Heavy sweating or perspiring is an unavoidable consequence of strenuous physical activity and an essential physiological reaction. Our bodies sweat as a means of regulating core body temperature and without it we would overheat and suffer hyperthermia. Mike Wilson from UK technology centre SATRA explains how footwear has become an important factor in how efficiently temperature regulation occurs.

Comfort for the sweating foot

Liquid sweat produced on the skin cools us down by evaporation which removes heat energy from the body to convert liquid to vapour. The rate of evaporation, and hence the rate of body heat loss, is also affected by the wind chill factor—as air flowing over the skin or clothing accelerates heat loss by rapidly removing the warm moisture from the surface.

The extremities, i.e. the hands and feet, are the first areas on the body to respond to the body's need to lose or conserve heat in order to maintain a steady core body temperature and protect the vital organs such as the heart. Therefore footwear—which we need to wear for the majority of sporting and leisure activities for comfort and to protect the feet from injury—becomes an important factor in how efficiently temperature regulation occurs.

In cold conditions footwear is beneficial because it insulates the foot and helps to keep it warm. As the air temperature drops, thicker socks and more thickly insulated footwear can be worn. But in warm conditions, when we need to sweat, footwear is simply an obstacle to losing heat and a barrier to temperature regulation. And however minimal the construction, all footwear will inhibit heat loss and reduce the rate of sweat evaporation. As a result even good footwear design and material selection can only hope to minimise the obstacles and maximise the liquid and vapour moisture transport mechanisms through the layers of materials.

Treadmill testIng in SATRA's climatic chamber.

SATRA

Striving for comfort

The goal of any sports footwear is to maintain the skin, and the hose next to the skin, in as dry a condition as possible. If perspiration is held next to the skin it can create a feeling of clamminess and discomfort. The skin will also reabsorb the liquid making the tissue more sensitive to heat, pressure and rubbing, giving rise to an increased risk of soreness, blisters and infections.

As the foot heats up and the blood flow to it increases, it also swells in size, making the footwear a tighter fit and this is the main cause of discomfort from hot feet. Take the shoes off and the discomfort immediately goes away.

There are numerous factors which affect foot sweat rates, including climate or environmental conditions—specifically air temperature and humidity levels—the level of physical exertion, the clothing being worn and the individual's unique physiology. Diverse climates around the world place great demands on footwear whether worn outside or indoors.

Testing conditions

Environmental conditions are an important factor and vary greatly around the globe.

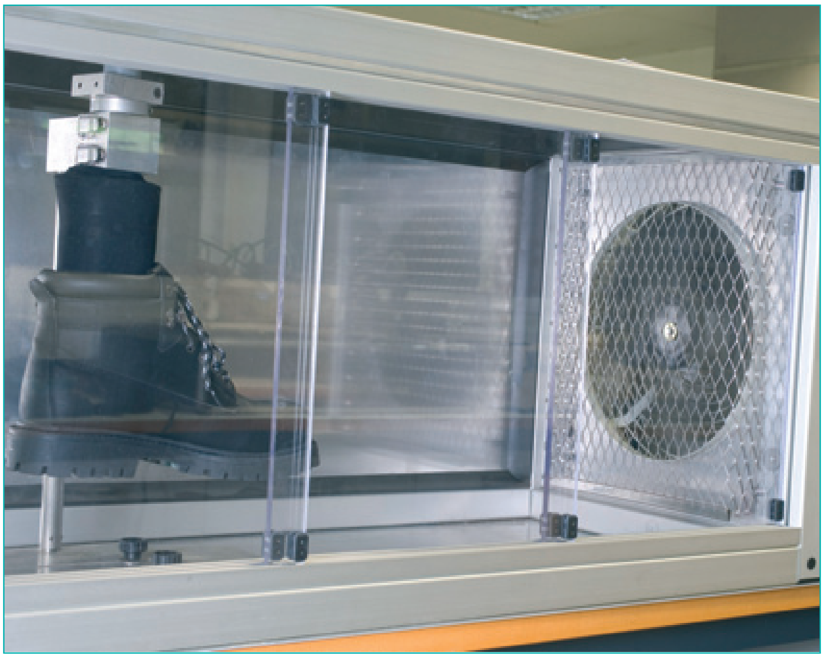
Whilst New York sees temperatures ranging from -5°C to +28°C, but has a fairly constant humidity all year round of about 60-70%rh (relative humidity), in San Francisco the temperature is more even at 7°C to 20°C and humidity is also constant, but at a higher level of 70-80%rh. Milan and Berlin experience similar temperatures to New York and San Francisco respectively, but have more varied and higher humidity levels at 70 to 90%rh, respectively. However, the Middle East is hot and dry. Riyadh in Saudi Arabia sees temperature ranges of 8°C to 42°C and has less than 50%rh, but in many coastal areas the climate is more temperate. Indonesia is hot and relatively humid (23–32°C; 75–85%rh); Moscow and Helsinki experience temperatures down to -20°C. Then there are the real extremes where temperatures may reach 50°C or drop below -50°C. In these latter cases humidity can be very low, less than 10%rh, but anywhere in the world when it rains will see humidity shoot up to near 100%.

The level of physical activity, both the rate of energy expenditure and duration of exercise, is also a key factor and can even override climatic conditions. For example, Arctic adventurers have to guard against sweating too much as wet undergarments may freeze to the skin when exercise stops; whilst top tennis players sweat profusely in all of the conditions they encounter on the world circuit.

As a result foot sweat rates are highly variable. At foot skin temperatures below 25°C the foot tends to sweat very little, however even moderate exercise, for example 30 minutes brisk walking at room temperature of about 20°C, raises foot sweat rates to more than 5g/h and in-shoe humidity levels to more than 90%.

Under more arduous exercise conditions or at higher ambient temperatures sweat rates can increase dramatically rising to, for example, 35g/h over 90 minutes walking at 40°C.

Females are thought to perspire less than males and to start sweating at higher temperatures, although sweat rates may reduce with age: children have been found to have 2–3 times greater foot sweat rates than adults. However, there is little definitive experimental data to rely upon for sweat rates and SATRA has found large differences between similar individuals that can mask general trends. Indeed, individuals' sweat rates under standard test conditions have been seen to vary from day to day depending on what they had been doing in the previous 24 hours.



The SATRA test comprises a heated foot form suspended in a wind tunnel.

SATRA

Machine over man

To investigate the role played by footwear in dealing with different sweat rates and in maintaining foot comfort and foot health, a whole shoe laboratory test is required that simulates the human sweating foot. A machine test eliminates the wearer variability factor from the equation and enables controlled, systematic studies to be readily undertaken. Material tests can be helpful, but most footwear comprises a number of layers of different materials and even the shoemaking process itself can affect the moisture transportation properties of the materials.

The foot also contains a number of capillary tubes delivering water to the surface of the foot at a controlled rate. Once the system is primed, the test hose and footwear is attached and a warm, humid in-shoe environment rapidly develops. The liquid moisture vapour is then gradually—by means of absorption, wicking and permeation—transported through the shoe upper materials and eventually evaporated into the atmosphere.

Absorbing information

Absorption is the ability of materials to take in moisture and contain it. The water is held within the molecular structure and cannot be physically 'squeezed out' until saturation levels are reached. Socks (hose) in close contact with the foot will absorb moisture straight from the skin. This moisture will spread to absorptive linings and/or uppers that are in contact with the sock.

Absorption may be considered a 'stand alone' moisture disposal mechanism because it is not dependent upon other factors for foot comfort, at least in the short-to-medium term. However, once the absorption capacity of materials is reached (saturation), water will remain as a liquid and the foot will become damp and uncomfortable.

If absorptive materials are present on the outside of the shoe, moisture present within the material will be subject to evaporation in suitable conditions.

Through wicking liquid away by capillary action, usually between fibres, moisture held this way is usually easily removed by 'squeezing out'. Wicked moisture, like absorbed moisture, will spread to dry material within a shoe. If absorptive materials are in contact with the wicking fabric, moisture will tend to accumulate in these absorptive materials and, if not, moisture may well wick back to the foot when levels and pressure within the shoe are sufficiently high.

In the vapour state, moisture molecules are fast moving and, given a free passage through pores in the lining and/or upper, they will permeate straight through and escape to the surrounding atmosphere if there is a humidity gradient.

However, water vapour only passes from a high humidity environment into a lower one and permeation is therefore only possible if lower humidity environmental conditions are present outside the shoe. Once the outside of the shoe becomes effectively wet (100% humidity) then permeation through the upper ceases (as will the evaporation of absorbed or wicked liquid water from the surface of the upper material).

Finding a balance

The main driving force for moisture transport is the temperature and humidity gradient between the inside and outside of the footwear. Depending on the external temperature and other material factors, condensation (vapour to liquid) and re-evaporation (liquid to vapour) may occur several times and in different layers before the moisture eventually passes out of the shoe. When the external atmosphere is itself at saturation humidity or the shoe upper material is actually wet, there will be negligible moisture transfer out of the shoe.

Foot form with hose attached prior to testing
SATRA

A complete shoe test, such as the one described here, enables all these moisture disposal mechanisms to come into play in a realistic way. Depending on the hose and footwear design, up to 75-80% of the water delivered to the foot can escape completely leaving the hose comfortably dry. On the other hand, impermeable uppers trap all the moisture inside the footwear, which may build up in either the hose or footwear lining materials depending on the wicking and absorption properties of the various layers of materials. If the lining materials are absorbent, the hose can remain relatively dry.

Absorption and wicking can be sufficient to provide short-to-medium term comfort but for longer term comfort and to prevent excess moisture build-up inside the shoe, permeability is essential.

The Satra test therefore differentiates between different footwear constructions in which all of these mechanisms play a part. It can also be used to study how footwear will perform under different end-use conditions. The foot temperature and sweat rates can be adjusted to simulate both moderate and severe conditions, from hiking on a mild day to playing intense vigorous sports such as squash and tennis.