DETERMINATION OF THE THERMOREGULATORY SPECIFICATIONS FOR THERMAL MANIKINS

ZAVEC PAVLINIC, D.; BALIC, J. & MEKJAVIC, I.B.

Abstract: *Triad person-clothing-environments set specific requirements in the development and optimization of products in the field of personal protective equipment that integrates into the transportation, living and working environments. The optimal balance in the triad as well the effectiveness of its relationship depends on the clothing, environments to which workers are exposed while performing their activities and on their performance. The aim of the present study was to determine the optimal combat clothing ensembles conducting hikes and guard duty during winter and summer months. During the trials, the subjects were instrumented to obtain skin and core temperatures, clothing microenvironment temperatures and humidity, as well as oxygen uptake and heart rate. In addition to providing data regarding thermal and evaporative resistances, the manikins also provided data for a numerical model of human temperature regulation, which was used to simulate the field trials. According to the given facts the relationship discussed in the paper is man-clothing-environment triad in terms of thermal comfort, requirements for the simulation of thermoregulation and the use of heat manikin.*

Key words: *thermal manikin, thermoregulation, clothing, thermal resistance, comfort*

Authors' data: Dr. Zavec Pavlinic, D[aniela]*; Prof. Dr. Balic, J[oze]**; Prof. Dr. Mekjavic, I[gor]***, *Biomed d.o.o., Stari trg 4, 1000 Ljubljana, Slovenia, **Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia, ***Josef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia, dzpavlinic@gmail.com, joze.balic@uni-mb.si, igor.mekjavic@ijs.si

This Publication has to be referred as: Zavec Pavlinic, D[aniela]; Balic J[oze] & Mekjavic, I[gor] (2011). Determination of the Thermoregulatory Specifications for Thermal Manikin, Chapter 03 in DAAAM International Scientific Book 2011, pp. 031-044, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-901509-84-1, ISSN 1726-9687, Vienna, Austria, DOI: 10.2507/daaam.scibook.2011.03

1. Introduction

Until recently, sweating thermal manikins were used only for determining whole body and/or regional thermal and evaporative resistances of clothing ensembles and sleeping bags in accordance with ISO and EN standards listed in Table 1. With the advent of numerical models of human temperature regulation, the focus has now shifted to developing manikins that will also incorporate algorithms allowing the prediction of thermal comfort, based on the prevailing heat loss from the manikin to the surrounding environment. It is therefore not surprising that manikins capable of simulating human thermoregulatory responses, and providing feedback regarding thermal comfort, are now being used not only in the development of protective clothing, but also in the development of environmental control systems for automobiles and living/working environments (Candas, 2002; Candas, 2009).

International standards governing thermal manikin tests
• ISO NP - Measurement of thermal insulation of clothing with a thermal manikin (ISO TC92 WG17)
• ISO DIS 14505:2001 - Evaluation of the thermal climate in vehicles, part 1 and 2 (ISO TC159/SC5/WG1)
• ISO FDIS 9920:2006 - Ergonomics of the Thermal Environment - Estimation of the Thermal Insulation and Evaporation Resistance of a Clothing Ensemble
• ISO 15831:2004 – Clothing - physiological effects: measurement of thermal insulation by means of a thermal manikin.
• ISO 11079 (1993) - Evaluation of cold environments: determination of required clothing insulation IREQ.
• ISO 7730:1994 - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
• ISO DIS 7933:1989 - Hot environments - analytical determination and interpretation of thermal stress using calculation of predicted heat strain, PHS.
• ISO 7920 Estimation of the thermal characteristics of clothing (ISO TC159/SC5/WG1)
• ASTM F1291 Standard method for measuring the thermal insulation of clothing using a heated thermal manikin
• EN 397 - Safety helmets
• ENV 342: 2004 - Protective clothing against cold
• EN 511: 1994 - Protective gloves against cold
• EN 13537: 2002 - Requirements for sleeping bags

Tab. 1. International standards and thermal manikins

The optimization of air conditioning systems in automobiles is of particular importance, since the US Department of Energy estimates that upwards of 10% of the

total fuel consumption in the western world is used to cool vehicle interiors. It is hypothesized that the amount of fuel used by air-conditioning systems could be reduced, were the air-conditioning systems designed more efficiently. Possibly the most important factor, which determines how the air-conditioning system is used is the thermal comfort/discomfort of the automobile ambient as perceived by the occupants. The primary goal of car occupants in achieving thermal comfort is to reduce the temperature and humidity of the interior. However, an inappropriate distribution of the conditioned air within the vehicle compartment may establish thermal and humidity gradients across the surface area of the occupants, which may be perceived as thermally uncomfortable. In addition, the heat exchange between the occupants and the car seats also adds to the perceived comfort/discomfort.

As thermal manikins would enable the detection of influences from the environment and would be capable of responding in a physiological manner to the surrounding ambient, the field of development of personal protective equipment would be given the option of precise optimization and the area of automotive and construction industry would be given the development of high added value products with the aim of improvement of health and safety of the end user. This type of approach could be used not only for systems incorporated in cars, but also for design of systems for home, work, indoor recreational environments, etc. Although existing thermal manikin measurements represent a significant step forward realistic description of clothing systems behavior and their effects on heat exchange between human body and the surroundings, improvements have to be made in terms of requirements of person-clothing-environment triad relation. The manikins capable of thermoregulatory functions are needed not only for development of a new generation of thermal manikins for the clothing industry, but the establishment of a new manufacturing approach, together with a new business concept. Essential to the customized production of personal protective clothing is the possibility of obtaining three-dimensional scans of the body and using thermoregulatory manikin to simulate the thermoregulatory responses of workers under different working (environmental) conditions.

2. Background

Personal protective clothing is normally worn by workers exposed to extreme environmental conditions, providing protection from thermal, nuclear, biological, and chemical hazards. Protective clothing ensembles must allow them to work optimally in such environments, and should not hinder their performance. Current trends include incorporating nanotechnology in such clothing to provide biofeedback and to alter the characteristics of the clothing, when necessary.

In addition to protection, protective clothing must also fulfill the requirements of thermal comfort. Any investigation of comfort must begin with recognition that comfort is a state of mind. It is difficult to identify all the factors, which affect comfort. Even if the analysis of comfort is restricted only to thermal comfort, the data are subjective, and it is unlikely that a wide range of individuals will provide the same ratings of comfort for a given combination of clothing and environment. The

development of protective clothing must therefore take into consideration the anticipated range of environmental temperatures and humidities, and the range of working activities performed by the wearer in such environments. Therefore the triad person-clothing-environment describing the criteria for product development from a thermal and ergonomic comfort point of view has to be determined *a priori* (Goldman, 2007). Evaluation of personal protective equipment for soldiers, fire-fighters, rescuers and workers in extreme working environments, must therefore account for numerous factors that depend on physical requirements of the mission and/or working activities and environmental conditions to which personnel will be exposed. Therefore the process of protective clothing development must consider the environmental influences, exposure time, and to risk of injuries (Figure 1).

Fig. 1. Relation of dangerous influences – exposure time – risk

With regards to thermal comfort, personal protective equipment must enable adequate thermal exchange between the user and environment, and must not hinder mobility. Under normal conditions, thermal and ergonomic comfort (freedom of movement, level of load) is of primary importance, but under extreme environmental conditions, prevention of injuries may become the principal objective. Working in extremely hot and/or cold environments can result in substantial elevations in thermal discomfort and, in extreme circumstances, in overheating (hyperthermia), heat stress, burns, disturbance in cardiovascular system, dehydration or overcooling (hypothermia), cold and non-cold injuries (Mekjavic et al. 2005). Optimal combat clothing ensembles must maintain core temperature and must prevent skin temperature from falling below 20°C. Fall of tissue temperature below 0°C causes freezing injuries. However, finger and toe temperatures below 20°C impair performance, and if unduly prolonged can result in non-freezing cold injury. Fingers

and toes are especially difficult to protect from cold, because strong vasoconstriction reduces blood flow to almost zero during cold exposure (Mekjavic 2005). In cold environments elevations in core temperature, as a consequence of heavy work, may be anticipated, particularly if well insulated garments are worn. In general, small displacements in core temperature are not of concern, as long as normal thermal balance can be re-established under normal resting conditions (Leithhead and Lind, 1964). Designers of protective clothing must therefore incorporate strategies in the garments that allow modification of heat exchange between the wearer and the environment. In warm working environments, it is recommended that core temperature does not surpass 38°C (Mekjavic et al. 2010, Eiken et al. 2010).

Despite the tremendous developments in the field of “intelligent clothing” or “smartwear”, the tools used in the development and evaluation of such clothing remain rudimentary. The multilevel approach depicted in Fig. 2, based on the proposal of Umbach (1987) and revised by Zavec Pavlinic and Mekjavic (2009), has been proposed for the development and evaluation of protective clothing.

The role of thermal manikins is to simulate the human body in terms of shape and heat exchange with the environment. Present manikins are not capable of simulating regional heat loss, as this information was not available until recently (Machado Moreira et al., 2008,). The current focus in the development of manikins is the incorporation of numerical thermoregulatory models in the control systems regulating heat loss patterns in manikins (Wissler, 1985; Fiala 2001). Recent studies (Zavec Pavlinic, et al. 2009, Zavec Pavlinic et al. 2011, Morabito et al. 2011) have demonstrated that data regarding thermal and evaporative resistance obtained with sweating thermal manikins are useful for simulating human thermoregulatory responses to different environmental conditions, at different levels of work activity.

The original multilevel approach proposed by Umbach (1987) comprised the Biophysical analyses on textile materials and garments followed by Laboratory and Field studies (center panels in Fig. 2). These difference levels of analyses were interspersed with simulation of the results with numerical models of textile and clothing function, and of human thermoregulatory responses (left panels in Fig. 2). As a consequence of the work performed in the present study, this approach has been revised to include an analysis of the compatibility of textile materials, which should be conducted prior to the analysis of textile combinations on the skin model.

Recent technological advances have introduced whole body or segmental 3D scanning. These scans can be used to produce individualized patterns for a particular garment design. Computer simulations can also provide suggestions for modifications of original designs to ensure optimal ergonomic and wear comfort. The clothing ensemble should not impair performance, and this should also be evaluated. Finally, The farthest right panel in Fig. 2 introduces a new concept of a WEAR index. This index, which is specific for each garment ensemble, provides the optimal range of environmental temperatures and humidities for a given activity, for a given garment. Future modifications to this approach will be the substitution of classical thermal

manikins with manikins capable of thermoregulatory function. This development will also undoubtedly introduce new avenues of analysis in this model.

Fig. 2. Recommended process in the development and/or evaluation of functional clothing ensembles

Most manikins are used for research purposes only, but industries have discovered several applications for manikin measurements in product development and control (Table 2; Holmer, 1999).

Arguments for the use of thermal manikins
• simulation of human body heat exchange: whole body or local
• integration of dry heat losses in a realistic situation
• measurement of heat exchange
• objective method for measurement of clothing thermal insulation
• quick, accurate and repeatable
• cost-effective instrument for comparative measurements and product development
• provide values for prediction models: clothing thermal insulation and evaporative resistance and heat losses

Tab. 2. Features of thermal manikin

3. Methods

The aim of the study was to optimize the Slovene Armed Forces (SAF) combat clothing systems for cold and mild hot environments. In cold outdoor climates the complex planning of appropriate combinations of clothing ensembles is important to ensure prevention of cold injury. In mild hot environments clothing-induced impairment of heat exchange may cause overheating and impact on performance. The study comprised field trials performed during the winter and summer months in the Julian Alps and Adria region (Slovenia), respectively. In addition to measurements of body temperatures, heat exchange, heart rate, oxygen uptake and respiration, we also requested that the subjects provided us with subjective ratings of thermal and moisture (dis)comfort. The thermal and evaporative resistance of the clothing ensembles was assessed with a thermal manikin.

HIKE & GUARD DUTY	Place:	Julian Alps	Adriatic Coast
	Date:	January/February, 2006	September 2005
	Ambient temperature:	from -16.8 to 4.9 °C	from 20.7 to 23.6 °C
	Relative humidity:	from 10.0 to 99.6 %	from 60.6 to 74.8 %
	Wind speed:	from 0.1 to 12.0 m/s	from 0.1 to 0.8 m/s
	Radiation:	from 42 to 101 W/m ²	from 30 to 280 W/m ²

Tab. 3. Location of the field tests, dates they were performed and the prevailing weather conditions

Fig. 3. The altitude and oxygen uptake during the winter (Julian Alps region) and summer studies (Adriatic coast)

During the winter study subjects participated in two separate trials. In one they performed 3-hr guard duty, and in the other a 3-hr hike (12 km on different terrain). In the summer study they performed a 12 km hike only. The elevation profile for the hiking trail in both the summer (Adriatic Coast; Figure 4), and winter (Julian Alps; Figure 5) studies, is shown on Fig. 3. The winter and summer hikes comprised three 50-min periods of walking interspersed with 10-min rest periods.

Ambient temperature, relative humidity, radiant temperature, and wind speed were monitored continuously during the hike and guard duty, albeit only in one location. During the hikes, the load-carriage system weighted 20 kg, in contrast to 5 kg during the guard duty.

Fig. 4. Depiction of the summer hikes conducted on the Adriatic coast. Subjects are wearing a portable system for measuring breath-by-breath oxygen uptake, ventilation, and heart rate. The temperature and humidity data is sampled and stored by a data acquisition system located in the backpack

Fig.5. Depiction of the winter hikes conducted in Julian Alps

In both field studies we measured subjects' skin temperature (6 sites), heat flux (6 sites), gastric temperature (radio pill), forearm-fingertip and calf-toe skin temperature gradients (indices of vasomotor tone in the fingers and toes, respectively), heart rate, ventilation and oxygen uptake. In addition, we also measured the clothing microenvironment temperature and relative humidity (first clothing layer) at 6 different locations: arm, chest, back, thigh, glove, helmet and boot (only temperature). The list of measured variables is presented in Table 4.

Variable:	Unit:	Description:
Environmental variables		
T_a	$^{\circ}\text{C}$	Ambient temperature
RV	%	Relative humidity
V_{wind}	m/s	Wind speed
SR		Radiation
Cardiorespiratory variables		
HR	l/min	Heart rate
VO_2	ml/min	Oxygen consumption
V_e	l/min	Ventilation
Body temperature		
T_{core}	$^{\circ}\text{C}$	Core temperature
$T_{\text{sk\_forearm}}$	$^{\circ}\text{C}$	Skin temperature – forearm
$T_{\text{sk\_arm}}$	$^{\circ}\text{C}$	Skin temperature - arm
$T_{\text{sk\_chest}}$	$^{\circ}\text{C}$	Skin temperature - chest
$T_{\text{sk\_back}}$	$^{\circ}\text{C}$	Skin temperature - back
$T_{\text{sk\_thigh}}$	$^{\circ}\text{C}$	Skin temperature - thigh
$T_{\text{sk\_finger}}$	$^{\circ}\text{C}$	Skin temperature - finger
$T_{\text{sk\_toe}}$	$^{\circ}\text{C}$	Skin temperature - toe
$T_{\text{sk\_calf}}$	$^{\circ}\text{C}$	Skin temperature - calf

	Unit:	Description:
Clothing temperature		
$T_{\text{cl\_arm}}$	$^{\circ}\text{C}$	Clothing temperature - arm
$T_{\text{cl\_chest}}$	$^{\circ}\text{C}$	Clothing temperature - chest
$T_{\text{cl\_back}}$	$^{\circ}\text{C}$	Clothing temperature - back
$T_{\text{cl\_thigh}}$	$^{\circ}\text{C}$	Clothing temperature - thigh
T_{boot}	$^{\circ}\text{C}$	Temperature - boots
T_{helmet}	$^{\circ}\text{C}$	Temperature - helmet
Skin heat flux		
Q_{arm}	W/m^2	Heat flux - arm
Q_{chest}	W/m^2	Heat flux - chest
Q_{back}	W/m^2	Heat flux - back
Q_{thigh}	W/m^2	Heat flux - thigh
Q_{calf}	W/m^2	Heat flux - calf

Tab. 4. Measured variables

The protocol of the study was approved by the National Committee for Medical Ethics at the Ministry of Health (Republic of Slovenia). All subjects were aware that they could either discontinue an experiment, or withdraw their participation in the study at any time.

The thermal resistance of the clothing ensembles (R_t) was determined with a thermal manikin (Biomed d.o.o., Ljubljana). The thermal resistance for sensible heat transfer from skin to ambient is often measured in nearly still air and an empirically derived correlation is then used to account for the effect of wind and motion (Havenith & Nilsson, 2004, 2005; Qian & Fan, 2006). The regional thermal insulation (R_t) of a garment in units of clo is computed as follows:

$$I_i = \frac{A_i (T_{s,i} - T_{amb})}{0.155 Q_i} \quad (1)$$

where:

A_i = surface of the particular manikin element (arm, chest, back, thigh)

$T_{s,i}$ = surface temperature of element i ($^{\circ}\text{C}$)

T_{amb} = ambient temperature ($^{\circ}\text{C}$)

Q_i = rate of heat transfer from element i (Watts)

0.155 = conversion factor (1 clo = 0.155 $\text{m}^2 \text{ K/W}$)

One **clo** is the amount of insulation required to keep a resting person warm in a windless room at 21.1 $^{\circ}\text{C}$ when the relative humidity is less than 50%. An insulation of 1 clo is provided by a three-piece suit and light underclothes. At -40°C , an insulation of 12 clo is required; light activity lowers the insulation required for comfort to 4 clo.

The manikin used in the present study had 4 segments: arms, legs, front torso and back torso. Surfaces of the particular manikin segments were: arm = 0,36 m^2 ; chest = 0,42 m^2 ; back = 0,42 m^2 ; thigh = 0,56 m^2 . The manikin was dressed in the clothing ensembles worn in the field trials (Fig. 3). During the tests, heat flux from the manikin surface was measured while the manikin skin (surface) temperature was maintained at 35°C with the ambient temperature in the climatic chamber maintained at 15°C . These conditions ensured that the thermal flux was greater than 20 W/m^2 .

Fig. 6. The thermal manikin positioned in the climatic chamber. The left panel depicts the naked manikin, whereas the middle and right panels depict the under- (middle panel) and outer- (right panel) layers of a clothing ensemble tested

4. Results and discussion

Garment thermal resistances (R_{Ti}) derived using Eqn. 1 are presented in Table 2. Combat clothing ensembles 1 to 7 in Table 3 are recommended for use in cold environments, whereas ensembles for summer conditions are numbered 8 to 12.

On the basis of the physiological data obtained during the field trials, and tests of thermal resistance conducted with the thermal manikin, the optimal clothing ensemble for the winter hikes and guard duty were determined to be ensembles 3a,

and 4a, respectively. For the summer hikes the optimal ensemble was determined to be ensemble 8.

Combat clothing ensembles	Arms	Legs	Torso front	Torso back	Overall	
	[clo]	[clo]	[clo]	[clo]	[clo]	[m ² K / W]
1	2.73	2.51	4.44	2.54	3.06	0.46
2	3.72	3.69	3.66	4.03	3.77	0.56
2a	2.69	3.71	3.15	3.86	3.35	0.50
3	2.69	2.81	3.06	2.47	2.76	0.41
3a	3.08	1.92	2.52	2.47	2.50	0.38
4	2.54	3.04	4.87	2.73	3.29	0.49
4a	3.03	3.94	4.37	4.60	3.98	0.60
5	2.95	3.47	3.69	2.59	3.17	0.48
6	3.04	1.44	2.75	2.31	2.27	0.36
7	2.91	3.30	3.76	4.24	3.55	0.53
8	1.21	1.83	1.25	1.39	1.42	0.21
9	2.28	2.66	2.43	1.55	2.23	0.34
10	1.08	2,18	1.63	1.23	1.53	0.23
11	2.35	2.86	2.12	1.95	2.32	0.35
12	1.97	2.04	1.90	1.32	1.56	0.27

Tab. 2. Clothing thermal resistances of the combat clothing ensembles. Ensembles 3a and 4a were determined to be optimal for the Winter hike, and guard duty, respectively. Ensemble 8 was determined optimal for Summer hikes

5. Conclusions

Thermal manikins are useful tools for evaluating the thermal and evaporative resistances of clothing ensembles. However, they may not be optimal in designing protective clothing, as they do not simulate the pattern of regional heat loss. The current focus of manikin development is the incorporation of thermoregulatory models in the regulation of heat loss from the manikin surface. Simulation of human regional heat loss patterns, would improve the usefulness of manikins in the development of clothing ensembles.

Future development should also provide user-friendly platforms (Figure 7), which will allow storage of all physiological and manikin test data for garment ensembles, and assigning a WEAR index of the archived ensembles. Decisions regarding optimal clothing ensembles for a given mission will then be based on the activity, location and personnel engaging in the mission. Dedicated clothing and human thermoregulatory models will allow the choice of optimal clothing for the mission, and provide simulations of performance during the mission, as well as in the event of accident scenarios.

Fig. 7. Components of technological platform for optimizing protective clothing ensembles

6. Acknowledgements

This study was supported, in part, by Knowledge for Security and Peace grant administered by the Ministries of Defence, and of Science of the Republic of Slovenia (M2-0018), and awarded to I.B.Mekjavic.

7. References

- Candas, V. (2002). To be or not to be comfortable: basis and prediction. In: Tochihara, Y. (Editor). *Environmental Ergonomics X*. Fukuoka, Japan. ISBN: 4-9901358-0-6. pp. 795-800
- Candas, V. (2009): How local skin temperatures and sensations affect global thermal comfort? V: Mekjavić, Igor B. (ur.), Kounalakis, S. N. (ur.). *Environmental ergonomics XII*. Ljubljana: Biomed, pp. 343. ISBN 978-961-90545-1-2
- Eiken O, Grönkvist M, Kölegård R, Danielsson U, Zavec D, Kounalakis S, Mekjavic I. (2010): *Ter-misk belastning hos soldater som bär svensk markstridsutrustning*. STH Memo H-2010-0047. (in Swedish)
- Fiala D, Lomas KJ and Stohrer M. (2001): Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *International Journal of Biometeorology*; 45: pp.143–159
- Goldman R.F., Kampmann B. (2007): *Handbook on clothing; Biomedical Effects of Military Clothing and Equipment Systems*, 2nd Edition, NATO Research Study Group 7 on Bio-medical Research Aspects of Military Protective Clothing
- Havenith, G. & Nilsson, H.O.: Correction of clothing insulation for movement and wind – a meta-analysis. *European Journal of Applied Physiology*, 2004; Vol. 92, pp. 636-640
- Havenith, G. & Nilsson, H.O.: Erratum for Correction of clothing insulation for movement and wind– a meta-analysis. *European Journal of Applied Physiology* 2005; Vol.93, pp. 506
- Holmer, I. (1999): Thermal manikins in research and standards, Proceedings of the Third International Meeting on Thermal Manikin Testing 3IMM at the National Institute for Working Life, October 12-13; Nilsson, H.O. and Holmer I. (eds), ISBN 91-7045-554-6, ISSN 0346-7821
- Wissler, E.H. (1985): *Mathematical simulation of human thermal behaviour using whole body models*. In: Shitzer A, Eberhart RC (eds) Heat transfer in medicine and biology—analysis and applications. Plenum, New York, pp. 325–373
- Machado Moreira et al. (2008): *Sweat Secretion from Palmar and Dorsal Surfaces of the Hands During Passive and Active Heating*, Aviation, Space, and Environmental Medicine, Vol. 79, No. 11, p.1034-1040
- Machado Moreira et al. (2008): *Local differences in sweat secretion from the head during rest and exercise in the heat*, Eur J Appl Physiol, 104:p.257–264, DOI 10.1007/s00421-007-0645-y
- Machado Moreira et al. (2008): Sweat secretion from the torso during passively induced and exercise-related hyperthermia, Eur J Appl Physiol (2008) 104:265–270, DOI 10.1007/s00421-007-0646-x
- Morabito, M., Zavec Pavlinić, D., Crisci, A., Capecchi, V., Orlandini, S., Mekjavic, I. B.: Determining optimal clothing ensembles based on weather forecasts, with particular reference to outdoor winter military activities. *International Journal of Biometeorology*, 2011, Volume 55, Number 4, pp. 481-490

- Mekjavic, I.B. et al. (2005): "*Foot temperatures and toe blood flow during a 12 km winter hike and guard duty*" In: Prevention of Cold Injuries. RTO-MP-HFM-126, RTO/NATO, pp. 5-1 – 5-4
- Mekjavic IB, Simunic B, Zavec Pavlinic D, Eiken O, Candas V. (2010): Evaluation of the Slovene Armed forces desert ensemble. *Aviation Space and Environmental Medicine*, Vol. 81, pp. 281
- Qian, X. and J. Fan (2006). Prediction of Clothing Thermal Insulation and Moisture Vapour Resistance of the Clothed Body Walking in Wind. *Annals of Occupational Hygiene*, Vol. 50, No. 8, pp. 833–842
- Umbach K.H. (1988). Physiological tests and evaluation models for the optimisation of the performance of protective clothing. In: *Environmental Ergonomics. Sustaining Human Performance in Harsh Environments*. Eds.: Mekjavic I.B., E.W. Banister and J.B. Morrison. Taylor & Francis: Philadelphia, pp. 139-161.
- Zavec Pavlinic D. & Mekjavic I.B. (2009): Potrebe okolja sooblikujejo specifične bojne oblačilne sisteme, *Slovenska vojska*, No. 16, pp. 29 – 31.(in Slovene)
- Zavec Pavlinic D., Wissler E.H., Mekjavic I.B. (2009): Modeling thermophysiological responses of military personnel conducting a variety of activities during simulated field operations in a cold environment: *Presented at NATO Conference, HFM-168, "Soldiers in cold environments"*, 20-22. April, 2009, Helsinki, Finland
- Zavec Pavlinić, D., Mekjavić, I. B. (2010): The process of development of functional clothing ensembles for industrial application. V: Simončič, B.(ur.), Hladnik, A. (ur.), Pavko-Čuden, A. (ur.), Ahtik, J. (ur.), Luštek Preskar, B.(ur.), Demšar, A. (ur.), Urbas, R. (ur.). *41st International Symposium on Novelties in Textiles and 5th International Symposium on Novelties in Graphics and 45th International Congress IFKT*, Ljubljana, Slovenia, 27-29 May 2010. Symposium proceedings. Ljubljana: Faculty of Natural Sciences and Engineering, Department of Textiles, 2010, pp. 157-163. [COBISS.SI-ID 23704871]
- Zavec Pavlinic D., Wissler E.H., Mekjavic I.B. (2011): Using a mathematical model of human temperature regulation to evaluate the impact of protective clothing on wearer thermal balance, *Textile Research Journal* 0040517511414971, first published on September 14, 2011 as doi:10.1177/0040517511414971
- Zavec Pavlinić, D., Hursa Šajatović, A., Mekjavić, I. B. (2011): Determination of optimal thermal insulation of the Slovene armed forces winter clothing ensemble. V: Adolphe, D. C.(ur.). *11th World Textile Conference AUTEX 2011*, 8-10 June 2011, Mulhouse, France. *Book of proceedings: 150 years of research and innovation in textile science*. Mulhouse: Ecole Nationale Supérieure d'Ingénieurs Sud-Alsace, pp. 73-77