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THERMAL MANIKIN AND ITS STABILITY FOR ACCURATE AND REPEATABLE MEASUREMENTS

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Abstract
Thermal manikins are used for testing the thermal insulation of different types of protective clothing. Data about thermal insulation is required when new protective clothes are designed or for the optimization of the existing ones. Thermal insulation usually plays an important role when researching or developing optimal protective clothing used in hot environmental conditions. The aim is to develop protective clothing that will ensure the lowest possible thermal load for the user. To get accurate information about thermal insulation, the measuring system for its determination should be stable. One of the possibilities is to use a thermal manikin presenting the anatomic shape of the human body. The measurement accuracy and stability of the measuring system based on the thermal manikin are investigated and assessed on the basis of statistical analysis. Accurate measurements can be ensured with statistics. Only accurate data has an application value for the industrial development.

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Key Words: Thermal Insulation, Thermal Manikin, Measurement Validity and Reliability, System Stability Assessment

1. INTRODUCTION

Safety is not only the first component of values statement, but is always the first consideration in system design requirements, work practices and company policy. Knowledge, experience and knowhow are shared resources between the different applications to bring the best available solutions, when a high risk of suffering critical interaction with hazardous environment is present. To ensure reliable and safe systems different products or methods are available, for example: protection systems [1-3], safety sensors, controllers, scanners [4], correct design of devices (ergonomics) [5, 6], application of innovative principles [7], heat transfer simulation for cosmetic products [8], virtual human models [9] etc.

Thermal insulation is one of the most important parameters that should be considered when developing protective clothing intended for use in an extreme environment with high temperatures. It describes the amount of heat transfer through the layers of textile materials of which the particular protective clothing is made.

To determine thermal insulation a thermal manikin can be used, which best illustrates the anatomic shape of the human body. By using this measurement system, thermal insulation can be defined for an entire garment, for a clothing system or for a certain segment only (‘regional’). Regional thermal insulation is important when heat transfer through the layers of textile material only needs to be ensured in specific parts or segments of the garment. The thermal manikin that we used has 19 segments [2, 10-12]. By measuring the temperature and heat flow in the individual segments it is possible to define regional thermal insulation.

Thermal manikins have a long tradition. Representing the anatomic shape of the human body, they were first used in the early 1940s [11] when a simple one-segment manikin made from copper was used for the needs of the American army. The idea of development and

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manufacture was based on testing firearms and protective equipment in World War II. After that, several more sophisticated manikins were developed [13, 14]. Nowadays there are more than 100 thermal manikins in use worldwide [15-18]. Each new example represents a significant improvement in technique and approach [19-23].

2. RESEARCH PROBLEM

The most important result that we are looking for when carrying out tests using a thermal manikin is thermal insulation, which increases with each added textile layer inside the clothing system (Fig. 1). In order to convert the measurements into useful data, the thermal resistance (R_{ti}) and total clothing thermal insulation value (I_i) can be calculated automatically for each of the nineteen segments separately or for all the segments together.

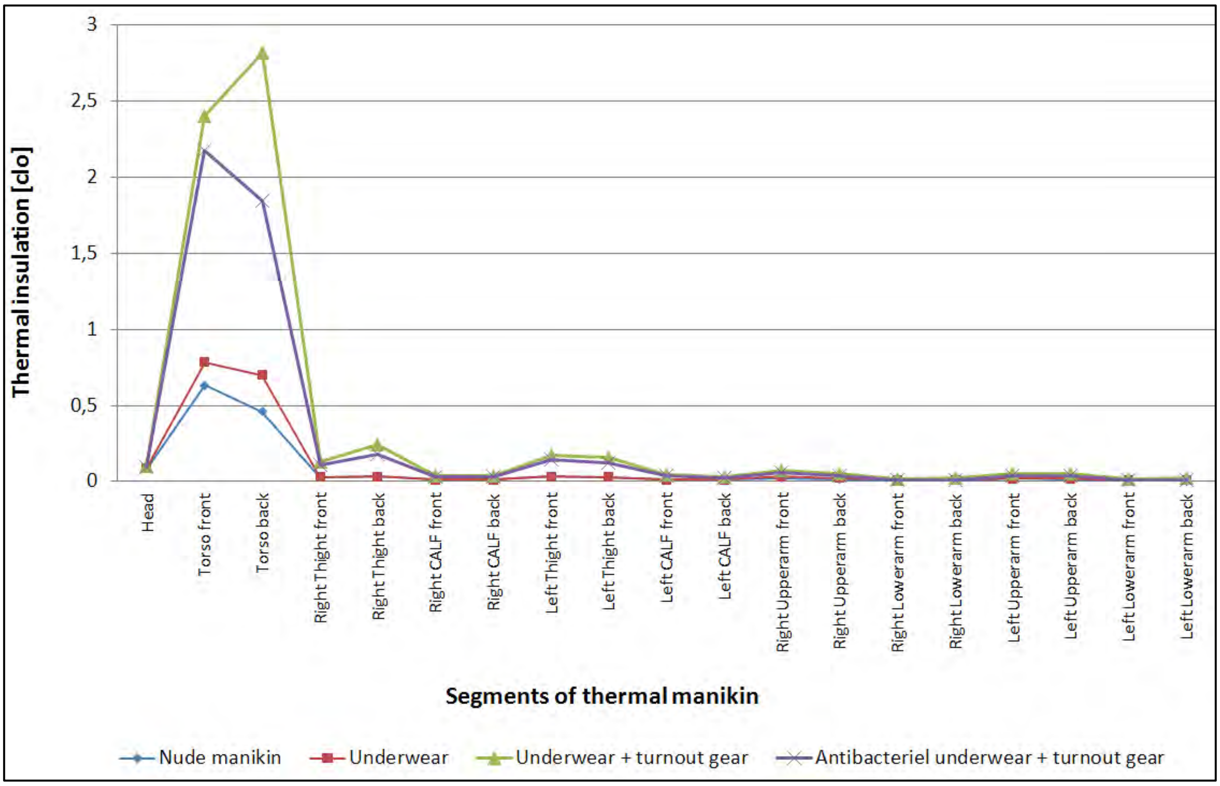


Figure 1: Thermal insulation.

Thermal resistance of a particular manikin segment in clo is calculated as follows:

$$R_{ti} = \frac{T_{s,i} - T_{amb}}{0.155\, Q_i} \tag{1}$$

where:

$T_{s,i}$ – surface temperature of a segment I (K)
T_{amb} – ambient temperature (K)
Q_i – rate of heat transfer (Wm^{-2})
0.155 – factor for conversion from (m^{2}K W^{-1}) to (clo)

The total clothing thermal insulation of a manikin segment in clo is calculated as follows:

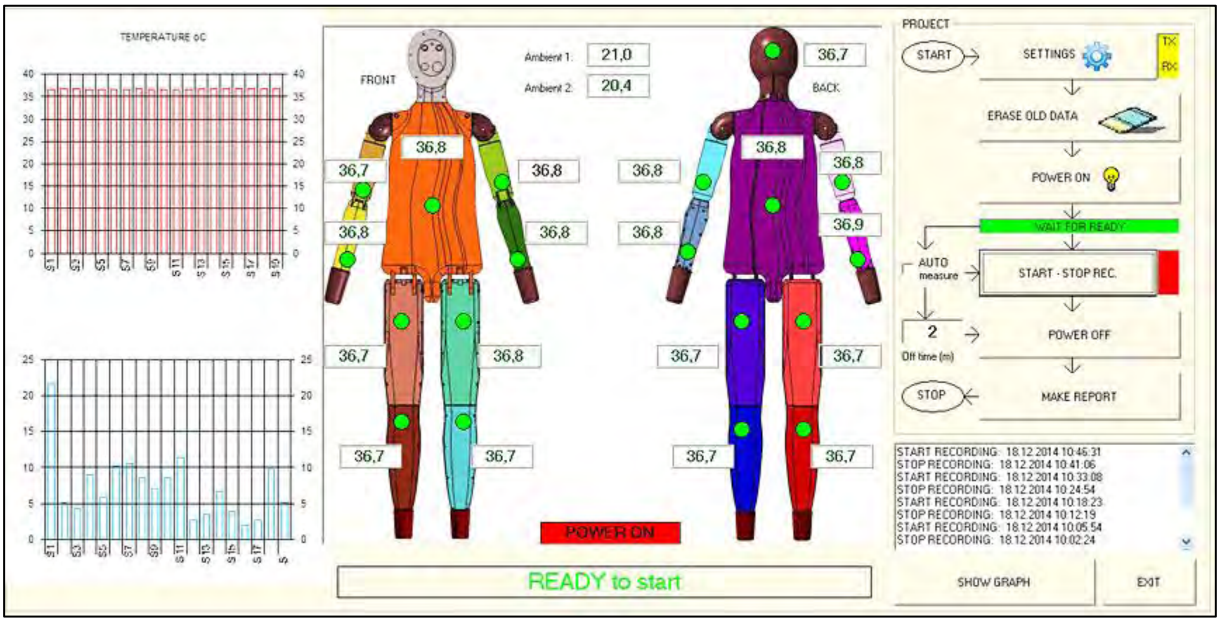
$$I_i = \frac{A_i (T_{s,i} - T_{amb})}{0.155\, Q_i} \tag{2}$$

where:

A_i – surface of the particular manikin segment (m^2).

Measurements using a thermal manikin are very suitable for determining the thermal insulation of protective and working clothes. Since textile materials are not homogeneous, the same measuring conditions (ambient temperature and humidity) should be ensured every time when measurements are taken. It is also very important that the measuring system – in our case a thermal manikin – is stable.

For data capturing a suitable user interface was developed. The user interface is designed to ensure a good overview of all the crucial data, temperature and power. It enables simple and controlled testing according to the ISO 15831 (2004) [23] standard. Each of the nineteen segments communicates with the control unit and the data on the user interface is shown in real time (Fig. 2). If a failure occurs, the operator can see which segment is not functioning.



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START RECORDING:  18.12.2014 10:46:31
STOP RECORDING:  18.12.2014 10:41:06
START RECORDING:  18.12.2014 10:33:08
STOP RECORDING:  18.12.2014 10:24:54
START RECORDING:  18.12.2014 10:18:23
STOP RECORDING:  18.12.2014 10:12:19
START RECORDING:  18.12.2014 10:05:54
STOP RECORDING:  18.12.2014 10:02:24
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Figure 2: Control panel of the TmpTelo interface.

The control panel presents all nineteen segments with measured regional temperatures. On the left side there is also a graphic presentation of reached temperature and current power (in % of the maximum possible load) conducted to a certain segment. The right-hand side allows measurements according to the ISO 15831 (2004) standard, with a documented report.

With this user interface, the measured results of each of the nineteen segments can be displayed in real time (Fig. 3). Any impact from the environment can be observed both while increasing the surface temperature and during measurement. All the measured data can be saved or printed out.

The heating of all the nineteen segments from ambient room temperature to a set temperature of 36°C is presented. The tags from 1 to 19 present the manikin segments and tag 20 presents temperature of the environment. Due to the different masses and applied power, the segments are not heated at the same rates during the pre-heating phase. The measurement began in stable conditions.

The following four sets of thermal conditions with different clothes were tested using a thermal manikin (Fig. 4):

1. Naked manikin
2. Thermal manikin with underwear
3. Firefighter clothing with flame retardant uniform
4. Firefighter clothing with antibacterial protection

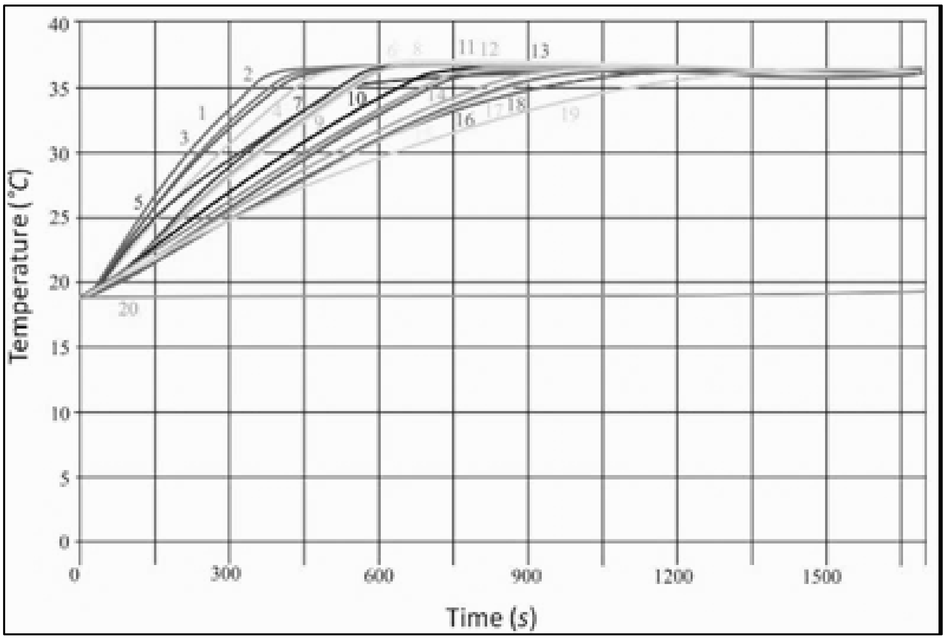

Figure 3: Graphical presentation of real time measurements.

Figure 4: Thermal manikin – naked and dressed (with underwear and in a firefighter suit).

For the analysis of the problem, descriptive statistics and Paired sample *t*-test as multivariate analysis of variance were used.

2. RESEARCH FRAMEWORK

Using a thermal manikin, the temperature and heat flux were measured. Based on the known areas (cm^2) of individual segments, the thermal resistance was calculated, Eq. (1). Then the thermal insulation was calculated, Eq. (2) in units called clo (1 clo = 0,155 m^2°C/W). Since the values of thermal insulation and temperature are in linear combination, the relationships between three variables were observed: temperature in linear combination with thermal insulation, heat flow and thermal power (Fig. 1). Fig. 1 presents our overall research framework concerning the system reliability and validity for thermal insulation through two hypotheses stated in the null form. Since the heat flow and the thermal power are in complete linear combination (correlation =1), only two hypotheses stated in the null form were tested:

Hypothesis 1: There is a strong and positive relationship between temperature and heat flow.

Hypothesis 2: There is a strong and positive relationship between temperature and power.

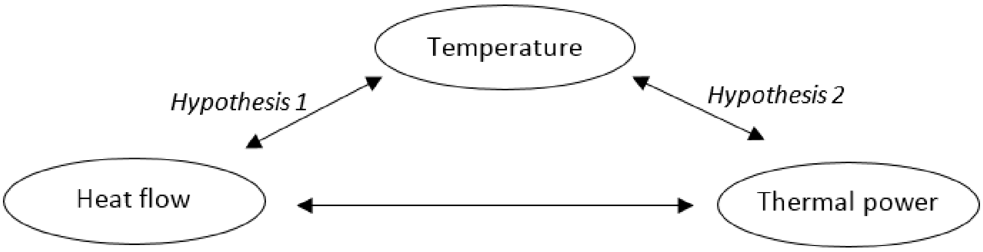

Figure 5: Conceptual framework.

3. METHODOLOGY

The presented research was divided into the following phases:

- a wide-ranging data collection was performed on the 19 observed segments of the thermal manikin, measuring three values: temperature, heat flow and power. Seventy-five measurements were performed on a naked manikin, 122 on a thermal manikin with underwear, 132 on a manikin dressed in firefighter clothes with a flame retardant and 150 measures on a manikin dressed in firefighter clothes with antibacterial protection;
- the research hypotheses were tested using SPSS statistical program package;
- the resulting data was subjected to reliability and validity analyses to determine the measurement properties, and then analysed using uni- and multivariate statistical techniques.

Since the aim of quantitative research is to get familiarized with the concept to be studied and to generate the hypothesis to be tested, the emphasis of research was put on:

a. the facts and causes of behaviour [24],
b. the information in the form of numbers that can be quantified and summarized,
c. the mathematical process used for analysing numerical data,
d. the final result expressed in statistical terminology [25].

3.1 Measurement error

The use of multiple variables and the reliance on their combination in multivariate techniques also draws attention to measurement error [26]. Measurement error is the degree to which the observed values are not representatives of the ‘true’ values. Measurement errors have many causes, ranging from data entry errors to the imprecision of the measurement and also the inability of respondents to provide information accurately. For this reason, all variables used in multivariate techniques can have some degree of measurement error. To assess the degree of error present in any measurement, the validity and reliability of the measure should be addressed.

3.2 Validity

The validity of a measure refers to the extent to which it measures what is intended to be measured [27]. In other words, validity is the degree to which a measure accurately represents what it is supposed to do [26]. Ensuring validity starts with thorough understanding of what is to be measured and then making the measurement as ‘correct’ and accurate as possible. If validity is ensured, the researcher must still consider the reliability of the measurement. Validity does not guarantee reliability, and vice versa. A measure may be accurate (valid) but not consistent (reliable). Also, it may be quite consistent but not accurate. Thus, validity and reliability are two separate though interrelated conditions.

3.3 Reliability

Reliability is the degree to which the observed variable measures the ‘true’ value and is ‘error free’; it is, therefore, the opposite of measurement error [26]. In more formal terms, reliability is the extent to which a set of two or more indicators ‘share’ their measurement of a construct. The indicators of highly reliable constructs are highly intercorrelated, showing that they are all measuring the same latent construct. With decreased reliability, the indicators become less consistent and thus poorer indicators of the latent construct. Reliability can be computed as 1.0 minus the measurement error.

Kirk and Miller [28] identify three types of reliability in quantitative research, which relate to:

- the degree to which a measurement, given repeatedly, remains the same,
- the stability of a measurement over time and
- the similarity of measurements within a given time period.

3.4 Paired sample *t*-test technique

The Paired sample *t*-test is a technique that belongs to a group of multivariate analysis of variance [26]. Multivariate analysis of variance is the multivariate extension of the univariate techniques for assessing the differences between group means. The *t*-test assesses the statistical significance of the difference between two independent sample means. To determine whether the two messages are viewed differently (meaning that the treatment has an effect) a t statistic is calculated. The t statistic is the ratio of the difference between the sample means ($\mu_1 - \mu_2$) and their standard error. The standard error is an estimate of the difference between means to be expected because of a sampling error, rather than real differences between means.

4. ANALYSIS AND RESULTS

4.1 Descriptive statistics

In the following Tables I to IV, researched variables for all four types of thermal conditions with different clothing (naked manikin, thermal manikin with underwear, firefighter clothing with a flame retardant and firefighter clothing with antibacterial protection) are explained by:

- the minimum and maximum values,
- the mean value of each variable,
- the standard error and standard deviation.

As we can see in Tables I and II, there are some deviations within data on specific measuring points (marked in bold).

Table I: Naked manikin data.

	Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.
t1	36,8	37,1	36,96	,009	,081	pw1	22,22	26,82	24,33	,143	1,24	pwcm1	154,4	186,3	169,06	,998	8,65
t2	36,8	37,0	36,90	,007	,060	pw 2	15,38	21,76	18,83	,182	1,57	pwcm2	**44,1**	**62,4**	53,99	,521	4,51
t3	36,9	37,0	36,98	,004	,039	pw3	18,32	29,40	22,14	,318	2,75	pwcm3	**56,2**	**90,2**	67,93	,974	8,44
t4	36,8	37,1	37,01	,010	,089	pw4	17,36	34,90	23,38	,626	5,42	pwcm4	204,2	410,6	275,04	7,368	63,80
t5	36,8	37,2	37,02	,009	,079	pw5	13,14	31,80	19,27	,623	5,40	pwcm5	154,6	374,1	226,77	7,337	63,54
t6	36,9	37,1	37,00	,010	,088	pw6	14,90	29,40	19,51	,457	3,96	pwcm6	289,4	571,1	379,05	8,885	76,95
t7	36,9	37,1	37,02	,007	,062	pw7	16,58	27,50	20,29	,378	3,27	pwcm7	322,1	534,2	394,17	7,349	63,64
t8	36,9	37,1	37,04	,007	,064	pw8	14,50	31,38	20,24	,558	4,84	pwcm8	170,6	369,2	238,20	6,572	56,91
t9	36,8	37,1	37,03	,008	,074	pw9	17,30	32,06	21,85	,485	4,20	pwcm9	203,5	377,2	257,09	5,713	49,47
t10	36,9	37,1	37,01	,010	,087	pw10	14,02	26,12	17,33	,343	2,97	pwcm10	272,3	507,4	336,75	6,669	57,76
t11	36,9	37,1	37,02	,008	,069	pw11	18,64	30,84	22,84	,336	2,91	pwcm11	362,1	599,1	443,78	6,536	56,61
t12	36,8	37,0	36,86	,007	,063	pw12	**5,72**	**11,00**	7,96	,149	1,29	pwcm12	139,0	267,4	193,45	3,636	31,48
t13	36,8	37,0	36,88	,007	,065	pw13	9,80	14,52	12,38	,141	1,22	pwcm13	238,2	352,9	301,15	3,429	29,70
t14	36,8	37,2	36,97	,015	,132	pw14	13,46	16,90	15,33	,127	1,09	pwcm14	376,7	472,9	429,17	3,554	30,78
t15	36,8	37,2	36,99	,015	,128	pw15	12,42	16,10	14,29	,109	,94	pwcm15	400,6	519,3	461,19	3,513	30,42
t16	36,8	37,2	36,96	,015	,134	pw16	**7,64**	**11,94**	10,29	,121	1,05	pwcm16	185,7	290,2	250,20	2,952	25,57
t17	36,8	37,1	36,96	,011	,099	pw17	10,60	15,22	12,62	,129	1,12	pwcm17	257,6	369,9	306,88	3,153	27,30
t18	36,8	37,2	37,01	,017	,145	pw18	13,22	18,40	15,79	,154	1,33	pwcm18	369,9	514,9	442,13	4,309	37,32
t19	36,8	37,3	37,08	,018	,154	pw19	13,70	21,60	16,96	,180	1,56	pwcm19	441,9	696,8	547,21	5,809	50,31

Table II: Manikin with underwear data.

	Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.
t1	36,8	36,8	36,80	,001	,015	pw1	21,4	24,2	23,81	,041	,453	pwcm1	148,8	168,2	165,43	,285	3,148
t2	36,7	36,9	36,83	,005	,055	pw 2	11,0	18,8	14,37	,202	2,239	pwcm2	**31,5**	**53,8**	41,20	,581	6,418
t3	36,7	36,9	36,84	,005	,065	pw3	9,6	21,7	14,08	,303	3,356	pwcm3	**29,5**	**66,7**	43,21	,932	10,295
t4	36,5	36,9	36,73	,008	,092	pw4	18,0	29,2	23,04	,231	2,554	pwcm4	211,7	343,2	271,03	2,720	30,052
t5	36,5	36,9	36,74	,010	,117	pw5	15,7	27,5	20,66	,279	3,092	pwcm5	184,7	323,5	243,07	3,293	36,374
t6	36,4	36,9	36,72	,012	,142	pw6	18,4	31,1	23,44	,330	3,646	pwcm6	357,4	603,7	455,40	6,412	70,833
t7	36,5	36,9	36,76	,011	,125	pw7	17,3	30,6	22,76	,332	3,673	pwcm7	336,4	594,4	442,11	6,460	71,356
t8	36,5	36,9	36,73	,009	,102	pw8	16,1	27,4	20,63	,256	2,834	pwcm8	189,4	322,1	242,79	3,018	33,340
t9	36,6	36,9	36,77	,009	,104	pw9	16,9	27,1	22,17	,288	3,189	pwcm9	198,8	318,8	260,86	3,396	37,518
t10	36,4	36,9	36,71	,010	,115	pw10	15,9	27,5	21,15	,264	2,926	pwcm10	309,6	534,5	410,89	5,146	56,848
t11	36,5	36,9	36,74	,010	,116	pw11	20,8	32,5	25,69	,289	3,198	pwcm11	404,0	631,3	499,07	5,624	62,123
t12	36,8	36,9	36,84	,004	,046	pw12	**1,7**	**8,2**	4,69	,140	1,546	pwcm12	**42,8**	199,3	114,09	3,403	37,593
t13	36,8	37,0	36,85	,004	,049	pw13	4,5	12,9	7,36	,130	1,441	pwcm13	110,3	313,5	178,92	3,170	35,018
t14	36,7	36,9	36,82	,005	,060	pw14	9,4	17,8	13,27	,204	2,262	pwcm14	263,0	498,7	371,60	5,732	63,314
t15	36,6	36,9	36,82	,008	,088	pw15	4,3	15,3	9,06	,235	2,602	pwcm15	138,7	493,5	292,22	7,599	83,940
t16	36,8	36,9	36,84	,004	,043	pw16	5,3	11,4	8,05	,151	1,668	pwcm16	129,8	277,1	195,62	3,670	40,546
t17	36,8	36,9	36,85	,004	,044	pw17	5,5	12,9	8,80	,173	1,919	pwcm17	135,6	313,5	214,00	4,225	46,668
t18	36,8	36,9	36,84	,004	,045	pw18	11,0	17,6	13,74	,174	1,927	pwcm18	307,8	492,5	384,72	4,883	53,938
t19	36,7	36,9	36,84	,006	,063	pw19	8,2	18,1	12,06	,198	2,194	pwcm19	267,0	585,8	389,12	6,407	70,769

4.2 Paired sample *t*-test

The basic idea of the Paired sample *t*-test is simple. If the treatment had no effect, the average difference between the measurements is equal to 0 and the null hypothesis holds. On the other hand, if the treatment did have an effect (intended or unintended), the average difference is not 0 and the null hypothesis is rejected.

The first analysis (Table V) performed on the naked manikin shows differences between the observed measurement points. Pairs 3, 6, 7, 9 and 15 show little correlation between temperature and heat flow, so for this first measurement set the null hypothesis cannot be accepted for all the measurement points.

A more specific view shows that for 12 measurement points, the null hypothesis can be accepted with 99 % probability but, as mentioned before, for other measurement points the hypothesis cannot be accepted.

Table III: Firefighter clothing with a flame retardant data.

	Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.
t1	36,8	36,9	36,84	,004	,042	pw1	18,2	23,9	21,29	,134	1,550	pwcm1	126,7	166,0	147,96	,937	10,772
t2	36,8	36,9	36,86	,003	,038	pw 2	2,8	9,7	5,62	,159	1,827	pwcm2	8,0	27,8	16,13	,456	5,239
t3	36,8	37,0	36,87	,005	,059	pw3	1,6	12,2	4,57	,196	2,258	pwcm3	**5,1**	37,4	14,02	,603	6,928
t4	36,8	37,1	36,90	,009	,108	pw4	2,4	10,6	6,04	,117	1,353	pwcm4	28,2	124,7	71,11	1,386	15,925
t5	36,8	37,1	36,89	,009	,111	pw5	**0,2**	5,5	3,25	,096	1,107	pwcm5	**2,8**	64,7	38,25	1,134	13,035
t6	36,7	37,0	36,86	,008	,101	pw6	4,7	11,0	8,04	,119	1,371	pwcm6	91,2	213,6	156,31	2,318	26,641
t7	36,8	37,0	36,87	,007	,087	pw7	5,0	10,2	7,99	,094	1,086	pwcm7	97,5	198,1	155,20	1,836	21,096
t8	36,8	37,1	36,90	,009	,106	pw8	1,2	8,6	4,63	,116	1,336	pwcm8	14,1	101,1	54,56	1,368	15,725
t9	36,8	37,1	36,90	,009	,107	pw9	1,6	9,5	5,07	,116	1,336	pwcm9	18,8	112,4	59,70	1,368	15,719
t10	36,7	37,0	36,85	,008	,098	pw10	2,7	8,8	6,22	,125	1,443	pwcm10	52,4	171,7	120,98	2,441	28,048
t11	36,8	37,1	36,89	,009	,103	pw11	6,2	12,0	9,62	,100	1,158	pwcm11	120,4	234,2	186,98	1,958	22,496
t12	36,7	36,9	36,82	,004	,041	pw12	**0,0**	7,1	2,78	,119	1,374	pwcm12	**0,0**	172,5	67,69	2,908	33,411
t13	36,7	36,9	36,86	,004	,044	pw13	1,6	10,2	4,01	,160	1,843	pwcm13	40,8	247,9	97,50	3,899	44,805
t14	36,7	37,0	36,82	,006	,066	pw14	4,3	14,9	8,47	,237	2,728	pwcm14	122,5	417,0	237,14	6,647	76,369
t15	36,5	36,9	36,81	,007	,089	pw15	1,6	17,3	5,78	,311	3,582	pwcm15	51,6	558,0	186,65	10,058	115,568
t16	36,8	36,9	36,86	,003	,038	pw16	1,2	7,8	3,85	,138	1,593	pwcm16	31,1	189,5	93,58	3,371	38,732
t17	36,8	36,9	36,85	,003	,042	pw17	1,0	8,6	3,68	,141	1,620	pwcm17	25,2	209,0	89,57	3,429	39,401
t18	36,7	37,0	36,84	,005	,063	pw18	4,9	16,5	8,46	,238	2,742	pwcm18	138,2	461,7	236,82	6,681	76,759
t19	36,7	36,9	36,83	,005	,061	pw19	1,3	13,7	5,42	,276	3,172	pwcm19	43,8	441,9	174,85	8,906	102,327

Table IV: Firefighter clothing with antibacterial protection data.

	Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.		Min	Max	Mean	St.Err	St.D.
t1	36,7	36,8	36,78	,002	,030	pw1	20,4	23,5	21,23	,069	,845	pwcm1	142,2	163,2	147,52	,479	5,873
t2	36,7	36,8	36,77	,003	,037	pw 2	4,5	7,7	5,29	,087	1,070	pwcm2	13,0	22,3	15,17	,250	3,069
t3	36,6	36,9	36,75	,005	,070	pw3	1,0	9,4	5,05	,159	1,957	pwcm3	**3,1**	28,8	15,52	,490	6,004
t4	36,8	36,8	36,80	,001	,016	pw4	4,1	7,0	6,56	,040	,499	pwcm4	48,7	82,5	77,29	,479	5,872
t5	36,7	36,8	36,79	,001	,014	pw5	3,7	6,8	3,99	,034	,427	pwcm5	44,0	80,7	46,95	,410	5,024
t6	36,7	36,8	36,77	,002	,036	pw6	7,1	10,5	8,15	,083	1,020	pwcm6	139,4	204,3	158,33	1,618	19,825
t7	36,8	36,9	36,81	,002	,031	pw7	5,3	8,9	8,00	,079	,979	pwcm7	103,7	173,2	155,48	1,553	19,023
t8	36,8	36,8	36,80	,00	,00	pw8	5,1	5,1	5,10	,00	,00	pwcm8	60,0	60,0	60,00	,00	,00
t9	36,7	36,8	36,78	,002	,029	pw9	5,1	8,3	5,85	,066	,814	pwcm9	60,9	98,3	68,80	,782	9,578
t10	36,7	36,8	36,77	,003	,036	pw10	5,1	8,5	6,25	,085	1,047	pwcm10	100,6	165,5	121,40	1,661	20,354
t11	36,8	36,8	36,80	,000	,009	pw11	8,2	10,2	10,14	,022	,277	pwcm11	160,4	198,1	197,04	,440	5,393
t12	36,6	36,8	36,78	,004	,051	pw12	0,4	7,5	2,50	,110	1,351	pwcm12	**9,7**	182,3	60,79	2,682	32,849
t13	36,6	36,9	36,77	,004	,054	pw13	0,8	9,0	4,11	,124	1,520	pwcm13	19,4	218,7	99,89	3,017	36,954
t14	36,5	36,9	36,79	,007	,086	pw14	4,3	18,4	8,68	,253	3,107	pwcm14	122,5	514,9	242,88	7,100	86,964
t15	36,5	36,9	36,81	,007	,086	pw15	2,0	15,9	6,32	,269	3,303	pwcm15	64,5	513,5	203,89	8,700	106,563
t16	36,6	36,9	36,80	,005	,071	pw16	0,4	9,4	3,79	,168	2,063	pwcm16	11,6	228,4	92,15	4,094	50,149
t17	36,6	36,9	36,77	,005	,066	pw17	**0,2**	8,6	3,85	,151	1,852	pwcm17	**5,8**	209,0	93,74	3,675	45,018
t18	36,5	36,9	36,79	,009	,117	pw18	4,3	18,4	8,87	,311	3,820	pwcm18	122,5	514,9	248,28	8,730	106,922
t19	36,5	36,9	36,78	,009	,120	pw19	1,6	15,7	6,40	,334	4,101	pwcm19	54,2	506,4	206,58	10,803	132,314

The analysis (Table VI) for the tests with the manikin with underwear gave better results, showing very high correlation between temperature and heat flow; consequently, the null hypothesis can be accepted with 99 % probability, except for pair 19.

Table V: Correlations between paired samples for the naked manikin.

		N	**Correlation**	**Sig.**
Pair 1	t1 & pw1	75	,365	,001
Pair 2	t2 & pw2	75	,407	,000
Pair 3	t3 & pw3	75	,070	,550
Pair 4	t4 & pw4	75	-,597	,000
Pair 5	t5 & pw5	75	-,532	,000
Pair 6	t6 & pw6	75	-,092	,435
Pair 7	t7 & pw7	75	,143	,221
Pair 8	t8 & pw8	75	-,217	,062
Pair 9	t9 & pw9	75	,090	,444
Pair 10	t10 & pw10	75	,386	,001
Pair 11	t11 & pw11	75	,406	,000
Pair 12	t12 & pw12	75	-,265	,022
Pair 13	t13 & pw13	75	-,338	,003
Pair 14	t14 & pw14	75	-,679	,000
Pair 15	t15 & pw15	75	-,028	,814
Pair 16	t16 & pw16	75	-,482	,000
Pair 17	t17 & pw17	75	-,422	,000
Pair 18	t18 & pw18	75	-,376	,001
Pair 19	t19 & pw19	75	,429	,000

Table VI: Correlations between paired samples for the manikin with underwear.

		N	**Correlation**	**Sig.**
Pair 1	t1 & pw1	122	-,996	,000
Pair 2	t2 & pw2	122	-,934	,000
Pair 3	t3 & pw3	122	-,539	,000
Pair 4	t4 & pw4	122	-,999	,000
Pair 5	t5 & pw5	122	-,993	,000
Pair 6	t6 & pw6	122	-,993	,000
Pair 7	t7 & pw7	122	-,973	,000
Pair 8	t8 & pw8	122	-,999	,000
Pair 9	t9 & pw9	122	-,990	,000
Pair 10	t10 & pw10	122	-,992	,000
Pair 11	t11 & pw11	122	-,997	,000
Pair 12	t12 & pw12	122	-,619	,000
Pair 13	t13 & pw13	122	-,265	,003
Pair 14	t14 & pw14	122	-,491	,000
Pair 15	t15 & pw15	122	-,277	,002
Pair 16	t16 & pw16	122	-,696	,000
Pair 17	t17 & pw17	122	-,637	,000
Pair 18	t18 & pw18	122	-,639	,000
Pair 19	t19 & pw19	122	-,098	,285

Similar situation can be observed for the next analysis (Table VII) where firefighter clothing with a flame retardant was tested. Analysis results show high correlation for most pairs, except for pairs 3, 6, 8, 9 and 10. The last analysis (Table VII) shows test results of firefighter clothing with antibacterial protection. Since there is a very high correlation between temperature and heat flow, the null hypothesis can be accepted with a very high probability of 99 %.

Table VII: Correlations between paired samples for firefighter clothing with a flame retardant.

		N	Correlation	Sig.
Pair 1	t1 & pw1	132	-,728	,000
Pair 2	t2 & pw2	132	-,691	,000
Pair 3	t3 & pw3	132	-,156	,073
Pair 4	t4 & pw4	132	-,303	,000
Pair 5	t5 & pw5	132	-,404	,000
Pair 6	t6 & pw6	132	-,116	,186
Pair 7	t7 & pw7	132	-,422	,000
Pair 8	t8 & pw8	132	-,166	,056
Pair 9	t9 & pw9	132	-,136	,121
Pair 10	t10 & pw10	132	-,135	,123
Pair 11	t11 & pw11	132	-,288	,001
Pair 12	t12 & pw12	132	-,860	,000
Pair 13	t13 & pw13	132	-,853	,000
Pair 14	t14 & pw14	132	-,675	,000
Pair 15	t15 & pw15	132	-,817	,000
Pair 16	t16 & pw16	132	-,639	,000
Pair 17	t17 & pw17	132	-,469	,000
Pair 18	t18 & pw18	132	-,503	,000
Pair 19	t19 & pw19	132	-,447	,000

Table VIII: Correlations between paired samples for firefighter clothing with antibacterial protection.

		N	Correlation	Sig.
Pair 1	t1 & pw1	150	-,992	,000
Pair 2	t2 & pw2	150	-,995	,000
Pair 3	t3 & pw3	150	-,999	,000
Pair 4	t4 & pw4	150	-,989	,000
Pair 5	t5 & pw5	150	-,991	,000
Pair 6	t6 & pw6	150	-,991	,000
Pair 7	t7 & pw7	150	-,971	,000
Pair 9	t9 & pw9	150	-,993	,000
Pair 10	t10 & pw10	150	-,990	,000
Pair 11	t11 & pw11	150	-,987	,000
Pair 12	t12 & pw12	150	-,994	,000
Pair 13	t13 & pw13	150	-,997	,000
Pair 14	t14 & pw14	150	-,947	,000
Pair 15	t15 & pw15	150	-,939	,000
Pair 16	t16 & pw16	150	-,994	,000
Pair 17	t17 & pw17	150	-,998	,000
Pair 18	t18 & pw18	150	-,963	,000
Pair 19	t19 & pw19	150	-,967	,000

5. CONCLUSIONS

The paper presents an attempt to evaluate the measurement accuracy and stability of a measurement system when determining thermal insulation. Thermal insulation is one of the most important parameters that we look for while carrying out tests using a thermal manikin. Since measurement with a thermal manikin is very suitable for determining the thermal insulation of protective and working clothes, we wanted to know how accurate and, consequently, how stable our system with the thermal manikin is.

Measurement accuracy and reliability, which can be, generally speaking, indicated as system stability, were assessed on the basis of statistical analysis. For the analysis of the presented problem, descriptive statistics and the Paired sample *t*-test as multivariate analysis of variance were used.

The Paired sample *t*-test gave us a deeper insight into the system stability, which is the aim of our research. Performed analysis and research results show that the system is stable in the most part, but in some measuring points there were some deviations.

With regards to the present results, further research would be useful on weather a greater numerical sample or with more combinations of clothes to avoid demonstrated deviations. Also, minimizing the use of hazardous materials and promoting recycling is important.

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