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The Assessment Proposal for Long-Term and Short-Term Tolerable Hygrothermal Microclimatic Conditions

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Summary

A group of four efficient mine rescuers 25 to 35 years old were exposed to a load of a cyclo-ergometer (stages A and B) and a hand ergometer (stage E) in a climate chamber. The total 120 min period of work was divided into four work intervals, 30 min each. There were 5-min breaks between the individual intervals. The load on the ergometer was selected in the range of 25 to 150 W, T_g=20 to 40 °C, rh=40 to 80 % and v_a=0.2 to 1.5 m. s^{-1}. The thermal resistance of the working suit was 0.65 clo at stage A, 1.07 clo at stage B and 0.81 clo at stage E. A total of 200 experiments with 50 combinations of the work and climate loads were made. The heart rate, oxygen consumption, carbon dioxide production, body temperature, skin temperature, water loss by sweating and perspiration, dry and wet bulb air temperature, air velocity and globe temperature were measured during the experiments. The expected production of sweat (SR) and the amount of accumulated heat in the body (Q_{max}) were calculated for each combination of the work-climate conditions by a computing program ISO 7933:1989 as well as by our own program. Good agreement was reached between the measured and predicted SR values, calculated by the ISO program (r=0.871) as well as between the values calculated by the two programs, respectively (r=0.985). The experimental results have shown good agreement between the predicted and actually measured values of temperature of the body core as an index of short-term tolerable climate load. The values of short-term tolerable time of work calculated at the level of accumulated heat in the body of 50 W.h.m^{-2} resulted in an increase of body core temperature by 0.8 to 1.0 K. The values of heart rate did not mostly exceed 140 beats/min, reaching in exceptional (three) cases values above 150 beats/min. The authors recommend to limit the long-term work-heat (climatic) load during a higher metabolic rate (M>80 W.m^{-2} including the basal metabolic rate) of acclimatized males and females at a sweat rate SR=270 g.h^{-1}.m^{-2}, of non-acclimatized persons at SR=206 g.h^{-1}.m^{-2}. The limit for low metabolic rates (M≤80 W.m^{-2}) for non-acclimatized and acclimatized persons is proposed for long-term tolerable loads of SR=147 g.h^{-1}.m^{-2}. The short-term tolerable load by heat storage within the organism for all categories is proposed as Q_{max}=50 W.h.m^{-2}.

Key words
Microclimate – Work at high temperatures – Work and rest regime – Physiological limits – Climatic chamber – Hygienic standards for workplaces

Introduction

The hygrothermal microclimatic conditions in workplaces are assessed in the Czech Republic according to part VI of the Standards No. 46/1978 Digest, Health Regulations of Health Ministry of Czech Republic "Hygienic Requirements for Working Environment". Jokl's work (Jokl 1970, 1972, 1989) laid the theoretical principles for these Regulations. These include the hygrothermal microclimate tolerance under long-term (the whole shift) and short-term working conditions. The long-term tolerable microclimate is limited by the sweat rate (SR) = 270 g.h^{-1}.m^{-2} with corresponding maximal water loss per shift (D_{max}) = 2160 g.m^{-2}. The short-term tolerable one is limited by heat storage in the human body, its highest value being estimated as 138 kJ.m^{-2}. These limits were also the starting point for the still valid Regulations for the Evaluation of Microclimatic Conditions in Mines.

The ISO Recommendation is an important directive for national regulations to be respected. First of all, the International Standard ISO 7933:1989 (E) applies to this field of tolerable microclimatic conditions. Different limits for non-acclimatized and acclimatized persons are introduced allowing for resting (metabolic rate $M<65$ W.m^{-2}) and working periods ($M\geq65$ W.m^{-2}).

There are two limiting values for a long-term and short-term tolerable microclimate: warning and dangerous. The calculation is based on a heat balance equation:

$$M - W = C_{res} + E_{res} + K + C + R + E + S$$

where

M – metabolic rate (free energy production) (W.m^{-2})
W – effective mechanical power (W.m^{-2})
C_{res} – heat transfer by convection in respiratory airways (W.m^{-2})
E_{res} – heat transfer by evaporation in respiratory airways (W.m^{-2})
K – heat transfer by conduction in the skin (W.m^{-2})
C – heat transfer by convection on the skin (W.m^{-2})
R – heat transfer by radiation from the skin (W.m^{-2})
E – heat transfer by evaporation from the skin (W.m^{-2})
S – heat storage in the human body (W.m^{-2}).

The tolerable working period (of the whole shift, i.e. long-term) according to ISO 7933 is limited by the admissible percentage of skin wetness, the required sweating rate not exceeding the maximal value.

The short-term tolerable load is limited by heat storage in the human body (Q_{max}). As a warning value 50 W.h.m^{-2} and as a dangerous value 60 W.h.m^{-2} are proposed by ISO 7933 for acclimatized and non-acclimatized persons. The increase of body core temperature (T_b) by 0.8 and 1.0 K, respectively, and a mean increase of skin temperature (T_{sk}) by 3.5 and 4.0 K, respectively, corresponds to these values (ISO 7933:1989).

It was shown on a group of four rescue workers under experimental conditions in a climatic chamber (Jirák *et al.* 1990) that all combinations of work and heat load will be tolerable for long periods if the water loss by perspiration and respiration does not exceed 320 g.h^{-1}.m^{-2} and the metabolic rate will be in the range of 100 to 450 W net (53–237 W.m^{-2} net). A load that is supposed to be tolerable for long periods is one that during which increased values of heart rate (HR), minute oxygen consumption (V_{O_2}) and body core temperature (T_b) no longer change in relation to work duration (Fig. 1). Taking into account the fact that all data are from well acclimatized and highly experienced rescuers, we have recommended for an average person SR = 270 g.h^{-1}.m^{-2} as a long-term tolerable limit, i.e. 2160 g.m^{-2} for an eight-hour shift.

The aim of our work has been to prove the predictive reliability of ISO software program, to test the recommended limits of long-term and short-term tolerable heat load and to prepare a standard regulation draft respecting international recommendations as far as possible, which could be applied even by persons without special knowledge in work physiology or in computing techniques.

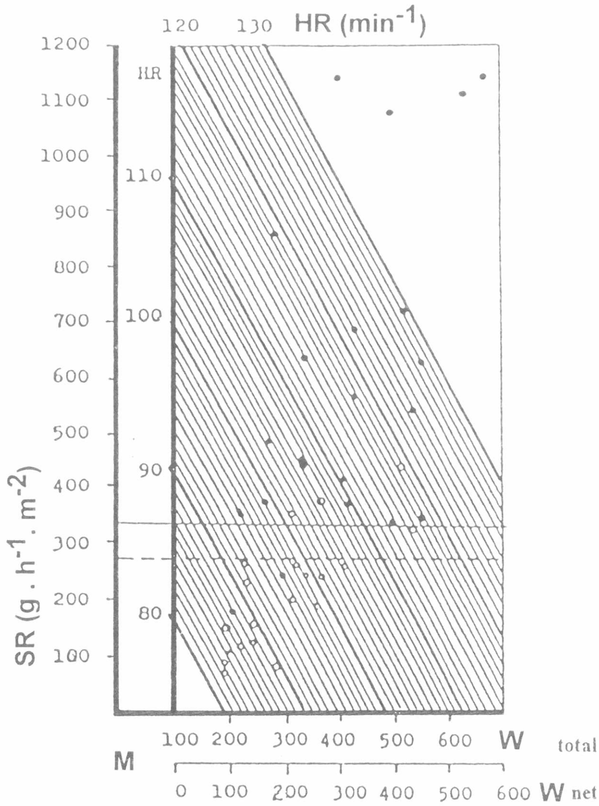

Fig. 1. *Relationship among metabolic rate (M), sweat rate (SR) and heart rate (HR). Empty symbols are the combinations of M and SR by which balanced state of HR was reached, full symbols are the combinations by which HR as a function of time increased significantly. The full line (SR = 320 g.h^{-1}.m^{-2}) represents the limit of the balanced state reached by the subjects, broken line (SR = 270 g.h^{-1}.m^{-2}) is the limit value of SR for the average of adapted population.*

Methods

The investigation was performed on a group of four efficient mine rescuers 25 to 35 years old, well adapted to their work. The basic somatometric characteristics and the results of physical fitness assessment of the subjects before the experiments in the climatic chamber are presented in Table 1.

The investigation took place in a climatic chamber of the Institute of Hygiene in Ostrava whose inside dimensions are 2 x 2 x 2 m. The conditioned air is supplied through the perforated ceiling and is sucked away by the air ducts through holes located on both sides near the floor. The temperature control of the supplied air makes it possible to regulate any combination of air temperature and relative air humidity within the ranges of 20 to 50 ± 1.0 °C and 5 to 100 ± 6 %. The chamber wall temperature can also be controlled over a wide range.

Table 1. The somatometric and physical fitness characteristics of the subjects (V_{O2max}) determined by the gradation load test according to Hollmann (1963).

Subject	Age	Mass	Height	Body fat	Body area	V_{O2max}	$V_{O2max/kg}$
No.	[years]	[kg]	[cm]	[%]	[m^2]	[l/min]	[ml/min]
1	25	84	172	12.2	1.94	3.29	39.23
2	25	78	180	10.2	1.96	3.16	40.76
3	35	93	183	15.4	2.14	3.51	35.45
4	35	83	181	13.2	2.02	3.35	41.18

Table 2. Physiological data (averages of all four subjects) taken during the first 30 min of work on a cyclo-ergometer, the subjects being exposed to various combinations of work and heat (climatic) load during stage A (one-layer clothes, thermal resistance 0.65 clo, T_g = T_a).

Stage	Load	T_{g160}	rh	HR_{mean}	HR_{max}	SR	T_{bor}	V_{O2}	M
	[W]	[°C]	[%]	[min^{-1}]	[min^{-1}]	[$g.h^{-1}m^{-2}$]	[°C]	[l/min]	[W/m^2]
A-1-a	25	22	55	82.8	83.0	78	36.3	0.577	94
b		28	47	87.5	86.5	108	36.7	0.629	107
c		33	46	89.7	90.0	265	36.9	0.732	110
d		40	47	94.9	95.7	375	37.1	0.812	132
A-1-a	25	22	71	84.3	85.0	59	36.3	0.551	96
b		28	73	90.5	89.5	120	36.9	0.771	118
c		35	77	91.4	93.2	342	37.2	0.685	107
A-2-a	50	21	69	96.0	95.5	82	36.2	0.856	141
b		27	67	96.1	95.2	193	36.5	0.906	151
c		33	61	96.2	97.0	241	36.8	0.927	160
d		40	51	99.8	101.2	448	37.2	0.940	162
A-3-a	75	21	75	104.2	106.2	184	36.5	1.045	178
b		27	70	109.6	108.5	259	36.8	1.157	195
c		32	67	109.9	112.3	404	37.1	1.185	202
d		39	49	112.5	116.0	572	37.6	1.216	205
A-4-a	100	22	81	116.1	117.0	305	36.5	1.503	256
b		27	71	113.2	117.5	320	36.9	1.391	240
c		32	62	119.0	125.0	547	37.2	1.507	259
d		39	58	130.1	137.7	764	37.8	1.483	256
A-5-a	150	20	76	141.7	145.2	439	36.3	2.269	394
b		27	74	143.2	149.5	618	37.2	2.302	393
c		33	59	145.7	155.0	652	37.7	2.255	392
d		38	51	149.4	162.2	844	38.1	2.333	406

The value H_{mean} is an average from the sixth to thirtieth min value of the first working interval, HR_{max} is the heart rate at the end of the first working interval. Underlined and bold letters indicate the combinations of such work and heat loads whose increase of the investigated value in relation to time was significant both within a) the first working interval, b) the whole duration of the working test (regression analysis).

Table 3. Physiological data (averages of all four subjects) taken during the first 30 min of work on a cycloergometer, the subjects being exposed to various combinations of work and heat (climatic) load during the stage E (rescuer suit plus respirator, thermal resistance 1.07 clo, metabolic rate the same as in stage A, $T_g = T_a$).

Stage	Load [W]	T_{g160} [°C]	rh [%]	HR_{mean} [min^{-1}]	HR_{max} [min^{-1}]	SR [$g.h^{-1}m^{-2}$]	T_{bor} [°C]	M [W/m^2]
B-1-a	25	22	69	91.1	91.1	149	36.5	94
b		25	65	93.7	93.7	150	36.8	118
c		32	60	94.2	96.8	349	36.6	107
d		40	42	99.7	101.3	491	37.0	132
B-2-a	50	21	76	100.1	100.1	142	36.8	141
b		27	65	102.6	102.6	258	36.9	151
c		34	62	100.7	103.0	451	36.8	160
d		39	56	101.9	106.3	640	37.1	162
B-3-a	75	22	68	111.3	111.8	380	36.8	178
d		39	52	121.0	136.7	690	37.6	205
B-4-a	100	20	73	117.6	125.5	429	36.5	256
d		39	58	131.8	149.5	735	37.8	256
A-5-a	150	20	70	136.2	147.7	457	37.2	394
d		39	67	154.0	167.2	1325	38.5	406

The value HR_{mean} is an average from the sixth to thirtieth min value of the first working interval, HR_{max} is the heart rate at the end of the first working interval. Underlined and bold letters indicate the combinations of such work and heat loads whose increase of the investigated value in relation to time was significant both within a) the first working interval, b) the whole duration of the working test (regression analysis).

Table 4. Physiological data (averages of all four subjects) taken during the first 30 min of work on a cycloergometer, the subjects being exposed to various combinations of work and heat (climatic) load during stage E (miner suit, thermal resistance 0.81 clo).

Stage	T_{g160} [W]	T_{a160} [°C]	rh [%]	v [$m.s^{-1}$]	SR [$g.h^{-1}m^{-2}$]	$T_{b,r}$ [°C]	T_{sk} [°C]	M (W/m^2)
E-1-a	25.9	27.3	61.3	0.2	298	37.4	32.6	175
b	34.9	26.1	61.7	1.5	329	37.2	31.9	204
c	26.5	26.1	84.1	0.2	369	37.1	34.7	197
d	26.1	25.2	81.7	1.5	437	37.1	33.4	185
E-2-a	29.9	32.0	60.3	0.2	412	37.4	34.7	199
b	30.6	30.9	65.6	1.5	401	37.3	34.9	182
c	29.7	30.1	85.2	0.2	420	37.5	35.1	194
d	30.8	30.7	83.5	1.5	493	37.4	35.2	192
E-3-a	34.8	36.1	65.0	0.2	603	37.7	35.6	205
b	33.9	34.8	62.9	1.5	513	37.6	35.4	182
c	34.0	35.0	78.9	0.2	743	38.1	36.2	205
d	35.0	35.0	84.7	1.5	650	38.1	36.3	195
E-4-a	38.8	41.0	62.6	0.2	808	38.2	36.9	178
b	40.5	41.2	62.3	1.5	671	37.9	36.5	210
c	39.3	39.9	80.9	0.2	861	38.7	37.6	233
d	40.2	39.9	84.1	1.5	1085	38.8	38.3	211

The subjects were loaded by pedalling on a cyclo-ergometer (60 revolutions per minute for 120 min split into four 30 min periods) in two stages of observations A and B. Five-min breaks were put between the working periods (subjects resting in the climatic chamber). The load in ergometer was chosen in the range of 25 to 150 W. The subjects wore a one-layer suit of total thermal resistance 0.65 clo (short cotton underpants, two-piece cotton pyjamas, cotton socks, light shoes) in stages A_1 to A_5. This was raised to 1.07 clo (standard suit of savers: cotton shirt, short cotton underpants, a two-piece miner working suit with a flame-proof finish, leather gloves, rubber boots, cotton socks, oxygen respirator Type BG weighing 12.5 kg with an all-face mask and special helmet) in stages B_1 to B_5. One hundred and thirty-six measurements was obtained with 34 combinations of work and climatic loads during stages A and B, climatic conditions were within the following ranges: T_g = 20−40 °C, relative humidity = 40−80 % and V_a = 0.25 $m.s^{-1}$. Exact measured values were published by Jirák *et al.* (1990).

The experimental conditions of stages E_1 to E4 were similar to those of stages B, with the exception that instead of the cyclo-ergometer a hand ergometer was used. The air velocity in stages E_1 to E_4 was 0.2 and 1.5 $m.s^{-1}$, the relative humidity 60 % and 80 %, respectively. The thermal resistance of clothing was 0.81 clo (cotton shirt, short cotton underpants, two-piece miner working suit with a flame-proof finish, cotton socks, leather shoes) in stage E. A total of 64 measurements with 16 combinations of work and heat load were performed in stages E. Two hundred measurements of 50 work and heat (climatic) load combinations were obtained in all. The measured values of the cyclo-ergometer load, the metabolic rate and hygrothermal conditions in the climatic chamber and physiological values during the individual stages are presented in Tables 2, 3 and 4.

The following values were measured during the experiments: heart rate (HR), lung ventilation per minute (V), oxygen consumption per minute (V_{O_2}), carbon dioxide per minute (V_{CO_2}), body core temperature (T_b) − measured in the mouth ($T_{b,or}$) and the auditory passage ($T_{b,ac}$) in stages A and B, and in the rectum ($T_{b,r}$) in stages E, blood pressure and skin temperature on the thorax (chest), skin and forearm. Mean skin temperature (T_{sk}) was calculated according to Burton's formulae (2). The sweat rate (SR) was calculated from the difference between nude subject mass before the experiment increased by the mass of liquids taken during the experiment minus nude subject mass after the experiment. Dry and wet air temperature (T_a) and (T_w), relative air humidity (rh) and globe temperature (T_g) were registered during the whole experiment.

The average values of physiological parameters within the time intervals of all four subjects were calculated for each work and heat load combination. Then the regression lines for the relationship of physiological values to time were calculated for each combination. The exposure time, during which the physiological limits ($T_{b,r}$ increase by 0.8 and 1.0 K and HR increase to 140 and 150 beats/min) had been reached, was calculated from the curves. The sweat rate (SR) and body heat storage (Q_{max}) for each combination of work and heat load were calculated partly by ISO software 7633:1989 (E), Annex D, partly by using our own software (Jiráková 1991) based on the research for long-term tolerable work duration (Jokl 1970, 1989) proved by the experiments of Jirák and Zlámal (1978) and supplemented with some other physiological parameters. The measured and physiological values from each experiment were put into the equation. Correlation analyses and Spearman's coefficient were used for the comparison of calculated and measured values.

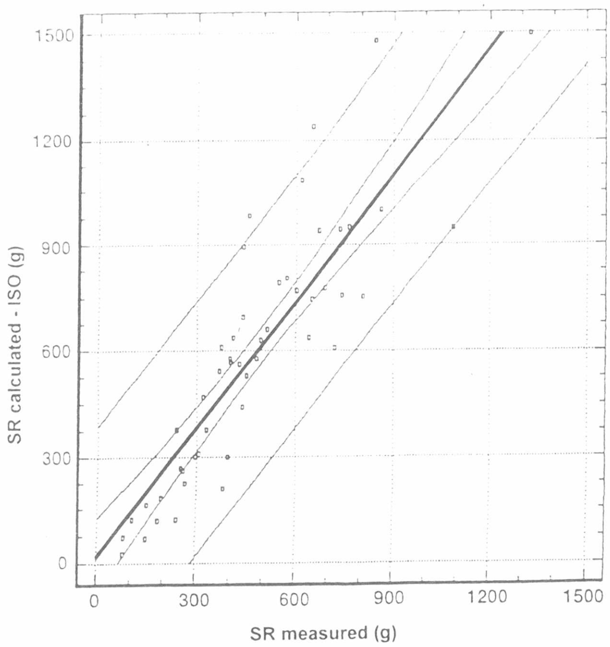

Fig. 2. *Relationship between the water loss by sweating and respiration measured (SR measured) and SR calculated by the ISO program (SR calculated − ISO) taking into account the work efficiency. N = 50, r = 0.871, P<0.001.*

Results

The proof of long-term tolerable work

The correlation between the rate of water loss by perspiration and respiration calculated by ISO software program and actually measured (including work efficiency, i.e. work done on an external system per unit of energy expended by an organism during the performance of work less that of basal metabolism – see Glossary of Terms for Thermal Physiology, *J. Appl. Physiol.* **35**: 959, 1973) is shown in Figure 2. The same relationship but without work efficiency being respected is in Figure 3. The relationship is very good, see correlation coefficients r = 0.871 and 0.814. The better result was obtained in the case that work efficiency was not taken into consideration. The regression line in Figure 2 (work efficiency respected) indicates that the predicted values of SR are somewhat higher than those measured during higher loads. Almost the same results were also obtained by our own software program. The correlation coefficient characterizing the closeness of the relationship between values calculated by the ISO software program and by our own program was r = 0.980, if work efficiency was being respected, and r = 0.985, if it was neglected (Fig. 4).

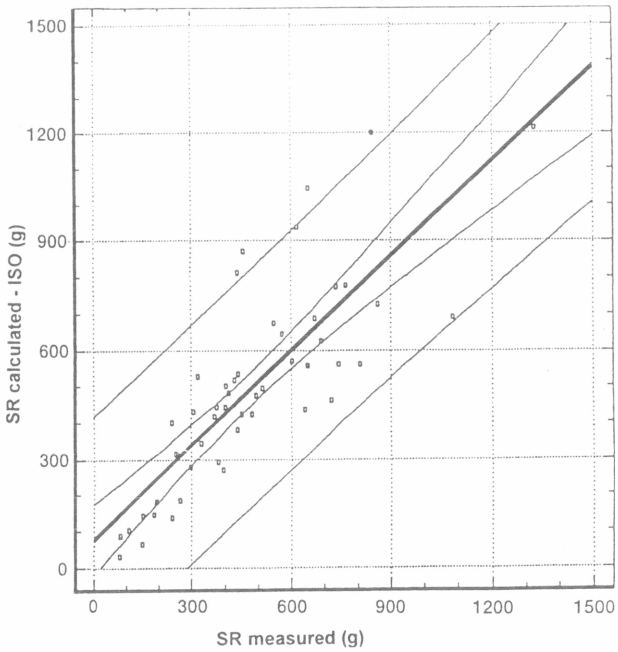

Fig. 3. *Relation between the water loss by sweating and respiration measured (SR measured) and SR calculated by the ISO program (SR calculated – ISO) with work efficiency neglected. N = 50, r = 0.814, P<0.001.*

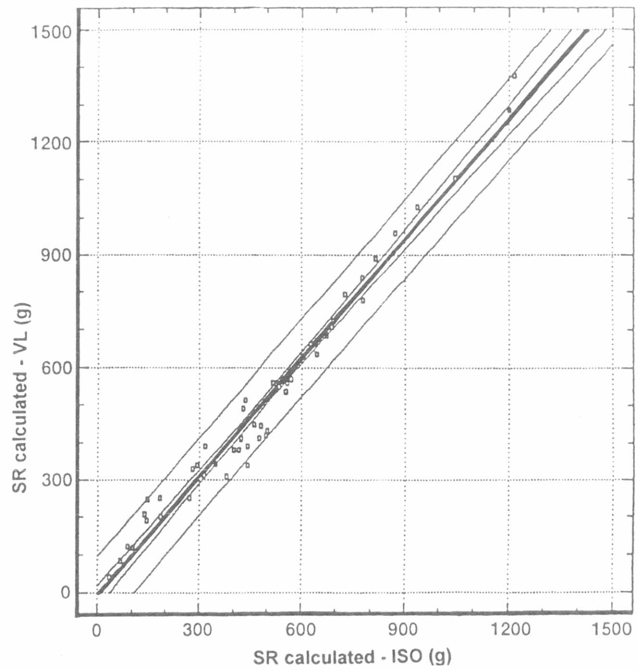

Fig. 4. *Relationship between the water loss by sweating and respiration calculated by the ISO program (SR calculated – ISO) and SR calculated by the author's own program (SR calculated – VL). The work efficiency was neglected. N = 50, r = 0.985, P<0.0001.*

Table 5. Statistical evaluation of the relationship between the short-term tolerable work-time calculated by ISO software program for Q_{max} = 50 W ($t_{Qmax\ 50\ W}$) and the measured corresponding values of the HR increase up to 140 beats/min (t_{HR140}) or to 150 beats/min (t_{HR150}).

X	Sp	N	$x = X - t_{Qmax\ 50\ W}$			
			x	s	t	p
t_{HR150}	0,866	25	14,2	22,2	3,21	0,0037
t_{HR140}	0,850	25	4,8	19,7	1,23	0,2308

X – measured periods of HR increase up to 140 beats/min (t_{HR140}) or to 150 beats/min (t_{HR150}), Sp – Spearman's coefficient of serial correlation, x – average value of the difference between t_{HR140} or t_{HR150} and short-term tolerable work-times calculated by ISO software program ($t_{Qmax\ 50\ W}$), N – number of measurements, s – standard deviation of the differences between X and the short-term tolerable work-time calculated by ISO software program ($t_{Qmax\ 50\ W}$), t – t value of the two-tailed paired t-test, p – statistical significance.

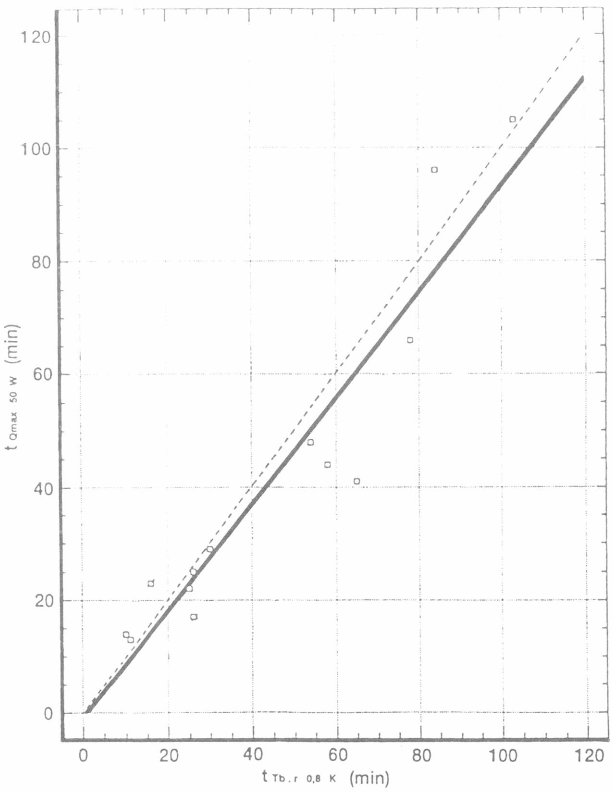

Fig. 5. *Relationship between the short-term tolerable time of work calculated by the ISO program ($t_{Qmax\ 50\ W}$) and the time of work, when the temperature of body core increased by 0.8 K ($t_{Tb,r\ 0.8\ K}$). N = 13, r = 0.950 and P<0.0001.*

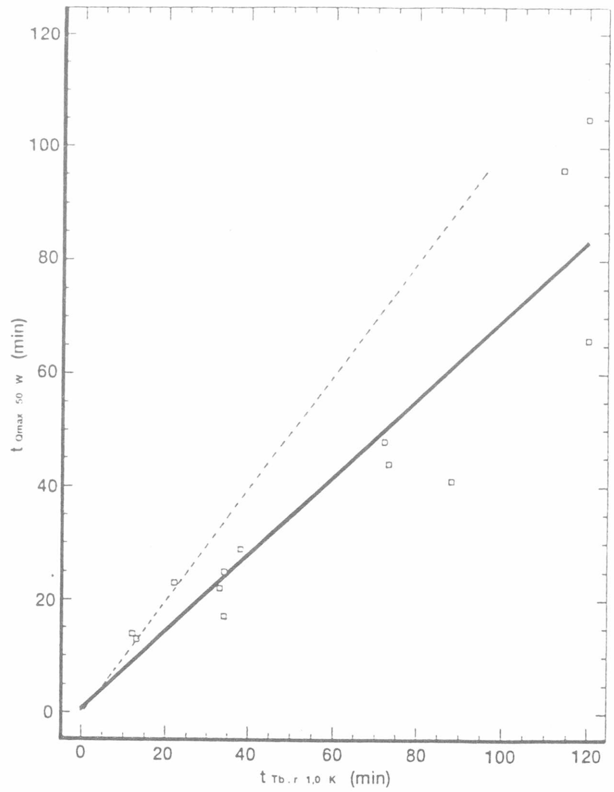

Fig. 6. *Relationship between the short-term tolerable duration of work calculated by the ISO program ($t_{Qmax\ 50\ W}$) and the duration of work, when the temperature of body core increased by 1.0 K ($t_{Tb,r\ 1.0\ K}$). N = 13, r = 0.921 and P<0.0001.*

The evidence of short-term tolerable work

Statistical coincidence evaluation of measured and calculated values by ISO software for the short-term tolerable work period is shown in Figures 5 and 6 and in Table 5. Q_{max} = 50 W.h.m^{-2} was used as a limit value for the theoretically calculated short-term tolerable work duration ($t_{Qmax\ 50\ W}$). The period needed for $T_{b,r}$ increase by 0.8 K ($t_{Tb,r\ 0.8\ K}$) or by 1.0 K ($t_{Tb,r\ 1.0\ K}$) and HR increase to 140 beats/min (t_{HR140}) and 150 beats/min (t_{HR150}) was investigated. Only the results with short-term tolerable work duration (both measured and calculated) shorter than 120 min could be used for short-term tolerable work duration comparison.

The relationship between short-term tolerable work duration calculated by ISO software program for criterion Q_{max} = 50 W.h.m^{-2} and measured time during which $T_{b,r}$ increased by 0.8 K (Fig. 5) or by 1.0 K (Fig. 6) was calculated by the correlation analysis method. Only results from stage E are presented (13 combinations of work and heat load altogether) because, owing to technical problems, it was impossible to measure $T_{b,r}$ during stages A and B. The following relationships were found:

1. $t_{Qmax\ 50\ W} = -0.6066 + 0.9401 \cdot x_1$
   ($r = 0.9496$, $P<0.0001$)
2. $t_{Qmax\ 50\ W} = 0.9311 + 0.6868 \cdot x_2$
   ($r = 0.9211$, $P<0.0001$)

where $x_1 = t_{Tb,r\ 0.8\ K}$, $x_2 = t_{Tb,r\ 1.0\ K}$

Both of them are presented in Figures 5 and 6. The relationship between calculated and measured values is very close as indicated by the regression line in Figure 5. It is also evident that short-term tolerable work, calculated by the ISO software program, was longer in eight cases though the period during which the $T_{b,r}$, increase by 0.8 K had taken place. The regression line in Figure 6 is shifted to the right, i.e. the values calculated by ISO software program are usually shorter than the periods during which the increase of $T_{b,r}$ by 1 K took place. In one case (see Fig. 6), $t_{Qmax\ 50\ W}$ was just the same and only in two cases slightly longer than the period during which the increase of $T_{b,r}$ by 1K had taken place.

Spearman's coefficient of correlation and paired t-test were used for the statistical assessment of the relationship between the values $t_{Qmax\ 50\ W}$ and the corresponding measured values characterized by the HR increase to 140 beats/min or 150 beats/min. It is evident from these results (Table 5) that the periods during which HR 140 beats/min was reached can be supposed to be the same as the values of the short-term tolerable work-time calculated by the software program ISO. The periods of HR increase to 150 beats/min are significantly longer than ISO values (t-test). Moreover, it has been found that in 12 cases of 25 combinations of work and climatic load, the limit value of the short-term tolerable load is reached the same as calculated by the ISO software program for HR lower than 140 beats/min, while HR was the same or higher in 13 cases, HR 150 beats/min was exceeded in three cases and then only very slightly.

Discussion and Conclusions

The good predictive reliability of software ISO as well as of our software for the calculation of sweat rate has been proved as a criterion of a long-term tolerable load. The long-term tolerable average value of SR = 320 $g.h^{-1}.m^{-2}$ found by us and its corresponding value of D_{max} = 2560 $g.m^{-2}$ per shift (valid for a male with a calculated body surface of 1.8 m^2 according to Dubois) for the group of four rescuers (Fig. 1) are higher than the "warning" value for acclimatized persons according to the ISO recommendation (SR = 270 $g.h^{-1}.m^{-2}$ and D_{max} = 2167 $g.m^{-2}$), but they are lower than the "dangerous" value (SR = 360 $g.h^{-1}.m^{-2}$ and D_{max} = 2889 $g.m^{-2}$).

The warning values of the whole-shift admissible sweat loss for acclimatized and non-acclimatized population according to ISO are fully in agreement with our results. The dangerous values can only be accepted for very fit and well-adapted young subjects and only for extraordinary, emergency work, such as that of mine savers during rescue operations.

The experimental results proved the good agreement of predicted and actually measured values of core body temperature as a criterion of short-term tolerable heat load. The values predicted at the level of Q_{max} = 50 $h.m^{-2}$ led to a $T_{b,r}$ increase by 0.8 to 1.0 K. It was also proved that under our experimental conditions, the value of HR = 150 beats/min was not exceeded even in borderline conditions, if the predicted duration of short-term tolerable work was respected.

Table 6. The limit values of long-term tolerable work and heat load

Free energy production (M) $W.m^{-2}$	Criterion	Non-acclimatized persons	Acclimatized persons
	Max.sweat rate*		
Male: ≤80 Female: ≤80	SR_{max} $g.h^{-1}.m^{-2}$ $W.m^{-2}$	147 100	147 100
Male: 80-168 Female: 80-137	SR_{max} $g.h^{-1}.m^{-2}$ $W.m^{-2}$	206 140	270 184
	Max.water loss		
Male: ≤80 Female: ≤80	D_{max} $g.m^{-2}$ g**	1176 2117	1176 2117
Male: 80-168 Female: 80-137	D_{max} $g.m^{-2}$ g**	1646 2963	2160 3900

** Sweat rate in $g.m^{-2}.h^{-1}$ can be converted to heat rate (heat flux) $W.m^{-2}$. 1 $W.m^{-2}$ corresponds to sweat rate 1.47 $g.m^{-2}.h^{-1}$. It is 2.6 $g.h^{-1}$ for standard person of 1.8 m^2 surface area. ** Valid for standard person of 1.8 m^2 surface area.*

The ISO 7933:1989 recommendation is based on admissible skin wetness calculated for the duration of long-term tolerable work and simultaneously the required sweat rate need not exceed the maximal possible sweat rate. The admissible percentage of skin wetness, or the Heat Stress Index according to Belding and Hatch (1956), therefore serves as the principal criterion of tolerable work duration. It is our long-term experience with the measurement and assessment of work and heat conditions in foundries and in other hot plants (Jirák and Zlámal 1978) that the sweat rate is a good criterion for long-term tolerable heat loads and that heat storage in the human body is a good criterion for short-term tolerable heat loads. Hence, both are sufficient for the estimation of whole-shift work duration as well as for the estimation of a work and rest regime if it is not possible to arrange hygrothermal conditions allowing continuous work during the whole shift.

Table 7. Long-term (t_{Qmsh}) and short-term (t_{Qmmax}) tolerable working time of acclimatized males (v_a = 0.1 m.s^{-1}, $T_g \geq T_a$, rh<70 %, one-layer suit 0.64 clo)

Tg	Tolerable working time (tQm)	Work class according to total metabolic rate M [W.m^{-2}]							
		I	IIa	IIb	IIIa	IIIb	IVa	IVb	V
[°C]	[min]	80	105	130	160	200	250	300	350
20	sh	480	480	480	480	403	323	232	188
	max	480	480	480	480	403	323	151	47
22	sh	480	480	480	480	403	323	218	179
	max	480	480	480	480	403	323	87	38
24	sh	480	480	480	480	403	282	207	171
	max	480	480	480	480	403	282	61	32
26	sh	480	480	480	480	403	245	196	163
	max	480	480	480	480	403	157	47	27
28	sh	480	480	480	480	352	230	186	156
	max	480	480	480	480	352	83	37	24
30	sh	480	480	480	468	280	217	177	150
	max	480	480	480	468	280	56	30	21
32	sh	480	480	480	348	262	205	169	144
	max	480	480	480	348	111	41	25	18
34	sh	480	480	392	308	245	195	161	138
	max	480	480	392	151	59	31	21	16
36	sh	385	433	351	287	230	185	154	132
	max	385	433	130	66	38	24	17	14
38	sh	274	395	324	268	217	176	148	127
	max	274	106	63	42	28	20	15	12
40	sh	247	362	301	251	205	168	142	123
	max	90	56	40	30	22	16	13	11
42	sh	226	335	281	236	194	160	136	118
	max	52	38	30	23	18	14	11	10
44	sh	207	311	263	223	185	153	131	114
	max	36	28	23	19	15	12	10	9
46	sh	191	290	248	211	176	147	126	110
	max	27	22	19	16	13	11	9	8
48	sh	178	272	233	200	168	140	121	106
	max	22	18	16	13	11	9	8	7
50	sh	166	256	221	190	160	135	117	103
	max	20	17	15	13	11	9	8	7

The proposal of new Hygienic Regulations of the Czech Republic is based on the present state of knowledge and it respects the following principles:

1. Long-term and short-term tolerable work are limited by the energy output (metabolic rate) which can be produced by an average male or female for a long time (during an 8 hour shift) or for a short time (during a certain work operation) under optimal microclimatic conditions. The recommended limit values for physical work in the Czech Republic for men and women 18 to 60 years old are at the level of 33 % and 66 % V_{O2max}, respectively, and 70 % V_{O2max} for an average man or woman aged 45 years (Jirák 1978, Methodology 1978). The long-term admissible free energy production of 168 $W.m^{-2}$ for males and 137 $W.m^{-2}$ for females (236 W net for men and 156 W net for women) corresponds to this value (Methodology 1978). The short-term admissible free energy production for males is 362 $W.m^{-2}$ (575 W net) and for females 290 $W.m^{-2}$ (395 W net) (Methodology 1978).
2. Long-term tolerable work duration (t_{Qmsh}) is limited by the quantity of water lost by perspiration and respiration. We recommend to differentiate the limit values according to the metabolic rate of work – for performance at a low metabolic rate (M $80 \leq W.m^{-2}$) and for work at $M > 80$ $W.m^{-2}$ for acclimatized and non-acclimatized persons. Non-acclimatized persons are supposed to stay for 3 weeks after the beginning of work at the evaluated workplace. The limit values are presented in Table 6. The long-term and short-term tolerable limits of work and heat (climatic) load for non-acclimatized persons should respect ISO recommendation.
3. Short-term tolerable work duration (t_{Qmax}) is determined by the amount of heat storage in the human body which is 50 $W.h.m^{-2}$ for acclimatized as well as for non-acclimatized persons. The increase of human body core temperature by 0.8 to 1.0 K, and the heart rate increase up to 150 beats/min (depending on the ratio of metabolic and climatic load) correspond to this value.
4. For work performance at a low metabolic rate ($M \leq 80$ $W.m^{-2}$), with a predominance of mental effort and of work requiring high attention (office work, operators, especially crane operators, dispatchers), optimal hygrothermal microclimatic conditions are recommended. During the work at a low metabolic rate not requiring higher concentration the optimal conditions can be exceeded, but the long-term admissible values should never be exceeded.

Based on these principles, tables for long-term and short-term tolerable work in the relationship to free energy production (work performance is differentiated into eight classes and M = 85 to 350 $W.m^{-2}$ is taken into account) and to various hygrothermal microclimatic conditions have been elaborated. Tables for acclimatized and non-acclimatized males and females clothed in one-layer suit of thermal resistance 0.64 clo, for air velocities 0.1, 0.5 and 1.0 $m.s^{-1}$, relative air humidity ≤ 70 %, globe temperature $T_g \geq Ta$ (air temperature), T_g within the range from 20 to 50 °C are available. If the duration of long-term tolerable work, estimated from these tables, is shorter than 480 min, the optimal work and rest regime can be calculated easily with respect to the presented physiological limits. As an example, this is demonstrated in Table 7 (for tolerable work limits of acclimatized males and for $v_a = 0.1$ $m^{-1}.s$).

Note

The tables are available from the authors on request.

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