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Classification of soft-shell materials for leisure outdoor jackets by *clo* defined from thermal properties testing

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Abstract. Materials for outdoor activities are produced in various combinations and lamination helps to combine two or more components for gaining high comfort properties and lighten the structure. Producers can choose exact suitable material for construction of part or set of so called layered clothing for expected activity. Decreasing the weight of materials when preserving of high quality of water-vapour permeability, wind resistivity and hydrostatic resistivity and other comfort and usage properties is a big task nowadays. This paper is focused on thermal properties as an important parameter for being comfort during outdoor activities. Softshell materials were chosen for testing and computation of *clo*. Results compared with standardised *clo* table helps us to classify thermal insulation of the set of fabrics when defining proper clothing category.

1. Introduction
The most accurate methods for determining clothing insulation are measurements on heated manikins and measurements on active subjects. Thermal manikins can measure the sensible heat loss from the artificial skin in a given environment. Thermal properties can be represented by Total thermal insulation of clothing plus air layer *clo* value which is standardised and tightly related to the thermal resistivity. *clo* value is calculated from the well known relation where *I=1 clo* is equal to the thermal resistivity 0,155 [$m^2.K.W^{-1}$] and raised from total value of classical men suit [1,2,3]. Another source defines it as a the amount of clothing needed by an inactive person to feel comfortable at a room temperature of 21°C in a light breeze having a 10 [$cm.s^{-1}$] air flow rate with a relative humidity less than 50% [4]. Naked person *clo* is equal to zero [1,2,3].
The surface area for heat transfer is increased when clothing layer and dependent on the clothing thickness. For example McCullough and Jones define *clo* from 0.2 to 1.7 for indoor ensembles as mentioned in [5,6].

Table 1. *Clo* ranges for selected types of clothes [4,5,6,7]

	Clo	Body surface area covered [%]
Shirts (long-short sleeves)	0.18-0.33	30-52
Sweaters, (long-short sleeves, thin-thick knit)	0.20-0.41	28-47
Suit jackets (denim-tweed)	0.42-0.56	50
Trousers (long, denim-tweed)	0.21-0.40	45
Shoes	0.03-0.06	5-7
550-800+ fill Down	0.7-1.68	Sleeping bag

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2. Materials

Softshells are composed from three layers at least. Upper material needs to provide protection against rain and wind in preserving surface abrasion resistance and required design. Middle membrane layer is designed for two-sided comfort. Membrane characteristic both for hydrophilic and hydrophobic is major in penetration of water-vapour/sweat from the inside out while liquid water/rain remain at the upper surface. Lining material provides protection of membrane from the inner surface. Types of lining vary according to the season from the light-weight "half" layers or printed layers over warp knitted materials to the relatively thick fleece for thermal insulation. Composition of softshells should provide better properties in one fabric and offer an effective option for outdoor clothing.

Table 2. Expected range of the selected properties for outdoor softshell

	Range of property	Notes
Water-vapour permeability resistance	6-20 [$Pa.m^2.W^{-1}$]	Values below 6 $Pa.m^2.W^{-1}$ only with special construction, values around 20 $Pa.m^2.W^{-1}$ are mostly with thermal insulated lining
Hydrostatic resistance	5-20 [$m.H_2O$]	Leisure activities from 8 $m.H_2O$, sports activities at least 10 $m.H_2O$, the highest value not limited 20 $m.H_2O$
Air permeability	Below 5 [$mm.s^{-1}$]	Windproofness in required

Thermal absorptivity b [$W.s^{1/2}.m^{-2}.K^{-1}$] of sports materials from fine fibres mostly in infinite state from PES which can be used for the first layer should be from 20 to 40 [$W.s^{1/2}.m^{-2}.K^{-1}$]. Light brushed and fleecy synthetic knitted materials has got absorptivity generally from 30 to 50 [$W.s^{1/2}.m^{-2}.K^{-1}$]. Light synthetic PAN knitted materials from shaped cross-section has got absorptivity from 40 to 90 [$W.s^{1/2}.m^{-2}.K^{-1}$]. Woven fabrics and PES knitted materials has got thermal absorptivity generally from 70 to 120 [$W.s^{1/2}.m^{-2}.K^{-1}$] how written at [8].

Set of 17 samples was chosen as representatives of nowadays production in softshells with membrane incorporated and with use of jackets and other clothing parts for leisure activities and outdoor staying. Tested samples are in wide range with woven or knitted upper material mostly made from 100% PES as often in commercial materials supplemented with 100% PAD examples for comparison. Materials for combination with softshells were made from synthetic fibres in today´s production.

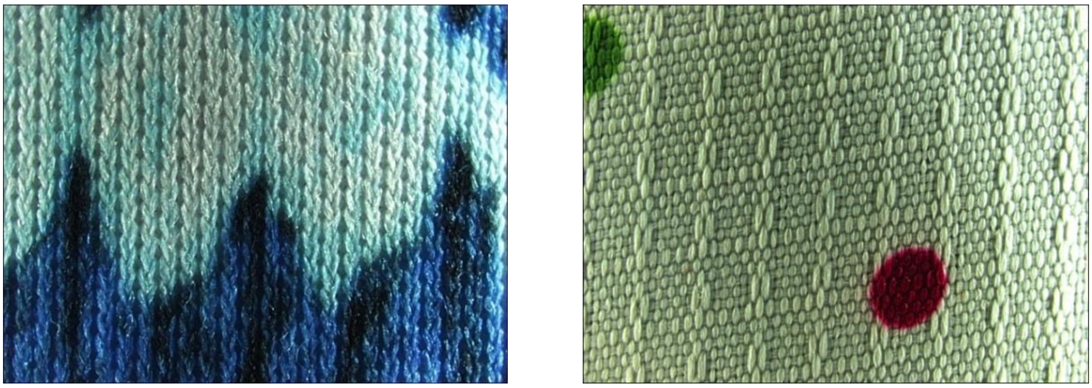

Figure 1. Examples of tested materials.

3. Methods

It is presented results of thermal properties with the simple calculation to *clo*. Thermal properties was measured on instrument Alambeta which is suitable to measure various thermal properties, see more in Instruction manual [9]. Upper sensor has got skin temperature where inner side of material is and thermal flow goes to the upper surface of material and to the lower sensor. Samples were dry in standard conditions of air temperature and humidity. Optimal thickness of samples for Alambeta device is formally 0.5 – 8.0 mm and all samples match this requirement with few exceptions but measurement was tested without detected errors for all of data in statistic process.

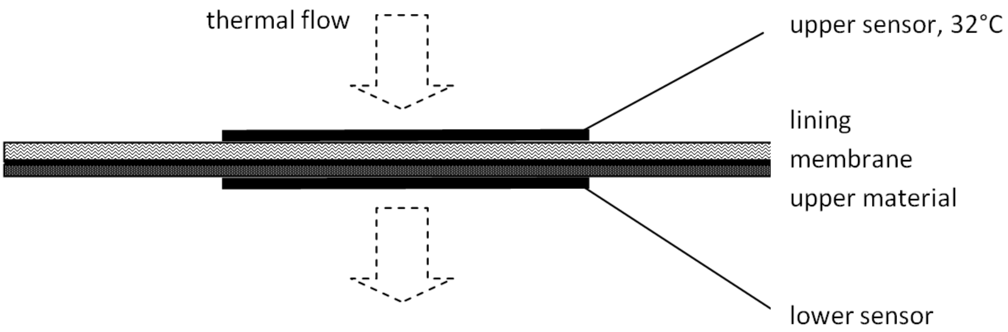

Figure 2. Scheme of thermal measurement at Alambeta.

4. Results and Discussion

Dependency of thermal properties on the thickness is confirmed from the theoretical expectations. Our data show correlation of thermal resistivity on the thickness in 0.933 when on areal density is lower at value 0.599.

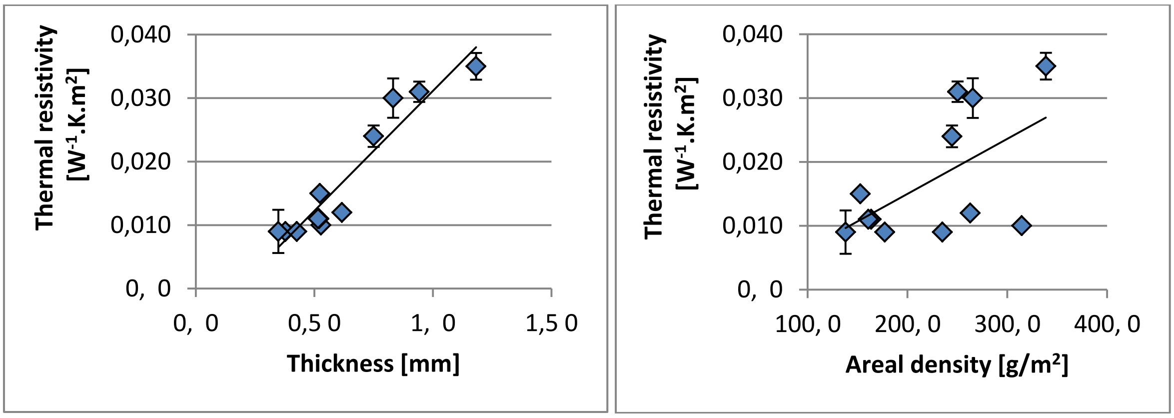

Figure 3. Thermal resistivity to thickness and to areal density

Results are discussed according to the standards which material setting is suited to the defined type of clothing. Results confirmed that lighter softshells embody thermal insulation and lower *clo*. Those materials are still suitable for outdoor use while user needs to be informed to get extra infilling for activities with lower movements or when decrease of temperature is expected. Testing confirmed also that softshells are well defined as a light jackets.

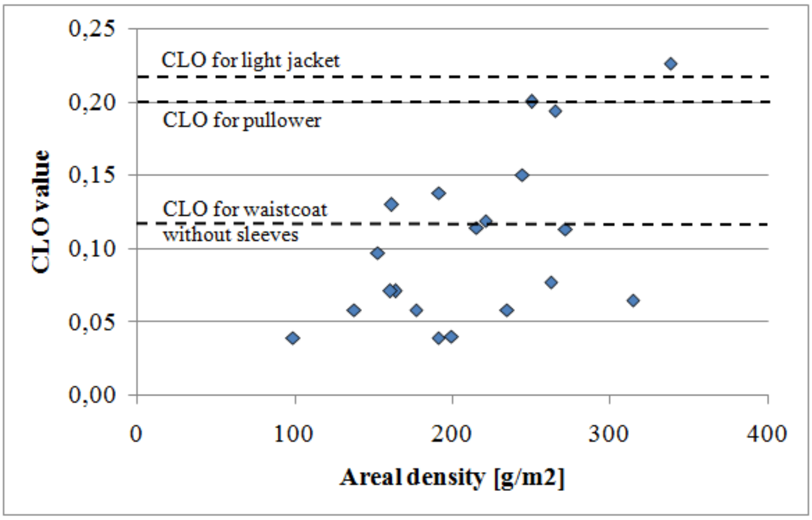

Figure 4. Clo value for tested softshells as a single layer

Because softshell is used for layered clothing we tested also their combinations with second and first layers to find benefiting layer set for optimal protection with comfort of user. The best combinations of the first, second and third layers were chosen from tested variations. Two layer combination was found as effective with woven upper material, membrane and insulating lining in softshell and knitted first layer. This combination can be enough effective for winter purpose during exercising activities. The combination of light jacket is theoretically with 0.262 *clo* and three layer combination at 0,426 *clo* for clothing at the upper part of the body when ideal 1 *clo* means covering whole body.

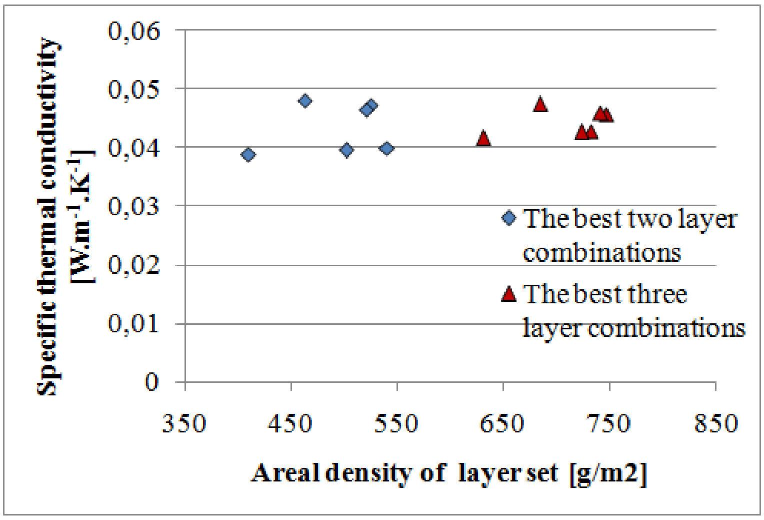

Figure 5. Thermal conductivity to areal density

Determination of correct use of materials can be discussed also by the exercise load. The optimal layering of clothes can vary from person to person, we can just recommend expected thermal comfort in general from the experimental data.

Weather conditions for the first winter case are low wind and no freezing. Human activity is stronger exercising like long distance skiing. Recommended material for upper layer is windproof material and all tested softshells can be used. They also satisfy with the good water-vapour permeability values. Combination with moisture management underwear is of course important. Relatively thin materials

of softshells provide also good movement in clothes. Thermal insulation is necessary only to the level of generator - moving body - is not enough or stops.
Climatic unfavourable conditions require more thermal insulation layering same as low physical load like downhill skiing and standing in winter conditions. Three layer combinations are necessary to reach sufficient thermal insulation at least for some time. Softshells can be recommended in limited exposition times or with indispensable insulation second layer adjusted by weather conditions.
Nowadays practice allow us also using four layer set. The first layer is without discussion the same, moisture management material is the best. Second layer is classical insulation part when fleece fabrics are used to absorb moisture from the first layer. Third layer is jacket with fill down or similar kind of insulation materials in light weight. Fourth layer is softshell with excellent windproofness, water repellence and sufficient water-vapour properties.

5. Conclusions

Today´s trend is light weight and thin clothing. Softshells offer it with good comfort properties with their flexibility of construction. It was chosen the best combination of two layers set for active behaving and three layers set for passive or worse weather in winter season for outdoor activities when softshell is one from them as a surface layer protecting human skin and under materials. It was expected more increase of thermal insulation when combination of softshell and thermal isolative second layer not that visible from thermal resistivity but *clo*. *Clo* value should be good informative parameter for customers before buying clothes for exact activity together with the rest of comfort properties.

Acknowledgments

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