Microclimate Control in the Foot-Stocking-Shoe System

The wearing of safety shoes to protect the feet should be just as much common practice as the wearing of a helmet to protect the head. In principle. However, experience shows that far too many industrial accidents with serious foot injuries occur because the injured person was not wearing safety shoes. Why not? "Too warm, too heavy, too ugly". Although there have recently been quantum jumps in design and weight reduction of safety shoes, there is still room for further improvement in the foot microclimate. A joint research project conducted by PFI and the Hohenstein Institute for Textile Innovation gGmbH (HIT) has therefore examined possible improvements to the foot-stocking-safety shoe system. In a nutshell: Stockings play a crucial role.

The wearing comfort of stockings and shoes depends to a large extent upon how well they manage temperature and moisture levels around the foot. That is why manufacturers advertise those properties, like water vapour absorption and water vapour permeability, which promise dry feet and a comfortable foot microclimate. This is particularly important for shoes worn during intense physical activity such as sport shoes, trekking shoes, work and safety shoes, all the way to military and police footwear. Unfortunately, however, practical experience shows that work and safety shoes are frequently not worn because they fail to offer a sufficient level of comfort.

Additionally, the lack of comfort offered by the foot-stocking-shoe system heightens the risk of injuries to the feet and accidents. Standards applicable to safety shoes only take into account water vapour absorption and permeability of the individual materials used in the shoes. However, shoes are made up of a combination of materials and the impervious nature of soles, steel caps, steel insoles, and counters has so far received little attention.

To our knowledge, there have been no scientific studies dealing with the foot-stocking-shoe system. Most publications consider only one component of this system and not the interaction between all of them.

The Test and Research Institute Pirmasens (PFI) and the Hohenstein Institute of Textile Innovation (HIT) have just completed a research project devoted to the influence of the shoe and stocking combination on shoe microclimate in work and safety shoes. The foot-stocking-shoe system of safety shoes was analyzed as representative of all other types of shoes, because this type of shoe is worn throughout the entire working day and is suitable for studies relating to intense physical activities. The results of these investigations are transferable to all other shoe types. This was the very first time that a systematic and extensive study with a varied sample selection has been undertaken to analyze the complex interaction of the foot-stocking-shoe system.

This project should answer some of the open questions surrounding the moisture and thermal balance in this system and provide a scientific basis for development of measures for controlling moisture and temperature levels by judicious use of stocking and shoe materials.

Before starting the laboratory experiments and wearing tests, it was first established what materials are actually used in making safety shoes and stockings. The range of materials is expectedly very wide. The five most commonly used materials were therefore selected from each category. Twenty-five combinations were tested with the PFI Comfort Tester (Figure 1) and the Sweating Foot Device of the Hohenstein Institute (Figure 2).

These two devices simulate sweating of the foot in two different ways. The Comfort Tester uses water vapour. Hohenstein's Sweating Foot device works with water droplets emanating from orifices in the 13 individual components of the metal foot, thus modelling the function of the sweat glands. This test device also permits simulations in the area of temperature management.

Fig. 1: PFI Comfort Tester

Fig. 2: Hohenstein's Sweating Foot device

PFI Comfort Tester

Short term and long term tests were carried out with the Comfort Tester. The short term test simulates a high level of exertion during intense physical activity with sweating and subsequently reduced physical activity with drying of the foot. The long-term test simulates a complete working day with varying demands.

Figure 3 shows the course of the short term test. The individual components of the artificial foot-stocking-shoe system were weighed prior to the start of the test and at the times shown (see Figure 3).

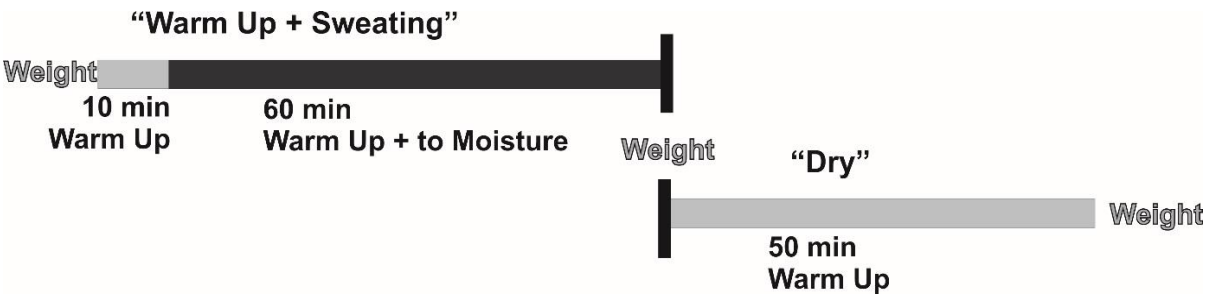

Fig. 3: Course of the short-term test

Differences in the weights of all components of the system were compared and analyzed.

Tests with the Hohenstein Sweating Foot Device

Tests with the Hohenstein Sweating Foot device go through three phases of 60 min each, adding up to a total time of 180 min (see Figure 4).

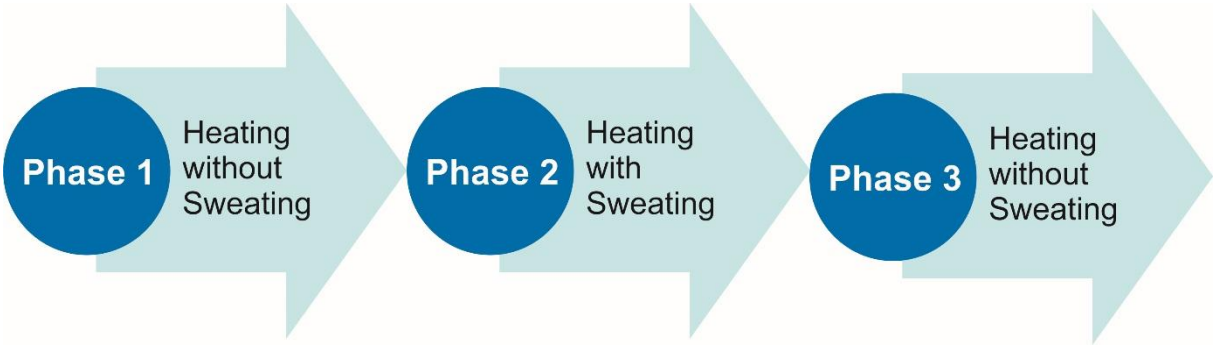

Fig. 4: Course of HIT test

The thermal transmittance and the water consumption of the Sweating Foot device were recorded and analyzed for each phase and each constituent element.

Results of Tests with the PFI Comfort Tester

The results of the short-term and long-term tests showed that it is very important to consider all the components as a system. Stockings have an immense influence on the properties of the system. They can block or support the transport of moisture from the foot into the shoe. The materials of the shoe determine the quantity of moisture absorbed from the stocking and evaporated into the environment. Different materials give rise to different evaporation rates.

Textile shoe materials and stocking materials containing cotton and polyamide favour the transport of moisture. Leather materials absorb a large quantity of moisture but need a long time to release it.

Results of the HIT Tests

Hohenstein was able to determine the thermal transmission resistance as well as the water vapour permeability resistance. Result: With regard to thermal transmittance, the safety shoes are the dominate component in the foot-stocking-shoe system. The influence of different stocking materials could not be documented.

The Hohenstein tests provided further details regarding water vapour permeability resistance. The leather shoe (upper and lining) had the highest resistance. The different combinations showed different values. Shoes with a leather upper and a leather lining had the highest resistance values. Shoes with a lining made of textile and the membrane shoe showed the lowest values. The lowest resistance was measured for stockings made of blended fabrics consisting of polypropylene (PP), cotton (CO), polyamide (PA), polyacrylonitrile (PAN), and elastothane (EL). Stockings made of wool and wool blends showed the highest resistance.

Wearing Tests

Wearing tests with real persons were conducted to complete the simulation tests with subjective assessments. PFI and HIT carried out tests involving different physical activities.

PFI combined the subjective assessments with measurements of the temperature in the shoe (Figure 5) and recorded the weight of stockings and shoes before and after the tests. Two young male test persons had to rate their perception of temperature and moisture during physical activity of varying intensity.

The result was that the stocking and safety shoe system is not able to transport moisture from the foot during intense physical activity. The test persons already described their feet as feeling uncomfortably wet after a short wearing time. All temperatures over 33°C were perceived as too warm. The test persons were not able to clearly distinguish between feelings of heat and moisture. They rated the leather shoes as more comfortable than the textile shoes.

Fig. 5: Test person with thermal sensors in the shoes (PFI)

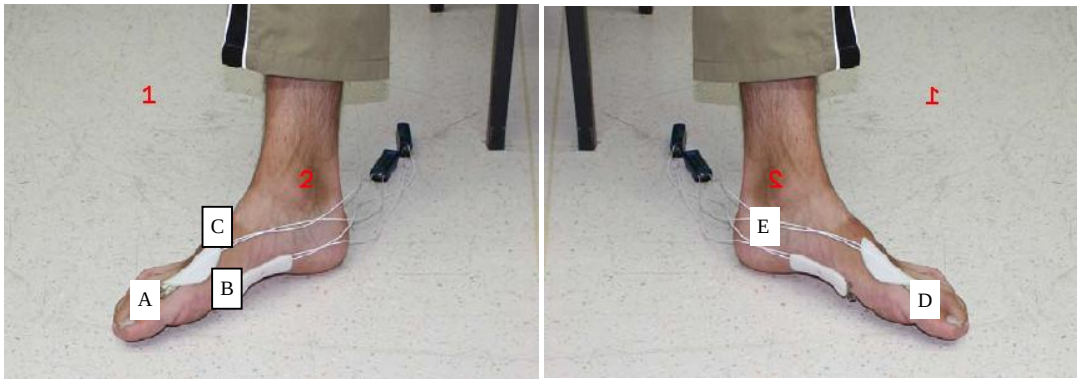

Fig. 6: Test person with thermal and moisture sensors on their feet (HIT)

The HIT tests with test persons clearly favoured shoes with textile lining and shoes made entirely of textiles over the other shoes investigated. Leather shoes and shoes with a woollen lining showed a higher level of moisture uptake. The test persons rated the temperature at the foot as too warm, depending on the stocking-shoe combination. The least comfortable combination was the leather shoe with a wool stocking.

The wearing tests indicated a wide range of individual ratings and deviations from the simulation tests. The results make clear that further research in this field is necessary. Stockings and shoes must be considered as a system. It is possible to improve the properties of the system in order to achieve noticeably better comfort.

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