

# INTEGRATING AN ACTIVE PHYSIOLOGICAL AND COMFORT MODEL TO THE NEWTON SWEATING THERMAL MANIKIN

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## INTRODUCTION

Well established methods exist to characterize the thermal and water vapor resistance of garments using thermal manikins and numerous computational models are currently in use to predict physiological state and perceived thermal comfort. Recent work has been undertaken to integrate these manikins and models into a single simulation tool that can generate accurate physiological response and provide local and global discomfort data in a wide range of environmental exposures.

This paper presents the method by which a multi-segmental human thermoregulation model was integrated with a physical thermal manikin. The thermoregulation model had previously been adapted to calculate tissue temperatures for a human body described by a surface mesh [3]. The surface-mesh based model is referred to as a “pure virtual thermal manikin” and the integration of this pure virtual thermal manikin with a physical thermal manikin instrument is referred to as a “hybrid thermal manikin.”

Although the surface mesh used by the pure virtual thermal manikin is well-suited to the calculation and application of non-uniform boundary conditions (solar loading, radiation, conduction and convection), the accuracy with which local clothing insulation values, convection coefficients and contact resistances can be measured/estimated subsequently limits the accuracy of comfort predictions. A clothed, hybrid thermal manikin placed in situ allows for a more accurate prediction of human thermal comfort by eliminating the need to provide boundary conditions to a virtual thermal manikin simulation. Instead, the actual heat loss from the physical thermal manikin (as its surface temperatures are controlled to be the same as human skin temperature would be in the same thermal environment) are incorporated into the virtual thermal manikin calculations.

It is hypothesized that the combination of a rapid thermal response thermal manikin with a physiological model dynamically compensating for the physical manikin’s non-human thermophysical properties will improve control stability and performance.

## METHODS

The base elements in this work are drawn from existing commercial products. The Newton sweating thermal manikin from Measurement Technology Northwest (MTNW) is widely used for garment and environmental heat loss evaluation. For this study, a manikin segmented into 26 regions, Figure 1, was used.

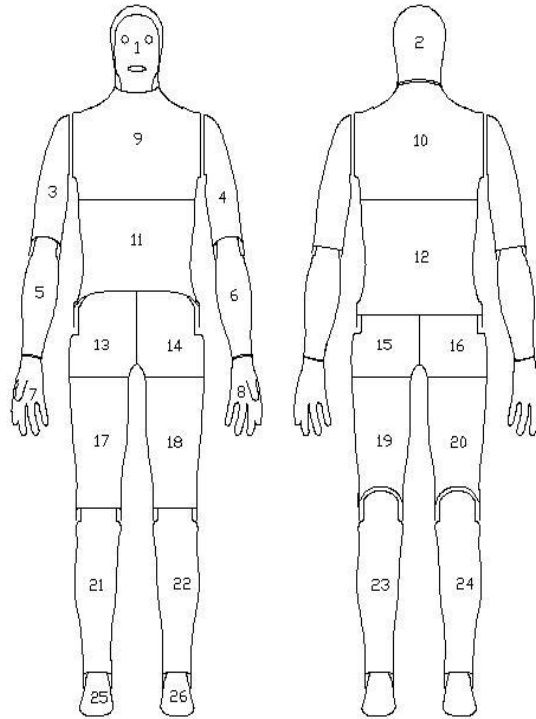


Figure 1 – Newton Thermal Manikin

The human thermoregulation model is based on RadTherm, a finite difference thermal analysis program developed by ThermoAnalytics, Inc. RadTherm resolves steady state and transient heat transfer solutions including radiation, conduction, and convection, and includes a Thermal Comfort model based which predicts human thermoregulatory response, thermal sensation, and thermal comfort for complex and asymmetric environments.

Physiological response is based on the Fiala model [1,2]. Respiratory heat loss is calculated from air temperature and relative humidity and is then subtracted from the whole-body energy balance performed by the thermoregulation model. Heat loss due to sweating can be accounted for in a similar manner, or by passing sweat rates to the physical thermal manikin if it supports weating capability. Thermal sensation and comfort are calculated from the predicted body core temperature and measured skin temperatures using the Berkeley Comfort Model [4].

An incremental course of action was developed to integrate, refine, and validate the manikin-model system. A thermal manikin simulator device was built by MTNW for development testing, which included 26 independently controlled heaters corresponding to a 26-zone Newton manikin. By varying the calibration constants and heater voltage of the simulator, the individual zones could be adjusted to mimic a thermal manikin.

Figure 2 illustrates the intended data flow of the system. The manikin provides the boundary layer interface to the clothing and environment and generates metabolic heating levels as requested by the regulation model. ThermDAC manikin control software was

customized to include a dynamic data stream for communication with the external model. Manikin skin temperature, heat flux, and current sweat rate were output in the data stream, along with ambient temperature and relative humidity. RadTherm analysis software was modified to include a corresponding interface layer for the manikin data stream. A compatibility model was built within RadTherm to map the 26 Newton manikin zones to corresponding nodes in the Human Comfort Module.

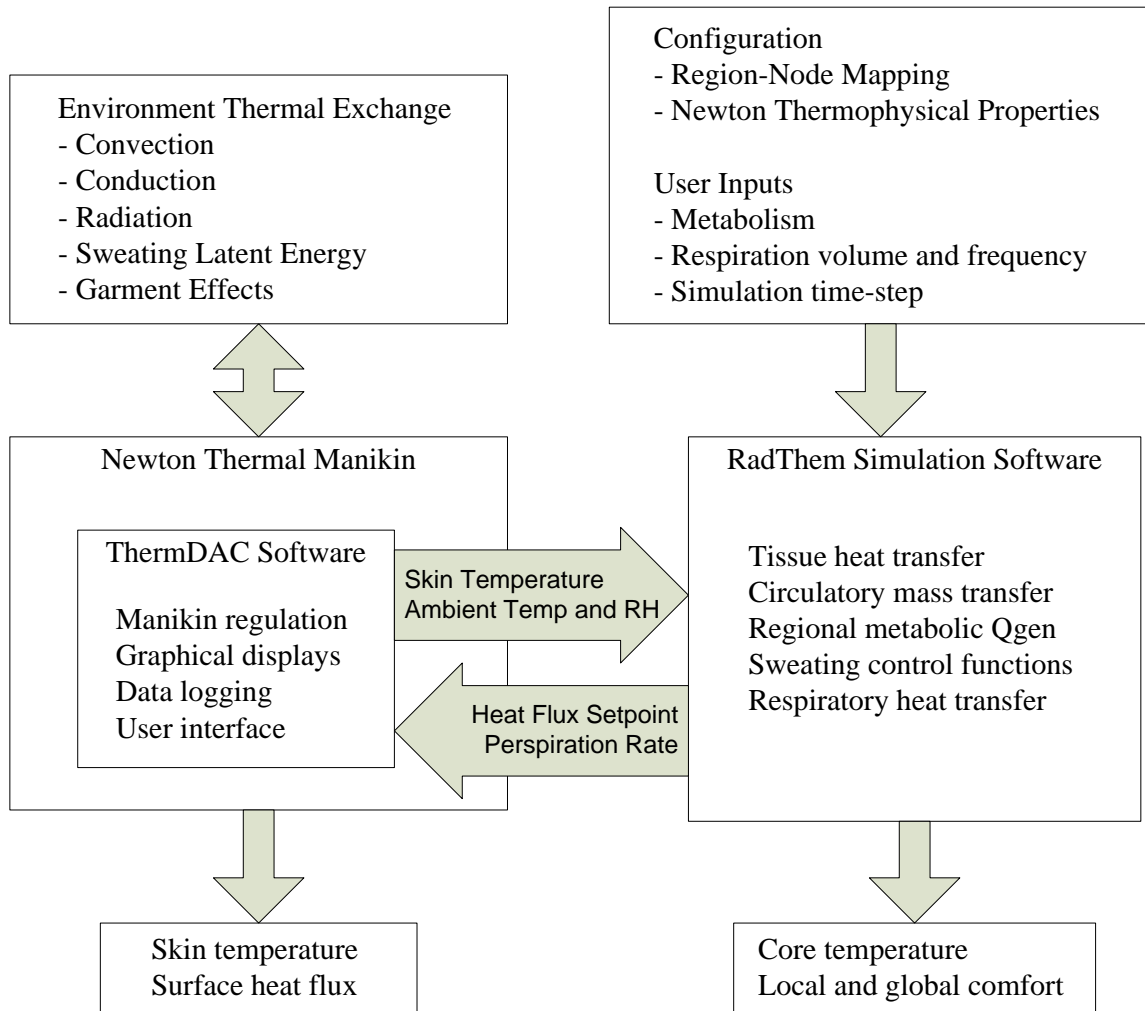


Figure 2 – Manikin-Model Data Stream

Initial work by TAI and MTNW focused on developing a data exchange protocol and optimizing the compatibility model to achieve stable regulation of the simulator. The sweating coefficients and respiration heat transfer were set to zero in the model to reduce the complexity of initial integration. The desired outcome of this preliminary work was to obtain stable convergence of the hybrid simulator system under model regulation that correlated well with the pure model results. Although the simulation was not representative of actual human conditions, replicating the output of a pure model-based system with a combined model-physical system supported the viability of this method.

Following successful thermoregulation of the manikin simulator, the resulting model was applied to the actual 26 zone Newton manikin. This work included characterizing Newton's thermophysical properties and adapting the simulator-based configuration to the actual manikin. Preliminary convergence studies were performed in uncontrolled room air conditions, followed by homogenous controlled environment experiments to determine steady state surface temperature distributions.

## RESULTS

The stability of the system was excellent, producing no oscillation during stabilization or at steady state. Stabilization of the simulator occurred within 20 minutes, and the full manikin converged to a final state within 4 hours due to its increased thermal mass. The agreement on steady state skin temperature between the pure virtual system and the hybrid simulator was excellent at a metabolic rate of 0.8 met, and fair at 2.0 met.

The hybrid thermal manikin converged with a similar temperature distribution as the pure virtual scenario and manikin simulator, but all values were offset above the reference scenario. This mismatch indicates some discrepancy between the experiments, either in the boundary layer definition for the manikin or environmental parameters of the simulation.

Figure 3 illustrates the steady state temperature distribution of the pure virtual simulation, and the two physical systems, manikin simulator and thermal manikin, all operating at a 0.8 met heat generation rate in a 25 degree C environment.

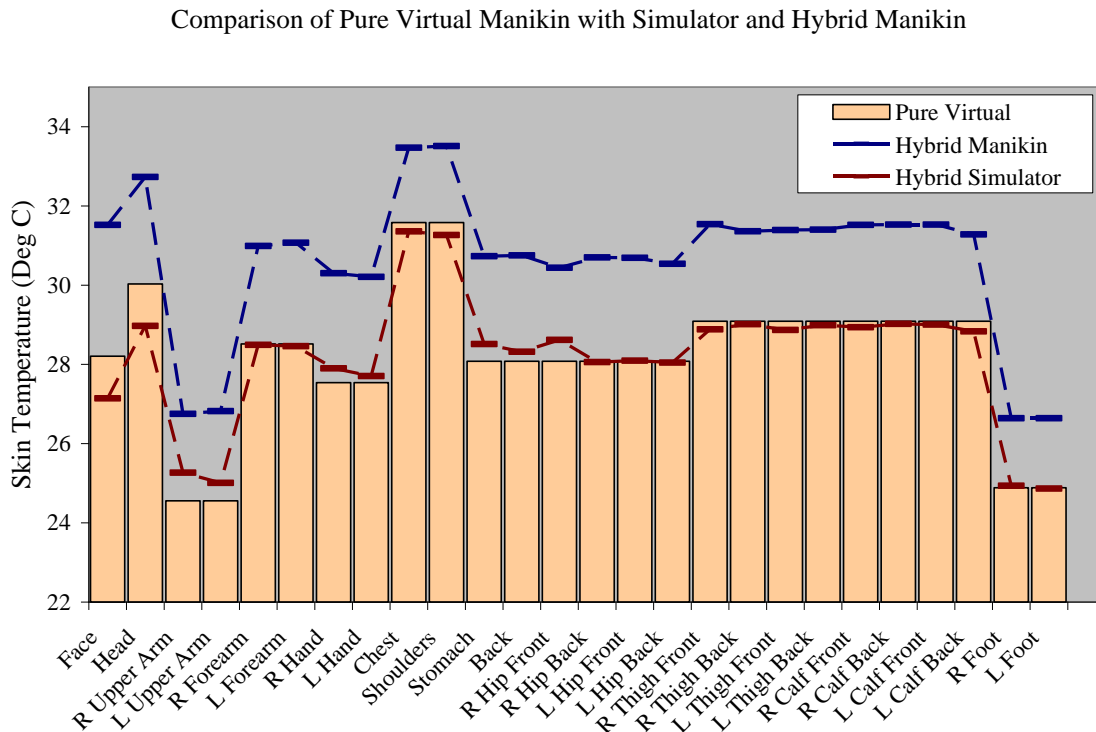


Figure 3 – Steady-state skin temperature distribution for model-only and hybrid devices

The final temperature of the upper arms is not realistic for both simulation and virtual manikin, being artificially low in relation to the rest of the body. The Fiala model includes 2 segments that are not present as isolated zones in the 26-zone manikin: the neck and the shoulders. The neck was simulated pure-virtually, i.e., only in RadTherm, while the model shoulder nodes were mapped to the upper arms. Based on the initial results, it is now believed that the shoulders should be emulated pure-virtually as well and that the upper and lower arms of the manikin both should be mapped to the physiological model's arm segment.

## CONCLUSIONS

A project to integrate a physical thermal manikin with a virtual thermoregulatory model has been initiated and initial proof-of-concept study is completed. The feasibility of controlling a physical device with a thermoregulatory model has been demonstrated. Ongoing work is planned in the future, and will include:

- Refine the manikin-model combination for better agreement with pure simulation over a range of metabolic rates.
- Adjust the manikin-model mapping for the upper arms and shoulders to address the current artificially low skin temperatures.
- Enable existing perspiration and respiration functions in physiological model and validate the hybrid thermal manikin system against steady-state human subject tests
- Additional physiological validation work in transient environments
- Apply the existing UC Berkeley comfort algorithms once adequate physiological response has been achieved.

## REFERENCES

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