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# Factors influencing precision of determination of thermal parameters of textile fabrics

**Abstract**

Published data of thermal conductivity of particularly natural textile materials can be incorrect, due to uneasy way of testing of this parameter. Moreover, these data can be strongly affected by moisture of these materials. In the paper, the mentioned and other factors, which reduce the precision of thermal insulation and thermal contact properties of textile fabrics are presented and discussed.

**Keywords:** thermal conductivity and absorptivity, cotton, textiles, moisture, contact pressure, transient and steady state testing

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## Introduction

Thermal-insulation properties belong to basic properties of textile fabrics and play significant role in creating thermal balance between human body and environment. As one of the most important parameters of thermal comfort of fabrics their thermal resistance R is considered.[1] This paramater is defined by the effective thickness of the insulation layer divided by thermal conductivity λ of the used material.

Key factors affecting thermal conductivity of textile fabrics simultaneously involve fibre (yarn) thickness, composition and orientation, fabric structure and porosity and moisture content of the fabric. Moisture can influence thermal resistance of fabrics substantively, as thermal conductivity of dry textile fabrics mostly lies in the range of 0,035 to 0,9 W/m/K, whereas thermal conductivity of water $\lambda_w$ at room temperature reaches 0,61 W/m/K. Low thermal conductivity of dry fabrics is caused by high porosity (low filling coefficient F) of fabrics. Filling coefficient F of thermally insulating webs extends from 5 to 10%, knits may exhibit F between 15 to 40%, and woven fabrics present this factor mostly higher then 40%. The rest of the space in dry fabrics is occupied by air with the lowest thermal conductivity of common materias, which for still air $\lambda_a$ reaches 0,026 W/m/K (non fibrous thermal insulating structures, based on aerogels, exhibit thermal conductivity much lower that that of quite air, but their applicability is still complicated). That is why the resulting thermal conductivity λ of dry classical textile fabrics must not extend the level of 0,09 W/m/K. Contrary to these low levels of thermal conductivity of classical dry textile fabrics, thermal conductivity of common non-extended synthetic and chemical textile polymers in a form of block of foil, is much higher, extending from 0,2 W/m/K for polypropylene to 0,5 W/m/K (for viscose). The lowest thermal conductivity levels of textile fabrics, achievable by advanced commercial thermal insulating fibrous layers were presented[2] and displayed on the Figure 1. As we can see, thermal conductivity of the excellent Thermolite Active web lies just sligthy above thermal conductivity of still air. However, when considering relative high compressibility of this fibrous structure, other fibrous webs (like Polarguard) may provide higher thermal resistance under conditions of their practical use – see in the last chapter of the paper.

Regretfully, in last decades, some researchers on textile physics informed the textile audience, that thermal conductivity of cotton fibres lies in the range 0,04 – 0,05 W/m/K. This is evidently a wrong statement. Cotton fibre is a natural polymer in linear form, it does not exist in a form of three dimensional block, but it is just a thin and compact linear body. Thus, its thermal conductivity should be similar to thermal conductivity of viscose foil with similar composition as cotton, presenting thermal conductivity λ of about 0,5 W/m/K (at laboratory air temperature and humidity). Viscose cellophane is often used in a form of a foil for packaging food. Hence, the published incorrect values of thermal conductivity of cotton fibres evidently present the thermal conductivity levels typical for cotton fabrics. However, as stated above, even these values strongly depend on the fabric structure, porosity, moisture and finishing.

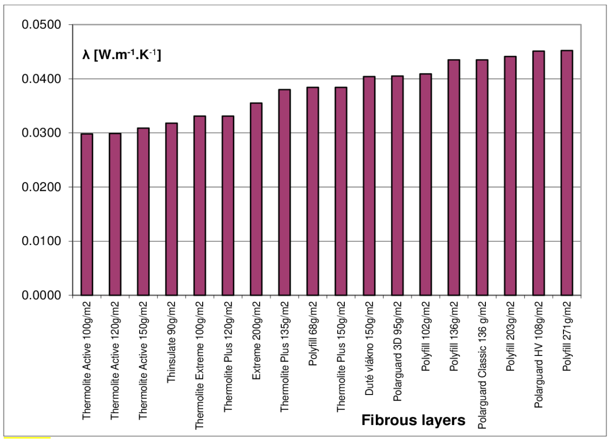

**Figure 1** The lowest thermal conductivity levels of textile fabrics, achievable by advanced commercial thermal insulating fibrous layers at varying square mass (filling coeficients). Determined by the ALAMBETA tester (SENSORA) at contact pressure 200 Pa.[2]

## Effect of moisture on thermal insulation and thermal contact properties of textile fabrics

Many authors created relatively simple mathematical models for determination of thermal resistance of textile fabrics. Most of them were statistical models, which do not respect the physical bacground of the solved problem. That is why good algebraic models which involve all the parameters affecting thermal resistance of fabrics in real mutual relationship can be more useful for predicting of thermal resistace of fabrics at large extension of the related parameters.

Most of the historical and recent algebraic models do not involve yet the effect of fabric moisture on its thermal resistance, see e. g. the serial + parallel models by Sheta, Fricke, Shumeister, Militky, Mangat and Ju Wie and the continuous dispersed base models by Maxwell – Eucken (M+E), Levy, Hes + Stanek, EMT models etc.

Recent models already involve the effect of moisture on thermal resistance of fabrics, presented in papers by M. Mangat, R. S. Hollies and S. Naka. These authors respect the changes of filling coefficient F due to the increasing moisture content, but the filling coefficient of air keeps unchanged. That is why correllations of their model data with the related expriments can be less satisfactorily for higher levels of the fabric moisture. More precise model which is also applicable for high level of moisture in fabrics is based on recent PhD Thesis of Dr. Tariq Mansoor titled „Development of new algebraic models of thermal resistance of textile fabrics in wet state and their experimental verification“ and supervised by L. Hes. Main results of this Thesis were published (Figure 2).[3]

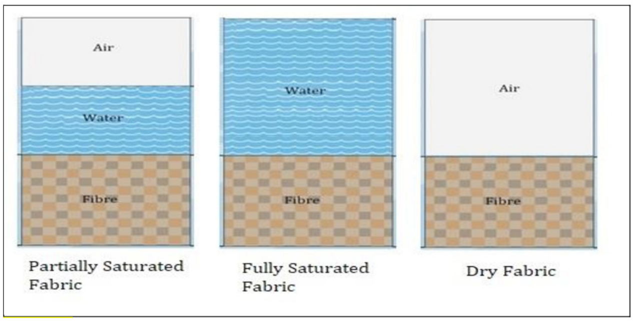

**Figure 2** Changes of the air filling coefficent of fabrics after their wetting.[3]

In his study, new algebraic model of thermal resistance of stepwise wetted knitted fabrics is described, in which the effect of moisture content newly involves the changes of water filling coefficient and changes of air filling coefficient. The influence of yarn orientation is respected by consideration of thermal conductivity of fabric in the plane direction and that for the perpendicular case. The novel approach also presents the introduction of the so-called „wetted solid body“ or „wetted polymer“ along with its filling coefficient, which enabled the integration of the accumulated moisture into some of the existing thermal resistance models of dry fabrics. His theoretical results based on the new model are compared with the experiments, based on the use of the non-destructive commercial ALAMBETA tester.[4,5] It was found, that for added relative moisture extending from 0 to 60%, coefficient of determination of all 7 analyzed knits ranged from 0,84 to 0,97, mostly exceeding the level of 0,92. In continuation of this study, applicability of the newly developed Mansoor + Hes thermal conductivity model should be extended and verified for woven fabrics also. The above new principle of the „wetted polymer“ was also succesfully used for modification of the M+E model, as follows

$$\ddot{e}_{fab} = \frac{\ddot{e}_a F_a + \ddot{e}_{wet\ polymer} F_{wet\ polymer} \dfrac{3\ddot{e}_a}{2\ddot{e}_a + \ddot{e}_{wet\ polymer}}}{F_a + F_{wet\ polymer} \dfrac{3\ddot{e}_a}{2\ddot{e}_a + \ddot{e}_{wet\ polymer}}} \qquad (1)$$

However, the proper determination of thermal resistance R of fabrics may not be as simple. The most simple is the case of classical measuring instruments which operate in the steady state mode and enable easy determination of thermal resistance of the measured samples from the the steady heat flow q passing due to the temperature drop Δt between both surfaces of the measured fabric with the thickness h, as follows (Figure 3):

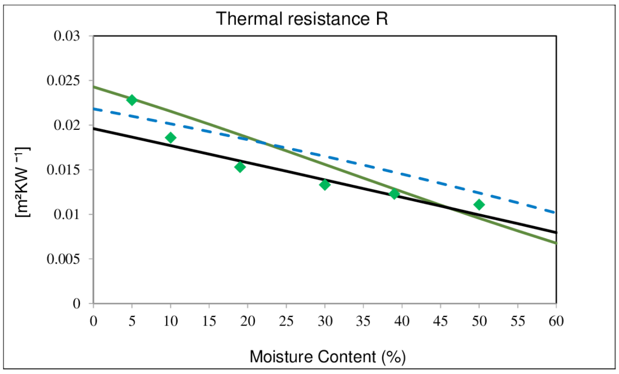

**Figure 3** The effect of the added moisture on thermal resistance of PES (65 %) + PP knits. The green points are the experimental results, the black curve passing through the experimental points presents the results of a new thermal model by Mansoor + Hes, the dashed line was calculated by the Shuhmeister model and the resting red line respects the Maxwell – Eucken model modified by Mansoor + Hes.[3]

$$\mathbf{R = \Delta t/q, \text{ where } R = h/\lambda} \qquad (2)$$

Here, thermal resistance R in fact may present total thermal resistance $R_{tot}$ of any multilayer fabric consisting of individual thermal resistances $R_i$:

$$\mathbf{R_{tot} = R_1 + R_2 + R_3 + \ldots} \qquad (3)$$

Having the knowledge of the total (average) thickness of the sample system (which sometimes is not easy), these steady state measuring instruments enable the determination of mean / effective thermal conductivity $\lambda_{eff}$ of the whole multilayer fabric system. This parameter then can be used for comparison of thermal insulation power of various fabric webs.

However, when instead steady state of heat flow level, a transient, short time heat flow impulse is used in the tester, the short temperature change may not penetrate through all the layers of the thick tested multilayer fabric where each layer may feature different thermal conductivity. Thus, the measured thermal conductivity should not be used for determination of the total thermal resistance R of the multilayer fabric. Even in case of measurement of thermal conductivity of a hairy or superficially finished fabric the measured thermal conductivity may differ from the $\lambda_{eff}$ serving for the calculation of the fabric thermal resistance R. The presence of thin hairy layer with different thermal parameters existing on a surface of most textile fabric may influence also the mean (more then purely superficial) value of thermal absorptivity (effusivity) b [$Ws^{1/2}/m^{-2}K^{-1}$] of textile fabrics given by the equation

$$\mathbf{b = (\lambda\rho c)^{1/2}} \qquad (4)$$

Here, ρ presents the fabric density and c is the specific heat of the fabric polymer. This parameter, chracterising thermal contact feeling of fabrics, was was newly introduced in 1987 by Hes [3] in the area of textiles and can be used for the calculation of the (not only initial) level of heat flow **q** passing between the skin (characterised by a constant temperature $\mathbf{t_1}$) and textile fabric of a temperature $\mathbf{t_2}$ according to the next equation (the details of solution for the boundary condition of 1st order are given[4–6]:

$$\mathbf{q_{dyn} = b\,(t_1 - t_2)/(\pi\,\tau)^{1/2}} \qquad (5)$$

Following the practical conditions of the measurement of the warm-cool feeling level, this value depends on the contact pressure, which may extend from 100 to 2000 Pa, considering the pressure

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of fingers during the manual hand evaluation of a fabric in a shop. That is why the b parameter may extend of 50 to 800 [Ws1/2/m2K].[7] Moreover, this parameter is also strongly influenced by the fabric moisture, as demonstrated.[2] Papers published on thistopic are quite rare, as the measurement of thermal absorptivity, which is a dynamic factor, must be very quick, but simultaneously the measurement time must not be extremely short, as it should correspond to real conditions (time) of the warm-cool feeling evalution by a hand (fingers).

From the above findings follows, that the sample moisture significantly influences the measured values of thermal parameters of fabrics. It is important to mention, that the determined values reflects the moisture level inside the sample during the proper measurement procedure, namely when testing the hydrophilic fabrics. This moisture level depends on the mean temperature inside the tested sample. Therefore, the moisture level may not correspond to the moisture level during the sample use at different temperature. When testing same sample by different testing method with different mean temperature inside the sample, the values of the measured thermal parameters can differ in both cases.[8] This conclusion emphasizes the importance of the knowledge of the fabrics moisture during testing of their thermal parameters (Figure 4).

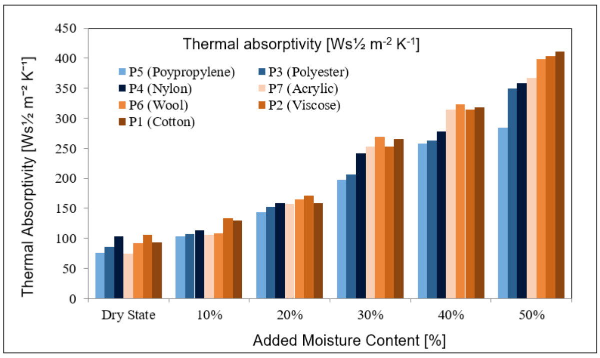

**Figure 4** The effect of the added moisture on Thermal absorptivity of plain knits with square mass extending from 109g/m$^2$ to 167g/m$^2$, thickness 0,82 to 1,2mm, measured by ALAMBETA tester at contact pressure 200 Pa.[2]

## Effect of contact pressure of on the experimentally determined thermal insulation and thermal contact properties of textile fabrics

Besides moisture, also the level of contact pressure of a sensing probe of the measuring instrument may influence the results of measurement of thermal parameters of the studied compressible porous materials like textile fabrics. With the increasing contact pressure causing the raising degree of compression, air gaps in fabrics (and yarns) with low thermal conductivity are stepwise reduced and replaced by a polymer with higher thermal conductivity. As regards the fabrics compressibility, the compression modulus E [Mpa] is a function of their packing coefficient μ, as follows from the Neckar´s[9] equation:

$$E_c=k^3\mu^3[1+2(\mu/\mu_o)^3]/[1-(\mu/\mu_o)^3]^4 \quad (6)$$

Here, k means the proportionality parameter in Mpa, depending on fibre material and processing, $\mu_O$ is the the lowest possible level of packing, e.g. 0,8 for cotton yarns.

Higher mean level of thermal conductivity then brings lower thermal resistance R of the analysed fabrics. Then, the experimentally determined thermal resistance R will be function of the contact pressure between the measured fabric and the measuring probe, see e. g. in the below Figure 5.

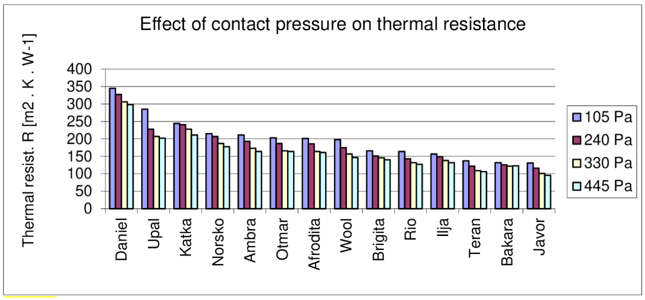

**Figure 5** The effect of contact pressure on thermal resistance of artificial furs.[10]

The analyzed commercial artificial furs with long hair made of PAN exhibited high compressibility and that is why their thermal resistance determined by the ALAMBETA tester is fairly lower at higher contact pressure. Similarly, thermal resistance of soft porous knits may be also substantially influenced by the contact pressure between their surfaces, whereas compact woven fabrics can be quite resistant against compression. Anyway, data on thermal resistance of textile fabrics determined under unknown contact pressure of the probe may not be reliable and may suffer from low precision.

## Conclusion

As presented in the study, published data of thermal conductivity of particularly natural textile materials can be incorrect, due to uneasy way of testing of this parameter, when the original polymer, like cotton, is available just in the form of fibres. As thermal comfort is gaining importance both in apparel textiles and sportswear, reliable measurements in fabric and garment forms are becoming increasingly necessary. Moreover, these data can be strongly affected by moisture of these materials and contact pressure of the measuring probe. In the paper, the effect of moisture on thermal conductivity, resistance and absorptivity is explained and discussed. Also other factors, which may inluence the precision of measurement of thermal insulation and thermal contact properties of textile fabrics are mentioned, namely the effect of the proper testing method.

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## Conflicts of interest

The authors declare no conflict of interest.

## References

1. Hes L. Some open questions of evaluation of comfort properties of functional clothing. *Journal of Textile Eng Fashion Technol.* 2020;6(4):148–151.
2. Hes L. The effective thermal resistance of fibrous layers in sleeping bags. *Res J of Textile and Apparel (Hong Kong Polytechnic).* 2004;8(1):27–33.
3. Mansoor T, Hes L, Bajzik V, et al. Novel method on thermal resistance prediction and thermo-physiological comfort of socks in a wet state. *Text Res J.* 2020;90:17–18.
4. Hes L. Thermal properties of nonwovens. Proc. INDEX 1987 Congress, Geneva; 1987.

**Citation:** Hes L, Unmar R, Rosunee S. Factors influencing precision of determination of thermal parameters of textile fabrics. *J Textile Eng Fashion Technol.* 2023;9(4):101‒104. DOI: 10.15406/jteft.2023.09.00341

5. Hes L, Doležal I. New method and equipment for measuring thermal properties of textiles. *J Text Mach Soc Jpn*. 1989;42:124–128.
6. Hes L, Araujo M. Simulation of the effect of air gaps between the skin and a fabric on resulting cooling flow. *Textile Res J*. 2010;80:1488–1497.
7. Abel PJ, Unmar R, Rosunee S. Engineering the comfort parameters of 100% cotton plain woven fabrics. *J Textile Institute.* 2022;113:9:1806–1815.
8. Hes L, Testinova P. Why Skin model testers of thermal comfort of fabrics sometimes display negative values of thermal reistatnce? Denkendorf-Aachen-Dresden Internat Textile Conference, 2016.
9. Neckar B, Das D. Theory of structure and mechanics of fibrous assemblies and yarns. Woodhead Publishing India; 2012. 310 p.
10. Hes L. Analysing thermal properties of furs. In: Abbott A, Ellison M, editors. Biologically Inspired textiles, Cambridge UK; Woodhead Publishing; 2008:150–167.

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