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Izvirni znanstveni članek

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Metoda ugotavljanja časa tolerance v ekstremnih razmerah podhlajanja ali pregrevanja organizma

Če smo izpostavljeni neprijetnemu okolju, ki lahko glede na okoliščine povzroči pregrevanje ali podhlajanje organizma, je življenjsko pomembno ugotoviti čas, ki nam omogoča delovanje v teh razmerah brez nevarnosti poškodbe posameznih delov telesa ali celo smrti. Ta čas lahko imenujemo čas tolerance. Kako hitro se bo organizem podhladil ali pregrel v danih razmerah, je odvisno od številnih dejavnikov, kot so: stanje okolja (temperatura, hitrost vetra, padavine), termoizolacijske lastnosti oblačila, količina izžarjene toplote v okolje v enoti časa, možnost prilagajanja termoizolacijske vrednosti oblačila, psihofizično stanje osebe, ki je izpostavljena ekstremnim razmeram v okolju, ipd.

Pri oblajanju osebe se posamezni deli telesa različno odzivajo na zunanje vplive. Najbolj občutljivi so prsti rok in nog, ušesa, nos in potem stopala in pesti. Posebna obravnava posameznih delov telesa in torza je izjemno težavna in kompleksna. Zaradi poenostavitve obdelave problema podhlajevanja in pregrevanja telesa človeka bomo predpostavili, da je bila opazovana oseba v začetni fazi v coni ugodja v suhem oblačilu, kar pomeni, da je celotno telo primerno toplotno izolirano.

Metoda temelji na primerjavi dejanske toplotne izolacije oblačila in potrebne v obravnavanih stanjih okolja in subjekta. Iz razlik dane in potrebne termoizolacje oblačila se da ugotoviti čas tolerance oziroma čas, ki je potreben, da se telo subjekta ohladi na srednjo kritično temperaturo v razmerah oblajanja. Pri pregrevanju pa dominantno vlogo ima izhlapevanje znoja.

Ključne besede: *čas tolerance, toplotni upor, oblajanje organizma, pregrevanje organizma, proizvodnja toplote, izžarevanje toplote, oblačilo, subjekt, toplota, vlaga, hitrost vetra, cona ugodja.*

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Method of Determination of Tolerance Time in Case of Body Cooling Down or Overheating in Extreme Conditions

In unfavourable environmental conditions, overheating or cooling down of a human body may occur. For such cases, it is of vital importance to determine the time available to the concerned person for performing activities without being seriously damaged or fatally impaired. This time can be called the tolerance time. How quickly an organism will cooling down or overheat in given conditions depends on many various factors, such as: environmental conditions (temperature, velocity of wind, precipitation), thermal resistance properties of clothing, amount of heat emitted into the environment in a unit time, possibilities of regulating the thermal resistance value of clothing, mental and physical state of the person exposed to extreme environmental conditions.

In the conditions of cooling down, individual parts of the body react differently to external influences. Most sensitive are fingers, toes, auricles, nose, feet and fists. It would be difficult and time consuming to investigate each part of the body and torso separately. In order to simplify the problem of cooling down and overheating, it is supposed that in the starting phase the observed person is in the zone of comfort and wears dry clothing, which means that the entire body is suitably thermally insulated. The method is based on the comparison of real thermal insulation of clothing and the required one for the investigated conditions of the environment and the state of the observed person. From the differences between real and the required thermal insulation of clothing, it is possible to determine the tolerance time, i.e. the time which is required by a human body to cool down to the mean critical temperature in the conditions of cooling down. In the conditions of overheating, sweat evaporation has a predominant role.

Key words: *time of tolerance, thermal resistent, cooling down of the body, overheathing of the body, production of the heat, loss of the heat, clothing subject, heat, moisture, velocity of the wind, comfort.*

1.0 UVOD

Človek občasno biva v neprimernem okolju (previsoka ali prenizka temperatura, kontaminirana – zastrupljena atmosfera ipd.), v katerem nima možnosti za spremembo količine oblačila. Poleg tega je omejena tudi prilagoditev s pomočjo spremembe količine izžarene toplote v okolje skozi površino kože. Za takšna izjemna stanja je zelo pomembno ugotoviti čas, v katerem lahko oseba opravlja določene aktivnosti v tem neprimernem okolju. To je področje psihomotorike, v katero se ne bomo podrobneje spuščali. Ko pravimo, da oseba lahko opravlja določene aktivnosti, mislimo na stanje, ko se temperatura na površini prstov rok zniža na manj kot 15 °C. V tem stanju se izredno zmanjša gibljivost prstov rok in zato subjekt ni zmožen opravljati del, za katera je potrebna popolna gibljivost prstov rok.

V realnem življenju smo pogosto prisiljeni delovati v izredno nevarnem okolju. To se nanaša predvsem na gašenje požarov in reševanje ljudi iz gorečih objektov, delo na prostem pri nizkih temperaturah, delo v kontaminirani coni na prostem ali v zaprtih prostorih ipd. V teh stanjih najpogosteje nimamo možnosti za prilagoditev količine oblačila stanju okolja, kar pomeni, da nimamo na voljo dodatnih plasti oblačila, če se začnemo ohlajati. V zastrupljenem okolju ne moremo spreminjati količine oblačila zaradi možnosti zastrupitve dihalnih organov in kože (bojni strupi ipd.). V teh primerih je bistveno realno predvideti čas (lahko ga imenujemo čas tolerance) bivanja in delovanja oseb, v katerem ne bo prišlo do resnejših poškodb telesa.

Izredno težko je natančno ugotoviti čas tolerance. Nanj vpliva veliko parametrov, kot so: temperatura in vlaga okolja, hitrost vetra in njegova smer pihanja, količina in kakovost plasti oblačila, kroj in oblika oblačila, stanje oblačila (suho ali mokro), kakovost površine zgornje plasti oblačila, karakteristike zgornje plasti oblačila (prepustnost za zrak in vodno paro, prepustnost ali neprepustnost za vodo), vrsta in intenziteta dela, ki ga opravlja oseba v izrednih razmerah, psihofizično stanje ipd.

Seveda meritve lahko izpeljemo na ljudeh, vendar ne v zastrupljenem okolju, ker obstoji določena verjetnost zastrupitve. Zato je v tem primeru težko izpeljati verodostojen poskus. Kljub temu je mogoče testirati vsa druga stanja. Teh pa je preveč. Že manjša sprememba v oblačilu zahteva nov preizkus. Zato je preprosteje in tudi ceneje izračunati čas tolerance za vsa stanja, ki bodo najpogosteje nastopila v realnem življenju v izrednih razmerah, in testirati na ljudeh le nekaj najbolj tipičnih stanj.

Razvili smo metodo ugotavljanja časa tolerance v katerem koli stanju okolja, stanju oblačila in stanju organizma človeka. Pri tem so upoštevane nekatere domneve, ki se zmeraj popolnoma ne ujemajo z realnim stanjem, kot je na primer kot pihanja vetra, zaščita ekstremitet,

1.0 INTRODUCTION

From time to time, a man has to act and stay in an inconvenient environment (too high or too low temperature, contaminated – intoxicated atmosphere, etc.) without having any possibility of changing the amount of clothing. Besides, adaptation by changing the amount of the emitted heat into the environment through the skin surface is limited. For such conditions, it is of vital importance to determine the period of time available to the concerned person for performing certain activities in such unfavourable circumstances. Anyway, this is the matter of the psychomotor science and will not be dealt with in detail in this paper. When we say that a person can perform certain activities, we have in mind the state in which the temperature on the surface of fingers falls below 15 °C. In such state, the motion ability of fingers decreases considerably so that the affected person is not capable of performing works that require total movability of fingers.

In real life, people are frequently forced to act in extremely dangerous situations, such as fire extinguishing and people rescuing from burning buildings, work in the open air at low temperatures, work in open or closed contaminated areas, etc. In such situations, it is usually impossible to adjust the amount of clothing to the circumstances, which means that there are no additional layers of clothing available to be put on in the case of body cooling down. In the contaminated environment, it is impossible to change the amount of clothing due to the risk of respiratory tract or skin intoxication (toxic gases, etc.). It is therefore very important to be able to predict the time (it can be called the tolerance time) available to a concerned person to stay or act in such dangerous conditions without suffering any serious damages of the body.

It is very difficult to precisely determine the tolerance time due to the influence of many various parameters, such as: temperature and humidity of environment, velocity and direction of wind, quantity and quality of clothing, style and shape of clothing, state of clothing (wet or dry), quality and properties of its outer layer (air and vapours permeable, waterproof, etc.), type and intensity of the performed work, mental and physical state of the person exposed to extreme conditions, etc.

The measurements can be carried out on people. This is not possible in contaminated areas due to potential of intoxication but it is possible to test all other situations. Since such situations occur very frequently and each change of clothing would require a new test, it is easier and much more cost effective to calculate the tolerance time for the most usual situations and to test on people only few most typical states.

We have developed the method of determining the tolerance time for any state of environment, clothing and organism. Certain presumptions, which are not always in accordance with real situations (e.g. angle of wind blowing, protection of extremities, thermal resistance thermalinusulation value of the body covering, (skin and subcutaneous tissue, which do not have constant temperature, while the body core has constant temperature 37 °C in the zone of comfort), influence of termoizolacijska vrednost plašča telesa (koža in podkožno tkivo, ki nimata stalne temperature v nasprotju z jedrom telesa, ki ima v coni ugodja stalno temperaturo 37 °C), vpliv kakovosti zunanje plasti oblačila na hitrost izhlapevanja znoja ipd. Pri ohlajanju organizma nastane problem zaščite ekstremitet (ušesa, nos, prsti rok in nog). Ušesa, nos in prste nog lahko primerno zaščitimo, da ne nastanejo poškodbe zaradi podhladitve. Problem so pesti in prsti rok. Ne moremo uporabiti rokavic, ki bi onemogočale uporabo rok za opravljanje določenih del. Če vzamemo kot merilo za izračun časa tolerance delovno sposobnost subjekta pri ohlajanju organizma, potem je čas tolerance čas, v katerem se temperatura prstov zniža pod 15 °C. Pri ohlajanju se toplota črpa iz organizma opazovanega subjekta in se zaradi tega znižuje povprečna temperatura telesa. Kako hitro poteka ohlajanje, je odvisno od spremembe termoizolacijske vrednosti oziroma toplotnega upora plašča telesa. Ta se lahko spreminja približno od 0,0343 do 0,0086 m^2.h.°C/kJ, kar je približno osemkratna vrednost [10]. Z ohlajanjem se delež plašča povečuje na račun deleža jedra. Poleg tega se znižuje tudi temperatura jedra telesa. Naš namen ni spuščati se v to področje. Zato se bomo bolj posvetili oceni stanja organizma opazovanega subjekta s tem, da bomo predvideli linearno odvisnost spremembe toplotnega upora plašča telesa v odvisnosti od srednje temperature telesa. Pri pregrevanju organizma je pomemben upor oblačila pretoku vodne pare.

Kljub tem pomanjkljivostim je mogoče metodo uporabiti v realnih primerih, posebno če se še dodatno izpeljejo preizkusi na ljudeh za nekatera najpogostejša stanja, ki bi lahko nastopila v izjemnih okolščinah.

2.0 TEORETIČNO OZADJE

Obravnavali bomo primere, ko lahko pride do pregrevanja in podhlajevanja organizma. Ne bomo obravnali situacij, ki so posledica požarov. V teh primerih so spremembe temperature hitre in drastične. Časi delovanja v teh razmerah pa so zelo kratki. Začetno stanje naj bo stanje ugodja. Človek naj bo v stanju ugodja v okolju, v katerem bo deloval. To se nanaša predvsem na zaprte kontaminirane objekte. Če pa oseba deluje na prostem, naj bo v začetku delovanja v coni ugodja. Stanje ugodje ali cona ugodja je tisto stanje, v katerem je temperatura na površini prsi okrog 33 °C in temperatura jedra telesa 37 °C ter sta proizvodnja in izguba toplote izenačeni. Čez čas se stanje lahko spremeni in oseba se lahko začne segrevati ali podhlajati. Osnovna predpostavka pri tem poskusu je nespremenljiva sestava oblačila. Oseba nima dodatnih delov oblačila, če se je začela podhlajati (alpinizem ipd,), niti nima možnosti odvreči določeno plast oblačila, če se je začela segrevati (kontaminirano okolje). Poleg tega bomo predpostavili, da oseba ves čas opravlja določeno aktivnost

the clothing outer layer quality on rapidity of sweat emission, etc.), have been taken into consideration. In the conditions of a body cooling down, the problem of the protection of extremities (auricles, nose, fingers and toes) occurs. Auricles, nose and toes can be adequately protected against damages due to cooling down but a real problem are fingers and the palm of the hand. Namely, the use of gloves would disable the affected person from performing the activity. If in the conditions of the body cooling down, the person's working ability is considered as the criterion for calculating the tolerance time, the tolerance time will be the time in which the temperature of fingers falls below 15 °C. In the process of cooling down, the heat is exhausted from the observed person's body and as a result, the body mean temperature decreases. How quick the process of cooling down will be depends on the change of the thermal insulating value or the body covering thermal resistance. It can change approximately from 0.0343 to 0.0086 m^2.h. °C/kJ, which is approximately an eightfold value [10]. During the cooling down process the share of the body covering increases on account of the body core share. Besides, the body core temperature decreases as well. However, the purpose of this paper is not to investigate this issue. We will use an approximate estimation of the state of the observed person's organism by assuming linear dependence of the change of the body covering thermal resistance in dependence of the mean body temperature. In the process of the body overheating, it is the resistance of clothing to the water vapour flow which is important.

Despite these deficiencies, the method can be used in real situations, particularly if accompanied by additional tests on people for some most frequent states that might occur in extreme conditions.

2.0 THEORY

The research encompasses the situations in which overheating and cooling down of an organism may occur. The situations resulting from fire will not be dealt with due to quick and drastic changes of temperature and very short time available for acting. The initial state is the state of comfort. The observed person is in the state of comfort in the environment in which he or she is going to perform a certain activity. This refers particularly to closed contaminated facilities. In the case of outdoor activities, the person will be initially in the zone of comfort. The state of comfort or the zone of comfort is the state in which the temperature on the chest surface is about 33 °C and the body core temperature 37 °C and when the production and the loss of heat are level. After a while, the situation may change and the person may start to warm up or cool down. The basic presumption in this experiment is the unchangeable composition of clothing. The person has no additional pieces of clothing to put on in the case of cooling down (mountaineering, etc.) and no possibility of taking off any layer of clothing in the case of warming up (contaminated environment). It is also presumed that the person performs z določeno intenziteto in zato izžareva v okolje stalno količino toplote skozi površino kože, in da so okončine osebe ustrezno zaščitene tako kot drugi deli telesa. Vsi izračuni se nanašajo na ravno površino, skozi katero se sicer izžareva manj toplote kot skozi valjasto ali sferno površino.[15] Na splošno lahko toplotni upor oblačila izrazimo z naslednjo enačbo:

the activity with constant intensity and emits a constant amount of heat through the skin into the environment as well as that the extremities and other parts of the body are adequately protected. All calculations refer to a flat surface through which less heat is emitted than through a cylindrical or spherical surface.[15] Generally, thermal resistance of clothing can be expressed with the following equation:

$$R_c = \sum_i \frac{d_i}{\lambda_i} = \frac{d_c}{\lambda_c} \quad (1)$$

Plast zraka na površini oblačila, za katero pravimo, da je negibna, daje tudi določen toplotni upor, ki ga lahko izrazimo z znano, eksperimentalno ugotovljeno enačbo[1], ki velja pri hitrosti vetra, ki je ≥ 1 m/s. Na toplotni upor te plasti zelo vpliva hitrost vetra. Ta odvisnost je prikazana z naslednjo enačbo:

The motionless air layer on the surface of clothing also provides certain thermal resistance, which can be expressed with a known, experimentally determined equation[1], which applies to the velocity of wind equal or higher than 1 m/s. The velocity of wind has an important influence on thermal resistance of this layer. This dependence is illustrated with the following equation:

$$R_a = \frac{0,0429}{0,4 + 2,0v^{0,5}} \quad (2)$$

Skupni toplotni upor lahko izrazimo z naslednjo enačbo:

Total thermal resistance can be expressed with the following equation:

$$R_s = R_c + R_a \quad (3)$$

Toplotni upor oblačila se tudi spreminja glede na hitrost vetra, količino vlage v oblačilu in spremembe temperature oblačila. Te spremembe lahko izrazimo s spremembo koeficienta toplotne prevodnosti, λ. To odvisnost lahko izrazimo z naslednjo enačbo za ravno površino[2]:

Thermal resistance of clothing also varies in dependence of the velocity of wind, percentage of humidity in clothing and temperature of clothing. These changes can be expressed with the change of heat conductivity coefficient λ. This dependence can be expressed with the following equation for a flat surface[2]:

$$\lambda_c = \lambda_0 \left(1 + k_T \Delta T_c + k_w \Delta G_c\right) + b c_a \gamma_a V_a d_c \quad (4)$$

Če upoštevamo enačbe od 1 do 4, lahko skupni toplotni upor oblačila in mirne plasti zraka na površini le-tega (enačba 3) izrazimo z naslednjo enačbo:

Considering Equations 1 to 4, total thermal resistance of clothing and motionless air layer on its surface (Equation 3) can be expressed with the following equation:

$$R_s = \frac{d_c}{\lambda_0 \left(1 + k_T \Delta T_c + k_w \Delta G_c\right) + b c_a \gamma_a V_a d_c} + \frac{0,0429}{0,4 + 2,0v^{0,5}} \quad (5)$$

V enačbi 5 smo upoštevali oziroma opisali tesnitev oblačila s koeficientom, *b*. V coni ugodja je temperatura na površini prsi okrog 33 °C, temperatura jedra telesa 37 °C in povprečna temperatura telesa, T_{av} je 36,6 °C. Pregrevanje ali podhlajanje organizma človeka nastopi takrat, ko pride do neravnotežja med proizvodnjo toplote v telesu in oddajanjem le-te v okolje. Če je proizvodnja toplote v organizmu manjša, kot so njene izgube skozi površino kože oziroma zunanjo površino oblačila v okolje, se bo začela zniževati povprečna temperatura telesa opazovane osebe. V nasprotnem primeru se bo toplota začela »skladiščiti« v telesu in se bo začela

In Equation 5, the tightening properties of clothing are described with coefficient *b*. In the zone of comfort, the temperature on the chest surface is about 33 °C, in the body core it is 37 °C and the mean body temperature T_{av} is 36.6 °C. Overheating or under cooling of the human body occurs when heat generation and heat emission are in imbalance. When less heat is generated than emitted through the skin or the outer surface of clothing into the environment, the mean body temperature starts to decrease. In the opposite case, the heat starts to accumulate in the body and the body temperature increases. If the mean body temperature in the initial (the zone of comfort) and final state as well as the mass dvigati telesna temperatura. Če so nam znani povprečni temperaturi telesa v začetnem (cona ugodja) in končnem stanju, teža osebe in specifična toplota telesa, c_b, lahko debalans toplote izračunamo z naslednjo enačbo:

and specific heat of the body c_b are known, the heat imbalance can be defined with the following equation:

$$\Delta Q_b = c_b G_b \left(T_{av2} - T_{av1} \right) \tag{5}$$

Iz enačbe 6 je razvidno, da je debalans toplote pozitiven tedaj, ko se toplota kopiči v telesu osebe, in negativen, če se toplota črpa iz telesa subjekta, tako da se zmanjšuje srednja temperatura telesa. Ta debalans je posledica izgub toplote, ki so lahko večje ali manjše, kot je proizvodnja toplote, ki se izžareva skozi površino kože in kot se porabi za izhlapevanje znoja in segrevanje ali ohlajanje vdihanega zraka. Če je debalans negativen, se oseba podhlajuje, če je pozitiven, se pregreva. V primeru, da ni debalansa ($\Delta Q = 0$) in je bila pred to meritvijo oseba v coni ugodja, je še zmeraj v nespremenjenem stanju. Debalans lahko izrazimo z naslednjo enačbo:

Equation 6 shows that the heat imbalance is positive in the case of heat accumulation in the body and negative in the case of heat emission from the body to such a degree that the mean body temperature decreases. This imbalance is the result of heat losses, which are higher or lower than the heat generated and emitted through the skin surface and the heat used for sweat evaporation and for warming or cooling the inhaled air. When the imbalance is negative, the person is cooling down, when it is positive, the person is overheating. If there is no heat imbalance ($\Delta Q = 0$) and the person was in the zone of comfort before this measurement, he or she is still in the unchanged condition. The imbalance can be expressed with the following equation:

$$\Delta Q_b = Q_1 - \left(Q_2 + Q_3 + Q_4 \right) \tag{7}$$

Posamezne toplote iz enačbe 7 so definirane z enačbami 8 do 11:

Individual heats in Equation 7 are defined with Equations 8 to 11:

$$Q_1 = \frac{\left(T_{skc} - T_{en} \right) St}{R_{s1}} \tag{8}$$

$$Q_2 = \frac{\left(T_{sk} - T_{en} \right) St}{R_{s2} + \Delta R_{t}} \tag{9}$$

$$Q_3 = c_W \varphi \left[a_0 + \frac{a_1 \left(T_{sk} + T_{en} \right)}{2} + a_2 v \right] St \tag{10}$$

$$Q_4 = \left(T_k - T_{en} \right) V_a \left(c_w \varphi G_{aw} + c_a \gamma_a \right) t \tag{11}$$

Enačba 8 velja za cono ugodja tedaj, ko zanemarimo izgube toplote med dihanjem in izgube zaradi izhlapevanja znoja. Če vstavimo v enačbo 7 izraze za posamezne toplote, enačbe od 8 do 11 in enačbo 7 rešimo po času t, dobimo splošno rešitev za izračun časa tolerance – enačba 12.

Equation 8 applies to the zone of comfort when heat losses during respiration and perspiration are neglected. If individual heats in Equation 7 are replaced with expressions in Equations 8 to 11 and Equation 7 solved by time t, a general calculation of the tolerance time is obtained – Equation 12.

$$t = \frac{\Delta Q_b}{\left[\frac{\left(T_{skc} - T_{en} \right) S}{R_{s1}} - \frac{\left(T_{sk} - T_{en} \right) S}{R_{s2} + \Delta R_{t}} \right] - c_w \varphi \left[a_0 + \frac{a_1 \left(T_{sk} + T_{en} \right)}{2} + a_2 v \right] S - \left(T_k - T_{en} \right) V_a \left(c_w \varphi G_{aw} + c_a \gamma_a \right)} \tag{12}$$

V enačbah od 1 do 12 simboli pomenijo: R_c – toplotni upor oblačila, m^2.h.°C/kJ; d_c – debelina oblačila, m; λ_c – koeficient toplotne prevodnosti oblačila, kJ/m.h.°C; R_a – toplotni upor mirne plasti zraka na površini oblačila; v – hitrost vetra, m/s; R_s – skupni toplotni upor oblačila in mirne plasti zraka na površini oblačila; λ – koeficient toplotne prevodnosti oblačila v katerihkoli pogojih; λ_0 – koeficient toplotne prevodnosti suhega

In Equations 1 to 12, the used symbols mean: R_c – thermal resistance of clothing, m^2.h.°C/kJ; d_c – thickness of clothing, m; λ_c – coefficient of heat conductivity of clothing, kJ/m.h.°C; R_a – thermal resistance of motionless air layer on clothing surface; v – velocity of wind, m/s; R_s – total thermal resistance of clothing and motionless air layer on clothing surface; λ – coefficient of heat conductivity of clothing in any conditions; λ_0 – coefficient of heat conductivity of oblačila v standardni atmosferi v mirnem vremenu; k_T – smerni koeficient (k_T = 0,0025) krivulje odvisnosti koeficienta toplotne prevodnosti od temperature oblačila; k_w – smerni koeficient krivulje odvisnosti koeficienta toplotne prevodnosti oblačila od količine vode v % v oblačilu (k_w = 0,04); ΔG_c – povečanje mase oblačila v % zaradi povečanja količine vode v oblačilu – odstotek vode v oblačilu; b – koeficient, ki ponazarja tesnjenje oblačila (pri oblačilu, ki dobro tesni, kot je v našem primeru, ima koeficient b vrednost 1), če oblačilo ne tesni, potem je $b > 1$; c_a – specifična toplota zraka (0,966 kJ/kg.°C); γ_a – gostota zraka (1,2 kg/m^3); V_a – volumenska hitrost pretoka zraka skozi oblačilo pri določeni hitrosti vetra, m^3/m^2.h; ΔQ_b – razlika med količino proizvedene toplote, ki ni uporabljena za delo mišic in notranjih organov, in izžarene toplote v okolje (v coni ugodja ΔQ_b = 0), kJ/m^2.h °C; c_b – specifična toplota telesa, kJ/kg.°C; G_b – teža telesa, kg; T_{av1} – povprečna temperatura telesa v coni ugodja (36,6 °C); S – površina kože, m^2; φ = (100 – RH)/100, kjer je RH relativna vlaga zraka izražena v %; T_{va2} – povprečna aktualna temperatura telesa, °C; T_{sk} – temperatura na površini kože, °C; T_{en} – temperatura okolja, °C; ΔR_{ti} – sprememba toplotnega upora plašča telesa glede na stanje v coni ugodja; c_w – specifična toplota izhlapevanja vode; a_0, a_1 *in* a_2 – koeficienti regresijske krivulje; V_a – količina izdihanega zraka v času opazovanja, m^3/h; T_{skc} – temperatura na površini kože v coni ugodja, °C; R_{s1} – skupni toplotni upor oblačila v coni ugodja; R_{s2} – skupni toplotni upor oblačila v aktualnih pogojih; T_k – temperatura jedra telesa, °C; G_{av} – količina vode v izdihanem zraku, gr/m^3.h; t – čas v urah, ki je potreben, da se doseže kritična temperatura podhlajevanja ali segrevanja telesa, oziroma čas, v katerem dosežemo vnaprej izbrano srednjo temperaturo telesa.

V enačbi 8 se toplota Q_1 nanaša na del proizvedene toplote v telesu, ki ne zajema toplote, porabljene za delo mišic in notranjih organov. Q_2 se nanaša na del toplote, ki jo oseba izžareva skozi površino kože in potem skozi površino oblačila neposredno v okolje v kateremkoli stanju organizma, kar pomeni tudi v območju ugodja ali pri pregrevanju oziroma podhlajanju organizma. Nekaj proizvedene toplote se porabi za izhlapevanje znoja (Q_3), nekaj pa pri dihanju (Q_4). Pri podhlajanju organizma se relativno malo toplote porabi za izhlapevanje znoja, ker se v tem stanju organizma pač izloča in izhlapeva zanemarljiva količina znoja. Pri pregrevanju organizma pa je izguba toplote zaradi izhlapevanja znoja bistvenega pomena za preprečevanje pregrevanja organizma in omogoča daljše delovanje v razmerah, ki pripeljejo do pregrevanja organizma. Zato bomo te izgube upoštevali pri pregrevanju.

Toplota Q_4, ki jo oseba oddaja med dihanjem, pa je odvisna od razlike temperature med jedrom telesa in okoljem, relativne vlage v okolju, vrste in intenzitete aktivnosti osebe oziroma števila vdihov in izdihov v enoti

dry clothing in standard atmosphere in still weather; k_T – heat conductivity coefficient/clothing temperature dependence curve coefficient (k_T = 0.0025); k_w – heat conductivity coefficient / % of humidity in clothing dependence curve coefficient (k_w = 0.04); ΔG_c – increase of clothing mass in % due to increase of water in clothing – percentage of water in clothing; b – coefficient illustrating tightening properties of clothing (if clothing tightens well as in our case coefficient b has value 1, if it does not tighten $b > 1$; c_a – specific air heat (0.966 kJ/kg.°C); γ_a – air density (1.2 kg/m^3); V_a – velocity of airflow through clothing at defined velocity of wind, m^3/m^2.h; ΔQ_b – difference between the amount of generated heat which is not consumed for muscles and internal organs functioning and the amount of emitted heat into the environment (in the zone of comfort ΔQ_b = 0), kJ/m^2.h °C; c_b – specific body heat, kJ/kg.°C; G_b – body mass, kg; T_{av1} – mean body temperature in the zone of comfort (36.6 °C); S – body superficies, m^2; φ = (100 – RH)/100, where RH is relative air humidity expressed in %; T_{va2} – mean real body temperature, °C; T_{sk} – temperature on skin superficies, °C; T_{en} – temperature of environment, °C; ΔR_{ti} - change of body superficies thermal resistance in dependence of state in the zone of comfort; c_w – specific water vapor heat; a_0, a_1 *in* a_2 – regression curves coefficients; V_a – amount of exhaled air during the observation time, m^3/h; T_{skc} – temperature on skin surface in the zone of comfort, °C; R_{s1} – total thermal resistance of clothing in the zone of comfort; R_{s2} – total thermal resistance of clothing in real conditions; T_k – body core temperature, °C; G_{av} – amount of water in exhaled air, gr/m^3.h; t – time in hours required to achieve critical temperature of body cooling down or overheating and the time in which a predefined mean body temperature is achieved, respectively.

In Equation 8, Q_1 refers to the fraction of the generated heat in the body, which does not include the heat needed for muscles and internal organs functioning. Q_2 refers to the fraction of the heat, which is emitted through the skin surface and clothing directly into the environment in any state of organism, including the zone of comfort and the process of overheating and cooling down. A certain amount of the generated heat is used for sweat evaporation (Q_3) and respiration (Q_4). In the process of cooling down, a relatively low amount of heat is used for sweat evaporation because in that state the organism excretes or evaporates only a negligible amount of sweat. In the process of warming up, however, the loss of heat due to sweat evaporation is extremely important for preventing overheating of the body and prolonging the tolerance time. These losses will be, therefore, considered in the process of overheating.

Heat Q_4, emitted by the person into the environment during respiration, depends on the difference between the body core temperature and the temperature of environment, relative humidity of environment, type and intensity of the performed activity, number of inhalations and exhalations in a unit časa in količine vdihnjenega zraka. Te izgube skrajšujejo čas doseganja kritičnega stanja med časom ohlajanja. Pri pregrevanju organizma pa podaljšujejo čas doseganja kritičnega stanja. Izgube toplote Q_3 bomo upoštevali le pri pregrevanju organizma opazovane osebe.

Proizvedeno toploto Q_1 lahko izmerimo oziroma vzamemo podatke iz literature. V kontaminiranem (strupenem) okolju opravlja oseba različna dela z različno intenziteto in pri tem proizvaja različne količine toplote v določenih časovnih presledkih. Vendar lahko uporabimo določeno srednjo vrednost, ki je najbolj verjetna glede na vrsto in intenziteto dela, ki ga opravlja opazovana oseba. V kontaminiranem okolju ne moremo neposredno meriti količine izžarjene toplote skozi površino kože, če nismo opremljeni s posebno laboratorijsko opremo. Seveda lahko simuliramo podobne razmere, kot jih bo imela oseba v kontaminiranem okolju.

Vsota izgub toplote (Q_2, Q_3 in Q_4) je lahko enaka količini proizvedene toplote (cona ugodja), večje (podhlajanje organizma) ali pa manjše od količine proizvedene toplote (pregrevanje organizma). V coni ugodja bomo v prvi aproksimaciji zanemarili Q_3 in eventualno tudi Q_4 in bomo predpostavili, da je termoizolacijska vrednost zaščitnega oblačila, ki ga ima oseba na sebi, enaka potrebni termoizolacijski vrednosti, da se ohrani cona ugodja v brezvetrju v suhem oblačilu.

V coni pregrevanja organizma ima toplota Q_3 pomembno vlogo. V tej coni ima pozitivno vlogo zmanjšanje termoizolacije plašča telesa in oblačila ter hitrost vetra. Pozitivno vlogo ima tudi toplota Q_4, vendar bi jo lahko zanemarili. V coni podhlajevanja pa ima pozitivno vlogo le povečanje termoizolacijske vrednosti plašča telesa. Zrak, ki ga vdihavamo, se zasiti z vodno paro in se segreje ali ohladi na temperaturo jedra telesa, T_k, kar je odvisno od temperature zraka, ki ga vdihavamo.

3.0 RAZPRAVA O TEORIJI

Enačba 12 je splošna rešitev za izračun časa (časa tolerance), v katerem lahko oseba brez poškodbe posameznih delov telesa opravlja določeno delo v posebnih razmerah, v katerih lahko pride do podhladitve organizma ali njegovega pregrevanja. ΔQ_b (enačba 6) je količina toplote, ki jo smemo dodatno izčrpati iz organizma, da se ta ohladi na kritično srednjo vrednost, na primer 30 °C, ali da se v organizmu ne nakopiči več dodatne toplote, kot je potrebno, da se srednja temperatura telesa dvigne na kritično vrednost, na primer 39 °C. Predpostavimo, da zaščitno oblačilo dobro tesni na odprtinah (konec rokava, pas, oba konca hlač, pas in spodnji del, ovratnik ipd.), sicer pa je zaščitno oblačilo prepustno za zrak in vodno paro. Strupene pline, če smo v kontaminirani (strupeni) coni, pa absorbira aktivno oglje v filtru maske in posebna aktivna plast (aktivirana grafitirana tkanina ipd.). Vse odprtine na

time and amount of the inhaled air. These losses shorten the time needed to reach the critical state during the cooling down process and extend it during the warming up process. Losses of heat Q_3 will be considered only in the process of overheating.

Heat Q_1 can be measured or taken from literature. In the contaminated (intoxicated) environment, a person performs different activities with different intensity and generates different amounts of heat in defined time intervals. Nevertheless, a certain mean value, which is the most probable with regard to the type and intensity of the performed work, can be used. In the contaminated environment, it is impossible to measure the quantity of the heat emitted through the skin surface directly without special laboratory equipment. It is possible, of course, to simulate the conditions similar to those in the contaminated area.

The sum of heat losses (Q_2, Q_3 and Q_4) can be the same as the amount of the generated heat (the zone of comfort), higher (cooling down) or lower (overheating). In the zone of comfort, the first approximation neglects Q_3 and possibly also Q_4 and presumes that the thermal resistance value of the person's protective clothing is the same as the thermal resistance value, which is necessary to preserve the zone of comfort in dry clothing and in still, non-windy weather.

In the zone of body overheating, heat Q_3 has an important role. In this zone, the decreased thermal insulation of the body covering and clothing as well as the velocity of wind have a positive effect. Although heat Q_4 has also a positive effect, it may be neglected. In the zone of body cooling down, only the increased thermal resistance value of the body covering has a positive effect. The inhaled air is saturated with water vapors and warms up or cools down to the body core temperature T_k, depending on the inhaled air temperature.

3.0 DISCUSSION ABOUT THEORY

Equation 12 is a general solution for calculating the period of time (the tolerance time) in which a person may, without damages of individual parts of the body, perform certain activities in extreme conditions in which overheating or cooling down of the body might occur. ΔQ_b (Equation 6) is the amount of the heat which may be additionally taken from the organism to enable it to cool down to the mean critical value, e.g. 30 °C, or to prevent accumulation of more heat than it is necessary for increasing the mean body temperature to the critical value, e.g. 39 °C. The presumption is that the protective clothing tightens firmly on openings (end of sleeves and trousers, waist, collar, etc.) otherwise it is considered air and water permeable. In a contaminated (intoxicated) area, toxic gases are absorbed by active carbon in the mask filter and a special active layer (activated graphitized fabric, etc.). If all openings in clothing are hermetically closed $b = 1$, if not oblačilu so hermetično zaprte. Zato je vrednost koeficienta $b = 1$. Če odprtine na oblačilu ne tesnijo, potem je $b > 1$. Problematično je ugotavljanje hitrosti izhlapevanja znoja. V prvi aproksimaciji smo predpostavili, da v coni ugodja in pri ohlajanju telesa lahko zanemarimo znojenje in izhlapevanje znoja. V coni segrevanja (kopičenje toplote v telesu) je znojenje intenzivno in se oblačilo prepoji z znojem. Zunanja površina oblačila je mokra.

Hitrost izhlapevanja v mirnem ozračju smo merili v standardni atmosferi (21 °C in 69 % RH).[11, 12] Hitrost izhlapevanja v odvisnosti od temperature in hitrosti vetra smo merili tako, da smo postopoma povečevali vrednosti temperature od 20 do 45 °C in hitrost vetra od 0 do 5 m/s (metoda ni standardizirana). Izbrali smo določene kote pihanja vetra na normalo površine oblačila. Pri merjenju smo simulirali oblačilo, prepojeno z znojem, in oblačilo, ki je na ovlaženi površini kože. Voda (znoj) hitreje izhlapeva s površine bombažne kot s površine volnene tkanine. Če je zunanja tkanina oblačila popolnoma premočena, ne prepušča zraka skozi pore v tkanini in zato ni dodatne površine (notranja površina por) za izhlapevanje znoja. Hitrosti izhlapevanja znoja ni mogoče enoznačno ugotoviti za vsa stanja in sestavo oblačila in ga je nujno eksperimentalno ugotoviti za vsak komplet oblačila posebej.

Dobro opremljenih laboratorijev za testiranje oblačil ni veliko. Storitve specializiranih, dobro opremljenih laboratorijev lahko uporabljajo predvsem vojska, policija ipd. Manjši uporabniki, na primer skupine alpinistov ipd., si kaj takega težko privoščijo. Poleg tega se pogosto spreminja sestava kompleta oblačila, če to ni predpisana in preizkušena uniforma. Vsaka sprememba bi zahtevala ponovitev celotnega preizkusa, kar je drago in neracionalno. Po drugi strani pa se lahko vprašamo, koliko je naša metoda zanesljiva. Preverjali smo zanesljivost metode glede vpliva hitrosti vetra na termoizolacijo oblačila. Upoštevali smo rezultate meritev spremembe termoizolacije polarne uniforme glede na hitrost vetra.[2] Izredno velik je vpliv hitrosti vetra na skupni toplotni upor oblačila, saj se je ta zmanjšal za več kot 60 % pri hitrosti vetra 10,7 m/s v primerjavi z vrednostjo pri hitrosti vetra 1,3 m/s. Iz zgornje primerjave se da sklepati, da je naša metoda vsaj delno verificirana, saj je vpliv hitrosti vetra parameter, ki ga je najteže vrednotiti glede na njegov vpliv na skupni toplotni upor.

Parametre, ki so potrebni za izračun časa tolerance z enačbo 12, lako izmerimo s pomočjo nekaj osnovnih laboratorijskih aparatov, kot so: aparat za ugotavljanje koeficienta toplotne prevodnosti, porozimeter (merilo hitrosti vetra), merilo debeline oblačila, precizna tehtnica ipd.

V enačbi 12 so zajeti tako rekoč vsi parametri, ki pomembno vplivajo na toplotno ravnovesje v človekovem organizmu. Eni igrajo pomembno vlogo pri ohlajanju organizma, drugi pri pregrevanju le-tega; tretji so pomembni tako pri ohlajanju kot pri pregrevanju organizma.

$b > 1$. It is difficult to determine the rapidity of sweat evaporation. In the first approximation, it is supposed that in the zone of comfort and during body cooling down, perspiration and sweat evaporation may be neglected. In the zone of warming up (accumulation of heat), however, perspiration is intensive and clothing gets soaked with sweat. The outer surface of clothing becomes wet.

The rapidity of evaporation is measured in standard atmosphere (21 °C and 69 % RH)[11, 12]. The rapidity of evaporation in dependence of temperature and velocity of wind is measured by gradually increasing the values of temperature from 20 to 45 °C and velocity of wind from 0 to 5 m/s (the method is not standardized). Several angles of wind blowing are chosen. The simulations of clothing saturated with sweat and clothing on the person's wet skin surface are used. Water (sweat) evaporates faster from a cotton fabric surface than from a woolen one. If the outside fabric of clothing is thoroughly wet, it does not permit air through pores in the fabric, so there is no additional surface (inside surface of pores) available for sweat evaporation. The rapidity of sweat evaporation cannot be determined generally for all states and all compositions of clothing but should be determined experimentally for each set of clothing separately.

Well-equipped laboratory for testing clothing are not abundant. The services of specialized well-equipped laboratories are available first of all, to the army, police, etc. Smaller users like groups of alpinists cannot afford them. Besides, the composition of a set of clothing, unless a uniform is directed and tested, changes frequently and each such change would require repetition of the entire testing procedure, which would be expensive and unreasonable. On the other hand, the question about reliability of our method arises. The reliability of the method with respect to the effect of the velocity of wind on the thermal resistance value of clothing has been verified. The results obtained with measuring the change of the thermal resistance value of polar uniforms in dependence of the velocity of wind are used.[2] The influence of the velocity of wind on total thermal resistance of clothing is extremely high. At the velocity of wind 10.7 m/s, total thermal resistance of clothing decreases by more than 60% if compared with the value at the velocity of wind 1.3 m/s. The above comparison at least partly verifies our method. Namely, the influence of the velocity of wind is a parameter, which is the most difficult to be evaluated.

Parameters, which are needed in order to calculate the tolerance time by using Equation 12, can be measured with few basic laboratory devices, such as: device for determining heat conductivity coefficient, porosimeter, wind speed meter, clothing thickness meter, precision scales, etc.

Equation 12 encompasses practically all parameters, which significantly influence thermal balance in a human body. Some of them play important role in the body cooling down, the others in its warming up and there are also parameters, which are important in both processes. Therefore, there is no uniform use of Equation 12. When Equation 12 is used, the state of the body – overheating or cooling down – has to be

Zato ni enovite uporabe enačbe 12. Pri njeni uporabi moramo upoštevati stanje telesa – pregrevanje ali ohlajanje. Pa tudi nekateri parametri imajo dvojno vlogo. Pri pregrevanju organizma imata znojenje in premočenje oblačila pozitivno vlogo – hlajenje organizma. Pri tem se predvideva, da vsaj del izločenega znoja izhlapi. Hitrost vetra pospešuje izhlapevanje znoja in s tem tudi ohlajanje pregretega organizma človeka. Če pa je organizem v stanju ohlajanja, imata znojenje in hitrost vetra negativen vpliv – pospešujeta hitrost ohlajanja telesa subjekta.

4.0 PRIMER UPORABNOSTI ENAČBE 12 ZA IZRAČUN ČASA TOLERANCE

4.1 Definiranje kompleta oblačila

V vsakdanjem življenju lahko spreminjamo komplet po potrebi. Če je njegova termoizolacija prevelika za dane razmere (pregrevanje organizma), določene dele odložimo, s čimer zmanjšamo skupno vrednost termoizolacije in lahko ohranimo organizem na temperaturi ugodja (ravnovesje med izgubo in proizvodnjo toplote v območju ugodja). Če je termoizolacijska vrednost kompleta oblačila v danih razmerah premajhna – izguba toplote je večja od proizvodnje (hlajenje organizma), dodamo kakšno plast kompleta. Če te možnosti nimamo, se pred podhladitvijo branimo s povečanjem proizvodnje toplote (povečana intenziteta aktivnosti). Ta obramba pred podhladitvijo ima svoje meje. Organizem se utrudi, volja do življenja slabi in je včasih zaradi podhladitve organizma končni rezultat smrt.

V življenju se lahko zgodi, da v danih razmerah ne moremo spreminjati sestave kompleta. To velja zlasti za gasilce, potapljače, reševalce pri nesrečah v kemičnih tovarnah in ko imamo opravka s strupenimi snovmi (tekočinami in predvsem s plini) v vojnem času, ko gredo reševalci zavestno v kontaminirano področje ipd.

Za ilustracijo takih problemov bomo obravnavali komplet zaščitnega oblačila [13], ki je primeren za uporabo v strupeni atmosferi. Sem sodijo uporaba plinske maske, neprepustnih obuval (gumijastih škornjev ipd.), zaščitnih rokavic idr. Šivi oblačil morajo biti izdelani tako, da strupeni plini nimajo neposredne možnosti stika s površino kože. Enako velja tudi za vse odprtine na oblačilu. Dobro je tudi, da je tako oblačilo hidrofobno ali celo oleofobno, če atmosfera vsebuje razpršene tekoče delce strupenih snovi. To je še zlasti pomembno pri obrambi pred tako imenovanimi bojnimi strupi, ki jih v tekočem ali plinastem stanju absorbira površina kože in hromijo živčni sistem. Enako velja tudi za številne druge izdelke kemične industrije. Saj lahko zelo pogosto beremo o ladjah, ki jih nihče noče sprejeti v svoja pristanišča, ker so natovorjene z zelo strupenimi odpadki.

Naš namen ni študij potrebnih lastnosti zaščitnih oblačil, marveč ugotavljanje možnosti za izračun časa

considered. Furthermore, there are few parameters, which have a double role. For example: in the process of body overheating, sweating and wetting of clothing have a positive effect – they cool down a body. It is supposed that at least a fraction of the emitted sweat evaporates. The velocity of wind accelerates evaporation of sweat and, consequently, the process of the overheated body cooling down. However, in the process of body cooling down, sweating and the velocity of wind have a negative effect – they accelerate the process of body cooling down.

4.0 EXAMPLE OF APPLICABILITY OF EQUATION 12 FOR THE CALCULATION TIME OF TOLERANCE

4.1 Definition of Set of Clothing

In everyday life, a set of clothing can be changed as necessary. If its thermal insulation is too high for given conditions (body overheating), individual parts of clothing can be discarded. In this way, total thermal resistance value is reduced and the temperature, which is comfortable to a body, is preserved (the balance between heat loss and heat generation in the zone of comfort). If the thermal resistance value of the set of clothing is too low in given conditions – heat loss is higher than heat generation (body cooling), a layer of clothing can be added. If there is no such possibility, the increase of heat generation (increased intensity of activity) can be a solution. However, such solution has its limits. A body gets tired, vitality is fading and sometimes death might occur as the ultimate result of cooling down.

There are situations when it is not possible to change the composition of the set of clothing. This is the case with firemen, divers, rescuers (accidents in chemical plants and contact with toxic liquids and gases in war time) who consciously enter a contaminated area, etc.

In order to illustrate such problems, a set of protective clothing [13], suitable for use in a contaminated atmosphere will be investigated. Such set contains a gas mask, impermeable footwear (rubber boots, etc.), protective gloves, etc. The seams and openings of clothing should not allow a direct contact of gases with the skin. It is also advantageous that such clothing is hydrophobic or even oleophobic, if the atmosphere contains dispersed liquid particles of toxic substances. This is particularly important in defense from the so-called war poisons which are absorbed through the skin surface in liquid or gaseous state and which have a paralyzing effect on nerve system. The same applies to many other products of chemical industry. We can frequently read about ships, which are not allowed to enter ports due to being loaded with very toxic wastes.

Our intention is not to study the required properties of protective clothing but to identify the possibilities of calculatolerance, v katerem uporabnik določenega oblačila lahko opravlja določeno aktivnost pod določenimi pogoji, ne da bi pri tem dobil resnejše telesne in morebitne duševne okvare.

4.2 Komplet oblačila in njegove lastnosti

Analizirali bomo možnost za ugotovitev oziroma izračun časa tolerance pri uporabi kompleta. Obravnavali bomo le del kompleta, ki pokriva trup telesa. Pri tem bomo predpostavili, da so okončine, vrat in glava enako termoizolirane kot trup glede hitrosti hlajenja in pregrevanja. Sicer pa je obravnava glave, vratu in okončin, posebno še pesti in stopal na rokah in nogah, izjemno zahtevna.

Zaščitno oblačilo sestoji iz prekrivne tkanine, grafitirane tkanine (oksidirana in aktivirana tkanina, ki je izdelana iz PAN multifilamentne preje, ki absorbira strupene pline oziroma tekočine) in podloge.

Preglednica 1: Vrednosti koeficientov toplotne prevodnosti in vsebine vlage v posameznih plasteh v standardni atmosferi in debelina posameznih plasti

Plast oblačila	Debelina, mm	λ, kJ/m.h.°C	Vsebina vlage, %
Prekrivna tkanina	0,35	0,1234	5,1
Grafitirana tkanina	0,87*	0,1000*	1,0*
Podloga	0,41	0,7751	6,1

* Verjetne vrednosti, niso merjene. Vrednosti v tej preglednici potrebujemo za izračun toplotnega upora oblačila.

Preglednica 2: Vrednosti nekaterih pomembnejših parametrov poroznosti posameznih plasti oblačila [3]

Plast oblačila	Parametri poroznosti				
	A	b	r	D_{max}, µm	D_s, µm
Prekrivna tkanina	0,3815	0,768	0,999	97	21,6
Grafitirana tkanina	1,1826*	0,683*	0,988*	267*	85,4*
Podloga	0,4942	0,779	0,993	141	29,1

Parametri poroznosti v preglednici 2 pomenijo: A in b – koeficient in eksponent (enačba 14), r – koeficient korelacije (enačba 14), D_{max} – maksimalni hidravlični premer pore v obravnavani tkanini, D_s – srednji hidravlični premer por

* Predpostavili smo, da je poroznost grafitirane tkanine približno enaka poroznosti pene, ki je bila impregnirana z aktivnim ogljem in je bila del kompleta. Parametrov kakovosti grafitirane tkanine nismo merili. Predpostavili smo, da je debelina 0,87 mm (pena 2 mm) in da ima enako vrednost koeficienta toplotne provodnosti kot pena. Tako pena kot tudi vlaknovina z naneseno plastjo aktivnega oglja nista moderni rešitvi. Tukaj gre predvsem za ilustracijo možnosti rešitve problema ugotavljanja časa tolerance.

ting the tolerance time, i.e. the period of time in which a wearer of such protective clothing can continue to perform a certain activity in certain conditions without incurring any serious physical or even mental injury.

4.2 Set of Clothing and its Properties

The possibilities of defining or calculating the tolerance time when the set of clothing is used are going to be analyzed. Only the part of the set of clothing, which covers torso, will be dealt with. Extremities, neck and head are supposed to be identically thermally insulated as torso in terms of the rapidity of cooling and heating.

Protective clothing is composed of a covering fabric, a graphitized fabric (oxidized and activated fabric made from PAN multifilment yarn, which absorbs toxic gases and liquids) and a lining.

Table 1: Values of heat conductivity coefficients and percentage of humidity in individual layers in standard atmosphere and thickness of individual layers

Layer of Clothing	Thickness, mm	λ, kJ/m.h.°C	Percentage of humidity, %
Covering fabric	0,35	0,1234	5,1
Graphitized fabric	0,87*	0,1000*	1,0*
Lining	0,41	0,7751	6,1

* assessed values (not measured). The above values are needed to calculate thermal resistance of clothing.

Table 2: Values of some more important porosity parameters of individual layers of clothing

Layer of Clothing	Porosity Parameters				
	A	b	r	D_{max}, µm	D_s, µm
Covering fabric	0,3815	0,768	0,999	97	21,6
Graphitized fabric	1,1826*	0,683*	0,988*	267*	85,4*
Lining	0,4942	0,779	0,993	141	29,1

The parameters of porosity in Table 2 mean: A and b – coefficient and exponent (Equation 14), r – correlation coefficient (Equation 14), D_{max} – maximum hydraulic diameter of pore in the investigated fabric, D_s – mean hydraulic diameter of pore

* it is supposed that the porosity of a graphitized fabric is approximately the same as the porosity of foam impregnated with active carbon which is a part of the set of clothing. The parameters of graphitized fabrics were not measured. It is supposed that the thickness is 0.87 mm (foam 2 mm) and the value of heat conductivity coefficient the same as that of foam. Neither foam nor nonwovens coated with active carbon are not modern solutions. Here, the focus is on illustration possibility of solving of the problem of defining the tolerance time.

Za realno analizo sistema je zelo pomembna poroznost kompleta. To velja tako za dve ekstremni stanji (pregrevanje in podhlajanje), kakor tudi za stanje ugodja. S poroznostjo je v precejšnji meri povezan upor prevajanju pare skozi oblačilo, kar je pomembno pri pregrevanju organizma. Pri podhlajanju organizma, posebno če piha veter, prevelika poroznost pospešuje hitrost ohlajanja organizma. Tudi ni zanemarljiva velikost por. Pri enaki volumenski hitrosti pretoka pod enakim tlakom je lahko odprta površina za pretok sestavljena iz velikega števila por, ki imajo majhen povprečni hidravlični premer, ali pa iz manjšega števila por, ki imajo relativno velik povprečni hidravlični premer por. Take možnosti pa ne smeno zanemariti. Skozi pore, ki imajo velik hidravlični premer, laže prodirajo strupeni plini in strupene tekočine. Lahko se zgodi, da skozi poro »pade« drobna kaplja strupene snovi. Parametre poroznosti lahko ugotovimo s pomočjo metode za ugotavljanje števila, velikosti in porazdelitve por v ploskih tekstilijah.[3]

4.3 Uporabnik oblačila

Oblačilo je lahko namenjeno otrokom, odraslim ženskim ali odraslim moškim. Slednji (odrasli) se lahko razlikujejo ne samo po spolu, temveč tudi po višini, teži, površini kože, intenzivnosti presnove, občutljivosti na temperaturo ipd. Razumljivo je, da ne moremo obravnavati širše palete razlik med uporabniki. Zato bomo vpeljali pojem povprečnega uporabnika. Ta ima težo 70 kg in površino kože 1,8 m^2 in proizvaja naslednje količine toplote, odvisno od tega, kako težko delo opravlja: lahko delo – 417 kJ/m^2.h; zmerno težko delo – 697; težko delo – 1.047 in zelo težko delo – 1.397 kJ/m^2.h. Hoja 3 km/h – 420 kJ/m^2.h je enako lahkemu delu – 417 kJ/m^2.h. [4]

4.4 Stanje organizma uporabnika

Organizem uporabnika je v kateremkoli stanju med skrajno povprečnima temperaturama telesa, 30 oziroma 39 °C. Povprečne telesne temperature ni lahko izračunati, saj moramo upoštevati, da je na primer temperatura ugodja na površini čela ali prsi okrog 33 °C, medtem ko je temperatura ugodja na konicah prstov nog le okrog 24 °C. [14] Razlika je okrog 11 °C. Temperatura jedra telesa, ki zajema večji del mase telesa, je 37 °C.

Glede stalnosti temperature lahko človekovo telo ločimo na dva dela. Zunanja plast je plašč telesa, katerega temperatura ni stalna. Za plaščem je jedro telesa, ki ima stalno temperaturo. Seveda se tudi temperatura notranjosti telesa spreminja in je v izjemnih razmerah višja ali nižja od 37 °C. Temperaturni gradient plašča je približno 3 °C/cm. To pomeni, da se temperatura telesa povečuje, ko gremo od površine telesa proti njegovi

Porosity of the set of clothing is very important for a reliable analysis of the system. This applies to both extreme states (overheating and cooling down) as well as to the state of comfort. Porosity is in close relation with the resistance of clothing to vapor transmission, which is important in the conditions of body overheating. In the conditions of body cooling down, particularly if wind is blowing, too high porosity accelerates the rapidity of body cooling down. The size of pores is not negligible. With the same volume flow velocity under the same pressure, the open surface for flow can be made up of a large number of pores with a small mean hydraulic diameter or from a small number of pores with a relatively large mean hydraulic diameter. This factor should not be neglected. Toxic gases and liquids easily penetrate through pores, which have a large hydraulic diameter. It can happen that a droplet of a toxic substance falls through a pore. Porosity parameters can be identified by using the method of determining the number, size and distribution of pores in flat textiles.[3]

4.3 User of Clothing

Clothing can be designed for children, women and men who differ in height, weight, skin surface, metabolism intensity, heat sensitivity, etc. It is impossible to include such a wide range of differences in the investigation. That is why a concept of an average user has been introduced. The average user weighing 70 kg with the skin surface 1.8 m^2 generates the following amounts of heat (depending on the intensity of work): easy work – 417 kJ/m^2.h; moderate work – 697 kJ/m^2.h; hard work – 1.047 kJ/m^2.h and very hard work – 1.397 kJ/m^2. Walk 3 km/h – 420 kJ/m^2.h is comparable with easy work – 417 kJ/m^2.h [4].

4.4 Condition of User's Organism

In any state, the user's organism is between two extreme mean body temperatures, i.e. 30 and 39 °C. It is difficult to calculate the mean body temperature due to its variation. Thus, the temperature of comfort on forehead and chest is about 33 °C and on the toe tips only about 24 °C. [14] The difference is about 11 °C. The temperature of the body core which encompasses a bigger part of the body mass is 37 °C.

As to the temperature constancy, a human body can be divided into two parts. The outer layer is the body covering which doesn't have constant temperature. Behind the covering there is the body core, the temperature of which is constant as well. Of course, the temperature of the body core changes in extraordinary conditions and may be higher or lower than 37 °C. The temperature gradient of the body covering is about 3 °C/cm. That means that the body temperature increases from outside towards inside for 3 °C in 1 cm depth.

notranjosti za 3 °C na globini 1 cm. To ne velja za vse dele telesa, je le povprečna vrednost za telo v celoti. Ker je temperatura ugodja na prsih okrog 33 °C, bo debelina plašča, če upoštevamo temperaturni gradient, okrog 1,3 cm. Srednjo temperaturo telesa lahko izračunamo s pomočjo naslednje enačbe:

This is the mean value for the entire body and does not apply to all parts of the body. Since the temperature of comfort on chest is about 33 °C, the thickness of the covering will be about 1.3 cm if we consider the temperature gradient. The mean body temperature can be calculated by using the following equation:

$$T = aT_1 + bT_2 \quad (13)$$

kjer so: T – srednja temperatura telesa, T_1 – srednja temperatura plašča telesa, T_2 – temperatura jedra telesa, a – delež plašča telesa (0,2), b – delež jedra telesa (0,8). Ta deleža veljata v coni ugodja.

Če pa golo osebo potopimo v vodo v coni ugodja, se vrednosti obeh koeficientov spremenijo. Povprečna debelina plašča se poveča, izmerjeni in izračunani vrednosti pa sta a = 0,35 in b = 0,65 [8, 9]. Tako je zato, ker se v vodi organizem hitreje ohlaja in se meja stabilne temperature pomakne bolj v notranjost telesa. Ker se temperatura, na primer na površini konic prstov rok lahko zniža na temperaturo, ki je nižja kot 15 °C, je razlika met temperaturo jedra in povprečno temperaturo na površini kože precej večja kot v coni ugodja, čeprav se tudi temperatura jedra znižuje.

Glede prevajanja toplote se plašč telesa dobro prilagaja spremembi stanja telesa, saj se vrednosti njegovega koeficienta toplotne prevodnosti gibljejo v mejah od 3,023 kJ/m.h.°C (pregret organizem) do 0,3790 kJ/m.h.°C (podhlajen organizem). To pomeni, da se njegova termoizolacijska vrednost spremeni za okrog osemkrat. Če upoštevamo debelino plašča in vrednosti koeficienta toplotne prevodnosti, lahko z enačbo 1 izračunamo mejne vrednosti termoizolacije plašča telesa, ki so 0,0471 (organizem v coni ugodja) do 0,0729 m^2.h.°C/kJ (podhlajen organizem).[4]

Kaj praktično pomenijo omenjene vrednosti? Pri pregretosti organizma plašč telesa prevaja toploto bolj kot voda, kar je bistvenega pomena za hiter prehod toplote iz notranjosti telesa na njegovo površino in naprej v okolje. Pri prenosu toplote skozi plašč je takšno stanje posledica razširitve ožilja (kapilar) in pospešenega kroženja krvi s površine telesa proti notranjosti (ohlajena venozna kri) in iz notranjosti proti površini telesa (vroča arterijska kri).

Če je organizem podhlajen, se ožilje skrči, kroženje krvi se izredno upočasni, s čimer se tudi zelo poveča termoizolacijska vrednost plašča telesa. Ta je približno na ravni termoizolacije plutovine enake debeline. [10] Zaradi povečanja termoizolacijske vrednosti plašča in znižanja temperature na površini kože telesa pri hlajenju organizma se upočasni izguba toplote, s tem pa se povečajo možnosti za preživetje tudi tedaj, ko bi se sicer hitro znižala telesna temperatura, če bi plašč imel enako termoizolacijsko vrednost kot pri pregretem organizmu. Zgornja kritična temperatura v jedru telesa znaša okrog 39 °C, kritični utrip pa 180 utripov/min.

Where T is mean body temperature, T_1 – mean temperature of body covering, T_2 – temperature of body core, a – share of body covering (0.2), b – share of body core (0.8). These shares apply in the comfort zone.

But if a naked body is dipped into the water in the comfort zone, the values of both coefficients change. The mean thickness of the body covering increases and the measured and calculated values are a = 0.35 and b = 0.65 [8, 9]. In the water, the organism cools down quicker and the boundary of stable temperature moves deeper into the body.

Since for example the temperature on the hands finger tips can decrease to the temperature lower than 15 °C, the difference between the temperature of the body core and the mean temperature on the skin surface is substantially higher than in the zone of comfort despite the decrease of the body core temperature.

As to the heat conductivity, the body covering is adapting well to the change of the body state. The values of its heat conductivity coefficient range from 3.023 kJ/m.h.°C (overheated organism) to 0.3790 kJ/m.h.°C (cooling down organism). This means that its thermal resistance value changes for about eight times. By considering the thickness of the covering and the values of heat conductivity coefficients, boundary values of the body covering thermal insulation which range from 0.0471 (organism in the zone of comfort) to 0.0729 m^2.h.°C(kJ (cooling down organism) can be calculated by using Equation 1.[4]

What do these values mean practically? In the state of overheating, the body covering conducts heat better than water, which is of key importance for rapid transmission of heat from the body inside to its surface and into the environment. In the process of heat transfer through the body covering, such condition is the result of the veins (capillaries) swelling and the accelerated blood circulation from the body superficies towards the body core (cooled venous blood) and from the body core towards the body superficies (hot arterial blood).

If an organism is cooling down, veins shrink, blood circulation slows down and the thermal resistance value of the coating considerably increases and is almost the same as that of cork of the same thickness. [10] Due to the increase of the thermal resistance value of the body covering and the decrease of the temperature on the body superficies in the conditions of body cooling, loss of heat slows down and the possibilities of survival increase even in the conditions in which the body temperature would decrease quickly, if the covering had the same thermal resistance value as in the case of over-