Thermal Characterization of Textiles: Do you feel comfortable in your footwear?

Abstract

The thermal characterization of functional wear becomes more and more important. Common characterization solutions are either non-quantitative (e.g. infrared camera) or stationary and expensive (e.g. guarded hotplates). This application note shows how a hiking shoe can be thermally characterized under actual conditions. GreenTEG's U-Value Kit, consisting of one heat flux sensor, two temperature sensors, and a data logger delivers quantitative data for the assessment. With its help, the thermal insulation properties (U-value) and the thermal behavior of the hiking shoe during different activities can be determined easily, fast, and accurately. Using the U-Value KIT from greenTEG for thermal characterization has the following advantages:

- It is possible to measure what the human body feels
- It is possible to measure under realistic conditions
- It enables comparisons of different experiments on the basis of the U-Value
- It is a low cost alternative to a guarded hotplate set-up

Mounting several sensors on different positions on the foot within two experiments enabled the determination of hotspots in the hiking shoe.

1 Introduction

The goal of this study is to demonstrate how greenTEG's measurement solution enables an easy and flexible determination of the insulation properties of a hiking shoe as well as the determination of the thermal comfort under different types of activities.

2 Experimental

For the experiment, greenTEG's high resolution data logger with two temperature sensor in combination with the gSKIN®-XM 29 9C heat flux sensor was used (Figure 1).

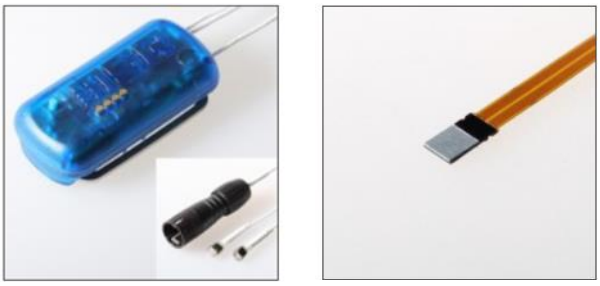

Figure 1: Test equipment from greenTEG used for the demonstration experiment: data logger with temperature sensors (left) and heat flux sensor (right)

Figure 2 shows the mounting of the sensors. In the **first experiment,** the heat flux sensor and temperature sensor T1 were fixed with medical tape, which is available at every pharmacy store, on the upper part of the foot. The second temperature sensor was placed on top of the outside of the shoe. The cables were secured with tape in order to avoid that the sensor is exposed to stress from the cables during the experiment. The logger was fixed to the lower part of the leg with tape so that it remained well attached but still allowed sporty activities.

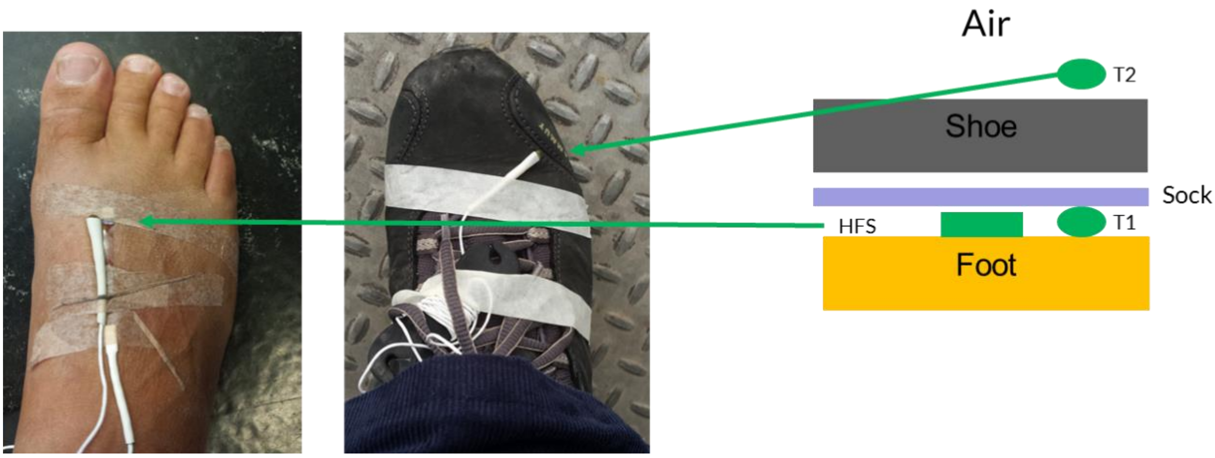

Figure 2: Illustration of the sensor attachment to the foot and the hiking shoe.

In the **second experiment**, the heat flux sensor and temperature T1 sensor were fixed with a tape on the inner side of the shoe (see Figure 3).

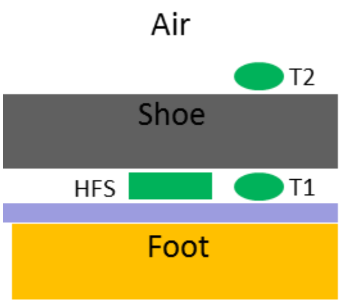

Figure 3: Illustration of the sensor attachment to the foot and the hiking shoe.

During both experiments the same types of activities were performed. The following table shows these activities.

Activity	Time	Propose
Deskwork	> 30 min	Steady state condition monitoring
Exercise (stair running)	~ 10min	Changing inside condition
Deskwork	> 30 min	Steady state condition monitoring
Outdoor walk	~ 15 min	Changing outside condition
Deskwork	> 30 min	Steady state condition monitoring

The data acquisition was started and stopped with the software for greenTEG's U-value Kit. However, the gathered data was not analyzed with this software, it was analyzed using Microsoft Excel due to the fact that greenTEG's software calculates the moving average which is not suited because changes in the U-value upon special events cannot be detected easily. The U-value was calculated point by point by applying the following formula: U-Value = Heat Flux / (T1 – T2).

3 Results and discussion

3.1 Sensors placed on the skin of the foot

Figure 4 shows the measurement results of the experiment where the sensors were placed on the skin of the foot as it is shown in Figure 2. The results reveals that steady state conditions are reached during desk work in a regular office in the first phase. The heat flux is around 30W/m^2 and the U-Value is approximately 5W/(m^{2}K).

At the beginning of the exercise, the heat flux increases because the foot releases energy in terms of heat. However, as the exercise time increases, the heat flux drops drastically even though the temperature difference is increasing. The temperature difference increases due to a change in the location. The exercise took place in a staircase where the environmental temperature was significantly lower than in the office. Accordingly, the U-value decreased. This is only possible when the temperature on top of the sensor approximates the skin temperature. Hence one explanation could be that due to the thermal capacity of the air in the shoe, which was heated up very quickly, some kind of heat accumulation occurred. Therefore, the heat, which is released from the foot, is stored between shoe and food and that is accompanied with discomfort (feeling hot).

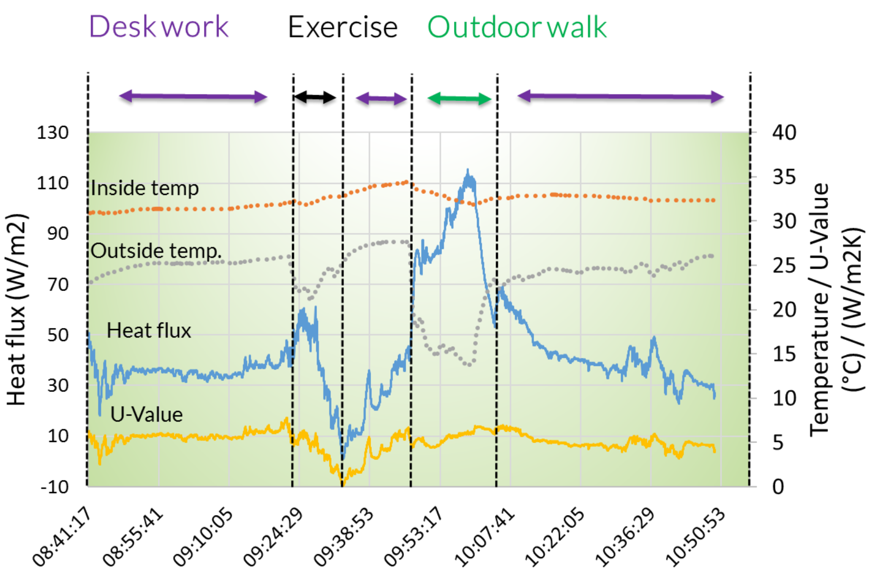

Figure 4: Heat flux, temperature and U-Value measurement on a hiking shoe during different activities with the heat flux and inner temperature sensor mounted directly on the skin of the foot.

In the next phase (deskwork), the heat flux and U-value raised to its initial steady state value. Towards the end of this phase, the temperature inside the shoe felt more comfortable again.

When going outdoors, the temperature measured on the shoe dropped to around 15°C. This larger temperature difference resulted in a much stronger heat flux. Now it can be observed that the U-value is not changing significantly. This is because the insulation properties of the shoe remain the same. This shows that it is important to determine the U-value. Environmental and human temperature can vary from experiment to experiment. The U-value, however, shows the thermal resistance which is independent from the outside or inside temperature (please consider: Changes in the material properties due to sweat or temperature, changes in the thermal interface resistance due to wind and changes due to sun radiation do still have an influence to the U-value).

3.2 Sensors placed to the inner upper side of the shoe

In the second experiment, the heat flux sensor and temperature T1 sensor were fixed to the inner upper side of the shoe by a tape. The gathered data is shown in Figure 5. There are two main differences in comparison to the first experiment. Firstly, the heat flux signal does have more noise, which has its origin in the movement of the foot in the shoe. Each time when pressure is exerted to the sensor due to physical activity, the heat flux increases. Evident for that conclusion is that the noise level increases during the outdoor walk and during exercise, where a lot of movement occurs. The noise in the signal is reduced during desk work when less physical activity is executed.

The second difference in comparison to the first experiment occurs during exercise. While the heat flux decreased in the first experiment when the sensor was attached to the skin, the heat flux in the second experiment when the sensor was attached to the shoe, increased. This can be explained by the increase in the temperature difference across the outer shell of the shoe.

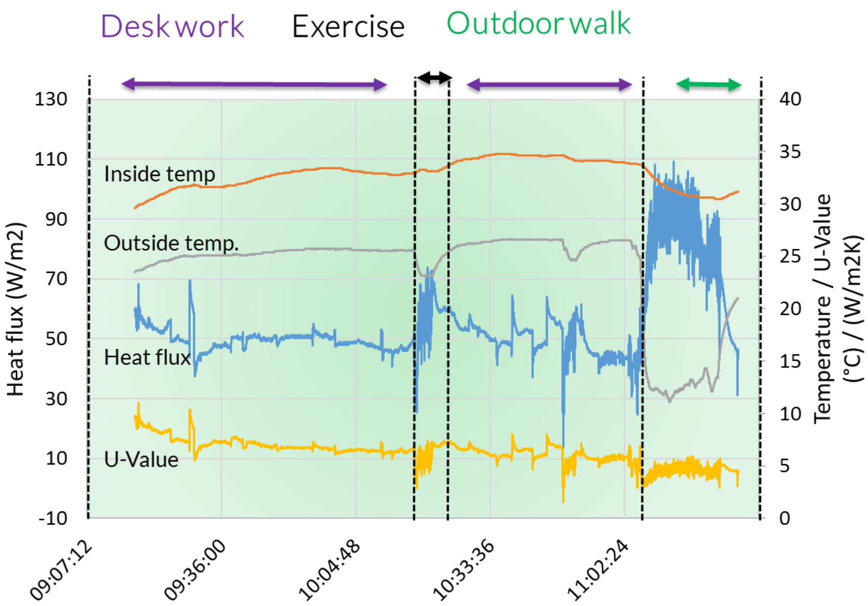

Figure 5: Heat flux, temperature and U-Value measurement on a hiking shoe during different activities with the heat flux and inner temperature sensor mounted at the inner upper side of the shoe.

The U-Value is in the same range as it was during the previous experiment shown in Figure 4. A slight decrease over time can be observed. A larger decrease occurred during the outdoor walk, which is related to a decrease in thermal interface resistance up on increased convection.

4 Conclusion

It was possible to get valuable data, which helps to improve footwear towards better thermal comfort during different activities. The U-value is a very important parameter that allows comparisons between different experiments although not all the conditions are exactly the same (which is mostly the case in experiments under actual conditions). Additionally, it is evident that when placing the heat flux sensor directly on the skin, the thermal comfort of the body at that particular position and situation can be determined.