
Evaluation of a Modular Layering Approach for Heat Loss Improvement in Structural Firefighter Turnout Garments

Meredith McQuerry, North Carolina State University, USA

Dr. Emiel DenHartog and Dr. Roger Barker, Textile Protection and Comfort Center, USA

Keywords: Firefighter, comfort, turnout, protection

Heat stress, due to overprotection, is an important cause of firefighter fatalities in specific working conditions (Rossi 2005). There are two vital, yet contradictory factors, which play a role in the heat stress a firefighter experiences. The multi-layer construction of firefighter turnouts hinders the ability of heat loss to occur by increasing thermal insulation and evaporative resistance. As thermal protection increases, through additional fabric layers, metabolic heat stress also rises causing further decrease in comfort. These factors work together to exacerbate the problem of heat stress which ranges from discomfort to illness, collapse and potentially even death (Nunneley 1989).

Structural turnout suits are designed to protect against the highest level of flame exposure a firefighter might encounter. Fire fighting activities, however, account for only 10 to 20% of all duties firefighters perform (Rossi 2005). Up to 99% of a firefighter's time may be spent performing normal working tasks in which the threat of heat and flame is low to nonexistent (den Hartog 2010). Therefore, firefighters need different turnout suits to prevent excessive heat strain in the majority of their work, while maintaining protection when needed most. While some suits, such as an USAR (Urban Search and Rescue) exist on the market today, the majority of departments, especially volunteer firefighters, cannot afford to purchase multiple suits for specific operations. By redesigning the current turnout into a modular system, heat stress may be reduced without creating an additional economic burden.

The development of a modular approach was evaluated by eliminating specific layers, to analyze their specific contribution to heat strain in certain working conditions, where threat of heat and flame are not present. The results presented here focused on the thermal comfort and heat strain aspects of a modular solution. The protective aspects were addressed in a separate study.

Sweating manikin testing on the individual and multi-layer arrangements of turnout suits was conducted. Laboratory testing on the garment level was used to measure both thermal insulation and evaporative resistance of each garment configuration. From these measurements, a predicted manikin THL value was calculated as an indicator of heat loss, according to the following equation:

$$Q_{t(\text{predicted}, 25\text{C}, 65\%RH)} = \frac{T_s - T_a}{R_t} + \frac{P_s - P_a}{R_{et}}$$

In total, seven different layer configurations were evaluated including three single layer garments, two double layer, and two triple layer arrangements. The traditional three layer arrangement of the outer shell (OS) + moisture barrier (MB) + thermal liner (TL) was used as the

standard control. All garments were tested assuming a technical rescue scenario, i.e. no fire exposure involved. Instead of wearing the full ensemble, the thermal sweating manikin was dressed in a pair of trousers, coat, boots, gloves, and helmet. Garments were tested in both static and dynamic conditions to determine natural convection and the effects of body movement and wind.

Statistical significance was determined using two-sample t-tests, assuming equal variance. In the static condition, statistically significant differences in manikin THL were found between the three layers when tested separately (OS vs. MB vs. TL) ($p < 0.05$). Differences in manikin heat loss between the individual layers were not as prominent in the dynamic condition. The moisture barrier had the highest dry heat loss, reflecting its low thermal resistance properties under dynamic conditions, and the lowest wet heat loss, demonstrating its relatively high evaporative resistance properties. The same holds true for the thermal liner which had the highest wet heat loss, reflecting a low evaporative resistance value under dynamic conditions, and the lowest dry heat loss, depicting its high thermal insulation value. The results show that the evaporative resistance under dynamic conditions is largely determined by fit and ventilation and much less by the evaporative resistance of the fabric as tested on a hot plate.

The OS+MB and OS+TL systems were similar in THL at 88.6 W/m^2 and 86.4 W/m^2 , respectively. These results indicate there are no practically significant differences between the two layer systems. The lack of change in THL when removing the impermeable moisture barrier layer is surprising and would imply that it is not as great a hindrance towards heat loss as previously thought. Differences between the two triple layer arrangements were more pronounced. In both test conditions, the traditional arrangement had a higher manikin THL, meaning the rearrangement of the MB against the skin was detrimental for heat loss, compared to the control. By reducing the system to a single, outer shell layer, manikin THL increased by 34 W/m^2 . This significant increase in heat loss would improve physiological comfort and reduce heat stress experienced by the firefighter.

Results from this study demonstrate the heat loss benefits of a modular turnout system for specific firefighter working conditions. When wearing the full three layer turnout suit, in conditions where intense physical activity is performed, the risk of heat stress is increased. By reducing the turnout system to a single layer suit, in specified conditions, the onset of heat stress would be reduced. For a two layer suit, the heat strain would also be reduced and no differences were found between removing the thermal liner versus removing the moisture barrier. This will initiate further studies to determine which configuration would provide the best protection and which system would give the lowest burden to the wearer.

Acknowledgement: This work was supported by the Assistance to Firefighters Grant program under grant No. EMW-2012-FP-01185.

References:

- Den Hartog, Emiel. 2010. "Challenges in Future Personal Protective Equipment - An Overview of Developments in User Needs." *Research Journal of Textile and Apparel* 14: 22–37.
- Nunneley, Sarah A. 1989. "Heat Stress in Protective Clothing." *Scandinavian Journal of Work, Environment & Health* 15 (1): 52–57.
- Rossi, Rene. 2005. "New Developments for Firefighters' Protective Clothing.pdf." *Technical Textiles* 48: 1–4.