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The present European Standard for footwear testing (Standard No. EN 344:1992; European Committee for Standardization [CEN], 1992) classifies footwear thermally by a temperature drop inside the footwear during 30 min at defined conditions. Today, other methods for footwear thermal testing are also available. The aim of this study was to compare EN 344:1992 with a thermal foot method. Six boots were tested according to both methods. Additional tests with modified standard tests were also carried out. The methods ranked the footwear in a similar way. However, the test according to standard EN 344:1992 is a pass-or-fail test, whereas data that is gained from the thermal foot method gives more information and allows further use in research and product development. A change of the present standard method is suggested.

standard thermal insulation footwear thermal foot model

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1. INTRODUCTION

The present European Standard for footwear testing (Standard No. EN 344:1992; CEN, 1992) classifies footwear thermally by a temperature drop inside the footwear during 30 min at defined conditions. Today, other methods for footwear thermal testing are also available. One of these methods uses a thermal foot model for measuring the insulation of footwear (Bergquist & Holmér, 1997; Kuklane & Holmér, 1998; Santee & Endrusick, 1988). Similar principles are successfully used in other European standards (Standard No. EN 511:1993; CEN, 1993; Draft Standard No. prENV 342:1995; CEN, 1995).

Only one study is available where standard EN 344:1992 (CEN, 1992) is compared with the thermal foot model method (Bergquist & Holmér, 1997). In that study the comparison was a part of a larger topic. The aim of this study was to compare EN 344:1992 (CEN, 1992) with the thermal foot method and propose a change of the standard method.

2. METHODS

2.1. Thermal Foot Method

The thermal foot model, which is used in this comparison, is described more precisely elsewhere (Kuklane & Holmér, 1998). The model is divided into 8 zones (toes, mid-sole, heel, mid-foot, ankle, lower calf, mid-calf, and guard zone). The surface temperature (34 °C) and power input to each zone are controlled by a computer program. Knowing the zone areas and the power input to them, it is possible to calculate heat losses from each zone or zone groups. The heat losses and the measured temperature gradient between foot surface and ambient air allow a calculation of insulation for one zone, combinations of zones, or for the whole footwear.

The comparison was made with four boot models, without or with a steel toe cap: AS (thin leather boot), BS and BN (thin rubber boots, S—with steel toe cap, N—no steel toe cap), VS (warm leather boot), WS and WN (warm leather boots, S—with steel toe cap, N—no steel toe cap). The boots without a steel toe were manufactured especially for research purposes. In a chosen trial the thermal foot model did not have any sock on it, the test was carried out without sweating or weight. After the footwear was donned, the thermal foot model was placed in a cold chamber on a copper-and-zinc plate (similarly to Standard No. EN 344:1992; CEN, 1992) for 90 min. The heat loss data from the last 10 min of cold exposure was used for the insulation calculation. All data were obtained in a special investigation and have been reported (Kuklane & Holmér, 1998).

2.2. European Standard EN 344:1992

The standard deals with all tests that are required for evaluating various occupational footwear. The method of determination of insulation against cold (section 5.9) was used for the comparison:

1. The test pieces were conditioned 7 days at 20 ± 2 °C and 65% relative humidity.
2. A specified thermocouple was fixed to the insole.
3. A heat transfer medium consisting of 4 kg of 5 mm steel balls were poured into the footwear.
4. After the temperature of the outsole became constant at 20 ± 2 °C, the test piece was placed on a copper-and-zinc plate into a cold box with an environmental temperature of —20 ± 2 °C for 30 min.
5. The temperature decrease was recorded and calculated to the nearest 0.5 °C.

If the temperature drop did not exceed 10 °C then footwear passed a test and was proper for use in cold.

The conditioning was carried out at two humidity conditions. The first test series were done according to the standard at 64.7 ± 0.7% relative humidity *(RH)*. For the second series the humidity was kept at 35.8 ± 0.9%, which is a common indoor humidity during winter time in Nordic countries.

During the tests the standard method was modified to available conditions. Instead of a cold box a cold chamber was used and on top of the footwear's upper edge (collar) was placed a thermal insulating cover with an elongated hole according to the standard. During the standard tests the cold chamber was at —19.3 ± 0.2 °C and the warm chamber was at 20.0 ± 0.1 °C (temperature gradient 39.3 °C). During the second series with conditioning at low humidity the cold chamber was at -20.3 ± 0.4 °C and the warm chamber was at 19.6 ± 0.1 °C (temperature gradient 39.9 °C).

In addition, two more tests were carried out according to the standard. One with a boot with low insulation (BS) and one with a boot with high insulation (WS). For BS (BS2) the temperature gradient was adjusted to a minimum (36.8 °C) within the allowed temperature limits (conditioning 18.5 ± 0.2 °C, test -18.3 ± 0.3 °C). For WS (WS3) the temperature gradient was adjusted to a maximum (42.1 °C) within the allowed temperature limits (conditioning 21.5 + 0.2 °C, test -20.6 ± 0.2 °C).

3. RESULTS AND DISCUSSION

The insulation values measured with the thermal foot model and the temperature decrease measured by standard EN 344:1992 (CEN, 1992) are ranked in Table 1. The methods ranked the footwear in a similar way. The differences between the footwear with and without steel toe cap were minimal.

The relatively big difference in relative humidity had practically no effect on the thermal properties of the footwear. At the same time, the difference in temperature gradient had a considerable effect on it. The gradient had a bigger effect on thin rubber boot (BS and BS2) than on warm footwear (WS and WS3, Table 1). It remained unclear, therefore, why standard EN 344:1992 (CEN, 1992) has such a small allowed deviation (±1%) for humidity and such a big one (+ 2 °C) for temperature. It could be related to that the thermal testing method in standard EN 344:1992 (CEN, 1992) was developed from the testing of the mechanical properties of leather and leather footwear. For mechanical properties the humidity can have higher significance than the temperature swinging around a certain value.

All the tested protective footwear for professional use passed the standard test and are classified as cold protective footwear, even the rubber boot. Human tests in a climatic chamber with the same rubber boot (with a thick sock) at two environmental temperatures (Kuklane, Geng, & Holmér, 1998) showed that at +3 °C the boot provided the needed protection, whereas at —12 °C the exposure was connected with unacceptable cold and pain sensation. If the cold is defined as any

TABLE 2. Comparison of the Methods

Aspect	EN 344:1992	Thermal Foot Model
Evaluation of footwear for cold conditions.	Pass or fail. (Allows better classification than the present formulation of EN 344:1992).	Allows classification at different levels of insulation for whole footwear and also for footwear parts, for example, soles, toes. From measured insulation it is possible to calculate temperature changes for various environmental conditions.
Evaluation of footwear for hot conditions.	Pass or fail. (Allows better classification than the present formulation EN 344:1992; sections 4.3.5.1 and 5.8.).	Allows classification at different levels of insulation for whole footwear and also for footwear parts. From measured insulation it is possible to calculate temperature changes for various environmental conditions.
Evaluation of wet and humid conditions.	Yes, for material (EN 344:1992; sections 4.4.5, 5.12, 4.4.6, 4.5.4, 5.13), not for whole footwear.	Allows simulation of sweating, measuring of insulation reduction due to wetting and of evaporation.
Additional information to the manufacturer.	None.	Can give information on different parts of footwear (discovering weak points in insulation).
Further use of measured data.	None.	Allows a complete evaluation of the thermal properties of footwear. The information can be used in mathematical models for the selection of footwear, calculation of exposure times, etc.

Notes. EN 334:1992—European Committee for Standardization (CEN, 1992).

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temperature below +18 °C then the thin rubber boot, of course, protects against cold. However, in this case most footwear is cold protective. The classification of thin rubber boots as cold protective footwear for subzero conditions is highly questionable. It can be supposed that most of the shoes that have the sole thickness of more than 10 mm will pass the test.

From previous paragraphs came out three reasons for a modification or change of the thermal testing sections of standard EN 344:1992 (CEN, 1992):

1. The requirement is a pass-or-fail test, and most footwear that is intended for outdoor use could possibly pass the test.
2. For use under different cold conditions the demand needs to be based on the actual performance of the different boots such as the insulation values.
3. The tests at temperature gradient extremes (BS2 and WS3) within limits allowed by standard EN 344:1992 (±2 °C) showed that the boot BS can rise in the rank whereas the boot WS can drop in the rank.

It can be supposed that relative humidity has a minimal effect, if any, on the dry thermal insulation values that are measured with the thermal foot model. During the sweat simulation the air humidity has an effect, however. Its magnitude will depend on the evaporative resistance of footwear. It is possible to simulate walking with a thermal foot model (Bergquist & Holmér, 1997; Kuklane & Holmér, 1997), as well. Still, the conditions that are contributing most to cooling are standing still and damp footwear.

The thermal foot method should replace the present standard method of footwear thermal testing. In Table 2 both methods are compared from various aspects. However, the thermal foot method needs some additional improvement and standardisation before it can be used as a standard, and more comparative tests with sweat simulation using different models and latest techniques (Giblo, Wajda, Avellini, & Burke, 1998; Uedelhoven, 1998) are required. It can be suggested to have two independent parts in standard: dry and wet testing. However, if patterns of the insulation change due to sweating will be found, then the change for particular conditions could be estimated from dry values.

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4. CONCLUSIONS

The standard method for thermal testing of footwear is only a pass-or-fail test and insufficient as a basis for selection of appropriate protection level under different cold and hot conditions. These demands require modification or change of the present standard.

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