamic sweating thermal manikin (Thermetrics, LLC; Seattle, WA) was used to predict physiological responses (Manikin PC, ThermoAnalytics; Calumet, MI) under constant ambient conditions to simulate a hot/humid outdoor working environment (33°C/65% RH). Four commercially available cooling technology t-shirts (SHIRT

1-4) and two active cooling vests (VEST 1 and 2) were tested in combination with a standard construction uniform. Shirt and vest materials varied by synthetic content blends (nylon, polyester, and spandex). Each garment was compared to the control (Figure 1), a standard construction uniform including a high visibility vest, hard hat, 100% cotton t-shirt, jeans, socks, boxers, boots, and gloves. Once each shirt and vest were tested individually, combination testing with the highest-performing cooling t-shirts and vests was conducted and compared to the control ensemble. A MET rate of 4.3 for masonry construction (Compendium of Physical Activities, 2019) was selected for the entire 1-hour duration of the test protocol. Three test replicates were performed for each cooling technology ensemble. Physiological responses including skin temperature (TSK), core temperature (THY), sweat rate (SWA), temperature sensation, and comfort perceptions of the human body were predicted. Data was analyzed for significance using one-way ANOVAs and individual two-sample T-tests.

***Results*:** Wearing VEST2 resulted in the lowest skin temperature and sweat rates, as well as the most favorable comfort perception of the vest configurations. A significant decrease in predicted TSK (Figure 2) was found when wearing both vests. Compared to the control, VEST2 had a 0.85°C decrease versus VEST1 at 0.65°C. This difference between vests may be explained by the larger surface area covered by the design of VEST2. Although not significant, SHIRT2 exhibited a 0.35°C decrease in TSK, which is a potentially meaningful improvement from the baseline value. Combination testing of both vests with Shirts 2 and 3, however, did not demonstrate similar results to the control when worn with a 100% cotton t-shirt, indicating the fiber content worn next to skin plays an important role in cooling pack effectiveness. For predicted core temperature (Thy), no significant differences were found between the control ensemble and the cooling garments. The lowest core temperature was demonstrated in VEST1 and SHIRT2 separately, both showing a 0.08°C decrease. Differences in SWA followed similar trends as TSK, with VEST2 showing the biggest improvement with a 2.28 g/min decrease compared to the control garment configuration. SHIRT2 was found to be most “comfortable”, which could be due to the ventilated construction of the fabric. For predicted temperature sensation, both vests resulted in the coolest perceptions.

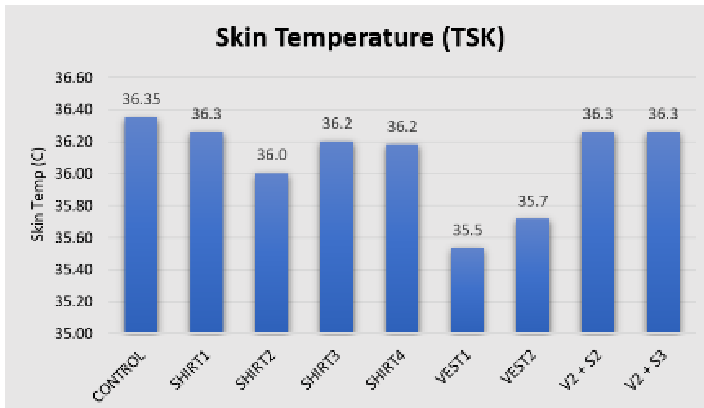

Figure 2. Average predicted skin temperature for each shirt, vest, and combination tested.

***Conclusions*:** The primary objective of this research was to determine the effectiveness of multiple cooling technologies including cooling vests with cooling packs, cooling minerals, ventilation, and wicking fabric technology. Under the specific ambient conditions, physiological protocol, and garment ensembles tested in this study, a significant decrease in TSK and SWA was present for both vests with cooling packs and SHIRT2 with a ventilated fabric construction. However, additional fabric layers, bulk, and weight associated with wearing the cooling vests compromised comfort perceptions. Limitations of this study include the inability to analyze TSK, THY, and SWA predictions for localized regions of the body. Future research should work towards developing cooling devices that effectively provide thermal comfort while not compromising the wearability of the garment to improve their use as preventative tools for HRI's in the construction workplace.

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The global cooling fabrics market size is estimated to be USD 2.0 billion in 2020 and is expected to reach USD 2.6 billion by 2025, at a CAGR of 6.0% from 2020 to 2025 (2020, Nov 09). *NASDAQ OMX's News Release Distribution Channel* https://www.proquest.com/wire-feeds/global-cooling-fabrics-market-size-is-estimated/docview/2458494622/se-2

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