# DESIGN AND APPLICATION OF A SWEATING HAND SYSTEM

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## INTRODUCTION

Measuring total heat loss, composed of both dry and evaporative components, is desirable to fully evaluate both the design and the end-use thermal performance of handwear. These measurements are optimally made at a saturated skin condition, but this has been difficult to achieve with previously available equipment. This is, in part, due to varying evaporation rates through different regions of the handwear.

Measurement Technology Northwest (MTNW) has adapted its metallic sweating skin to a 4th generation Sweating Thermal Hand Test System (STHTS) for Pittards Glove Leather Division in England (1). The hand system is the result of 10 years of manikin design evolution. It consists of a 9-zone, copper hand form with articulated fingers and thumb, and with thermal and fluid operation under computer control.

## MATERIALS AND METHODS

The sweating skin consists of a thin wicking metal layer, intimately bonded to the copper hand shell, which reduces the thermal decoupling and inaccuracies associated with fabric or plastic sweating skins. Fluid supplied to the zones is distributed by a capillary network within the metal skin and wicks out to the surface of the porous skin.

A positive displacement pump and precision valve network delivers metered flow to each region. Software-controlled digital timing is used for pump and valve control for accurate and repeatable dispensing rates down to near zero flow. The software allows independent flow rate selection for each zone and a unique feature that automatically steps up the flow rate by a user-selectable interval to identify the evaporation limit independently for each region of the glove.

### System Testing

To assess preliminary system performance and repeatability after construction, measurements of thermal insulation (clo) were taken with the hand system, nude and gloved, The subject glove was a lightweight, single-layer leather glove. At the time of testing, a climate-controlled chamber was unavailable, so all tests were performed in a stable laboratory environment with slight air circulation.

All tests used a skin set point temperature of 32°C for all regions of the hand and a nominal environment temperature of 20°C. Sweating tests used fluid flow rates that were periodically increased over the range of 100 to 500 $ml \cdot h^{-1} \cdot m^{-2}$, as described below. The testing procedure included installing and removing the handwear (when used) prior to each test to account for fit variability.

## Identification of evaporation limit

The measured clo value of handwear will decrease with the addition of evaporative heat loss until the evaporation limit of the glove/environment is reached. At that point, the skin is saturated and further addition of perspiration only generates runoff and free water in the glove, with no significant reduction in clo. To quantify this behavior, the following test was performed on a glove: (1) Install glove on dry hand model; (2) Heat hand to temperature and allow to stabilize; (3) Turn on fluid at 100 $ml \cdot h^{-1} \cdot m^{-2}$; (4) Increase fluid flow rate by 50 $ml \cdot h^{-1} \cdot m^{-2}$ every 30 min (100 $ml \cdot h^{-1} \cdot m^{-2}$ for nude hand tests) and (5) Terminate test when clo value has stabilized.

## RESULTS

The system repeatability data are shown in Tables 1 and 2. Steady-state values for clo are averaged over 15-min blocks. Coefficients of variation (CV) are also presented.

**Table 1.** Nude Hand Total Clo – Dry Test

| Test #1 | | Test #2 | |
|---|---|---|---|
| *Clo* | *CV* | *Clo* | *CV* |
| 0.72 | 2.0% | 0.71 | 3.0% |

**Table 2.** Gloved Hand Total Clo – Dry Test

| Test #1 | | Test #2 | |
|---|---|---|---|
| *Clo* | *CV* | *Clo* | *CV* |
| 0.85 | 1.0% | 0.88 | 2.1% |

Evaporation limits for individual hand regions were identified by calculating the percent change in clo value between each fluid flow rate (30-min intervals). When the change in clo value was within 3% of the previous flow increment, the evaporation limit was assumed to be reached. Evaporation limits varied between 250 and 500 $ml \cdot h^{-1} \cdot m^{-2}$ for the various regions of the hand. The graph in Fig. 1 illustrates the different response curve and evaporation limits for the hand and wrist sections.

## DISCUSSION

System repeatability is excellent considering these preliminary tests were not performed in an environmental chamber. Table 5 summarizes the percent variation for the various tests performed. Although the number of tests was small, the agreement was excellent.

**Table 3 - Nude Hand Total Clo at Increasing Flow Rates**

| | Test #1 | | Test #2 | |
|---|---|---|---|---|
| *Flowrate* $ml h^{-1} m^{-2}$ | *Clo* | *CV* | *Clo* | *CV* |
| 200 | 0.33 | 19% | 0.35 | 0.5% |
| 300 | 029 | 3.5% | 031 | 11% |
| 400 | 0.24 | 1.6% | 0.28 | 2.7% |
| 500 | 025 | 3.0% | 0.26 | 0.9% |

Table 4. Gloved Hand Total Clo at Increasing Flow Rates

| | Test #1 | | Test #2 | |
|---|---|---|---|---|
| Flowrate *ml h⁻¹ m⁻²* | *Clo* | *CV* | *Clo* | *CV* |
| 100 | 058 | 3.5% | 0.55 | 0.9% |
| 150 | 0.50 | 3.3% | 0.46 | 1.2% |
| 200 | 0.43 | 1.3% | 0.41 | 0.7% |
| 250 | 0.40 | 3.4% | 0.40 | 1.7% |
| 300 | 0.36 | 1.4% | 0.38 | 1.8% |
| 350 | * | * | 0.36 | 1.7% |
| 400 | * | * | 0.34 | 1.8% |
| 450 | * | * | 0.34 | 1.5% |
| 500 | * | * | 0.33 | 1.3% |

* data not available

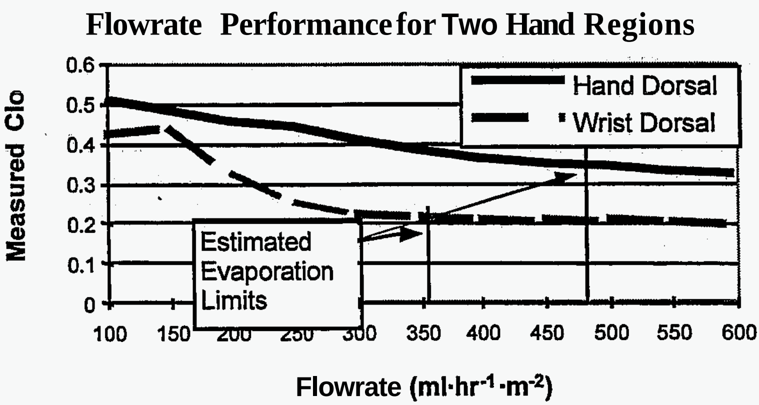


Figure 1. Response Curves for Two Hand Regions

Table 5. Repeatability Test Summary

| Test Type | Clo | Variation |
|---|---|---|
| **Nude Dry** | 0.72 | 1.0% |
| Gloved Dry | 0.87 | 2.5% |
| **Nude** Wet (300 $ml \cdot h^{-1} \cdot m^{-2}$) | 0.37 | 2.1% |
| Gloved Wet (300 $ml \cdot h^{-1} \cdot m^{-2}$) | 0.30 | **4.7** % |

Evaporation limit tests demonstrated that the different regions **of** a glove can exhibit significant regional differences in evaporation capability. The subject glove used in these tests had a closure over the wrist section. This is assumed to be the cause of the different performances **of** the dorsal hand and dorsal **wrist** regions shown in the Fig. 1 graph. Other variations were seen between the hand regions and the fingers due to the significantly different geometry and glove construction.

## CONCLUSIONS

Hand system performance met or exceeded the design parameters. The complete system demonstrated a thermal accuracy off 0.1°C, and power measurement and control **of 1%** or better. Perspiration flow rate is controllable by individual zone from near 0 to over 600 **$ml \cdot h^{-1} \cdot m^{-2}$.** Preliminary tests show stability and repeatability are within the tolerances of the instrument.

Low fluid flow rates generated measurable evaporative cooling with no free water **on** the handsurface. Higher flow rates produced beading and runoff **of** water, which closely mimics human perspiration behavior.

**This** sweating hand system can measure the evaporation limit, clo and permeability index **of** each thermal zone independently. Further tests with more stable environmental controls and additional glove samples are underway at Pittards' test lab in Somerset, England, to improve statistical confidence in the data.

## REFERENCE


1. Burke, **R.,** O'Neill, F. T. and Stricker, P. 1994, The development **of** a heat pipe driven manikin with variable **flow** irrigated skin, **in** ***The Sixth International Conference on Environmental Ergonomics, Proceedings*** (Toronto, Ontario, Canada: DCIEM **).**