A measurement setup to test instruments for detecting sweat

A: Design & technology
A.2. Sensors and Actuators

A MEASUREMENT SETUP TO TEST INSTRUMENTS FOR DETECTING SWEAT

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SUMMARY

The thermal neutral zone is the temperature range in which the body can manipulate the heat balance of the body using only vasomotion to maintain thermal comfort. In a warm environment, vasodilation will allow blood and heat to spread over a larger surface area, increasing the heat loss through passive means. When the heat loss needs to be increased further, people start sweating and the heat is lost by evaporating moisture from the skin.

Sweat can be used to monitor the thermoregulatory response of users and test subjects. This is similar to skin temperatures. Detection of the onset of sweating is an indicator for the upper boundary of the thermal neutral zone.

Up until now, detecting vasomotion, sweat and sweat rate requires highly controlled conditions and complicated instruments. There is a need to develop instruments that can be used in an office environment during field tests for the development of personal conditioning systems and future climate control systems. In this study, a test set up is build that can mimic the human skin with respect to temperature and sweat rate. Based on the results of the study suggestions are given for the further improvements and measurements on the human body.

INTRODUCTION

Personal conditioning systems (PCS) offer individual office workers the possibility to increase their comfort level above the level offered by the global environmental conditions (Pasut, Zhang, Kaam, & Zhai, 2013). This effect also means that the indoor global temperature does not need to be maintained within narrow boundaries. Maintaining these narrow boundaries may not only be very inefficient from the perspective of energy use, it does not deliver the desired effect in terms of comfort (Arens, Humphreys, de Dear, & Zhang, 2010) and the lack of thermal stimulation might be detrimental to health in the long run (van Marken Lichtenbelt & Kingma, 2013).

The thermal neutral zone (TNZ) is the temperature range in which the human body can maintain the body core temperature by regulating the heat balance using only vasomotion. This way, the metabolic rate does not need to be increased due to thermoregulatory action (Kingma, Frijns, & van Marken Lichtenbelt, 2012). People are generally comfortable within the TNZ. For the predicted percentage dissatisfied (PPD), one can say that the people that are dissatisfied have their TNZ outside of the offered environmental temperature.

For future application of PCS, assessment of the comfort level of individual users could lead to a much better application of energy for heating and cooling in a building. Abandoning the thermostat as the control point for a building climate system altogether in favour of an indicator that offers a better insight into the needs and demands of the occupants and the energy expenditure can be directly fitted to the demand. This user-in-the-loop approach is being developed by us (Vissers, 2012)(Filippini, 2009). However, this requires a better understanding into the boundaries and positions of the TNZ of the occupants.

The state of a person's thermoregulatory system can be estimated based on the skin temperature at the extremities (near the low boundary, this skin temperature will drop due to vasoconstriction) and the onset of sweating (Schellen, Pallubinsky, & Van Marken Lichtenbelt, 2014).

For warm discomfort, understanding the mechanisms leading to the onset of sweating is essential to determine the physiological processes in the user. The increase in internal heat production at temperatures above the TNZ is caused by active vasodilation leading to increased blood flow to the skin and activation of the sweat glands (Consolazio & Matoush, 1963) as cited by Kingma et al. (2012).

For the development of instruments that are able to detect the onset of sweating, a test set-up is developed. This to test the practical applicability of a number of instruments using different physical principles of sweating.

METHODOLOGY

In this study, a test set-up is built where different methods for determining the onset of sweating can be tested. The set-up consists of airtight glass box. In the box, the air temperature is controlled and can be increased using a 150 W incandescent light bulb. The air in the box is mixed by two small computer fans. A container is placed to simulate the skin. The container consist of a sponge in which water can be fed from below. The water level can be controlled by adjusting the water flowrate. A polyester cloth membrane is stretched over the sponge. The container can be heated independent from the air to simulate skin temperature. This way, the evaporation can be controlled.

In Figure 1. A schematic is shown of the test set-up. The air temperature and relative humidity (RH) in the box is monitored using three separate temperature and RH sensors.

In Figure 2, a detailed schematic of the container is shown. The container with the sponge is placed on top of the heating plate. Below the heating plate, insulation is used to prevent heat from leaking into the box from underneath. The surface temperature of the membrane can be maintained between 32 and 37 ^{o}C. This is the expected range skin temperatures at the extremities found in people sweating.

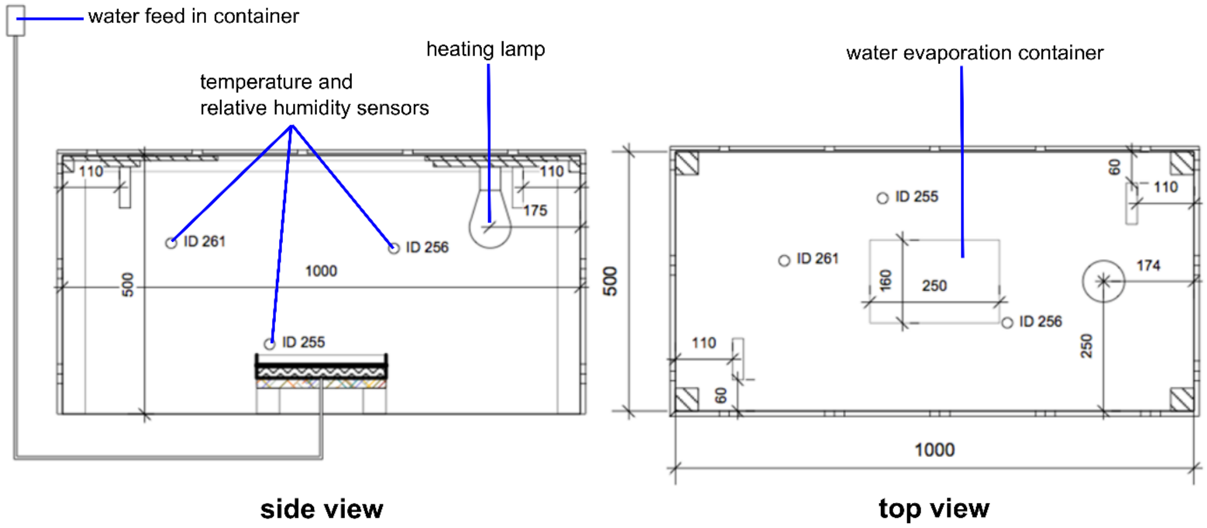

Figure 1. Side view and top view of the climate box in which the evaporation is measured. The air temperature in the box is controlled using a light bulb for heating.

The evaporimeter (Wheldon & Monteith, 1980), used as a first pilot to test the set-up is also visible in Figure 2. The method for assessing the flow of water vapour evaporated from the membrane is to measure the partial pressure of the water vapour at two different heights above the membrane in the same open tube. The principle used here is the difference in partial pressure over the distance between the sensors (Wheldon & Monteith, 1980). The partial pressure is calculated from the measured relative humidity and temperature. The difference in partial pressure in the two sensors is directly proportional to the mass of water evaporated from the membrane per unit surface area as shown in Equation 1 (Nilsson & Oberg, 1978).

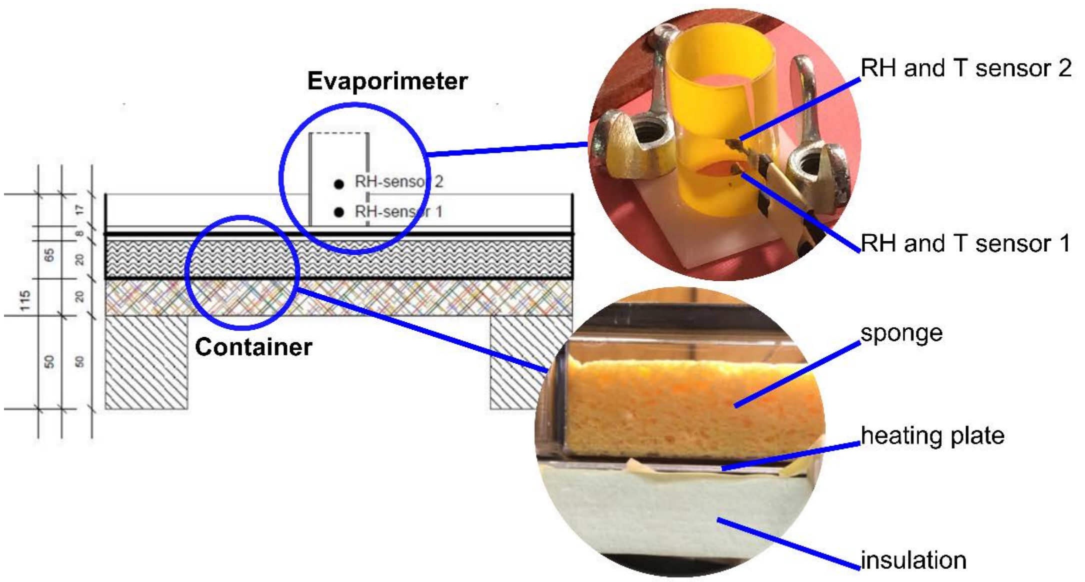

Figure 2. Detail of the water evaporation container. The water level as well as the temperature can be regulated. In this picture, the evaporimeter is included for measuring human sweat rate.

$$\frac{1}{A}\frac{dm}{dt} = -D\frac{dp}{dx} \quad (1)$$

In Equation (1), A [cm^2] is the surface area of the evaporimeter, dm/dt [mg/h] is the mass flow of water vapour through the tube, D is a characteristic of the instrument and dp/dx [Pa/cm] is the difference in partial pressure measured over the distance between the sensors in the tube. The left hand side of the equation with a unit of [mg/cm^2/h] is the evaporate rate.

For this first set of tests, the temperature in the climate box is maintained at 28 ^{o}C, which, for a normal office situation corresponds to a slightly warm environment.

RESULTS

Seven tests were conducted with water flowing into the container (indicated in Figure 3 as Test 1-7) and one with a dry surface (Reference). The reference test is used to show that detection evaporation can be achieved. The mean value of the air temperatures measured at two of the three different positions in the climate box was taken during the tests are shown in Figure 3. The third sensor was influenced by the heating lamp. That disturbed the measurement. Figure 4 shows the mean value of the relative humidity from the same sensors.

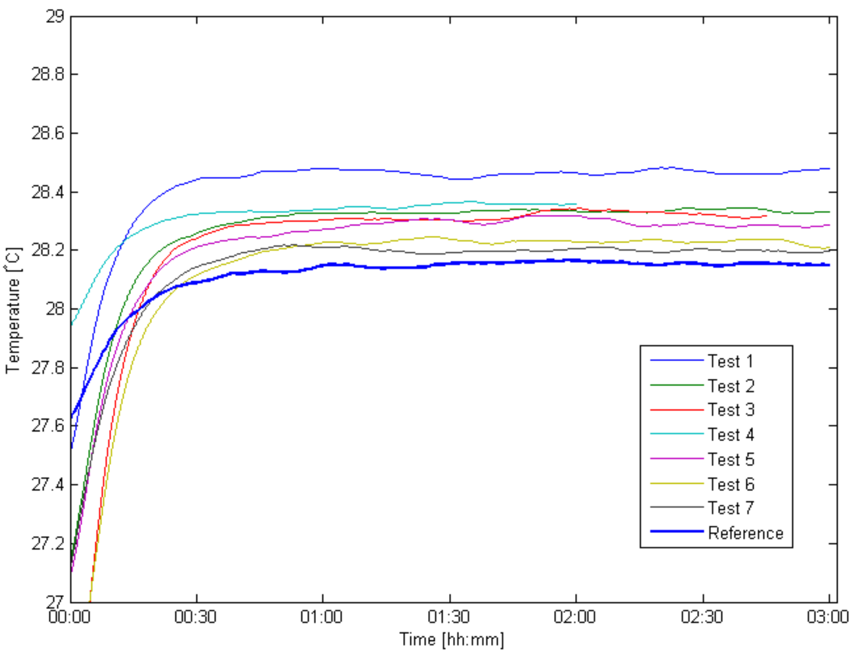

Figure 3. Temperature in the climate box during the tests

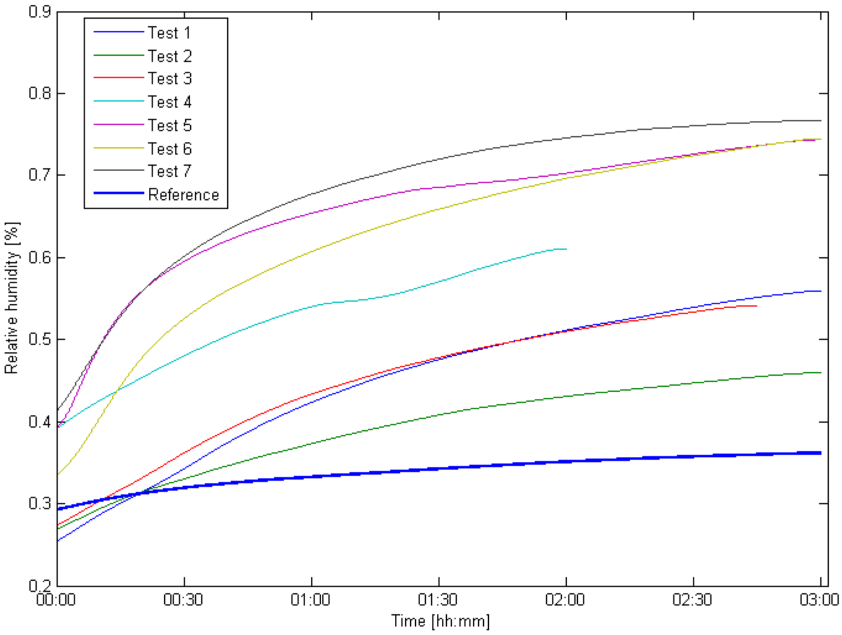

Figure 4. Relative humidity measured in the climate box

In Figure 4, the differences between the tests can clearly been seen. Test 1 through 4 were conducted with the water level left free after the beginning of the test. During test 3, the heating plate failed to heat up. In test 4, the water feed in system fell. This is also the reason that this test was cut short. During tests 5 to 7, 10 g of water was added to the outside reservoir every 15 minutes. This way, the water pressure under the membrane was increased slowly. The effect of filling itself is not visible, the width of the container spreads out the effect.

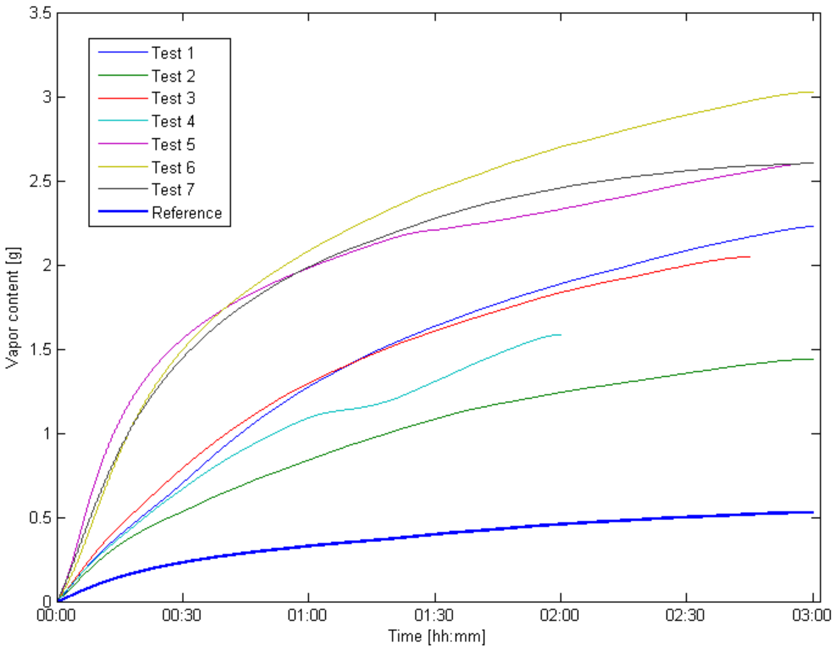

Figure 5. Total amount of water evaporated from the membrane as calculated from the sensors in the climate box

In Figure 5, the total amount of water vapour dissolved in the air in the climate box is shown for each test. This shows the total evaporation rate through the membrane in the climate box. The lowest evaporation rate achieved in the box (Test 3) was 0.026

mg/cm^2/min. This corresponds to a daily insensible water loss of a standardized person of 0.7 dm^3/day (Taylor & Machado-Moreira, 2013).
The measurement of the partial pressure using the evaporimeter were not stable. The reference case shows that when the evaporimeter is placed on a dry surface the value is more stable and the difference between maximum and minimum is within the limits stated in the sensors accuracy range, ±3% (Figure 6).

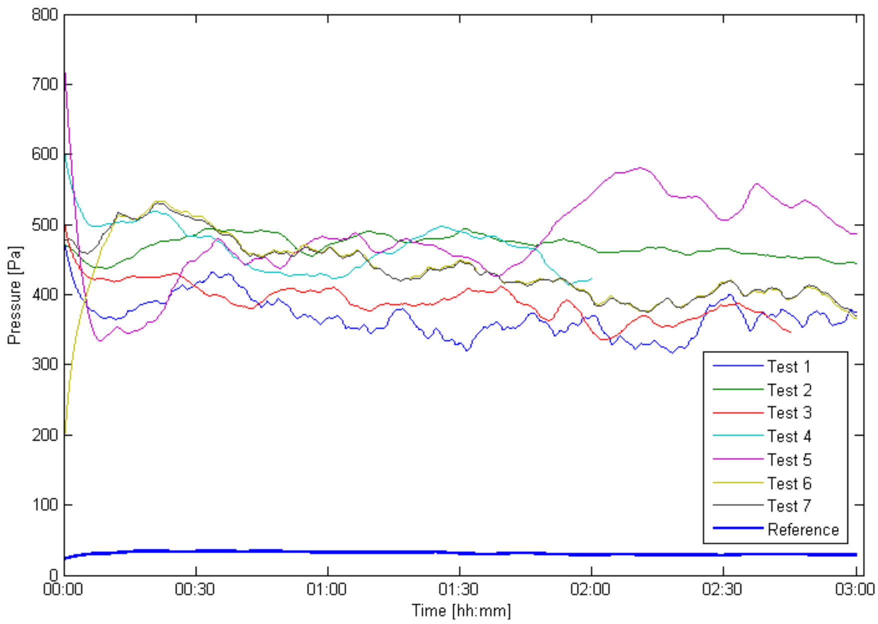

Figure 6. The difference between the partial pressures over the distance between the sensors in the evaporimeter.

DISCUSSION AND RECOMMENDATIONS

The climate box performed as expected. The problems encountered during the tests did not lead to situations that were far outside of realistic situations. Heating using the incandenscent lightbulb disturbed the sensors in the evaporimeter, these were not shielded against the radiative heating. The performance of the climate box can be improved by shielding the lamp from directly illuminating the sensors that are exposed.

The lowest evaporation rate measured in the climate box corresponded to the insensible water loss when people are not yet sweating. The other measurements showed higher evaporation rates, but did not yet reached a value close to the maximum sweat rate in dry heat of seated people, which is 0.99 mg/cm^2/min and occurs at the forehead (Taylor & Machado-Moreira, 2013).

The characteristic of the instrument, D, which should be a constant value, need to be obtained in order to apply the evaporimeter on testing human skin evaporation rate. However, no reliable constant D could be calculated from Equation 1. Because the evaporimeter couldn't give a stable measurement when the instrument was placed on a wet membrane. The instability of the sensors meant that the measurement of the evaporation rate could not be replicated with the evaporimeter. The instability could be solved by connecting the sensors in a Wheatstone bridge with two constant resistors. This will eliminate the disturbances caused by fluctuations in the water evaporation.

The inaccuracy of the evaporimeter could clearly be shown using this test setup. The sensors in the evaporimeter can be upgraded and alternative methods can be assessed, such as skin capacitance to measure moisture content and infrared reflectance.

CONCLUSIONS

For the purpose of testing instruments that are capable of detecting the onset of sweating and measure the sweat rate, a test setup is built in a climate box. The climate box is able to create the climate in which the sweat sensors can be tested. The skin is simulated by a polyester cloth membrane stretched over a sponge. The water pressure in the sponge can be controlled as can the membrane surface temperature.

The first test of this set-up was done using an evaporimeter. This instrument relies on two temperature and RH sensors to determine the mass flow of water vapour through the open tube by diffusion into the open space. The instrument can clearly show the onset of sweating. The stability of the instrument for direct determination of the sweat rate need to be improved.

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