BIOMED "HEAT STRESS" research project

Barcelona conference June 14 - 15 1999

Proceedings

EVALUATION AND CONTROL OF WARM WORKING CONDITIONS

ed. **Prof. J. Malchaire**

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BIOMED "HEAT"

Proceedings of the conference:

EVALUATION AND CONTROL OF WARM THERMAL WORKING CONDITIONS

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BIOMED "HEAT"

EVALUATION AND CONTROL OF WARM THERMAL WORKING CONDITIONS

BARCELONA JUNE 14 & 15 1999

Instituto Nacional de Seguridad e Higiene en el Trabajo

Dulcet, 2-10 08034 Barcelona

THE CONFERENCE IS ORGANISED BY THE NETWORK OF SCIENTISTS PARTICIPATING IN THE BIOMED-HEAT RESEARCH PROJECT, SPONSORED BY THE EUROPEAN COMMISSION.

SUPPORTING AGENCIES

- **INSHT, Instituto Nacional de Seguridad et Higiene en el Trabajo, Spain**
- **International Commission of Occupational Health**

OBJECTIVES

To present up to date research results and discuss:

- How to approach the problems, even in small and medium size companies?
- How to evaluate the climatic parameters, the work load, the clothing insulation,
- How to use the WBGT and the Predicted Heat Strain index
- How to assess the risk encountered, how to optimise the technical or organisational solutions, how and what to organise in terms of medical surveillance or protection?

SCIENTIFIC COMMITTEE

- J. Malchaire, Université catholique de Louvain, Belgium, co-ordinator of the research project
- G. Alfano, Faculta di ingegneria, Naples, Italy
- H. Gebhardt, ASER, Wuppertal, Germany
- B. Griefahn, Ifado, Dortmund, Germany
- G. Havenith, Loughborough University, UK
- I. Holmér, NIWL, Solna, Sweden
- B. Kampmann, RAG, Dortmund, Germany
- P.Mehnert, Ifado, Dortmund, Germany
- K. Parsons, Loughborough University, UK

P R O G R A M M E

Monday, June 14 1999

10:00	Welcome to the participants	E. Castejón
	PHILOSOPHY	
10:10	Position of the problem, the Biomed HEAT research project, presentation of the programme of the conference	J. Malchaire
10:25	Existing and future Standards on ergonomics of the thermal environment and thermal indices	K. Parsons
10:45	Strategy in 4 levels for the management of the thermal working conditions: Screening, Observation, Analysis, Expertise	H. Gebhardt
11:15	Coffee break	
11:45	Heat stress in industry in the Amazonian region	P. Dessureault
12:00	Investigation into heat stress in subsistence agriculture in Ghana	M. McNeil
12:15	Lunch	
	EVALUATION OF THE PRIMARY PARAMETERS AT THE FOUR LEVELS OF THE STRATEGY	
14:00	Measurement of the climatic parameters: techniques, instruments, accuracy …	G. Alfano
14:20	Evaluation of the metabolic rate	I. Holmér
14:40	Evaluation and selection of the clothing: influence on convection and evaporation	G. Havenith, I. Holmér K. Parsons, E. den Hartog
15:10	Coffee break	
15:40	Local insulation, local evaporative capacity and local sweat output also influence the overall thermal responses and the tolerance time	V. Candas
16:00	Discussion: clothing influence	
16:30	The application of the Swedish provisions "work in intense heat"	J. Westman
16:45	Investigations on thermal working conditions at workplaces in a paper manufacturing company - results of a stepwise approach	E. Feldbauer K.H. Lang
17:00	Thermal evaluations in glass industries	F.R. d'Ambrosio F. Strambi
17:15	Practical use of NF EN 12 515 standard with a computer programme	B. Landry
17:30	End of the first day of the conference	

Tuesday, June 15 1999		
	PREDICTED HEAT STRAIN INDEX (PHS) MODEL	
9:00	Introduction: review of ISO 7933	J. Malchaire
	Prediction of the skin temperature	P. Mehnert
	Estimation of respiratory heat losses	G. Alfano
	Skin-core temperature weighting	G. Alfano
	Heat storage distribution	J. Malchaire
	Prediction of the rectal temperature	J. Malchaire
	Increase in t_{co} due to activity	B. Kampmann
	Evolution of t_{sk} and SW as a function of time	G. Alfano
	Evaporation efficiency	H.J. Gebhardt
	Maximum wettedness	G. Alfano
	Maximum sweat rate	J. Malchaire
	Maximum water loss	B. Kampmann
	Limit criteria for heat storage	J. Malchaire
10:30	*Coffee break*	
11.00	*Validation of PHS*	J. Malchaire
11:20	Comparison PHS – ISO 7933	*A. Piette*
11:30	Comparison PHS - WBGT	B. Kampmann
11:45	New developments concerning the WBGT index	T. Bernard
12:00	Discussion	
12:30	Lunch	
	WHAT TO DO IN PRACTICE	
14:00	Medical aspects: selection and surveillance of the workers to heat	B. Griefahn
14:15	Traditional and modern monitoring methods of heat strain in workers exposure to extreme heat at work	R. Ilmarinen
14:30	Selection, training and short and long-term surveillance of workers exposed to heat: the situation in Germany	C. Piekarski
14:45	Heat strain and heat stress indices and what lies between them	Y. Epstein
15:00	Example of application	J. Malchaire
15:15	Coffee break	
15:45	Discussion	
16:15	Conclusions	J. Malchaire
	Closure of the conference	

MINISTERIO DE TRABAJO
Y ASUNTOS SOCIALES

INSTITUTO NACIONAL DE SEGURIDAD
E HIGIENE EN EL TRABAJO

The Instituto Nacional de Seguridad e Higiene en el Trabajo is very happy to be able to host the closing conference of the BIOMED "Heat Stress" research project and to welcome the partners in this project and all the participants.

Spain is a hot country and workers are exposed to hot conditions at many workplaces. We are therefore directly concerned by the results of this research. We are looking forward to analyse any index and intervention strategy that could make it possible to improve in practice the working conditions and better protect the workers.

Professor E. Castejón

ASSESSMENT OF THE RISKS OF HEAT DISORDERS ENCOUNTERED DURING WORK IN HOT CONDITIONS

Prof. J. Malchaire

Université catholique de Louvain, Unité Hygiène et Physiologie du Travail,

Clos Chapelle-aux-Champs 30-38, 1200 Bruxelles - Belgium

Objectives

Eight European laboratories conducted in the last 3 years a BIOMED HEAT concerted research project on the assessment of hot working conditions

The objective of the joint research project was to co-ordinate the work of the main European research teams in the field of thermal factors in order to develop and improve significantly the methods presently available to assess the risks of heat disorders encountered during work in hot conditions.

Items needing further concerted research concerned:

- The strategy to be used in the field to assess exposure, particularly in conditions which vary in time;
- The heat exchange coefficients through convection, radiation and evaporation in extreme conditions as well as taking into consideration the characteristics of normal and special clothing ensembles;
- The modelling of the physiological behaviour in response to work in the heat and, in particular, of the average skin temperature, the evaporative efficiency of sweating and the sweating response;
- The criteria for the determination of the maximum allowable exposure duration, taking into account the interindividual differences between workers.

The specific objectives of the research project were therefore:

1. To design and validate a strategy for the assessment of the strain related to hot working conditions, strategy that can be used by practitioners in the field to determine maximum allowable exposure durations and to optimise the improvement of the working environment;
2. To extend the validity of the present modelling of the role of the clothing;
3. To improve the validity of the present indices in case of high radiation, high humidity or high velocity;
4. To better define the criteria for the determination of the maximum allowable exposure duration and in particular the interindividual differences in sweating rate, evaporation efficiency, water loss and increase in core temperature.

The partnership

- Prof. J. MALCHAIRE, Occupational Hygiene and Work Physiology Unit, Catholic University of Louvain, Belgium
- Dr. H. GEBHARDT, Institut für Arbeitsmedizin, Sicherheitstechnik und Ergonomie, Germany
- Prof. Dr. B. GRIEFAHN, P. MEHNERT, Institut für Arbeitsphysiologie an der Universität, Germany
- Dr. B. KAMPMANN, Institut für Arbeitswissenschaften, Germany
- Prof. G. ALFANO, Universita Degli Studi di Napoli "Federico II", Italy
- Dr G. HAVENITH, E. den HARTOG, TNO Human Factors Research Institute, The Netherlands
- Prof. I. HOLMÉR, Division of Climate Physiology, Arbetsmiljöinstitutet, Sweden
- Dr. K. PARSONS, Human Thermal Environments Laboratory, Loughborough University, UK

Influence of clothing ensembles on heat exchange

One of the greatest limitations of the present prediction models is the influence of the clothing on heat exchanges at the surface of the body through convection, radiation and evaporation.

Methods and formulas were developed that take into account the dynamic effects associated with forced convection and the pumping effect associated with body movements and exercise.

The present method for dealing with evaporative heat exchange in clothing is to relate it to the dry heat exchange (convection + radiation) in clothing. Alternative methods and permeability indices were proposed to take into account the effect of fabric air permeability on clothing vapour resistance, considering the body movements and air velocity This leads to improved heat stress predictions for people wearing protective clothing.

Prediction of the average skin temperature as a function of the characteristics of the work situation and clothing

The present model was extended to more severe conditions with high radiation and high humidity and different clothes. As the index makes use of the exponential averaging in the minute per minute prediction of the sweating rate (Malchaire 1991), the internal temperature was taken into account for the prediction of the skin temperature.

Criteria for estimating acceptable exposure times in hot work environments

New criteria were developed concerning the maximum increase in core temperature and the maximum acceptable water loss, taking into account maximum values of skin wettedness and sweat rate and the fact that the subjects are acclimated or not to work in heat. These limits in order to protect 95% of the population

Measuring strategy

The standards available make it possible to investigate only the steady state climatic conditions. A general strategy was developed to assess the risks in any working situation with varying conditions of the climate, of metabolic rate or of clothing. This strategy includes three stages:

Several levels will be considered:

- an “observation” method for the recognition of the conditions that might lead to thermal stress;
- an “analysis” method designed to evaluate the magnitude of the problem and to optimise the choice of solutions;
- an “expert” method for in depth analysis of the working situation when needed.

Detailed methodologies were prepared for the three stages.

Validation

The different results were used to prepare a revision of all the standards and proposed procedures.

The modified approaches were validated through a set of lab and field experiments involving the whole range of conditions for which the model was been extended, namely conditions with

- high and low radiation, humidity and air velocity
- fluctuating conditions.

The Predicted Heat Strain Model

The Required Sweat Rate index was abandoned and a new index is proposed

Social value of the project

As a result of the research, occupational health specialists have available comprehensive methods to assess accurately the risks of heat disorders encountered while working in hot conditions and therefore to protect the workers.

The results of the joint research should make possible to reduce the cost of work accidents in industries as well as the cost of medical care due to morbidity contracted at the workplace.

These methods should make possible to guarantee the same level of safety and health in all industries in all countries and in particular in the Southern countries that are directly concerned by these working conditions. The development of more adequate standards will therefore pave the road toward a specific directive concerning the assessment of hot working conditions or, at least, clarify the requirements of the European directive EC 89/654 concerning the minimum safety and health requirements for workplaces.

The social impact of the proposed project is mainly the establishment of better working conditions and the prevention of accidents such as heat cramps and heat strokes at the workplaces, in particular in countries where hot working conditions are omnipresent.

References

1. Malchaire J., Gebhardt H.J., Piette A. (1999) Strategy for evaluation and prevention of risk due to work in thermal environment. *The Annals of Occupational Hygiene*. To be published in 1999
2. Mehnert P., Malchaire J., Kampmann B., Piette A., Griefahn B., Gebhardt H. (1999) Prediction of the average skin temperature in warm and hot environments. *European Journal of Applied Physiology*.

   To be published in 1999
3. Havenith G., Holmér I., den Hartog E.A., Parsons K.C. (1999) Clothing evaporative heat resistance. Proposal for improved representation in standards and models. *The Annals of Occupational Hygiene*.

   To be published in 1999
4. ISO 7933, Revised proposal

EXISTING AND FUTURE STANDARDS ON ERGONOMICS OF THE THERMAL ENVIRONMENT AND THERMAL INDICES

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Introduction

The International Standards Organisation (ISO) has produced an integrated series of international standards for the assessment of human responses to thermal environments. They include standards for the assessment of thermal comfort, heat stress and cold stress and many have been adopted as European and national standards. For hot environments a three tier approach is taken which involves a simple thermal index (WBGT) that can be used for monitoring and control of hot environments (ISO 7243); a rational index (SWreq) which involves an analysis of the heat exchange between a worker and the environment (ISO 7933); and a standard for physiological measurement which can be used in the establishment of personal monitoring systems of workers exposed to hot environments (ISO 9886). The simple index provides a first stage analysis and can confirm whether or not there is likely to be unacceptable thermal strain. Where a detailed analysis is required then ISO 7933 provides an analytical method that can provide a more extensive assessment and interpretation leading to recommendations for improvement to the working environment. Where a method needs to be confirmed, or conditions are beyond the scope of ISO 7243 and ISO 7933, then ISO 9886 provides guidance on physiological measurement and interpretation. This would be used in extreme environments where individual responses of individuals are required to ensure health and safety or in the case where personal protective equipment (PPE) is worn which is beyond the scope of ISO 7243 and ISO 7933. The ISO system therefore covers almost all exposures to hot environments. It would be useful however to extend the scope of the standards that provide a simple index or analytical approach.

Thermal indices

A heat stress index is a single number that indicates the degree of heat strain imposed on people exposed to a hot environment. The index is derived by integrating the effects of factors that contribute to heat stress in a way that reflects human response. It is generally accepted that these are air temperature, radiant temperature, air velocity, humidity and the activity level and clothing worn by the persons exposed to the environment. Numerous heat stress indices have been proposed over the last century. These can be conveniently divided into three types. Empirical indices derive data on human responses from exposure of human subjects to hot environments. The principle is that by studying responses over a wide range of conditions (from combinations of the six factors above) sufficient data will be derived to produce an empirical model that will allow the prediction of human response to hot conditions. The Predicted Four-Hour Sweat Rate (P4SR) is an example of such an index where fit young acclimatised subjects were exposed to a range of thermal conditions and sweat rates recorded after four hours. An empirical model was then derived that could be used to assess hot environments based upon a single number relating to an amount of sweat. The hotter the environment, the greater the amount of sweat predicted in four hours. Direct heat stress indices are based upon a physical instrument that responds to the environment in a way that can be related to human response. The wet bulb globe temperature (WBGT) index uses a naturally aspirated wet bulb, a black globe and a dry bulb thermometer. In combination these instruments respond to all of the environmental factors that affect human response (above). The WBGT index is derived by adding together weighted values of these instruments. Expected human response can be predicted from index values for conditions over a range of activities and clothing. A rational thermal index provides an analysis of the heat exchange between a clothed person and the hot environment. The analysis can be derived from measurements or estimates of the six relevant factors (above). From the analysis the sweat required to ensure that the body does not store unacceptable amounts of heat can be calculated. The SWreq index is an example of a rational thermal index.

Existing and future standards

Standards that support the heat stress standards include; for estimating the metabolic heat production for activities (ISO 8996); for estimating the thermal insulation and vapour permeation properties of clothing (ISO 9920); and for specifying measurement instruments (ISO 7726). Basic principles are described in ISO 11399 and other standards include those for medical screening of subjects (ISO DIS 12894), assessment of cold stress (ISO TR 11079), and thermal comfort (ISO 7730, ISO 10551). Future standards that may be developed include contact with hot, moderate and cold solid surfaces, quantities symbols and units, requirements for users with special needs and thermal environments in vehicles. Of particular relevance to the assessment of hot environments is the revision of ISO 7933. It is generally agreed that there are limitations in this rational method of assessment in terms of its scope. That is, it is limited in practical application because of the limited range of conditions over which it applies. It does not apply to conditions where special protective clothing is worn for example. There are also limitations in terms of its validity and usability. These issues are being addressed in a revision of the standard and some of the rationale for those revisions is presented in following papers.

STRATEGY IN 4 LEVELS FOR THE MANAGEMENT OF THE THERMAL WORKING CONDITIONS: SCREENING, OBSERVATION, ANALYSIS, EXPERTISE

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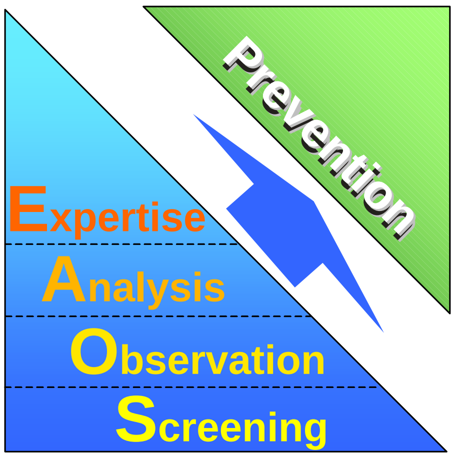
Introduction

One of the main reasons for the lack of risk prevention in industry, and particularly in SME's, is the cost of the assessment studies. Actually, the number of work situations and risk factors is so great that it is unrealistic and utopian to require investigating all of them in depth. This would be in fact a waste of time and money as, in the majority of the cases, simple prevention/control measures can be taken directly by the employers and the workers themselves, once they are aware of the problem. In some cases only, a more detailed study of the work situation is needed with the assistance of persons trained in occupational health and safety. In fewer situations even, the assistance of experts is required.

Strategy in 4 levels

With this in mind, a strategy in 4 stages was developed to be used for the management of the thermal working conditions. The approach can be summarised by the following graph. All stages are strictly orientated towards prevention as the main objective of the assessment of the risks linked to the thermal working environment is not to quantify the risks, but to prevent or to eliminate, or at least to reduce these risks. The strategy is presented here for the thermal working conditions. It may be developed in general for other stress factors as well.



Description of the stages

Stage 1: "Screening"

At the first stage, all or the majority of the risk factors or "problems" must be detected in order to provide a first overview of the working conditions. A "Screening" method is therefore necessary. It must cover briefly the majority of the factors related to safety, health and well being (psychosocial factors). The conclusions will be, whether there are complaints related to the climatic conditions, whether there might be "problems" and whether there is a need to investigate further.

Stage 2: "Observation"

The second stage is designed to be used by people from the company and, possibly, by the workers themselves. Therefore, it has to be simple to understand by untrained people and, in particular, by the workers. It must take advantage of what the users know best, that is, their working conditions, the technical process, the characteristics of the heat or cold sources and the possibilities for control measures. This method therefore acknowledges explicitly the competence and the skill of the workers and deliberately relies on them to improve the working conditions. It simply helps them to structure and systematise their approach, so that it is not solely based on perceptions and opinions.

Work was performed in the BIOMED HEAT research project, to develop worksheets to describe and evaluate working conditions as well as to assist in finding solutions for existing problems. These worksheets were improved, based on a validation study conducted with the participation of a total of 53 potential users.

Stage 3: "Analysis"

The third stage is designed to be used by occupational health specialists, that is, by occupational physicians, occupational hygienists, ergonomists… with a general training in the management of heat problems. It still uses concepts and techniques commonly accepted in the field, avoiding therefore more "scientific" considerations. When necessary for prevention, it requires measurements with instruments inexpensive, easy to use and readily available in the field. It remains oriented towards prevention and therefore uses measurements and indices that make possible to best identify the causes of the problems and the means to solve them.

At the end of the "Analysis", the user should be able to determine whether, for this working situation, a more thorough "Expertise" is necessary or not.

Stage 4: "Expertise"

This stage might be needed in very complex cases for which satisfactory solutions could not be found, even after a detailed "Analysis". The methodology to be used, the measurements to make, the evaluation to perform vary depending upon the problem. In addition, this stage will be carried out with the help of experts who should be able to decide the best procedure to collect the information indispensable to solve the problem. Therefore, there does not exist one unique expertise method. The BIOMED document is limited to the great lines of what this "Expertise" study should obviously include and report.

Conclusion

A strategy with four stages is proposed for the management and the control of the working conditions with thermal problems. It rests on two basic principles:

- It is *participative*: the workers play the essential role in the dynamics of the improvement of the working conditions. Occupational health specialists and experts are there to help these workers to find the solutions.
- It is *structured* in 4 stages which require complementary knowledge and competencies

This abstract and the presentation is based on:

J. Malchaire, Hj. Gebhardt, A. Piette: Strategy for evaluation and prevention of risk due to work in thermal environment, to be published in annals of Occupational Hygiene where the method and the stages are described in a details.

	Stage 1 *„Screening"*	**Stage 2** *„Observation"*	**Stage 3** *„Analysis"*	**Stage 4** *„Expertise"*
▫ When?	systematically	when a "problem" is detected	In complicated cases	In very complex cases
▫ How?	simple observations	qualitative observations	ordinary measurements	specialised measurements
▫ Cost?	very low	low	average	high
▫ Duration (order of magnitude)	20 min	2 hours	1 day	a few days
▫ By whom?	workers + management from the company	workers + management from the company	same + specialists	same + specialists + experts
▫ Competency - work situation: - ergonomics:	 high low	 high average	 average high	 low specialised

HEAT STRESS IN AMAZONIA

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Brazil is one of the largest countries in the world. Its economic development is also one of the most uneven. While some regions in the south, the one centred around Sao Paulo especially, enjoy a modern and relatively effective industrial development, Amazonia's vast regions remain underdeveloped. The Amazonian industry, most of it outdated, is essentially a primary sector one (i.e., gathering and initial processing of natural resources). Production techniques barely changed from the colonial epoch dominate many industrial sectors. Since equipment is lacking, work methods tend to be manual, which translates into heavy workloads.

In 1994, we co-operated with a working group on occupational safety at Universidade Federal do Parà (UFPA) in the city of Belém to develop a heat stress surveillance programme adapted to the local woodworking industry. Our primary goal was to determine an approach that would be both acceptable to the industry and enforceable by the authorities.

The Amazonian climate is remarkably stable throughout the year. Temperatures are warm, with little wind, and the humidity levels are extremely high. The Amazonian Basin receives the most rain in Brazil, and Belém is one of the most rained on cities in the world. The general pattern is for short, tropical rains that come at all times. Actually, the Amazon is not as hot as most people presume. The year-round average day temperature is 27 °C, but humidity is near saturation.

Environmental parameters registered over a 10-day period ranged from:

- T_a = 27 – 37 °C
- T_{wb} = 23 – 32 °C
- T_{nwb} = 24 – 32 °C
- V_a = n/d – 3 m/s
- T_g = 29 – 43 °C
- $WBGT_{in}$ = 26 – 30.6 °C
- $WBGT_{out}$ = 26.2 – 32 °C

Under such environmental stress, if work is heavy, the heat stress level becomes significant. Heavy workloads were observed in many instances in the woodworking industry. Some examples are: stove wood unloading, boiler-keeper, manual handling, classification, or gluing of wood sheets, and log cutting with a chain saw. The observed WBGT values are barely acceptable for a low level of energy expenditure. In the field, moderate and heavy workloads are performed continuously by 65 to 75 % of the workers. Cases of drastic over-exposure are frequent. Severe cases of heat strain (heat stroke or heat exhaustion should be experienced.

The regional office of the *Comissao interna de prevencao de accidentes*, the authority responsible for enforcing occupational health and safety regulation, has no record of heat-related fatalities or compensation. Brazil's working regulations are modern, and they are consistent with the types of industries found in the southern part of the country. The standard regarding heat stress, based on the WBGT temperature essentially follows the ISO 7243 standard. In Amazonia, OSH regulations are inapplicable and ignored by both industry and the governmental agencies responsible for overseeing its application but which have neither the expertise nor the instruments required to apply it.

To circumvent this lack of information, industrial managers were asked permission to monitor some of their employees. This authorisation was not granted. At last, the working group interviewed the only occupational physician in the Belém area. This qualified physician was affiliated to the medicine faculty at UFPA. Surprisingly, heat stress was not on the top of his priority list. In his opinion, heat-related disorders are very rarely seen in Amazonia provided water (or preferably tea) supply is plenty and that workers do not have to wear personal protective equipment. Some facts may explain that the level of strain seems to be tolerable despite a very high level of stress:

1. Light clothing insulation. Commonly, workers wear cotton shorts only and a pair of glove when necessary.

2. Typically, workers are short and small. This physiognomy yields a higher surface-to-volume ration compared to average Europeans or north Americans.
3. Workers are native or mulattos. These people are preferred by industry managers for they are known to better perform in the heat.

Choosing a fully satisfying heat stress index adapted to the Amazonia work force proves impossible without additional research. Also, financial constraints exclude any index, such as the required sweat rate, or even the WBGT, which requires a certain equipment. Heat strain monitoring must then be considered.

Whichever approach is selected, its proposed limits will need to take into account the population under study. Indeed, this population shows a resistance to heat that is undoubtedly superior to average. Occupational physiology would benefit from studying these people who exhibit a surprisingly low level of strain given the levels of heat stress to which they are subjected.

INVESTIGATION INTO HEAT STRESS IN SUBSISTENCE AGRICULTURE IN GHANA

Marc McNeill[1],

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Introduction

Tropical agriculture is often characterised by extreme environments with air temperature, solar radiation, and humidity all being high. Available literature shows that little research has been conducted into the effects of heat on the human thermoregulatory system when working in tropical agriculture. A survey of occupational disorders amongst Ghanaian farmers suggested that heat stress and heat related illnesses may be a problem, accounting for many of the 'fevers' attributed to work (McNeill and O'Neill, 1997).

This study aimed to investigate the effects of heat on a sample of Ghanaian farmers working outdoors, undertaking a task that farmers had complained of being laborious and stressful, that of making yam mounds. In summary the study aimed to address the following questions:

- Do farmers suffer from heat stress whilst working?
- What behaviour do farmers adopt in order to 'keep cool'?
- Are international standards that predict safe working practices in hot environments appropriate for Ghanaian farmers?

Method

Ten male farmers undertook a manual task, digging yam mounds, on their farms. Their behaviour was continuously observed throughout the working period. Heart rate was monitored and oral temperature taken before and after work. t_a, t_r (∅=0.05m), and *RH* were continuously recorded using a Grant squirrel datalogger. *v* was estimated using the Beaufort Scale. WBGT was derived from t_a, t_r, *RH* and *v*.

Results

The environment was dynamic with air and radiant temperature rising during the working day as the altitude of the sun increased (mean ± sd : t_a = 29.1°C±2.7; t_r = 40.7°C±9.1; *v* = 1.9m/s±1.3; *RH* = 67.2%±22).

All the subjects wore similar clothing, western dress typically comprising of cotton trousers and T-shirt or shirt. Subjects started work between 06:51 and 08:14. Subjects worked for a mean of 216 minutes (SD=90), of which a mean of 199 min (SD=76) was spent actually working. Reasons given for stopping work were feeling hot, fatigue, hunger, body pains and excessive dust. All subjects interrupted their pace of work to take brief pauses, however with the exception of three subjects, none took rest in the shade.

The mean physiological workload expressed as a percentage of an individual's effective heart rate range was 53% suggesting a fairly hard work rate with a mean heart rate of 132bpm. At the end of work, mean oral temperatures had risen by 0.6°C.

Discussion

Do farmers suffer from heat stress?

The negligible increase in oral temperature for all but one of the subjects suggested that the working conditions did not impose a stress on the human thermoregulatory system.

What behaviour do farmers adopt in order to 'keep cool'?

The farmers organised their work to avoid thermal stress by starting work early when air temperature and solar radiation were low and finishing work when they felt hot and fatigued. They were flexible in the number of hours worked, working constantly without rest. Adaptive clothing strategies were not observed, clothing having been removed to a minimum level before work began. Whilst it was not

[1] Now at Andersen Consulting, 2 Arundel Street, London, WC2 3LT

possible to quantify sweat loss, profuse sweating was evident in all subjects and dehydration was likely with evidence of little fluid replenishment.

Are international standards that predict safe working practices in hot environments appropriate for Ghanaian farmers?

ISO 7243 The mean WBGT (weighted over time) exceeded reference values, yet no subject experienced a rise in body temperature to 38°C. These results, whilst fairly inconclusive, suggest that ISO 7243 was over protective and that higher reference values for the population investigated could be used.

ISO 7933 As it was not possible to measure weight loss over the working period ,a comparison between actual sweat loss and sweat loss predicted by ISO 7933 could not be made.

There was a significant difference between predicted safe working times before excessive water loss and time actually worked (p=0.002) for 8 subjects. From the increases in oral temperature it could be seen that these reference values were not reached and ISO 7933 predictions thus erred considerably on the safe side. It is suggested that the primary reason for the marked differences in ISO 7933 predictions was the high input values for radiant temperature. The globe has been found to be inaccurate in outdoor situations with solar radiation (Parsons, 1993). In addition the small globe size combined with high air velocities may have further compounded inaccuracies with using the globe for mean radiant temperatures.

The finding of this limited research reflect that of Kähkönen *et al.*, (1992) who concluded that in a tropical working environment the climatic conditions for which ISO 7933 is applicable are too narrow. There is a need to further investigate the validity of the international standards for use in the tropical environment and in particular the effects of solar radiation on the human.

Limitations of study

The subjects represented an opportunity sample as finding farmers who were willing to take part proved difficult. Many farmers were reluctant to take part, as they could perceive no tangible benefits from participating in the research. Others were reluctant to allow strangers onto their farms for superstitious reasons. Without a flat surface it was not possible to use scales on the farm and hence body mass loss and sweat loss could not be measured. All the subjects claimed that they usually travel to the farm early to avoid the heat of the sun, walking in the dark to start work at sunrise and usually finishing by mid morning. During the study however, all subjects refused to leave home for the farm with the researchers before sunrise on account of their prescence. In the light of this, the start times for work may be not be representative of a typical working day.

Conclusions

- This study, whilst methodologically limited, suggested that the farmers did not suffer from heat stress when working outdoors in the conditions observed.
- Farmers did not take precautions to combat the risk of heat stress, such as regular breaks, fluid replenishment or wearing wide brimmed hats. They did however adopt a sensible approach to their working environment, starting work early in the morning when temperatures were relatively low and solar radiation was minimal, finishing work when they felt hot and fatigued, before the hottest part of the day.
- Difficulties in conducting field research ‘on the farm’ were encountered. These included logistical problems of transporting research equipment to the field, observer interference, and shortcomings with measuring techniques.
- This study suggested that international standards for estimating heat stress and strain in the tropical environment observed were overprotective. The results however were inconclusive and this merits further investigation.

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MEASUREMENT OF THE CLIMATIC PARAMETERS: Techniques, instruments, accuracy,…

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Introduction

It is well known that for evaluating the thermal environment in a workplace it is necessary to measure four physical parameters: air temperature, air velocity, air humidity and mean radiant temperature. By the values of these parameters and by the values of metabolic rate and thermal properties of the clothing, it is then possible to evaluate a thermal index. The accurate measurement of these four parameters is not simple and sometimes requires sophisticated and expensive instruments.

About the measurement of these parameters an international standard exists, the ISO 7726 (ISO, 1985), that was also approved by CEN as EN 27726 in the 1993 and that is under revision now (ISO, 1998). This standard is very efficient. For each parameter it specifies the necessary accuracy, response time and measuring range. It describes also measuring methods for homogeneous, non-homogeneous, stationary, non-stationary environments and, in annexes, describes the most important measuring principles.

Here, for each parameter we describe the principal difficulties for the measuring, by which it is possible to understand when less accurate, and less expensive, instruments and methods can be used in relation to the level of evaluation. We will refer only to heat stress problem and will not consider moderate thermal environment.

Air temperature

If in the workplace all the surfaces are at temperatures quite close to air temperature, no precaution is necessary. If there are surfaces at temperature greater than air temperature, more precisely if mean radiant temperature is greater than air temperature, then it is necessary to minimise the effect of radiant heat between the sensor and the environment. In practice, it is necessary to use a thermometer with a high reflective screen around the sensor and, possibly, with a device that increases air velocity around the sensor.

Air velocity

The accurate measurement of air velocity is quite difficult, essentially because the air velocity fluctuates randomly and its direction changes continuously. Moreover, often it is necessary to measure relatively low air velocity (<0,1 m/s). For this reasons many instruments, used in many engineering fields, are not usable for evaluating thermal environment and a suitable sensor is necessary. The most accurate instrument is the hot-sphere anemometer, which is not sensitive to the direction of the airflow and has a low response time. Obviously it is quite expensive.

A simpler, less accurate and less expensive method is to discover the main direction of the airflow by smoke and to use a directional instrument (hot-wire anemometer, cup-anemometer, etc.).

Air humidity

For thermal environment evaluation the partial pressure of water vapour shall be taken into account. In practice, this quantity is often obtained by measuring air temperature and simultaneously dew temperature, psychometric wet bulb temperature, or relative humidity and then calculating the water partial pressure. A great advantage of the water partial pressure is that normally it is uniform, therefore it is sufficient to measure it at one location only.

There are many types of instruments that are quite accurate and not much expensive (above all psychrometers). But it is very important to take some operative precautions. For the psychrometer it is necessary to ventilate the wet bulb at an air velocity of 4 m/s, at least, to use distilled water for wetting the wick, to verify that the wick remains always well wetted, to measure the atmospheric pressure by which the water partial pressure also depends.

Probably the hair hygrometers are still the most used instruments, because they are inexpensive and very simple. But it is very important to know that they need very frequent calibrations, the accuracy decreases rapidly without.

Mean radiant temperature

The mean radiant temperature refers to the shape of the human body and for this reason is a quantity difficult to measure accurately (Fanger, 1982).

Because its simplicity the globe thermometer is the instrument most used in practice. It is also simple to use and not expensive. But it over-estimates the radiation from the ceiling and the floor and has a very long response time. A more accurate method consists in measuring the plane radiant temperature in the six main directions (right-left, front-back, up-down) and then in calculating the mean radiant temperature as a mean value taking into account the shape factor of a person in the different directions. The method is very accurate but the measurement of the plane radiant temperature needs a sensor quite complex and expensive.

General considerations

The type of method and instrument used for the evaluation of thermal environment can be related to the level of evaluation.

For accurate measurements instruments should be certified and calibrated. But for instruments described before there are only few Institutes, generally private, qualified for these activities. For some quantities calibrations are not easy and there is no standard in this field.

Many instruments, especially electronic ones, give measured values with several digits. It must be clear that this has no relation with the real accuracy. This can mislead the user to believe that he is using a very accurate instrument (Olesen and Madsen, 1988).

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EVALUATION OF THE METABOLIC RATE

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Introduction

Metabolic rate is an important determinant of the resultant strain from exposure to a thermal environment. In particular in hot climates the high levels of metabolic heat production that follows with muscular work, aggravate heat stress, as large amounts of heat need to be dissipated mostly by sweat evaporation.

The mechanical efficiency of muscular work is low. In most types of industrial work it is so small (a few percent) that it is assumed to be nil. This means that the total energy consumption at work is assumed equal to the heat production. For the purpose of this presentation metabolic rate is assumed equal to the rate of heat production.

Determination of metabolic rate

Several methods exist for determination of metabolic heat production. Most of them are based on indirect observations or measurements, but also direct measurements of metabolic rate can be made. The international standard ISO 8996 (ISO-8996 1990) describes different evaluation methods. Methods are briefly described in the following.

The selection of method depends on the accuracy needed and this, in turn, is determined by the purpose of the evaluation and available heat stress assessment methods. The first two methods only apply with estimation methods as in ISO 7243 (WBGT). Methods 3-6 provide estimates of metabolic rate with an accuracy of ±15 %. Direct measurements will mostly be accurate within ±5 %.

Methods

Estimation based on classes of work

An example of this method is the classification of work provided in ISO 7243 (WBGT). Five classes of work are defined by a number of examples of work. Each class represents an average and a range of metabolic rate values.

Estimation based on occupational professions

ISO 8996 gives a large number of examples of metabolic rate values observed for typical professional activities. Values must be used with care since they are quite old and many activities may have changed in terms of physical workload, work methods, tools and equipment.

Estimation based on type and composition of muscular work

Metabolic rate is composed of one basic fraction independent of work and added to that, a fraction from muscular activities. Tables are available from which both fractions can be estimated. The work fraction is calculated on the basis of the type of work carried out, for example one arm work, arm and trunk work etc. Each example is classified as light, moderate and heavy, representing increasing values for heat production.

Estimation based on typical activities

Tables are available with measured values for selected activities in different types of industry.

Estimation based on time-weighting of defined activities

Edholm has proposed an observation method comprising a number of classes, each representing a standard activity or a defined activity. The metabolic rate for the activities are either predefined (standard) or measured (defined) for this particular or a similar one. The worker is observed and checked for a representative class every minute. The metabolic rate is calculated by adding number of minutes during one hour for each observed class and multiplying with the value for the class.

Estimation based on measurement of heart rate or ventilation rate

Several physiological variables are more or less linearly related to the increase in metabolic rate.

Heart rate increases with increased energy yield. Heat, however, may also exert and additional load on the cardiovascular system making an estimation of heat production difficult. Accordingly, the heart rate at work should be measured in the absence of heat stress in order to give a good estimate of metabolic rate. The accuracy increases if the worker is "calibrated" with simultaneous measurements of heart rate and energy consumption, for example with a bicycle ergometer,

Ventilation rate increases with metabolic rate and can be used for indirect determination of the latter. The evaluation can be based on standard curves for the ventilation-metabolic rate relationship or on individual calibration curves (see heart rate).

Direct measurement of oxygen consumption

The most accurate and precise method is direct measurement of oxygen consumption. This method, however, requires expensive equipment and more interference with the worker. The method should be used when very detailed analysis is required. It should also be used for development of more modern and accurate tables of typical activities and work movements to be included in a revised version of ISO 8996.

Concluding remarks

As mentioned, the selection of method, is determined by the purpose and the accuracy prescribed by available heat stress evaluation method. Using the WBGT for a rough estimate of heat stress, only requires a classification of work according to the first method above (No. 1). With analytical models (such as PHS) the metabolic rate has a large impact on the calculation of heat stress. A 20 % overestimation can easily result in an exposure becoming hazardous when close to limit values. Several validation studies of the methods in ISO 8996 have indicated a clear tendency for a marked overestimation of metabolic rate, in particular for light to moderate work. Differences of up to 50 % have been observed between estimations with the Edholm scale (No. 4) and direct measurements (No. 6) (Giedratyte, et al. 1999, Kähkönen, et al. 1992).

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EVALUATION AND SELECTION OF THE CLOTHING: INFLUENCE ON EVAPORATION

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Introduction

During heat exposure heat loss from the human body becomes, with increasing ambient temperature, more and more dependent on evaporative heat loss for the maintenance of thermal balance. The capacity for evaporative heat loss is attenuated by the use of (protective) clothing, however. This clothing creates an additional resistance to vapour transport, which results in increased thermal strain.

For the reasons given above, knowledge of clothing vapour resistance is extremely important for the evaluation of heat stress. Unfortunately, this topic is also quite complex.

Three level approach

Screening: For the screening level, the main goal is to determine whether vapour resistance of the clothing worn might be a problem in terms of heat stress. For this purpose, the workplace needs to be evaluated for the presence of clothing that will hamper sweat evaporation.

Observation: If such clothing is present, one needs to make a more complete inventory of the clothing at the workplace that is studied. One needs to categorise the clothing for its resistance to vapour transport. This can be done on the basis of the amount of covered body surface (heat exchange surface), on the basis of the thickness of the clothing (thickness = resistance), and finally on the basis of any presence of special layers within the clothing that have an effect on vapour resistance that is not related to their thickness (semi- or impermeable layers).

Using this inventory, the likelihood of problems with limitations of sweat evaporation can be assessed as well as its most likely cause, and possibilities for improvement can be determined.

Analyses: In case no direct solutions for the observed problems are available, one will have to analyse the heat stress in detail using analytical models. For this purpose one needs the actual values of clothing heat resistance. Two problems arise in relation to the definition of the evaporative resistance to be used in the calculations. The first is that, in contrast to data on clothing insulation for dry heat loss, little data are available on evaporative resistance of clothing systems, and actual measurement of the vapour resistance is complex and expensive. The second is that even when a value for the clothing's evaporative resistance is obtained, this value is only valid for the specific condition in which it is obtained as it will change with the wearers activity level, the air movement around the clothing (wind), the wearers posture etc. Little is known on how this evaporative resistance changes with posture changes, movement or wind. These problems were tackled in the Biomed research.

Biomed research on vapour resistance

In order to enable the user of standards to estimate vapour resistance without actually measuring it, several approaches were studied. The most relevant ones are based on the observation that the relation between mass transport of water vapour through the clothing and heat transport by convection through the clothing in a certain condition has been shown to be the same for most air permeable clothing types. This principle is used in current standards, either through the use of the permeation efficiency factor F_{pcl} or through the use of the moisture permeability index i_m. Both representations were studied for effects of wind and movement. Though their behaviour was internally consistent, it was found that F_{pcl} showed changes that were contrary to users intuition (it became lower when wind or movement were present). i_m on the other hand did behave in accordance with users intuition (larger when wind or movement were introduced). As users appear to have great difficulties working with entities like vapour resistance of clothing, it was therefore chosen to work with i_m.

Approach through i_m: In ISO 9920 the derivation of R_T using the permeability index i_m is described:

$$R_T = \frac{I_T}{i_m \bullet L} = \frac{0.06}{i_m}\left(\frac{I_a}{f_{cl}} + I_{cl}\right)$$

Thus, when i_m and the clothing insulation I_T are known, the vapour resistance can be calculated. ISO 9920 provides i_m values for typical clothing configurations, with a rule of thumb i_m of 0.38 for normal one or two layer permeable garments. Within BIOMED, the calculation of clothing insulation was improved, the table for i_m was extended, and the effects of wind and movement on i_m were studied which resulted in an empirical model for this relation. Using this approach for the determination of dynamic heat and vapour resistance, the total procedure would then be:

- determine static and dynamic heat resistance (Holmer et al.)
- estimate the static vapour permeability (from example tables)
- Use the correction factor to determine $i_{mdynamic}$:

$$i_{m\,dynamic} = (1. + 0.013 \quad \Delta I_T + 0.00026 \quad \Delta I_T^{\,2} \quad) \bullet i_{m\,static}$$

$$with\ \Delta I_T = \text{reduction in } I_T \text{ in } \%$$

$$if\ \ i_{m\,dynamic} > 0.9, \quad i_{m\,dynamic} = 0.9$$

- From this, calculate $RT_{dynamic}$

$$R_T dynamic = \frac{I_T dynamic}{i_m dynamic \bullet L} \quad with \quad L = \text{Lewis constant} = 16.7\ {}^{\circ}C \cdot kPa^{-1}$$

Conclusion

The use of the reduction factor for evaporative heat transfer, F_{pcl}, does not provide proper corrections of clothing vapour resistance for conditions where the wearer is moving or exposed to wind. Also, though mathematically correct, it changes in the opposite direction as users expect, given its textual description. As it is observed that the change in the clothing permeability index, i_m, due to movement and wind is similar for different garment types, it is suggested that this parameter be used for the description of these effects in future standards.

EVALUATION AND SELECTION OF THE CLOTHING: INFLUENCE ON CONVECTIVE HEAT TRANSFER

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Introduction

Convective heat loss is an important part of the heat loss from the human body, especially in moderate climates. Convective heat loss is impeded by the still air layer on the surface of a person and by the clothing insulation. An important aspect of the convective heat transfer is the effect of wind speed and movements on the convective heat transfer coefficients of the surface air layer and the clothing. To evaluate heat strain it is essential to have knowledge on the insulative effects of clothing.

Three level approach

Screening: For the screening level, the main goal is to determine whether the insulation of the clothing worn might be a problem in terms of heat stress. For this purpose, the whole clothing ensemble that people wear needs to be considered and evaluated to look for clothing with a high resistance to heat loss.

Observation: If clothing with a relatively high insulation to heat loss is present, one needs to make a more complete inventory of the clothing at the workplace that is studied. One needs to categorise the clothing for its insulative properties in terms of the amount of covered body surface (heat exchange surface) and on the basis of the thickness of the clothing (thickness = resistance). Using this inventory, the likelihood of problems with limitations of heat loss can be assessed and possibilities for improvement can be determined.

Analyses: In case no direct solutions for the observed problems are available, one will have to analyse the heat stress in detail using analytical models. For this purpose one needs the actual values of clothing heat resistance. For many clothing ensembles there are tables available in which the insulation values are provided. However, it must be remembered that those insulation values are only valid for people standing still in the absence of wind. An important aspect of the Biomed research project was to identify equations that describe the effect of body movements and wind, not only on the surface air layer but also on the clothing insulation.

Biomed research on convective heat loss

As stated above tables are readily available to find static insulation values of different clothing ensembles. One aspect of clothing in convective heat transfer is that the area of heat exchange at the clothing surface is larger than at the body surface. This increase in surface area is called the clothing area factor (fcl) and is determined by:

$f_{cl} = 1 + 1.97 * Icl$ (Icl in m^2K/W)

or: $f_{cl} = 1 + 0.305 * Icl$ (Icl in clo)

The Biomed research project mainly focussed on the combined effect of movement and wind on the surface air layer and the clothing insulation. In the literature the clothing efficiency factor, F_{cl}, has been introduced, which is the ratio of the nude insulation and the clothed insulation:

$$F_{cl} = (I_{cl} * (h_c + h_r) + 1/f_{cl})^{-1}$$

In this way it was aimed to incorporate the effect of wind and movements on clothing insulation. However, F_{cl} only incorporates the effects of wind on the surface air layer ($h_c + h_r$) and not on the clothing itself.

Within the Biomed project it was aimed to add the effects of effective air velocity on the clothing insulation (I_{cl}). Havenith and Nilsson & Holmer have suggested different correction equations, based on human experiments and manikin measurements respectively. During the project the experimental data of both labs were merged and analysed together. As a result the following equations were derived for the effects of effective wind velocity on the surface air layer and on the clothing insulation:

$$CORR_{Ia} = EXP^{(0.047 \cdot Vair^2 - 0.472 \cdot Vair + 0.117 \cdot Vwalk^2 - 0.342 \cdot Vwalk)}$$

$$CORR_{Icl} = 1.044 \cdot EXP^{(0.066 \cdot Vair^2 - 0.398 \cdot Vair + 0.094 \cdot Vwalk^2 - 0.378 \cdot Vwalk)}$$

Analogous to Goldman's approach the effect of wind and movement were combined in one effective air velocity:

$$v_{eff} = v_{air} + 0.0052 \cdot (M - 58)$$

This allows for the reduction of clothing insulation due to body movements other than walking.

The Biomed "Predicted Heat Strain" model requires the static clothing insulation as an input variable. Within the model the clothing insulation is handled as follows:

- Based on the values for the wind speed and the work intensity provided by the user, the reduction factors of insulation of the surface air layer and the clothing are calculated ($CORR_{Ia}$ and $CORR_{Icl}$).
- These corrected values for the total insulation are then used in the model to calculate the convective heat loss from the subject.

Conclusion

The use of the efficiency factor for the effect of wind and movement on convective heat transfer, F_{cl}, does not provide proper corrections. Also, though mathematically correct, it changes in the opposite direction as users expect, given its textual description. In the Biomed project new equations are identified that correct not only the surface air layer insulation but also the clothing insulation to wind and movements.

LOCAL INSULATION, LOCAL EVAPORATIVE CAPACITY AND LOCAL SWEAT OUTPUT ALSO INFLUENCE THE OVERALL THERMAL RESPONSES AND THE ASSOCIATED TOLERANCE TIME.

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Required sweat rate is used for assessing the intensity of the thermal load by predicting the physiological strain applied to the human body. It has the advantage of considering all ambient parameters as well as the consequences of the insulation provided by the garments. In this sense, it is a very interesting concept, which helps the people involved in industrial human care to predict the durations of safe heat exposure.

As it is often the case for empirical indices, conclusions might be sometimes less appropriate than expected, because the observed reactions may differ between individuals due to morphological an/or functional differences : any index based on mean values will give results which fit an average population (for instance 95%) but not ALL individuals. The problem becomes acute when the question of heat tolerance is raised, not for a mean value, but for absence of any individual damage.

When an index does not strictly reflect the reality, it is always because individual factors are not considered. In case of required sweating, three main factors are obviously not considered as specific values:

- local evaporative heat transfer coefficients, (h_e) which depend on morphological factors (shape of the body) but also on physical factors (local air velocities).
- local sweat output capacity (physiological factor).
- local distribution of thermal insulation (physical or behavioural factor), expressed in "clo".

The purpose of this paper is not to question about the validity of any index dealing with the general physiological consequences of heat stress nor about its practical implications. It aims at pointing out the importance of some specific factors, locally distributed. Knowing them and acting on them may help for a better understanding of sweat efficiency variations and for improvement of the situations leading to limited exposure durations.

In many cases under which limited exposure time is recommended, high levels of skin wettedness are predicted and high sweat rates or low evaporation are involved. As high sweat rate is often a consequence of poor evaporative efficiency (η = E/SW) due to high wettedness level (w= E/Emax), any factor affecting E, Emax or SW will be of significant influence : this is the case for h_e, local insulation and sweating. The interactions of these three factors will impact the overall phenomenon, more of less depending upon their variations.

This presentation will clearly show the following:

- the head has a medium h_e value but a high sweat capacity and is almost always uncovered (no insulation). Skin wettedness may therefore not be as high as elsewhere on the body because Emax is never reduced. It might be wetted anyway because it can sweat profusely. Generally speaking, the head will appear as a body part to be carefully treated.
- the trunk has a relatively poor sweating capacity, has a low h_e (the lowest of all body parts) and its "clo" value is generally high; for these reasons, although the trunk corresponds to the widest body part, its efficiency in body cooling will be rather poor.
- the hands have both a high h_e, can sweat a lot, and are mostly uncovered. Hands could be considered as important body parts for evaporative heat dissipation : but hand surface areas are small.
- comparing arms and legs shows that it seems preferable to favour the legs because of the larger body surface involved in the evaporative mechanisms ; arms and legs have quite similar h_e values, sweating capacities and almost same clo values, although arms present a small but systematic advantage at these three levels.

In conclusion, looking at the various local influences due to air velocity (or air renewal) or due to thermal insulation, both acting on the absolute h_e value, and considering the local sweat output capacity may appear helpful for the people in charge of the industry worker protection. Reducing the physiological heat strain resulting from severe environmental exposure is possible on acting on the various body segments. Head and legs appear as interesting body parts if additional air supply can be provided; upper limbs (arms and hands) could also be considered when they can be safely uncovered.

Overall heat intolerance is the result of the sum of the local heat dissipation restrictions: small but additive local improvements can result in significant reductions of heat intolerance risks.

In the next future, some computer models should be available tools for assessments of specific effects associated in the local thermal influences: impacts could be evaluated in terms of physical, physiological, behavioural and even affective consequences.

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CONCERNING THE APPLICATION OF THE NEW SWEDISH PROVISONS "WORK IN INTENSE HEAT"

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Background

In Sweden, an estimated number of 5, 000 to 10, 000 workers in glassworks, steelworks, the rubber industry, the food processing industry, paper-mills and saw-mills are exposed to heat of such an intensity that there could be a risk of heat stress. In an enterprise climate, where the competition becomes harder and a lot of new small firms appear, the Swedish National Board of Occupational Safety and Health decided that Provisions aimed at protecting workers towards harmful heat exposure were needed.

Short description of the Provisions and problems encountered during their application

The Provisions, which are called "Work in intense heat" came into effect on the 1st of May 1998. They are focused on the prevention of heat stress and settles that the WBGT method as described in the standard EN 27 243 should be used to estimate heat stress. The reference values in table A of the standard are defined as maximum allowable values for the WBGT index. Measurements should be made according to EN 27 243 and EN 27 726. The Provisions do not give recommendations for prevention of risks associated with short exposures in dry climates at very high globe temperatures, or in very humid climates at high natural wet-bulb temperatures.

After the Provisions came in the effect it has become apparent that their applicability for work in intense heat in practice is less than we would have thought. This is partly due to the fact that the Provisions do not handle

- short-time exposures at extreme conditions
- use of protective clothes or equipment
- exposure of intense IR-radiation that could lead to burns or eye problems
- long-time exposures at conditions were the WBGT method is not applicable

Questions in relation to the application of the WBGT standard

A number of questions have arisen in relation to the application of the WBGT standard

- In which temperature interval may the WBGT method be used?
    - The standard defines temperature intervals for each type of instrument. Should these intervals also be regarded as defining the allowed interval for the WBGT method.
    - Unfortunately definitions of the instruments are different in EN 27 243 and EN 27 726.
- The upper limit for the natural wet-bulb temperature is low compared to exposures that appear in the industry. EN 27 243 sets the limit for the natural wet-bulb temperature to 40 °C while ACGIH gives an upper limit of 50 °C.
- How should one act at temperatures higher than those defined for the instruments? Are such exposures so stressful that protective clothes, facemasks etc always should be used under such situations or are the limits introduced because the WBGT method no longer estimates heat stress outside these intervals?
- How much should the reference values be raised respectively lowered for different types of working garments (with Icl different from 0.6 Clo)?
- What is the shortest exposure time for which the WBGT method could be applied?
- If the WBGT method is used for natural wet-bulb temperatures higher than 40°C it seems to allow much longer exposure times than are actually possible to endure.
- Two different commercial instruments gave very different results at low humidity.

Concerning short exposures during extreme conditions

Two types of exposure occurring in the industry are short-time exposures in a dry climate of 140-160 °C and in a very humid climate with natural wet-bulb temperatures of 50-60 °C. During these short-time exposures the risk of burns on the skin and the respiratory tract sets the limit rather than heat stress. It is important to have an idea of the longest exposures that can be tolerated during such exposures and it would be valuable to be able to consult a standard that gave limits for these types of exposure and which included a "smooth" transition to the WBGT standard.

Short-time exposures at very high relative humidity

In Sweden the saw-mill industry gives recommendations (the actual recommendations are more extended) for work in wood dryers at different wet-bulb temperatures;

- In the dryer at wet temperatures of 45 °C or higher it is suggested that the whole body should be covered with clothes; gloves, face visor, isolating coverall and a helmet hood
- Maximal exposure times for different wet-bulb temperatures are given as:

wet-bulb temp. (°C)	maximal exposure time (min)
25	no limit
30	180
35	90
40	40
45	20
50	5
55	1

- At exposure times longer than those in the table it is suggested that a breathing mask provided with air supply should be worn.

At the lower natural wet-bulb temperatures the WBGT standard would allow shorter exposure times per hour than the table above, while at the higher natural wet-bulb temperatures it would allow far longer exposure times (if it was applicable). A reference to a few scientific publications suggests that the recommendations given above for high wet temperatures are probably reasonable.

Short-time exposures at very high globe temperatures

A rudimental review of the literature shows that for work in very dry situations:

- Risk of burns caused by naked skin getting in contact with heat conducting material is very high when the temperature gets high (also seen in EN 563).
- Very hot air may cause pain and short after that burns may develop. Exposure time for unbearable pain is given in the table below (1).

Table II				
temp °C	tolerance time		temp °C	tolerance time
170	approx 1 min		140	approx 1 min 45 sec
160	approx 1 min 15 sec		130	approx 2 min
150	approx 1 min 30 sec		120	approx 2 min 20 sec

1) Extracted from figure 2 in P Webb (1963) Pain limited heat exposure in Temperature: Its Measurement and control in Science and Industry Vol 3 Part 3. 245-250.

Considering a hypothetical case of an acclimatised worker doing light work in a climate with globe temperature =120 °C (highest allowable according to the standard) and natural wet-bulb temperature=34 °C (air with 40% humidity at 25 °C warmed to 120 °C) and being able to rest in WBGT=20 °C, the WBGT method would allow an exposure time equal to 15 min.

Conclusions for an eventual revision of the Provisions

In case of a revision of the Provisions it might be a good idea to take care of all common types of work in hot climates as well as intense heat radiation. It might also be a good idea to explain the differences between uncomfortably warm situations (as taken care of by EN-ISO 7730) and physiologically dangerous heat exposures as taken care of by the WBGT-standard.

INVESTIGATIONS ON THERMAL WORKING CONDITIONS AT WORKPLACES IN A PAPER MANUFACTURING COMPANY : RESULTS OF A STEPWISE APPROACH

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Introduction

Paper and cardboard are used by a great number of persons. Germany is first in Europe in paper manufacturing and ranks 6 in the world after the USA, Japan, Canada, Russia and China. The company considered in the present study produces about 520,000 tons of paper-products every year. In spite of highly modern manufacturing facilities, the thermal working conditions in this production field are still very stressful due the high temperatures, humidities and workloads.

Field of investigation

Many highly specialised machines are needed for manufacturing paper. The design and combination of the different units of equipment are determined by the type of products (paper or board) as well as by the type of raw materials used. Therefore, the “standard paper mill” does not exist. However, in principle, the basic paper-manufacturing process may be divided into four main areas: stock preparation, papermaking, surface improvement (coating or laminating) and finishing.

The paper manufacturing process requires high temperatures and high humidities, which influence the environmental conditions at the workplaces. These air temperature and humidities are the main source of thermal problems and represent a risk for the employee’s health. For this reason, the company asked for an assessment of the climatic conditions at the workplaces. A step approach was applied to develop advises for prevention and control measures.

Evaluation of the working conditions

Workplaces of three important production sections with known climatic problems were evaluated: the continuous grinder, the paper machine and the coating machine. In these three sections, were selected seven particular workplaces where the employees are exposed the most to the thermal environment.

The strategy applied is based on the stepwise approach developed in the BIOMED HEAT research (Malchaire et al., 1999). This strategy in four successive stages – Screening, Observation, Analysis and Expertise – analyses the thermal problems and describes and justifies the optimum prevention and control measures. This allows to approach and solve the problems progressively with the complementary competencies of the workers and other people from the company and if necessary with the assistance of occupational health specialists and experts.

The criteria to fulfil at each stage will be described and discussed, as well as the detailed results as an example at one of the seven workplaces.

At the Screening stage, the standardised documentation and evaluation instrument BDS was applied. At the Observation stage, the standardised working-sheets proposed by the BIOMED strategy were used. As a result, the Analysis stage appeared necessary and measurements were taken at the workplaces, in different conditions. The metabolic rate was assessed for several tasks, using the tables of group assessment and taking into account the durations.

All investigated workplaces were classified as having a thermal problems, according to national laws. Prevention measures were derived and presented to the company.

The following table gives an example of the result of the Observation stage for one particular workplace. The anticipated situation takes into account the supply of dry and cooled air.

X - present situation				O - anticipated situation			
	-3	**-2**	-1	0	1	**2**	**3**
Air temperature					**O**		**X**
Humidity				**O**		**X**	
Thermal radiation				**O**	**X**		
Air movements					**O**	**X**	
Work Load					**O X**		
Clothing				**O X**			
Opinions of the workers						**X**	

The following table summarises the results of the measurements and assessments performed during the analysis stage.

Investigated workplace	working conditions (time-weighted average values)						
	t_a [°C]	RH [%]	t_W [°C]	v_a [m/s]	E_{eff} [W/m²]	M [W]	I_{cl} [clo]
Wood-grinding-plant (machinist)	35,2	92	33,0	0,4	48	420	0,6
Wood-grinding-plant (assistant)	33,2	58	23,6	0,5	83	410	0,6
Manufacturing-plant (1.assistant)	35,8	60	27,0	0,4	84	380	0,6
Manufacturing-plant (3. assistant)	30,4	58	23,9	0,4	51	400	0,6
Coating plant (machinist)	33,6	47	24,3	0,6	120	510	0,6
Rollcoating plant (machinist)	34,1	57	26,9	0,4	114	400	0,6
Paper and coater (machinist)	38,0	48	28,2	0,5	218	400	0,6

Analysis: thermal working conditions at working places in a paper manufacturing company ((the highlighted workplace will be presented in detail)

THERMAL EVALUATIONS IN GLASS INDUSTRIES

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In this communication thermal environmental evaluations in glass industry are reported. Evaluations were performed in two glass industries placed in Toscana, a region in the centre of Italy. About 60 persons were examined, physical parameters and physiological strains (tympanic temperature and sweat rate) were measured. Obtained results and indices calculated according standards in force are reported.

PRACTICAL USE OF NF EN 12 515 STANDARD WITH A COMPUTER PROGRAMME

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Introduction

Safety is a major concern during maintenance works in nuclear power plants and risks linked to hot thermal working conditions are taken into account with the subcontractors in order to avoid all accidents.

The shutdown of a nuclear power plant for maintenance has to be as short as possible for economical reasons. Often, the medical department is asked to give rapidly an indication of how long the subjects may work in these hot conditions. This is the case, for instance, when commissioning the overhead crane in the reactor building or when controlling operations inside the vapour generator. These works have to be done as soon as possible, while the equipment is hardly cooled.

In practice, the medical or safety staff carries out site measurements of the black globe temperature, the air temperature, the wet bulb temperature or the relative humidity. Default values are taken for the air velocity and the clothing insulation. Values of metabolic rate are selected according to the type of work.

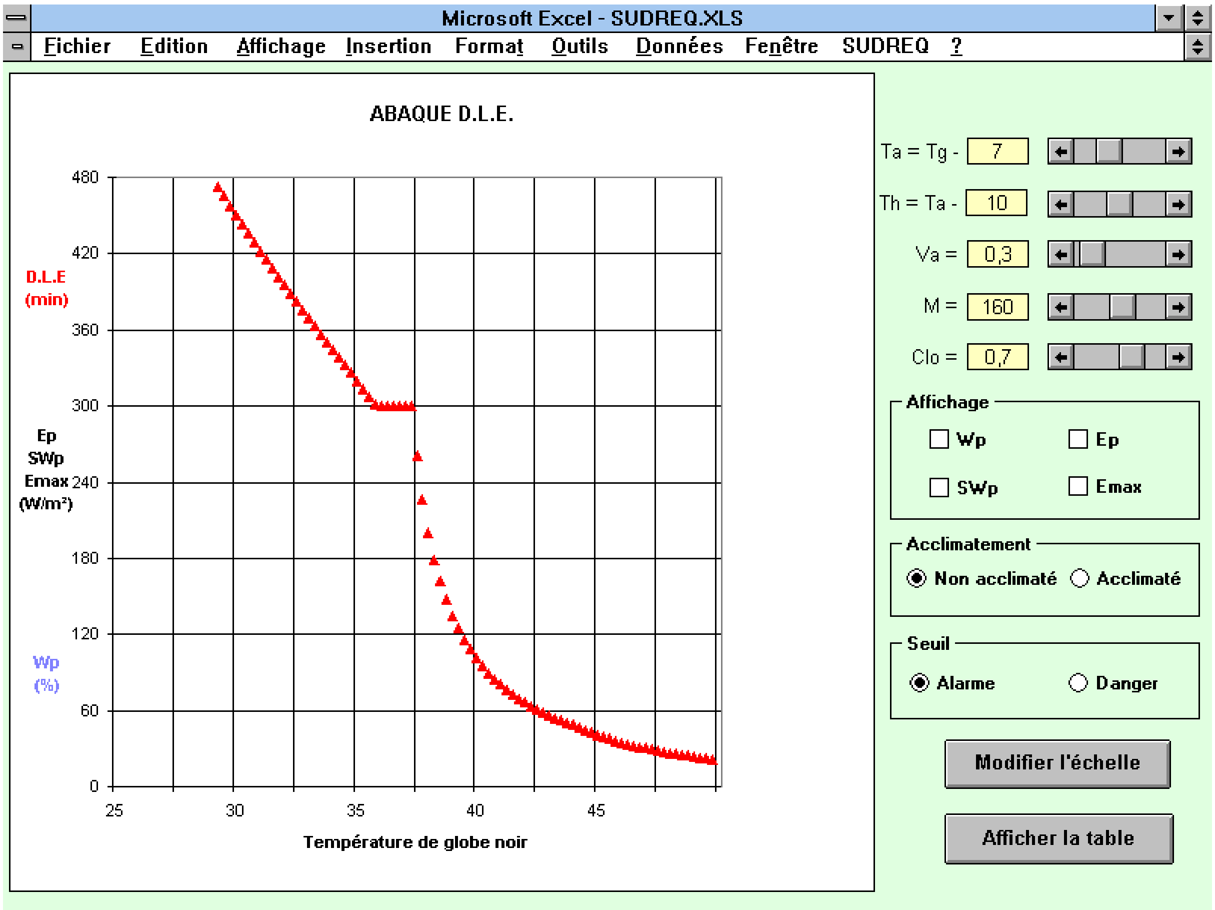
In optimum conditions, one person makes the measurements and transmits them to another who makes the estimation using a computer programme. When this is not possible, nomographs are used to give directly on the site a rough estimate of the duration of exposure (DLE).

It is essential that nurses or technicians making the measurements understand how the DLE is calculated. A graph of the DLE as a function of the parameters is important for that purpose.

This paper describes the computer programme developed at EDF for using the NF EN 12 515 standard in practice.

Presentation of the programme

- Screen used for the data: the climatic parameters and the job characteristics are introduced. Messages appear if aberrant data are keyed in (for example: air temperature and wet bulb temperature leading to a negative partial vapour pressure).
- Screen with the results: The user may choose between acclimatised and not acclimatised subjects and between the alarm or danger threshold. The DLE and corresponding messages are displayed. The operative temperature and water loss are given for information.
- Report: a report can be printed, in order to be circulated to the people concerned, such as foremen, safety officers...
- Graph: this screen shows the DLE as a function of the globe temperature. The other parameters may be modified, using sliders and the DLE graph is changed accordingly. The skin wettedness, the predicted evaporation rate, the predicted sweat rate and the maximum evaporation rate can also be displayed.



Conclusion

The computer programme makes possible to use with great flexibility the NF EN 12 515 standard. It is actually compulsory for practical use by nurses or technicians. A display of the DLE curve allows a better understanding of the prediction model.

It is hoped that the equations for the calculation of DLE in the revised standard will be clearly written, so that they can be included with no major problem in such a programme.

References

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INTRODUCTION: REVIEW OF ISO 7933

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ISO 7933 *"Analytical determination and interpretation of thermal stress using calculation of the Required Sweat Rate"* was published for the first time in 1989 after many years of development and many different versions inside ISO working group TC/59/SC5/WG1.

This standard was abundantly criticised and many papers were published comparing one version (not always specified) of the Required Sweat Rate index to sets of data.

Although such comparisons are limited to the particular set of data, the main criticisms concerned

1. the prediction of the skin temperature
2. the influence of the clothing on convection, radiation and evaporation
3. the combined effect of clothing and movements
4. the increase of core temperature linked to the activity
5. the prediction of the sweat rate in very humid conditions
6. the limiting criteria and in particular the "alarm" and "danger" level
7. the maximum water loss allowed.

This session will review the modification brought to the following algorithms.

1. Predicted skin temperature

The ISO 7933 algorithm was proposed in a study by Mairiaux et al. (1987) based on a limited set of data for mainly nude subjects. The skin temperature appeared to decrease with the clothing. The extensive BIOMED database was used to check and extend the validity of this expression.

2. Respiratory heat losses

Although these losses are quite limited in hot climates, compared to neutral and cold climates, they are often of the same order of magnitude than convective losses.

Furthermore, the heat storage is determined by the difference between the required and predicted evaporation rates. The respiratory losses are significant relative to this difference.

3. Skin core temperature weighting

ISO 7933 is implicitly assuming a skin-core weighting of 0.3-0.7 regardless of the skin and core temperature. This is contradictory to the literature and must be revised.

4. Heat storage distribution

The distribution of the heat storage between the core and the skin layer has to be investigated in order to be able to derive a valid estimate of the core temperature.

5. Prediction of the rectal temperature

As rectal temperature remains, with heart rate, the easiest physiological parameter to record at the work place, the modified model must attempt to predict it directly.

6. Increase in t_{co} due to activity

One main objection to the ISO 7933 method of interpretation was that it did not take into account the normal increase in core temperature due to activity even in moderate and neutral climate.

The PHS model will attempt to include this in the prediction of the core temperature.

7. Evolution of t_{sk} and SW with time

By far the main limitation of the ISO 7933 standard is to assume that a steady state is reached instantaneously. This makes rather impossible to predict the situation in case of intermittent exposure. Furthermore, heat accumulation is assumed to remain the same during the whole exposure, while it obviously tends to 0, towards an equilibrium state in core temperature.

Modifications will be brought to the model so that it makes it possible to predict the sweat rate, the skin and rectal temperatures at any time, taking into consideration all of the past exposure.

8. Evaporation efficiency

ISO 7933 adopted an expression for the computation of the evaporative efficiency as a function of skin wettedness. The validity of this expression must be confirmed based on more recent publications.

In addition, the algorithm presented in ISO 7933 assumes that the efficiency remains 50% when the required evaporation rate E_{req} is greater than the maximum evaporation rate E_{max}. In this case, the predicted evaporation rate is limited quite logically to E_{max}, but the sweat rate is predicted equal to $2.E_{max}$. For more humid environments, E_{max} is decreasing and therefore also the predicted sweat rate: a subject would sweat less in extremely humid climates. This is contradicted by the literature and the validity of the evaporative efficiency prediction for very humid conditions must be revised.

9. Maximum wettedness

ISO 7933 assumes that the maximum wettedness for unacclimatised subjects is limited to 0.85. This has to be confirmed.

10. Limit criteria

ISO 7933 proposed limits for acclimatised and unacclimatised subjects at 2 levels of protection:

- "alarm" level supposed to protect the entire population
- "danger" level supposed to protect most of the workers.

It was decided to revise these criteria because too vague and too stringent. Indeed, as will be seen later, the core temperature limit of 38°C in itself offers a large degree of safety, as heat strain effects are likely to occur only at temperatures of 39°C or higher.

11. Maximum Sweat Rate

ISO 7933 assumes constant values of maximum sweat rate for acclimatised and unacclimatised subjects. These values are reduced by a factor of 2 when the metabolic rate is smaller than 65 W/m^2.

This discontinuity leads to inconsistent results and must be revised. In addition the "danger" and "alarm" criteria will be abandoned and new values of SW_{max} must be included.

12. Maximum water loss

The limit values adopted in ISO 7933 must be revised for the same reason. In addition, some researches in the field, and particularly in mines, questioned these limits.

13. Limit of core temperature

The limit of 38°C commonly adopted and implicitly adopted in ISO 7933 was specified for the first time in a WHO document in 1969. Since then, this document was often quoted and altered. A revision of the basis of this limit and of the protection that it offers is necessary.

References

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PREDICTION OF THE SKIN TEMPERATURE

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Introduction

Heat stress indices based on the heat balance equation use either a fixed mean skin temperature or a prediction model, which incorporates some or all physical factors of the thermal environment as well as the clothing insulation and the metabolic rate. A fixed value is easy to use, however, in situations with intermittent exposure to heat, this can result in severe over- or under-estimations in the heat balance equation. The model used in the Required Sweat Rate index (ISO 7933) was considered to offer the best prediction so far as it is valid for a wide range of conditions. This model however was criticised for not being valid in conditions with high radiation and high humidity.

The aim of the present paper is to improve the prediction model using a very large database. The study was conducted as part of a concerted action in the frame of the BIOMED-2 research programme, conducted in co-operation by nine research teams across Europe.

Material and methods

A common structure was defined to pool in one database all different data from the partners. A total of 1113 files were gathered, where each file included minute by minute values of 10 parameters of stress and strain.

Using a special graphic programme, data points in steady state conditions were selected from each experiment, where a set of selection criteria was applied. Each observed skin temperature was a weighted average of at least 4 local measurements. As few data (less than 10%) were available for women, it was decided to derive the t_{sk} prediction model in using only the data from studies on men. Accordingly, the final TSK database included 1999 data points coming from 1399 conditions with 377 male subjects.

The analysis was performed separately for nude ($I_{cl} \leq 0.2$ clo) and clothed ($0.6 \leq I_{cl} \leq 1.0$ clo) subjects. The final TSK database was then split into 1212 data points for nude subjects and 787 data points for clothed subjects.

The relationship between the mean skin temperature, the primary parameters, the metabolic rate and the rectal temperature was assumed to be an additive model. A bootstrap method was used for the multiple correlation analysis (1000 samples).

Results

The mean age of the subjects amounts to 28.1 (± 10.3) years. Although this sample is rather young in average, it covers the ranges of age, weight and dimensions of the general working population.

The range of climatic conditions is rather broad and includes high radiant heat loads, high humidities and high air velocities. Major differences between the two subsets for nude and clothed subjects were found for air temperature, partial vapour pressure and the metabolic rate.

The Pearsons correlation coefficients between all pairs of independent variables were found to be sufficiently low so that multicollinearity problems in the linear regression model are rather unlikely.

The nonparametric bootstrap for the subset of <u>nude subjects</u> yielded to a prediction model without the metabolic rate being significant ($p > 0.05$):

$$t_{sk} = 7.19 + 0.064\ t_a + 0.061\ t_r + 0.198\ p_a - 0.348\ v_a + 0.616\ t_{re}$$

The multiple correlation coefficient between observed and predicted values is equal to 0.86 and 83.3% of the predicted skin temperatures are within the range of ±1°C of the observed values.

The following prediction model was obtained for the <u>clothed subjects</u>:

$$t_{sk} = 12.165 + 0.020\ t_a + 0.044\ t_r + 0.194\ p_a - 0.253\ v_a + 0.003\ M + 0.513\ t_{re}$$

Although the correlation coefficient (0.77) is lower than for the nude subjects, 81.8% of the predicted values are within the ranges of ±1°C of the observed values.

Discussion

The purpose of this study was to derive an improved model for the prediction of the mean skin temperature in warm and hot environments. The resulting models are based on the largest database ever assembled, from nine research laboratories all over Europe and in a wide range of ambient conditions. It can therefore be anticipated that the model will be valid for most situations in industry and for the general working population. Particularly the present models extend the validity to conditions with high radiant heat load or high humidity.

The comparison between the two models for nude and clothed subjects shows that the clothing decreases the influence of the air and mean radiant temperatures. This could be expected as the dry heat exchanges are reduced. On the contrary, the influence of the humidity remains approximately the same. It must however be mentioned that normal cotton clothes were used in all the reported studies.

The models clearly show an improvement of the prediction accuracy when the rectal temperature is included. Such an inclusion is justified physiologically, at least for warm and hot environments, as, through thermo-regulatory mechanisms, the core and skin temperatures are related to each other.

The current model used in ISO 7933 showed considerably smaller correlation coefficients (nude: 0.75, clothed: 0.56) when applied to the present database. The fact that the prediction for the nude subjects, using the ISO expression are much better than for clothed ones confirms the limitations already known.

The relevancy of the new expressions can also be tested by comparison with a fixed value of 36°C for the mean skin temperature. The average observed skin temperature in the present entire data set (N=1999) was equal to 35.6°C which is rather close to this fixed value. However, only 50.5% of the observed values were between 35°C and 37°C. As the highest temperatures are observed in the more severe exposure conditions, the underestimation of the skin temperature when using the fixed value would clearly lead to errors in heat balance calculations, particularly in the evaluation of body heat storage.

The present prediction models will be included in the revision and improvement of the ISO standard 7933. As few data were available in the database for clothing insulation values in the range 0.2 to 0.6 clo, a linear interpolation between the prediction for nude and for clothed subjects will be recommended.

THE PREDICTED HEAT STRAIN INDEX: Modifications brought to the required Sweat Rate index

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Respiratory evaporative (E_{res}) and convective (C_{res}) heat losses

Based on the work done by Livingstone et al. (1994) and Varene (1986), the following expressions were derived (with both C_{res}, E_{res} and M in Watts or in Wm^{-2})

$$C_{res} = 1.52\ 10^{-3}\ M\ (28.6 + 0.641\ p_{a,in} - 0.885\ t_{in})$$

$$E_{res} = 1.27\ 10^{-3}\ M\ (59.3 + 0.53\ t_{in} - 11.63\ p_{a,in})$$

Mean body temperature

From papers by Käkkönen (1993) and Colin et al. (1971), it is assumed that the relation between the "mean body temperature" (t_b), the rectal (t_{re}) and the skin temperature (t_{sk}) takes the form:

$$t_b = \alpha\ t_{sk} + (1 - \alpha)\ t_{re},$$

with.

- $\alpha = 0.30$ for $t_{re} < 36.8°C$
- $\alpha = 0.10$ for $t_{re} \geq 39°C$.
- α varies between 0.3 and 0.1 according to $\alpha = 0.3 - 0.09\ (t_{re} - 36.8)$.

Distribution of the heat storage in the body

Figure 1 illustrates the distribution of temperature at time (i-1) and time i in case of the storage of

$dS_i = Q_i - Q_{i-1}$ during minute i,

with

- Q_{i-1} : the total heat content of the body at time i-1
- Q_i : the total heat content of the body at time i

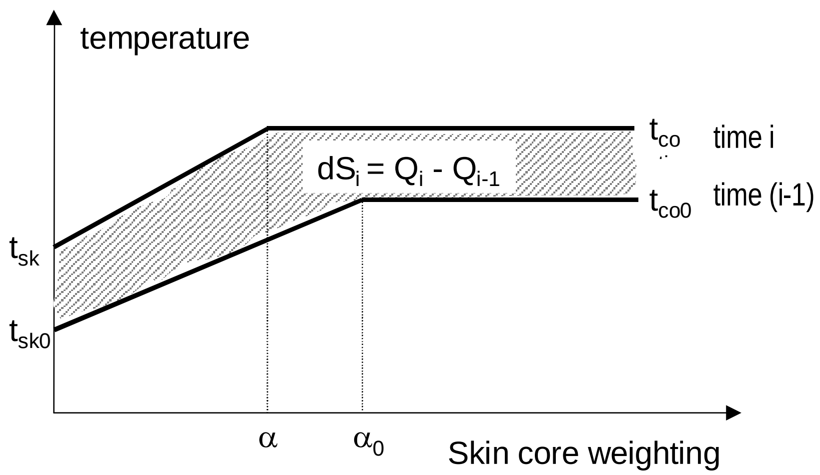

Figure 1: Distribution of heat storage in the body at times (i-1) and i

From this, it can be computed that:

$$t_{co} = \frac{1}{1-\frac{\alpha}{2}} \left[\frac{dS_i}{c_p} + t_{co0} - \frac{t_{co0} - t_{sk0}}{2}\alpha_0 - t_{sk}\frac{\alpha}{2} \right]$$

α and t_{co} have to be determined by iteration knowing that α varies as a function of t_{co} as indicated above.

Prediction of the rectal temperature (t_{re}) from the mean core temperature

According to Edwards et al. (1978), the rectal and oesophageal temperatures are linked by an expression such as:

$$t_{oe} = a\, t_{re} + b \frac{dt_{re}}{dt} + c$$

where dt_{re} is the increase in t_{re} from one minute to the next.

From the database it was found that: $t_{oe} = 1.31 + 0.962\, t_{re} + 7.03\, dt_{re}$

Assuming that $t_{co} = \frac{t_{oe} + t_{re}}{2}$, the following expression was derived

$$t_{re} = t_{re0} + \frac{2\, t_{co} - 1.962\, t_{re0} - 1.31}{9}$$

Exponential averaging for t_{sk}, SW

As shown by Malchaire (1991), the skin temperature and the sweat rate at time i can be computed according to the following expression:

$$V_i = V_{i-1}\, k + V_{max}\,(1-k)$$

where V_i is the value at time i

V_{i-1} is the value at time (i-1), Δt min before

V_{max} is the target value

$k = \exp(-1/\tau)$

τ is the time constant (in minutes).

Malchaire (1991) has reported values of the time constants equal to

- 3 minutes for skin temperature
- 10 minutes for sweat rate.

Evaporative efficiency of sweating

The predictions using the Hettinger et al. (1985) expression are very close to the recent data from Alber and Holmér (1994). The expression adopted in the current ISO-Standard 7933 (1989) can therefore be confirmed for the majority of workplaces, for a required skin wettedness smaller or equal to 1.

Problems, however, occur under very humid conditions, where, according to this expression and since the wettedness is limited to 1, a subject would sweat less. This is contradicted by the results of Zintl (1979) and Kohler (1976).Therefore the fact must be questioned that the sweating efficiency becomes and stays equal to 0.5 regardless of the sweating, as soon as the surface temperature is completely wet.

Actually, the skin being 100% wet, it is reasonable to assume that the layer of water can increase if the air humidity increases and therefore the efficiency continues to decrease.

The relationship can then be described by

$\eta = 1 - w^2/2$ for $w < 1$

$\eta = (2 - w)^2/2$ for $1 < w < 1.7$

$\eta = 0.05$ for $w > 1.7$

The predicted evaporation rate remains estimated using w limited to w_{max}: $E_p = w \; E_{max}$

while the predicted sweat rate is a function of η calculated above: $SW_p = E_p / \eta$.

w_{max} limit for non-acclimatised subjects

Based on works by Candas et al. (1979) and Alber-Wallerström and Holmér (1985), the value of 0.85 presently used in ISO 7933 is confirmed.

Maximum sweat rate: SW_{max}

Based on the publications by Gosselin (1947) and Araki et al. (1979), it is suggested to estimate the maximum sweat rate using the expression:

$$SW_{max} = 2.6\,(M - 58) \quad g/h \qquad \text{with M expressed in W}$$

in the range from 650 and 1000 g/h.

Expressed in Watts per square meter, this can be approximated by:

$$SW_{max} = M - 58 \quad W/m^2$$

in the range from 250 and 400 W/m^2

For acclimatised subjects, the sweating in a given environment is known to be greater and many researches report an increase of the sweat rate by a factor of 2 compared to unacclimatised subjects. This however does not refer to the maximum capacity for sweating.

Excluding the studies for which the maximum capacity was not reached, it appears that the maximum sweat rate would increase only, in average, by a factor of 25% for acclimatised subjects (Havenith 1997).

Increase in t_{co} associated with M

According to Saltin and Hermansen (1966), in a neutral condition, the equilibrium core temperature at a given metabolic rate is

$$t_{COR} = 0.002\,M + 36.6 \quad \text{(M expressed in Watts)}$$

and t_{co} reaches t_{COR} with a time constant of about 10 minutes.

It can be assumed that the body does not attempt to loose this heat storage and therefore does not sweat for it. Therefore SW_{req} is not determined from E_{req} but from $E_{req} - dS_R$, where dS_R is the heat accumulation at a given time to reach this equilibrium temperature.

Limit of internal temperature

The WHO technical report No 412 published in 1969 stated: *"it is inadvisable for deep body temperature to exceed 38°C in prolonged daily exposure to heavy work."*

This 38°C figure was proposed for the average subject, so that the probability of a particular subject to suffer from any heat disorder is negligible.

From works by Wyndham et al. (1965), two maximum rectal temperatures could be adopted

- 39.2°C which *"may rapidly lead to total disability in most men with excessive, often disturbing, physiological changes".*
- 42°: the maximum internal temperature to avoid any physiological sequels.

The probability for reaching these temperatures might be limited as follows:

- for 42°: less than 10^{-6} (less than one severe heat stroke every 4 years among 1000 workers) (250 days/year)
- for 39.2°: less than 10^{-3} (less than 1 person at risk among 1000 shifts).

From data by Wyndham and Heyns (1973) and Kampmann (1997a), it was found that the mean rectal temperature should be limited to 38°C as suggested by the WHO document to reach these low probabilities.

Maximum dehydration and water loss

Candas et al. (1985) reported that a 3% dehydration induces a "*hypertonic hypovolemia associated with increased heart rate and depressed sweating sensitivity*". The 3% figure can then be accepted as the maximum dehydration in industry (not in the army or for sportsmen).

Kampmann (1997b) reported, in hot working conditions in coalmines, with exposure lasting 4 to 8 hours, an average rehydration rate of 60%, regardless of the total amount of sweat produced (ranging from 1000 to 6000 g). Considering only the total sweat losses per shift greater than 2000 g, these data show that 95% of the subjects had a rehydration rate greater than 40%.

Based on these figures, it can be assumed that the maximum water loss is equal to

- 3% / (1 – 0.6) = 7.5% of the body mass for an average subject
- 3% / (1 – 0.4) = 5% of the body mass for 95% of the working population.

Influence of the radiation protective clothing

The model concerning the influence of the clothing characteristics on convection and radiation is valid only if the clothing has "normal" reflective characteristics.

When a reflective clothing is used (reflection coefficient F_R) covering the fraction A_p of the body surface.

A correction factor F_{clR} is introduced in the computation of the dynamic radiation coefficient:

$$F_{clR} = (1 - A_p)\, 0.93 + A_p \; F_R$$

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VALIDATION OF THE PHS MODEL

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Selection of the data points

The data gathered from the 8 partners led to a database including 1113 experiments with the minute per minute data collected for the primary parameters (t_a, P_a…) and for the physiological factors (t_{re}, sweat rate…). The database for lab experiments was randomly divided in two subsets, one for the development of the model (subset 1: 369) and one for the validation phase (subset 2: 378).

Most of them concerned men (1020) and 452 not acclimatised persons for 661acclimatised.

More than 50% of the lab experiments concerned nude subjects (clo value ≤0.2), while 95% of the field experiments were for clothed workers (clo value greater than 0.5).

The cumulative distributions of the 6 primary parameters for all lab and field experiments were computed.

From the 95% confidence intervals of the primary parameters, it is concluded that the model will only be validated for the parameters in the following ranges:

Ranges of validity of the PHS model		
	Min	Max
t_a °C	15	50
p_a kPa	0	4.5
t_r-t_a °C	0	60
v_a m/s	0	3
M w	100	450
I_{cl} clo	0.1	1.0

The PHS model makes possible to predict minute per minute sweat rate and rectal temperature. However, these parameters were observed at discrete occasions. In order to give to each experiment a statistical weight proportional to its duration, it was decided to select points using the following criteria:

- for the sweat rate: only use the mean sweat rate over the whole experiment;
- for the rectal temperature, selection of one data points per hour in each experiment according to several criteria.

Table 1 gives the numbers of data points selected.

Validation in laboratory experiments

Table 1 gives the results of the linear regressions between the observed and predicted values of rectal temperatures and sweat rates for lab (subset 1 and subset 2), for field and for both lab subsets together.

TABLE 1 – Regressions between observed and predicted rectal temperatures and sweat rates

	Lab experiments			field experiments
	subset 1	subset 2	subset 1 & 2	
sweat rate (g/h)				
n	327	345	**672**	**237**
observed (m ± s)	415 ± 159	432 ± 183	**424 ± 172**	**317 ± 187**
predicted (m ± s)	448 ± 151	454 ± 157	**451 ± 154**	**344 ± 132**
slope	0.786	0.900	**0.848**	**1.056**
intersection	63	23	**41**	**-46**
r	0.7461	0.7730	**0.7601**	**0.7448**
alpha	0.911	0.924	**0.918**	**0.851**
alpha IC95%	.537 - 1.506	.543 - 1.539	**.540 - 1.523**	**.328 - 1.936**
Obs - Pred (m ± s)	-33.2 ± 110.4	-22.1 ± 117.4	**-27.5 ± 114.1**	**-26.7 ± 125.1**
rectal temperature				
n	938	999	**1937**	**1028**
observed (m ± s)	37.44 ± 0.47	37.46 ± 0.48	**37.45 ± 0.47**	**37.40 ± 0.44**
predicted (m ± s)	37.46 ± 0.47	37.48 ± 0.48	**37.46 ± 0.47**	**37.40 ± 0.34**
slope	0.639	0.668	**0.664**	**0.770**
intersection	13.49	12.43	**12.57**	**8.60**
r	0.6444	0.6712	**0.6585**	**0.5940**
alpha	1.000	1.000	**1.000**	**1.000**
alpha IC95%	.979 - 1.020	.980 - 1.020	**.980 - 1.020**	**.981 - 1.019**
Obs - Pred (m ± s)	-0.01 ± 0.40	-0.01 ± 0.38	**-0.01 ± 0.39**	**-0.01 ± 0.36**

The slopes and coefficients of the linear regressions are about identical for the two lab subsets. Therefore the results will be presented for both subsets together.

Figure 1 compares the predicted and observed sweat rates.

The 95% confidence limits of the values are computed in the polar co-ordinates in order for the uncertainty to be proportional to the sweat rate.

The equation of the mean polar line is: $SW_{obs} = 0.918 * SW_p$ (with the 95% CI: 0.540 - 1.523)

Figure 1 shows that the regression line is about identical to the 45° line. Three points are higher than the upper limit of the 95% confidence interval. They come from three different partners and demonstrate the influence of interindividual differences. Indeed, for identical experiments but with other subjects, the data are above or below the regression line and in the confidence interval. The same is true for the data points below the 95% confidence interval lower limit.

FIGURE 1 - Observed and predicted sweat rates (with the 95% confidence interval) in the 672 laboratory experiments

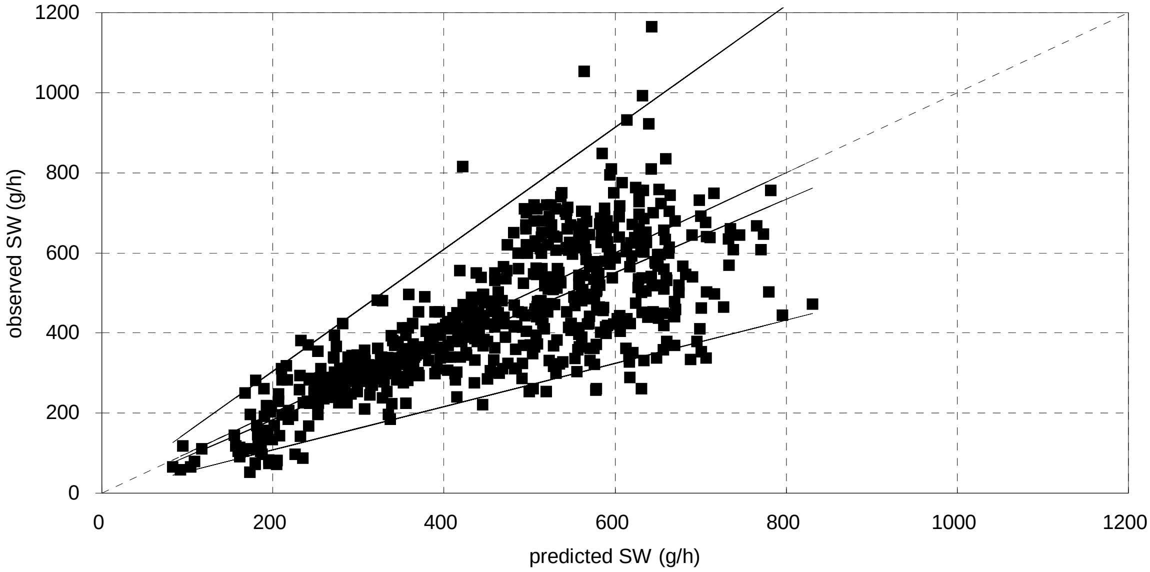
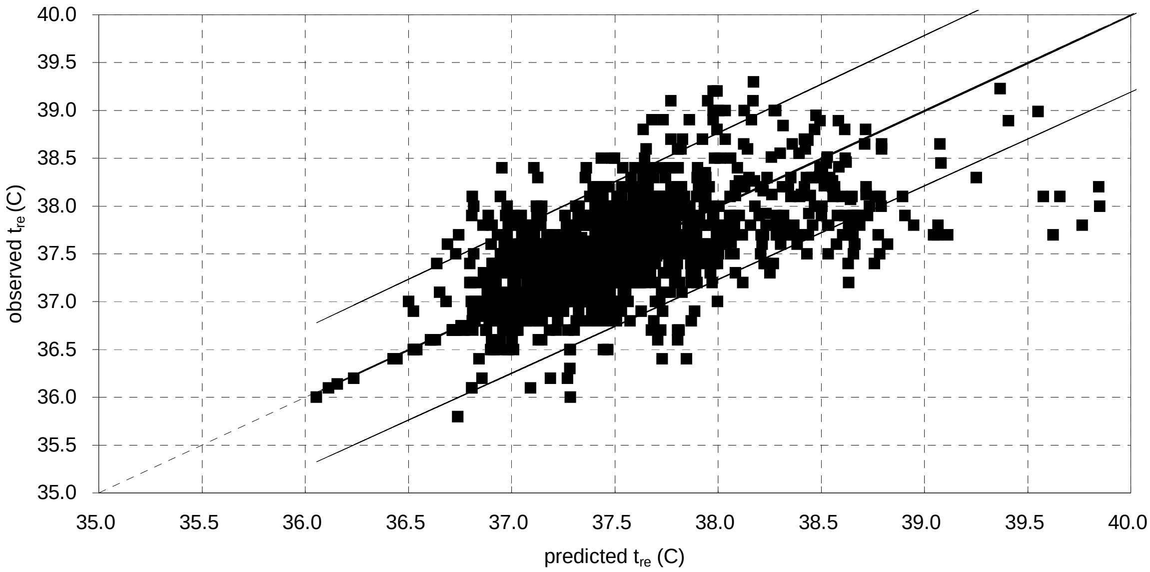


FIGURE 2 - Observed and predicted rectal temperatures (with the 95% confidence interval) in the 672 laboratory experiments



As described before, three points on average were selected per lab experiment to compare the observed and predicted rectal temperatures. Figure 2 compares the 1937 sets of values.

The means and standard deviations of the observed and predicted values are about equal. The correlation coefficient is equal to 0.66 and lower than for the sweat rates.

The equation of the mean polar line is:

$t_{re\ obs} = 1.000 * t_{re\ p}$ (with the 95% CI: 0.979 - 1.020)

Again, the points outside the 95% confidence interval (figure 2) are due to interindividual differences.

Validation in field experiments

Figures 3 and 4 compare the observed and predicted values of sweat rates (figure 3) and rectal temperatures (figure 4) for the 237 field experiments. As the durations of the field experiments were longer than for the lab experiments, 4 points per experiment were selected for the rectal temperature.

The precision of the climatic and physiological measurements is lower for experiments in the field. Therefore, the correlations between observed and predicted values are lower and the 95% confidence intervals are larger.

The equations of the mean polar line are:

$SW_{obs} = 0.851 * SW_p$ (with the 95% CI: 0.328 - 1.936)

$t_{re\ obs} = 1.000 * t_{rep}$ (with the 95% CI: 0.981 - 1.019)

FIGURE 3 - Observed and predicted sweat rates (with the 95% confidence interval) in the 237 field experiments

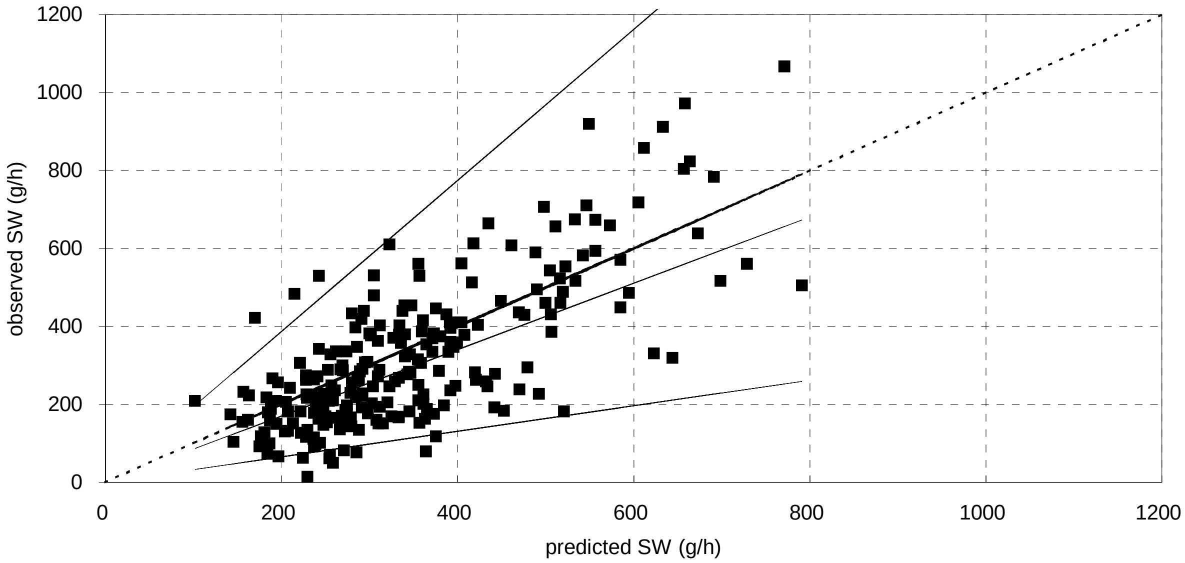
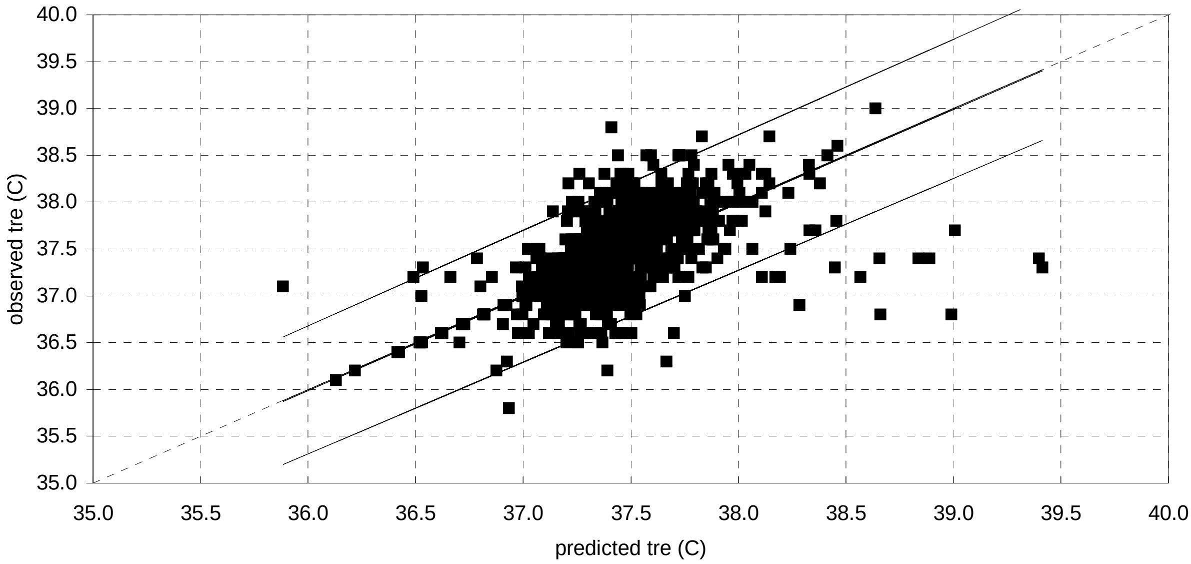


FIGURE 4 - Observed and predicted rectal temperatures (with the 95% confidence interval) in the 237 field experiments



Evolution of SW, t_{re} and DLE as a function of pairs of the primary parameters

The sweat rates and rectal temperatures were predicted for 2-hour exposures, in conditions with air temperatures varying between 25 and 50°C and one of the other parameters varying in the ranges indicated in the table 2.

TABLE 2 - Range of variation and normal values of the climatic parameters during the simulations

	Range	Normal values
Water vapour partial pressure p_a (kPa)	0.5 - 4.5	3
Mean radiant temperature (t_r – t_a) (°C)	0 – 60	0
Air velocity v_a (ms-1)	0 - 3	0.3
Clothing insulation (clo)	0 - 1	0.5
Metabolic rate M (W)	100 - 450	290

The simulations of 2 climatic parameters will greatly depend of the "normal" values chosen for the other parameters. These "normal" values are given in the table. However, these simulations will describe how the PHS model works and will show any problem in the model.

Figures 5 to 9 give the mean sweat rate (during the second hour of exposure) and the rectal temperature (at the end of the second hour). These figures give also the duration limit of exposures (DLE) (lowest value according to the two criteria: maximum water loss and rectal temperature equal to 38°C). The transition between both DLE is easily seen. DLE above 360 to 420 minutes are in most cases due to the risk of dehydration. Lower values are due to the risk of heat storage.

As the metabolic rate is equal to 290 watts for this simulation, the sweat rate reaches a maximum of 740 g/h. This will be also the case for the comparisons as a function of t_r-t_a, v_a, clo, except when the metabolic rate varies since the maximum sweat rate is estimated as a function of M.

When the difference between radiant and air temperatures is greater than 30°C, the sweat rate reaches the maximum value. Without radiation, the rectal temperature does not exceed 37.5°C until t_a is equal to 39°C. This 39°C threshold is reduced by 5°C when (t_r-t_a) increases by steps of 10°C.

Similarly, the same DLE is obtained for an increase of (t_r - t_a) by 10°C and a 5°C decrease in air temperature. This happens until the difference (t_r - t_a) exceeds 30°C. Above, radiation is so strong that the DLE is below 60 minutes.

The maximum sweat rate is reached between 37°C and 43°C when the velocity increases from 0 to 3 $ms^{-1.}$ The rectal temperature is around 37.5°C for about the same range of air temperature. The situation is getting worse with an increase in v_a, for t_a above 35°C, that is, above the skin temperature.

Whatever the air velocity, the DLE is shorter than 8 hours for air temperature above 35°C. Above, the DLE decreases with air temperature and increase with air velocity. In very humid conditions, the air velocity effect would be the opposite.

The model assumes that the maximum sweat rate varies as a function of the metabolic rate, with a lower limit of 250 W/m^2 and an upper limit of 400 W/m^2.

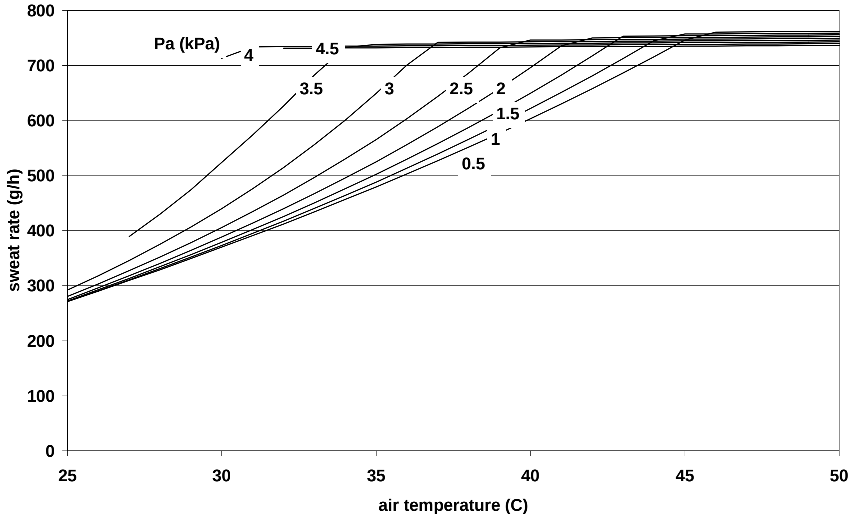
As the PHS model takes into account the increase in core temperature associated with M, the rectal temperature increases by 0.2°C for each increment of 100 watts of the metabolism.

The maximum sweat rate is reached for t_a = 35°C for a clo value of 1 and for t_a = 43°C for a nude person. Below these air temperatures, the sweat rate increases linearly with the clo value.

The rectal temperature remains around 37.5°C whatever the clo value, until the air temperature reaches 30°C for a clo value of 1 and 43°C for a nude subject.

For the "normal" conditions chosen in these simulations, the DLE increases as the clothing insulation decreases. This would not be true in case of high radiation.

FIGURE 5 - Evolution of the (a) sweat rate (mean value during the second hour of exposure), (b) rectal temperature (at the end of the second hour) and (c) DLE as a function of air temperature (t_a) and humidity (P_a)



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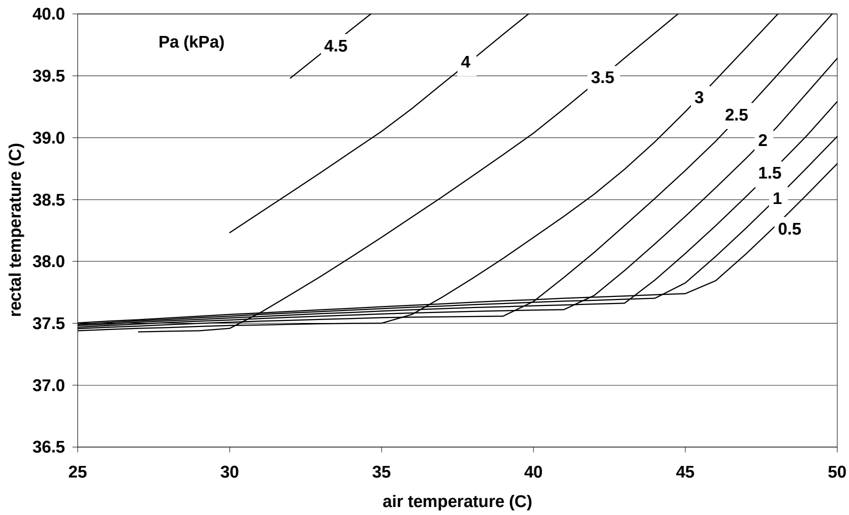

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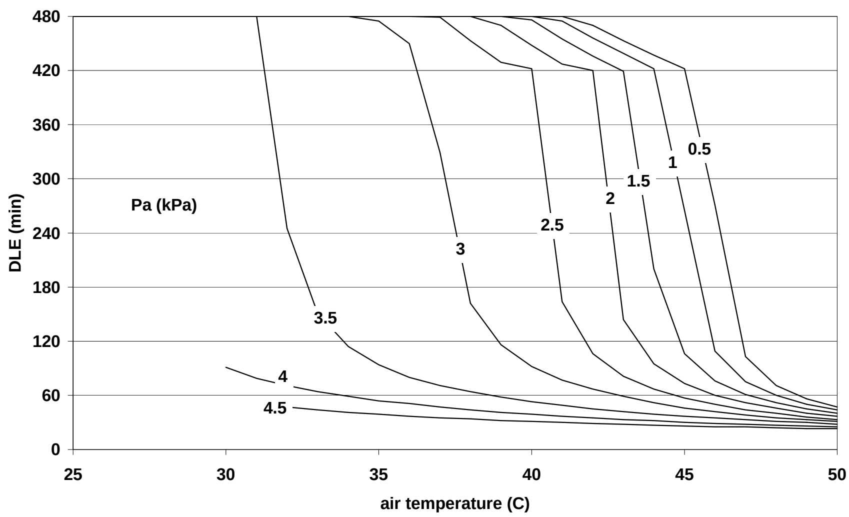

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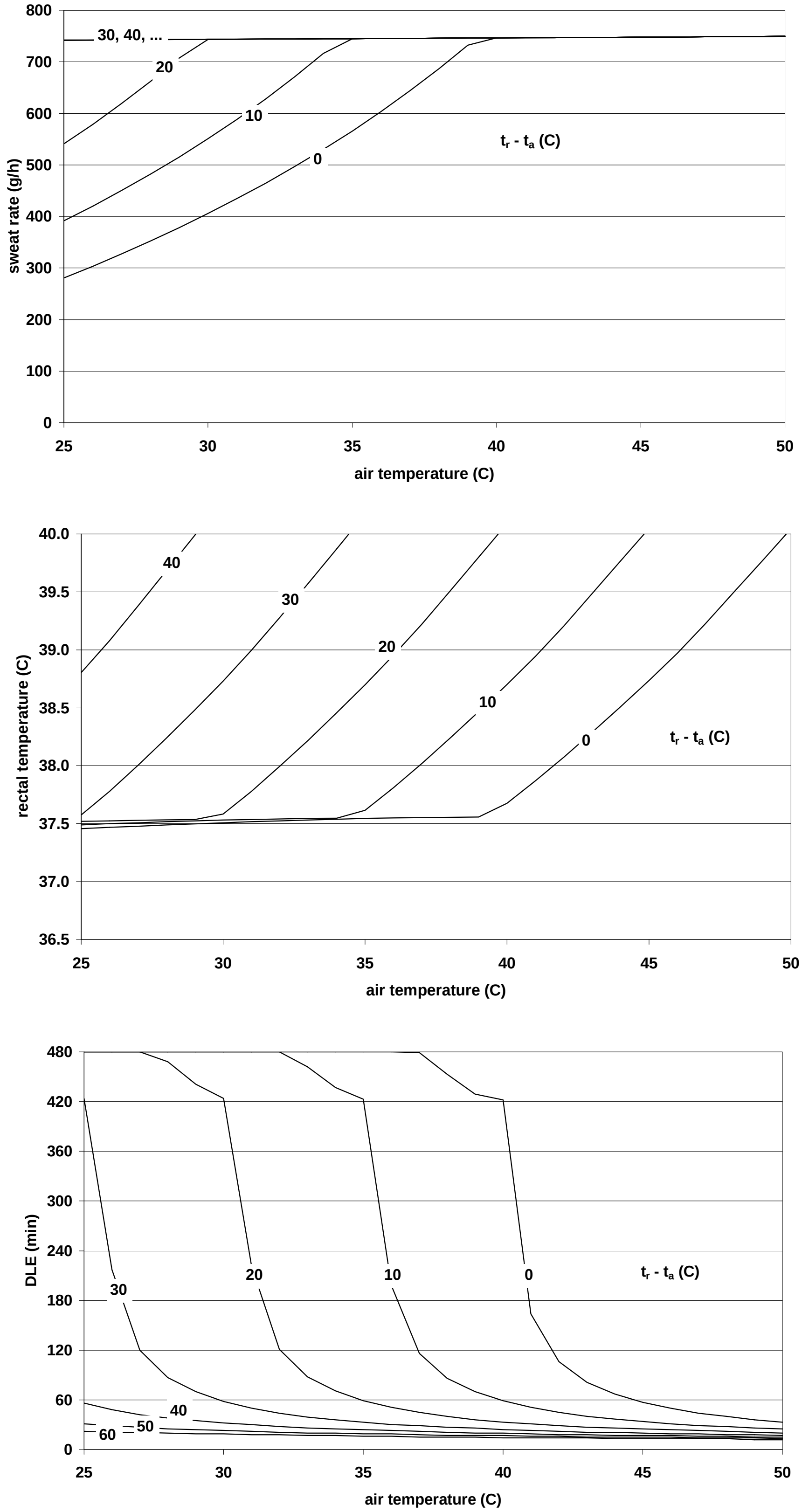
FIGURE 6 - Evolution of the (a) sweat rate (mean value during the second hour of exposure), (b) rectal temperature (at the end of the second hour) and (c) DLE as a function of air temperature (t_a) and radiation (t_r-t_a)



a

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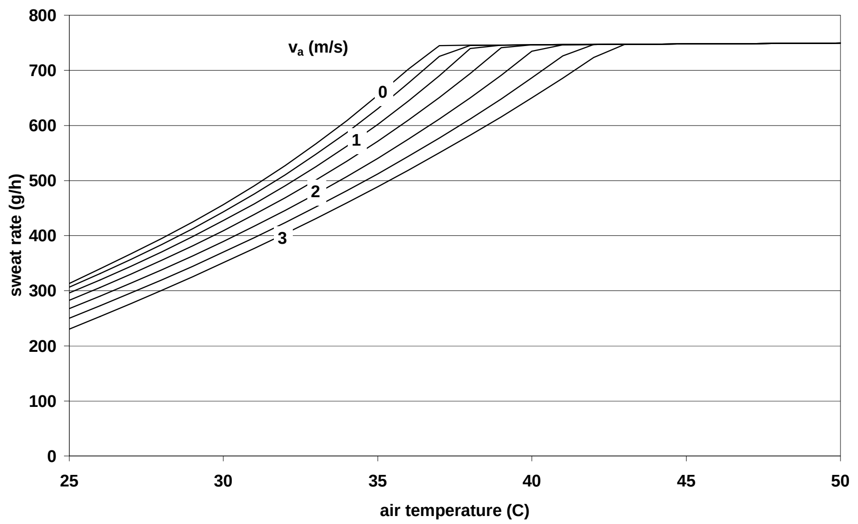
FIGURE 7 - Evolution of the (a) sweat rate (mean value during the second hour of exposure), (b) rectal temperature (at the end of the second hour) and (c) DLE as a function of air temperature (t_a) and air velocity (v_a)



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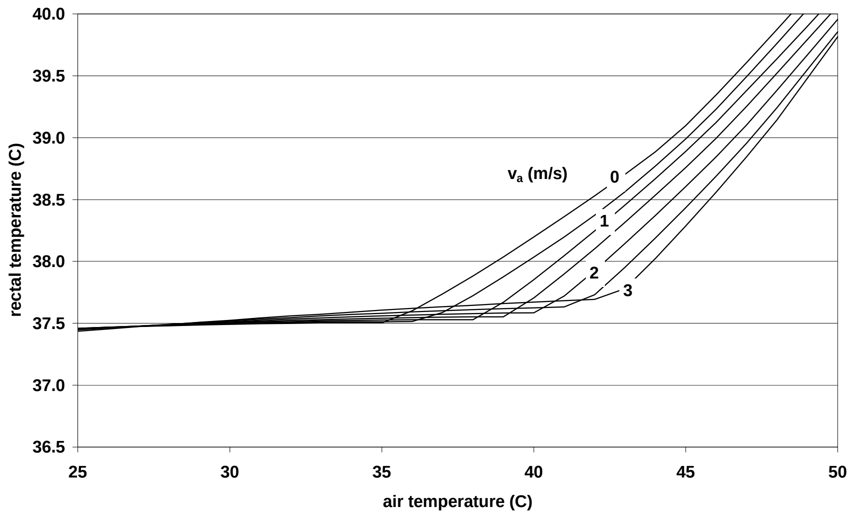

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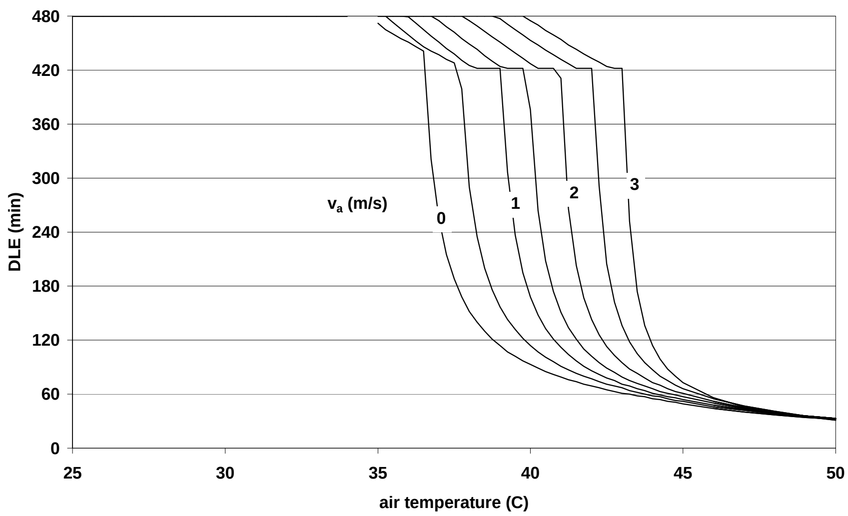

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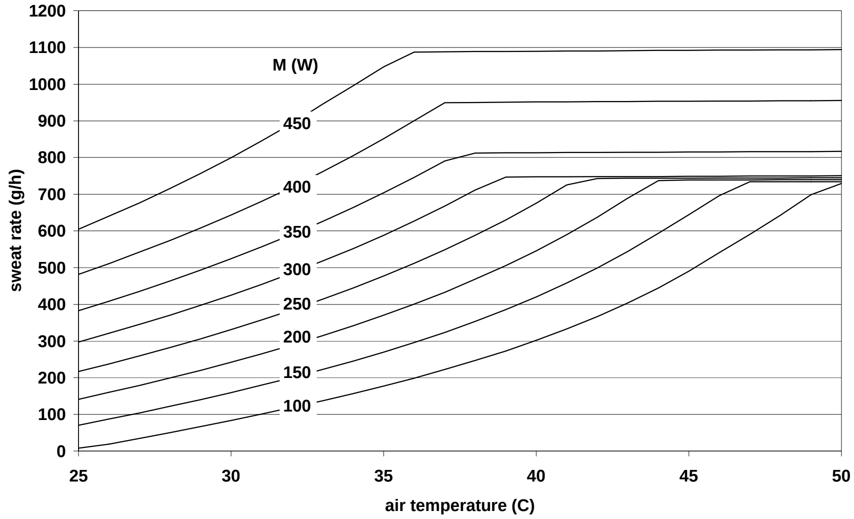
FIGURE 8 - Evolution of the (a) sweat rate (mean value during the second hour of exposure), (b) rectal temperature (at the end of the second hour) and (c) DLE as a function of air temperature (t_a) and metabolic rate (M)



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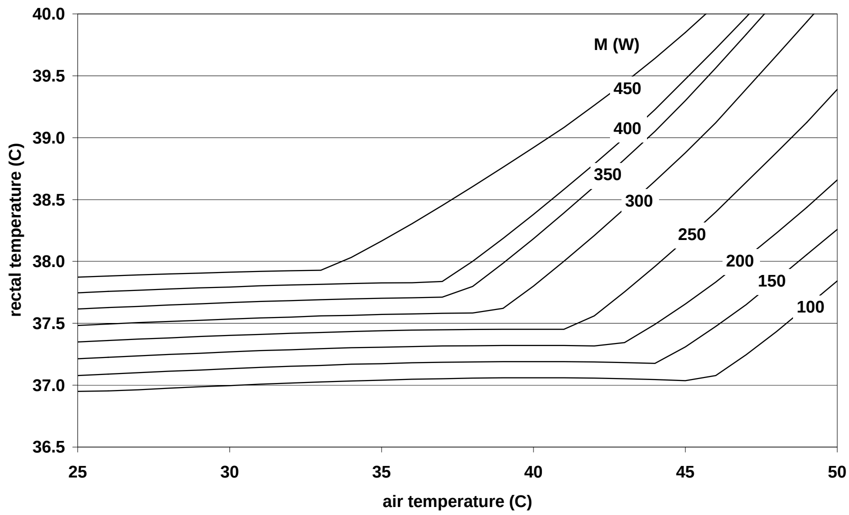

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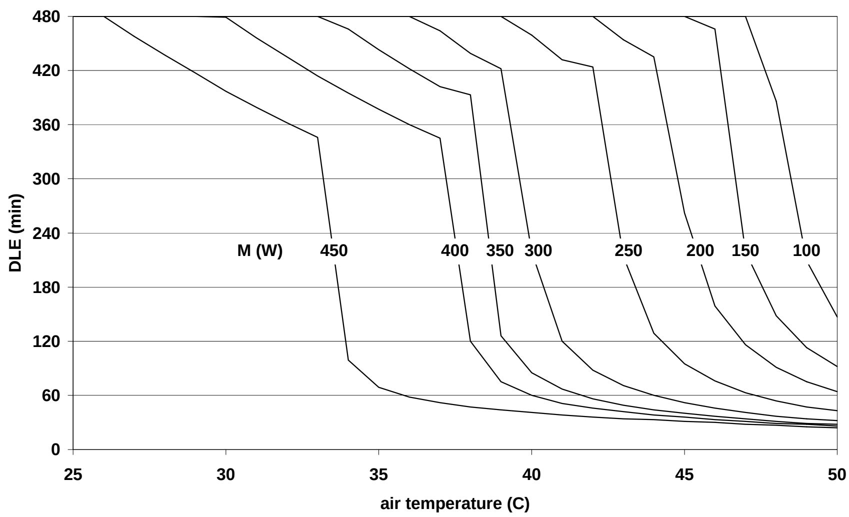

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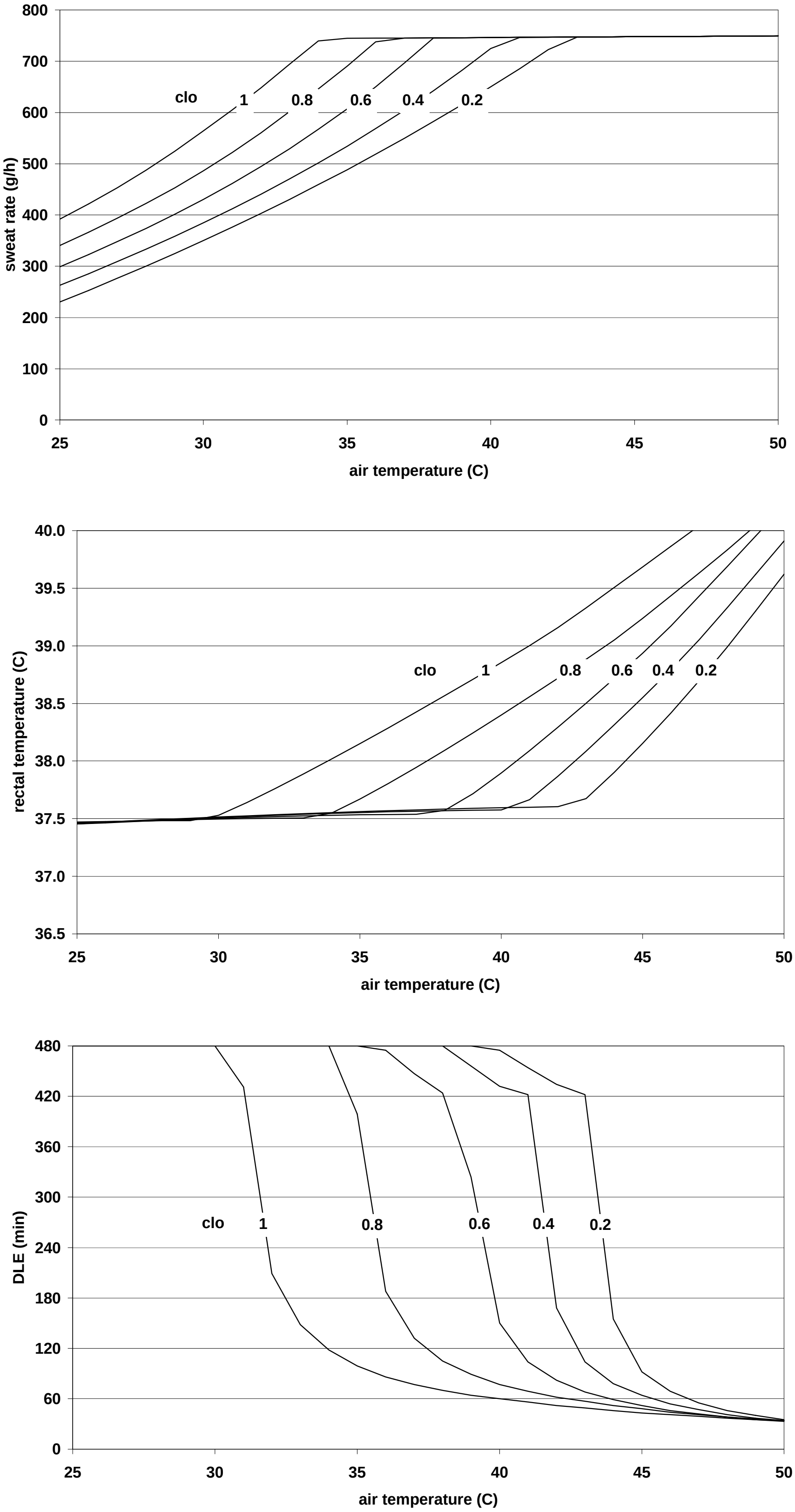
FIGURE 9 - Evolution of the (a) sweat rate (mean value during the second hour of exposure), (b) rectal temperature (at the end of the second hour) and (c) DLE as a function of air temperature (t_a) and clothing insulation (clo)



a

b

c

COMPARISON BETWEEN THE PHS MODEL AND THE ISO7933 STANDARD

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The modifications brought to the Required Sweat Rate model as it is in the ISO 7933 are so important that the comparison with the new PHS model is not relevant. Sweat rates and rectal temperatures are not predicted anymore for an "alarm" level and a "danger" level, that is, for sensitive people, but are for a mean subject. Therefore, 50% of the workers are expected to suffer from higher heat strain than predicted.

This "not relevant" comparison will still be done since it is important for the users in industry to know whether the PHS model results in different and better predictions than the Required Sweat Rate model of ISO 7933. As ISO 7933 predicts only the sweat rate and not the rectal temperature, comparisons of the two models will be restricted to the predicted sweat rates and the DLE values.

We will compare the DLE predicted by the PHS model (DLE_{PHS}: lowest of the two for dehydration and heat storage) and by ISO 7933 (DLE_{ISO}: "danger" level).

Evolution of SW and DLE as a function of pairs of the primary parameters

The two models were compared as in the presentation of A. Piette and J. Malchaire (Validation of the PHS model) for the PHS model, for the same combinations air temperature and one of the other parameters. For each simulation, all the climatic parameters were constant during two hours. The predicted sweat rate is the mean value during the second hour.

Figures 1 to 5 (a and b) give the results of the ISO 7933 simulations and can be compared with the corresponding PHS figures 5 to 9 of the presentation of A. Piette and J. Malchaire.

Comparison of the Sweat Rates (figures 1a to 5a)

- The sweat rate predicted by ISO 7933 (SW_{ISO}) shows some singularities in high humidity conditions. In very humid conditions (35°C, P_a > 3 kPa), SW_{ISO} decreases with an increase in partial vapour pressure. This is clearly erroneous, as shown by Zintl (1979) and Kohler (1976). The PHS model takes into account the decrease in evaporation efficiency for theoretical wettedness greater than 1 and predicts SW_{PHS} values consistent with these publications.
- SW_{ISO} and SW_{PHS} are about the same when the radiation load varies: the computation of the radiation heat exchange is the same in both models for non-reflective clothing.
- The influence of the air velocity on SW_{PHS} is greater than on SW_{ISO}, due to the modifications brought to the algorithms for convection and evaporation.
- SW_{ISO} and SW_{PHS} are about the same when the metabolic rate varies, except for the maximum value, constant in ISO (250 W/m²) and increasing with M for PHS.
- Clothing insulation equal to 0.8 and 1 clo lead to lower values of SW_{ISO}. This is obviously not correct and disappeared for SW_{PHS} due to the improved influence of the clothing.

Comparison of the DLE (figures 1b to 5b)

DLE_{ISO} shows some singularities in high humidities due to the errors on SW_{ISO} . DLE_{PHS} is greater than DLE_{ISO} when the limiting criteria is the maximum water loss. It is systematically lower when the criteria of limited heat storage (maximum t_{re}) applies. The same conclusions apply as soon as the radiation load varies and the DLE is below 4 hours approximately. The new way of computing t_{re} leads therefore to lower predicted work durations.

The same conclusions apply for air velocity, with however a much greater influence of the air velocity, for the metabolic rate due to the increase in SW_{max} with the metabolic rate and for clothing insulation.

It must be kept in mind that these simulations were done as a function of two parameters, the others being held constant. They refer therefore to particular cases and the quantitative conclusions may not be generalised. The only purpose of these studies was to analyse qualitatively whether the PHS model was giving more realistic results than ISO 7933. It can be concluded that this is the case.

Comparison of PHS and ISO 7933 predicted sweat rate using the BIOMED database

The ISO 7933 standard model makes possible to predict the sweat rate for constant climatic and working conditions. In case of several exposure conditions, the interpretation had to be done, first, for each sequence separately, and, later, globally, for the whole set of sequences.

The first problem to solve was the method to use for computing the SW_{ISO}, as, for all the experiments and studies included in the BIOMED database, all the primary parameters were known minute per minute. Three computation techniques were compared:

- Calculation of the averages of all the primary parameters, over the total duration of the experiment, and interpretation according to ISO 7933 considering only these average values.
- Computation of the predicted sweat rate for each minute successively. Computation of the average sweat loss SW_{ISO} over the total duration.
- Computation of E_{max} and E_{req} for each minute successively. Computation of the average E_{max} and E_{req} over the total duration. Final interpretation done from these mean values to predict the SW_{ISO} sweat rate. This is strictly consistent with ISO 7933, although extended to sequences of one-minute duration.

Table 1 gives the results of the linear regressions between the observed and predicted sweat rates, when using these three methods of interpretation for ISO 7933 and when using the new PHS models.

TABLE 1 - Linear regressions between the observed and predicted sweat rates: (3 interpretation methods for ISO 7933 model and PHS model).

	LAB EXPERIMENTS (n = 672)			FIELD EXPERIMENTS (n = 237)		
	Slope	Inters	r	Slope	Inters	r
SW_{ISO} from the means of the parameters	0.755	81	0.743	0.628	65	0.506
Mean of the min per min SW_{ISO}	0.715	98	0.702	0.877	-29	0.535
SW_{ISO} from the E_{max} and E_{req} means	0.757	75	0.744	0.663	52	0.523
PHS model	0.848	41	0.760	1.056	-46	0.745

The differences between the three modes of using ISO 7933 are small. As the method does not influence significantly the results, (and as the purpose here was not to determine how to use the existing standard!), the third method is used thereafter.

Figures 6a and 6b compare, respectively for the lab and field experiments, the observed and ISO 7933 predicted sweat rates.

The PHS model gives clearly better predictions, particularly for the field experiments, the correlation explaining 55% of the total variance instead of 27%.

The improvements brought by the PHS model are not totally reflected by these statistics.

Figure 7 compares the evolution of the SW_{ISO} and SW_{PHS} sweat rates during a lab experiment involving different sequences of work and climatic conditions. In this particular case, the averages of the SW_{ISO} and SW_{PHS} min per min values over the entire experiment are about the same. According to the regression analysis performed above, both models would therefore be considered as equally valid. This is not obviously the case when considering the evolution during the experiment. The SW_{ISO} is assumed to increase or decrease instantaneously as soon as a sequence starts, while the SW_{PHS} follows remarkably the observed values.

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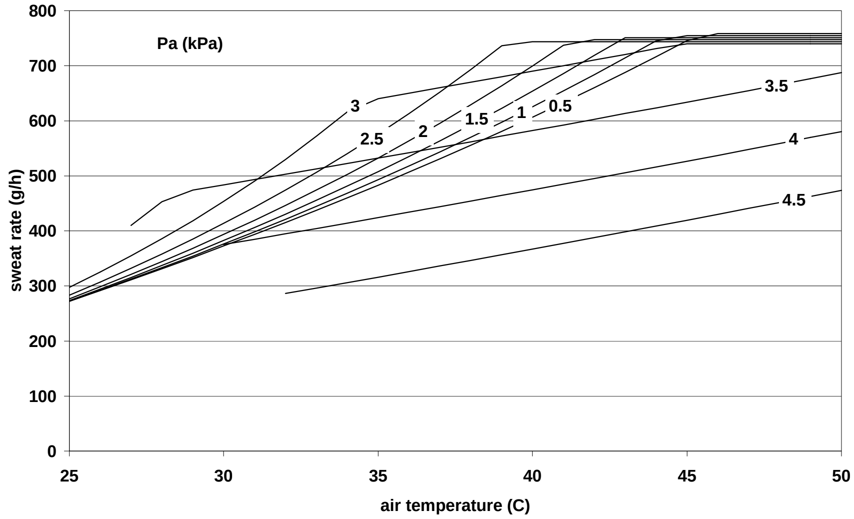
3. Zintl W. (1979) Physiologische Reaktionen im Bereich der Hitzetoleranzgrenze vor und nach Hitzeakklimation bei einer ruhenden Versuchsperson (Physiological reactions in resting test subjects at the limit of their heat tolerance before and after acclimatization to heat). Dissertation.

FIGURE 1 - Evolution according to ISO 7933 of (a) the sweat rate (mean value during the second hour of exposure) and (b) the DLE as a function of air temperature (t_a) and humidity (P_a) (c) Ratio between the DLE_{PHS} and the DLE_{ISO} in the same conditions



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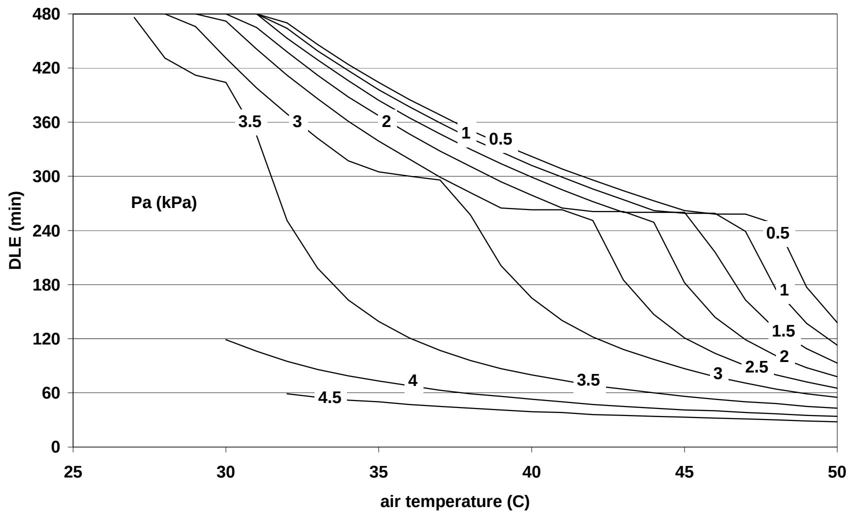

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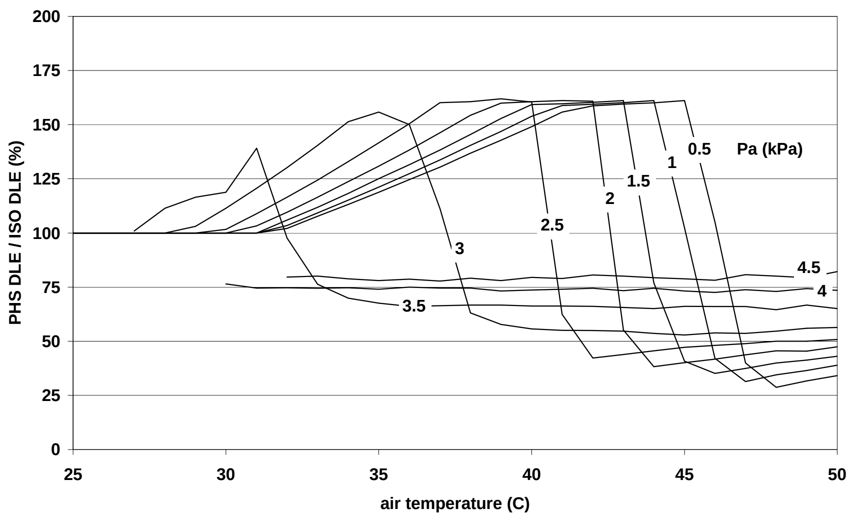

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FIGURE 2 - Evolution according to ISO 7933 of (a) the sweat rate (mean value during the second hour of exposure) and (b) the DLE as a function of air temperature (t_a) and radiation (t_r-t_a) (c) Ratio between the DLE_{PHS} and the DLE_{ISO} in the same conditions

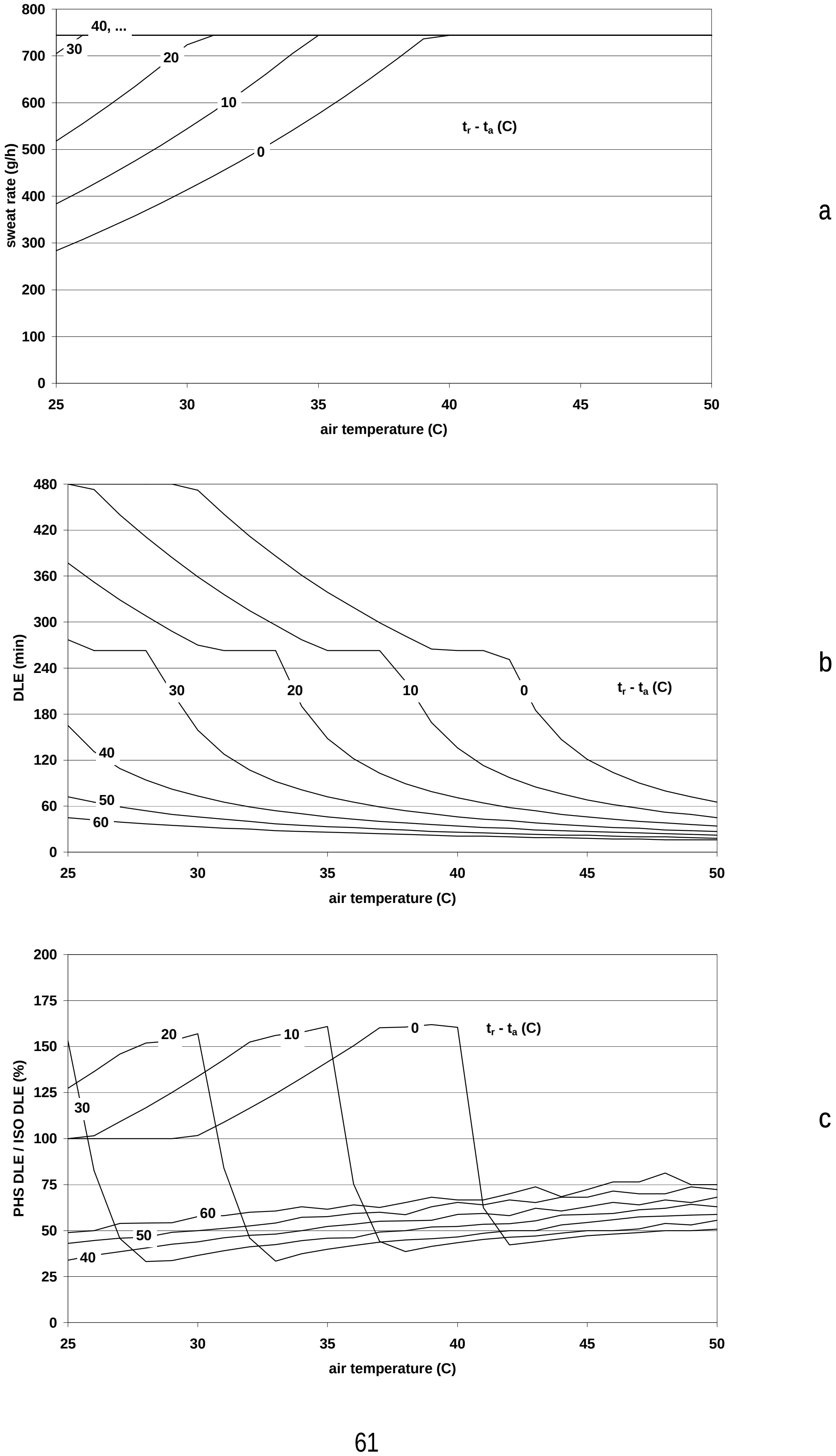
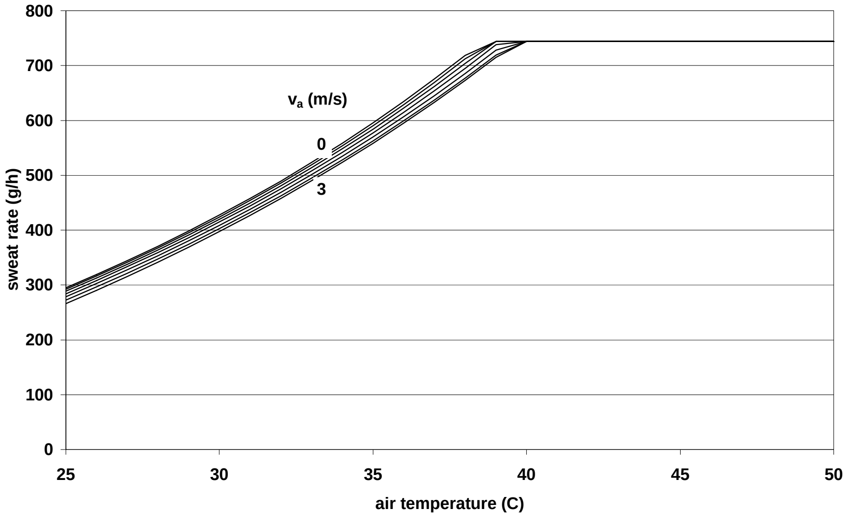


FIGURE 3 - Evolution according to ISO 7933 of (a) the sweat rate (mean value during the second hour of exposure) and (b) the DLE as a function of air temperature (t_a) and air velocity (v_a) (c) Ratio between the DLE_{PHS} and the DLE_{ISO} in the same conditions



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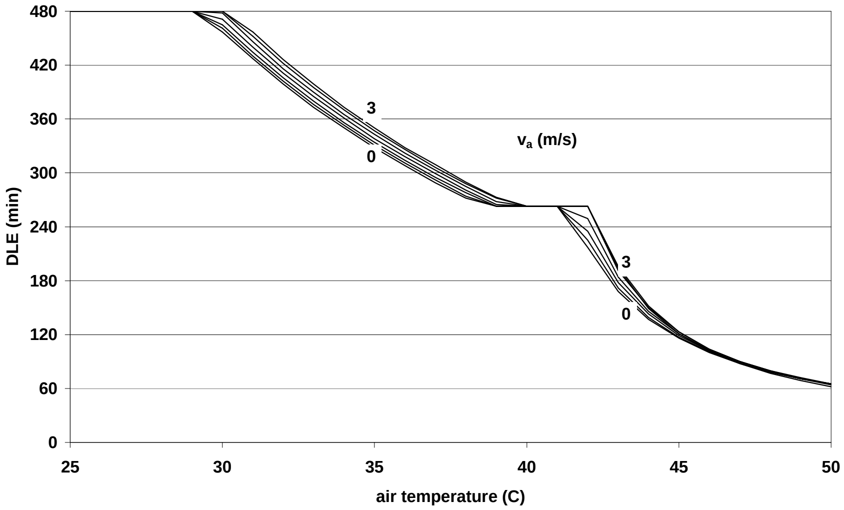

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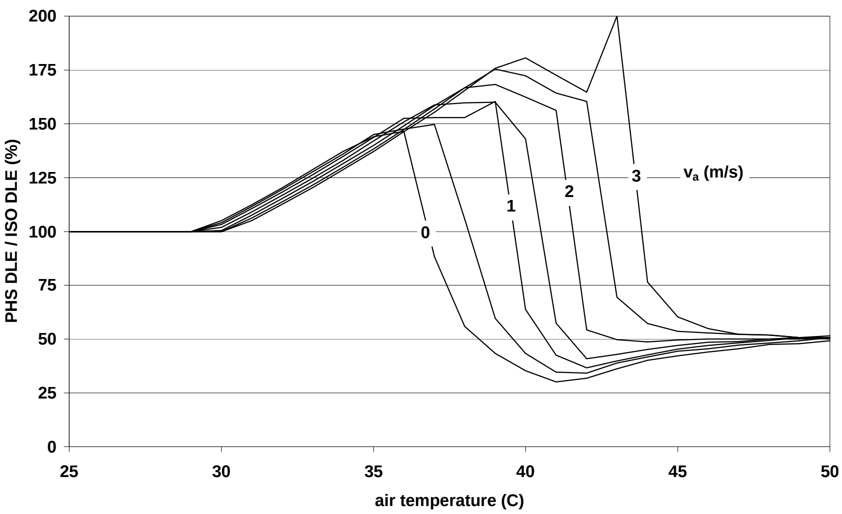

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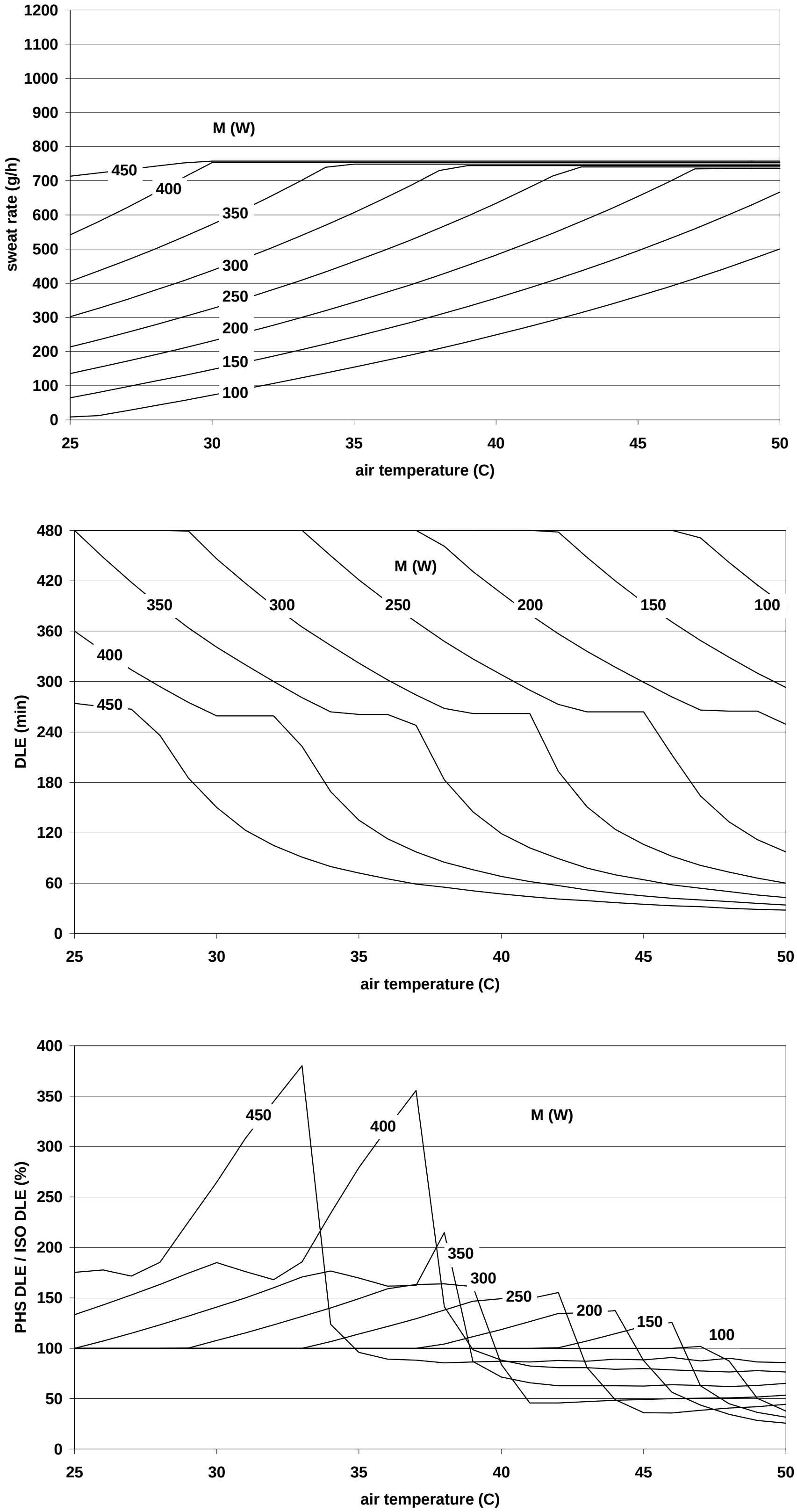
FIGURE 4 - Evolution according to ISO 7933 of (a) the sweat rate (mean value during the second hour of exposure) and (b) the DLE as a function of air temperature (t_a) and metabolic rate (M) (c) Ratio between the DLE_{PHS} and the DLE_{ISO} DLE in the same conditions



a

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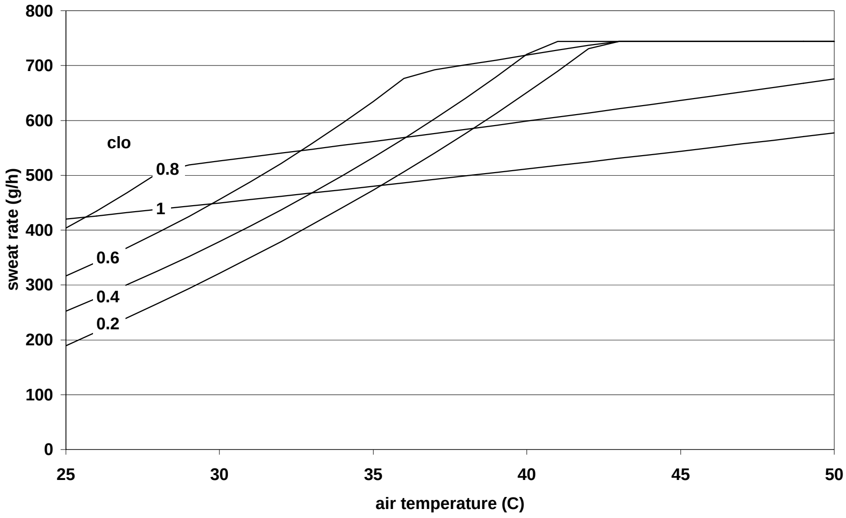
FIGURE 5 - Evolution according to ISO 7933 of (a) the sweat rate (mean value during the second hour of exposure) and (b) the DLE as a function of air temperature (t_a) and clothing insulation (clo) (c) Ratio between the DLE_{PHS} and the DLE_{ISO} DLE in the same conditions



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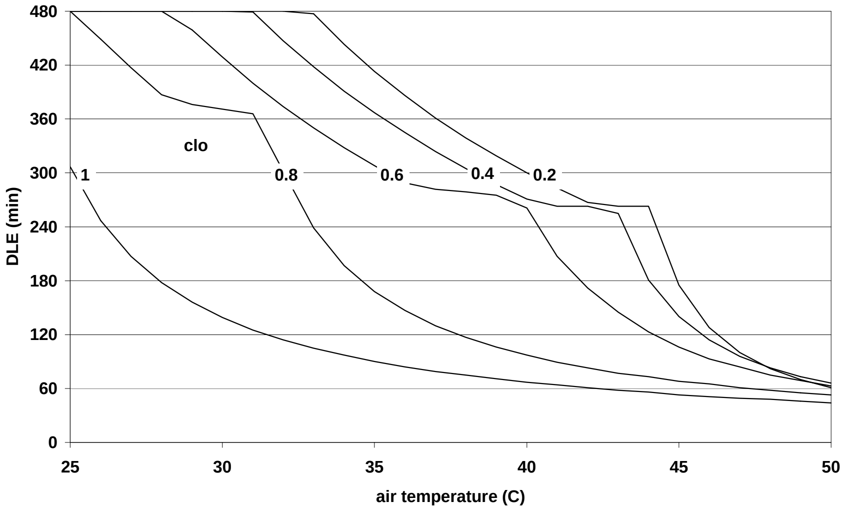

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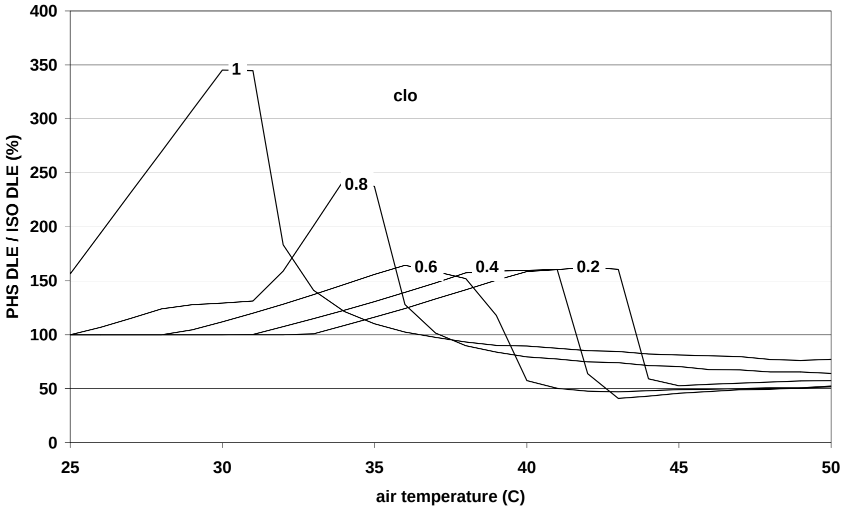

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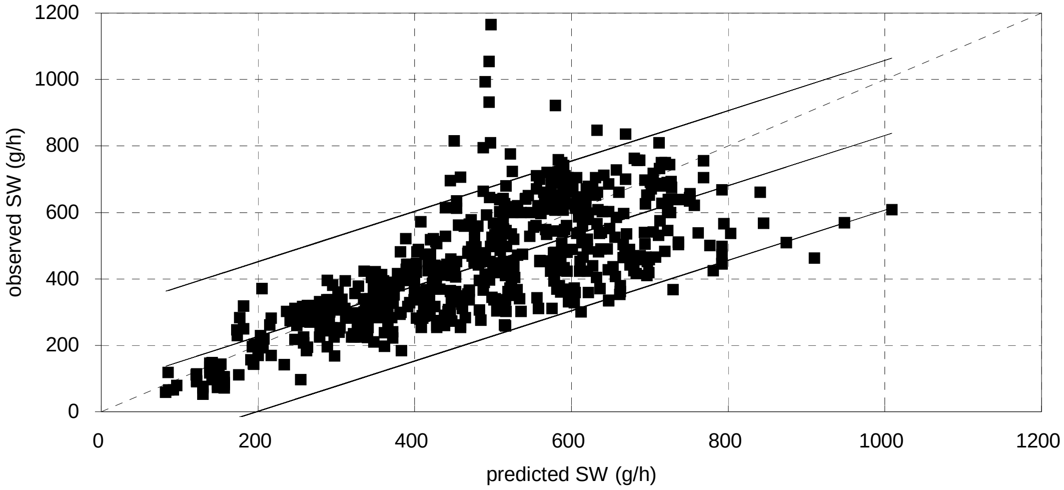
FIGURE 6 - Observed and ISO 7933 predicted sweat rate in the 672 laboratory experiments (a) and in the 237 field measurements (b).



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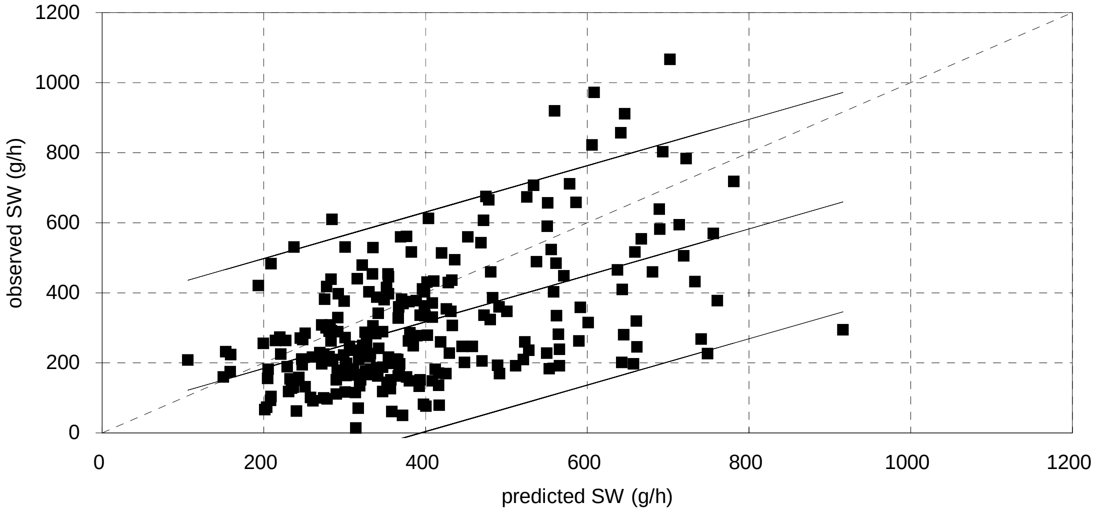
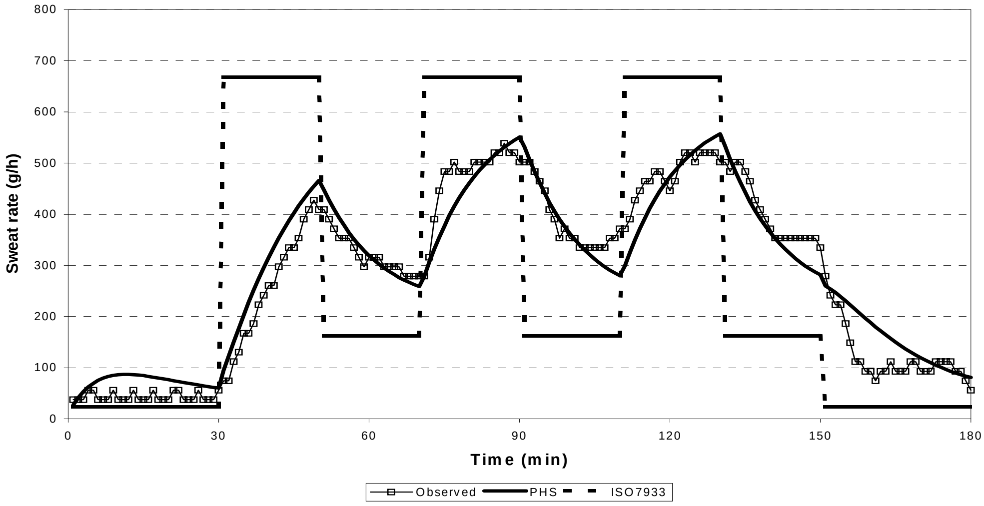


b

FIGURE 7 - Observed (SW_{obs}) and predicted sweat rates (using ISO 7933 (SW_{ISO}) and PHS (SW_{PHS})) in a laboratory experiment with 3 sequences of work and climate.



COMPARISON BETWEEN THE PHS MODEL AND THE WBGT INDEX

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Comparison of the DLE_{PHS} with the WBGT values

The DLE was computed in 3680 sets of conditions with the primary parameters varying in the range indicated in table 1. The clothing insulation was held constant to 0.6, as the WBGT index is valid only for this value.

TABLE 1 – Ranges and steps of variation of the 6 primary parameters

	Range	Step	Number of values
Air temperature (°C)	20-50	5	7
Relative humidity (%)	20-80	20	4
(t_r – t_a) (°C) (but t_r limited at 60°C)	0-40	10	<5
Air velocity (ms^{-1})	0.01-2	0.5	5
Metabolic rate (W)	100-450	50	7
Clothing insulation (clo)	0.6	-	1

At the same time, the WBGT and $WBGT_{limit}$ were computed for the same conditions according to ISO 7243.

This WBGT limit was computed using $WBGT_{limit}$ = 34.3 - M / 35.5 (with M in W).

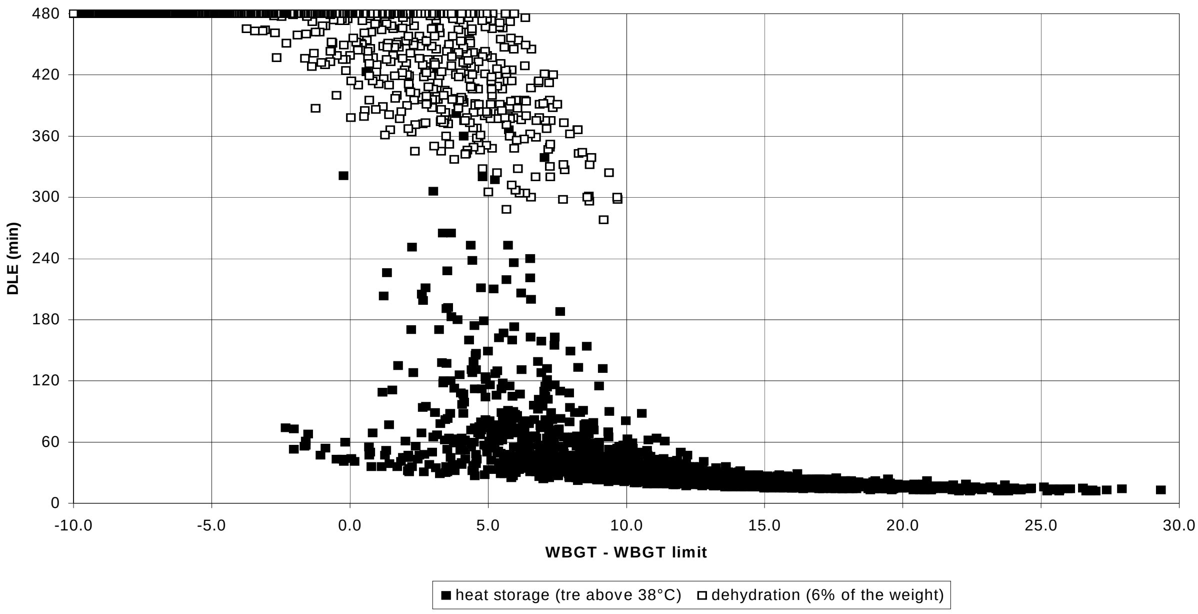
Figure 1 compares the DLE_{PHS} with the differences (WBGT - $WBGT_{limit}$). A positive difference means that the work may be performed continuously. A negative one implies, according to ISO 7243, that rest and recovery periods must be organised.

Most of the DLE lower than 4h are in conditions for which the WBGT difference is positive. In these conditions, according to the WBGT index, work cannot be pursued continuously and 1h work-rest regimens must be organised.

From this, the WBGT appears to play its role of screening method, suggesting that there might be a thermal stress problem. The PHS model can then be used to determine whether there is indeed a heat stress problem and to organise work accordingly.

Figure 1 shows that conditions exist when, on the contrary, the WBGT does not exceed $WBGT_{limit}$, while, according to the PHS model, the work duration should be limited.

FIGURE 1 - Evolution of the PHS model duration limit of exposure (lowest value between dehydration and heat storage DLE), according to the difference between the WBGT index and the WBGT limit (ISO7243)



This is the case for instance in the condition: t_a=20°C, t_r = 60°C, RH = 20%, v_a = 1 m/s, M = 450 W, clo = 0.6

for which WBGT = 31.7 and $WBGT_{limit}$ = 21.6.

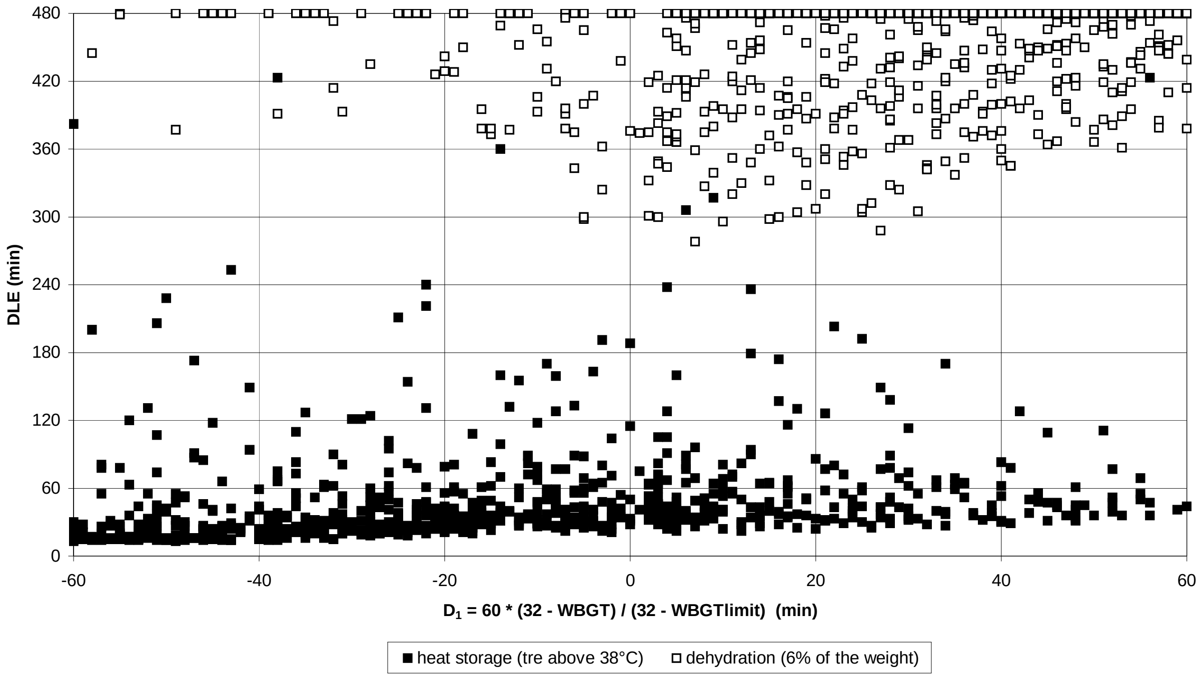
Indeed, t_{re} = 38°C is reached after 53 minutes but levels at 38.03°C. The DLE for dehydration is equal to 458 minutes and should be used. All the points in figure 1 with negative WBGT difference and DLE_{PHS} lower than 100 min correspond to such conditions and should not therefore be interpreted as limitations of the PHS model.

When the $WBGT_{limit}$ is exceeded, ISO 7243 proposes hourly work-rest regimens. It assumes, quite unrealistically since the climatic conditions might be severe in themselves, that rest is spent in the same WBGT conditions as work. In this case, as shown by Mairiaux and Malchaire (1990), the hourly work duration is given by:

$$D_1 = \frac{32 - WBGT}{32 - WBGT_{limit}} . 60 \quad (min)$$

As recovery is not possible for WBGT greater than 32, D1 takes negative and meaningless values in these conditions. Therefore the comparison between D_1 and the DLE $_{PHS}$ is limited at WBGT ≤ 32. Figure 2 shows that this approach of the WBGT imposes work duration limitations even in cases where, according to the PHS model, work would still be permitted for 8 hours continuously.

FIGURE 2- Comparison of DLE_{PHS} with the WBGT allowable duration of work per hour (rest taken in the same environment).

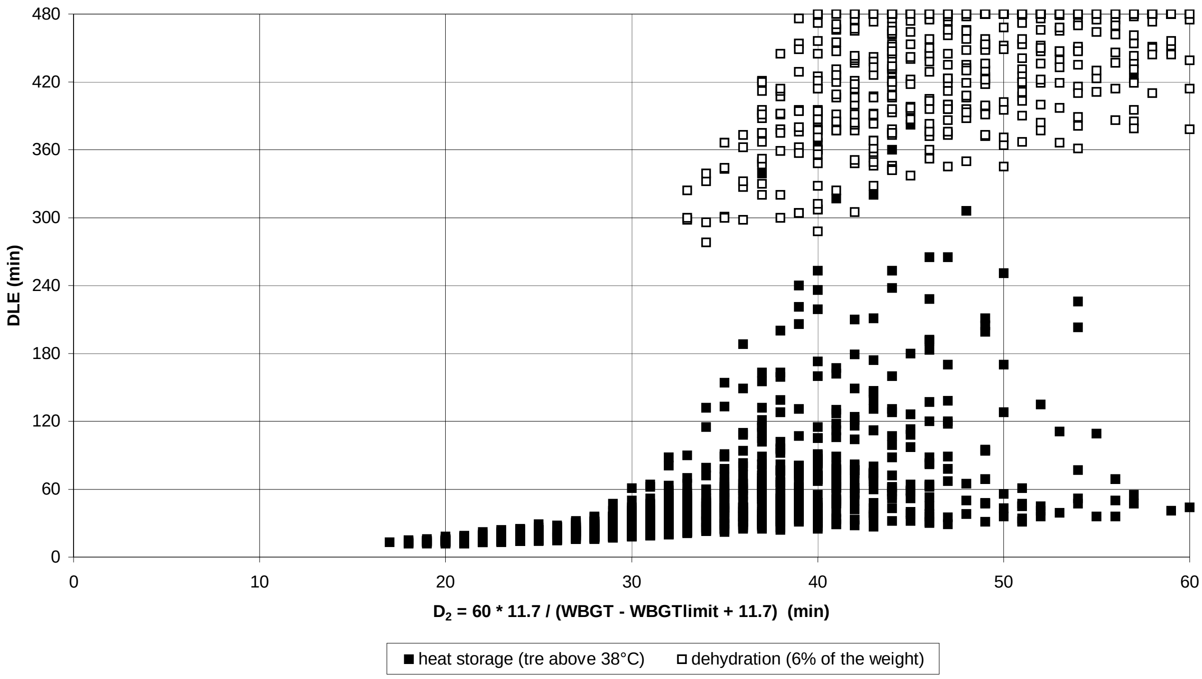


If rest is spent in a neutral and comfortable (PMV=0) environment such as: $t_a = t_g = 26°C$, RH = 40%, $v_a = 0.1$ m/s, WBGT = 20.3, then, the hourly work duration can be estimated by (Mairiaux and Malchaire 1990):

$$D_2 = 60 \cdot \frac{11.7}{(WBGT - WBGT_{limit} + 11.7)} \quad \text{(min)}$$

Figure 3 illustrates the comparisons between D_2 and DLE_{PHS}. For more severe conditions, the work durations are shorter according to both models.

FIGURE 3- Comparison of DLE_{PHS} with the WBGT allowable duration of work per hour (rest taken in a comfortable environment (PMV = 0, WBGT = 20.3)



Comparison between the work-rest regimens recommended by PHS and WBGT

In order to be compared with the D_2 duration defined above and based on the ISO 7243 WBGT standard, the DLE_{PHS} defined by the PHS model must be interpreted in another way:

- when the DLE_{PHS} is imposed by the risk of excessive water loss, it can be considered that rest periods must be organised every hour so that the 5 or 7.5% of the weight limit are reached only after 8 hours. It can be roughly assumed that the sweat loss during this rest period will approximately compensate the sweat loss deficit at the beginning of the work period (as SW follows a first order model with a time constant of 10 minutes).

  Therefore, the hourly work duration should be:

$$D_{SW} = \frac{DLE_{PHS}}{480} . 60 = \frac{DLE_{PHS}}{8}$$

- when DLE_{PHS} is imposed by the limit of 38°C of the rectal temperature, rest periods should be organised every hour so that, as implicitly adopted for the WBGT index, t_{re} returns to 37°C.

  In the comfortable rest environment defined above, t_{re} returns to 37°C approximately according to the following law :

$$t_{re} = t_{re0} - (t_{re0} - 36.8)\ (1 - \exp(-t/25))$$

  where t_{re0} is the rectal temperature at the end of the work phase

  t is the time (in minutes)

From this, it can be determined that the time to recuperate to 37°C (D_{rec}) varies as a function of the initial (equilibrium) t_{re0} according to the following expression:

$$D_{rec} = 40 + 25 \ln (t_{re0} - 36.8)$$

Therefore, if the same philosophy as in ISO 7243 is used for PHS, work must be limited every hour at time D_W at which the rectal temperature is such that it can be recovered in $60 - D_W = D_{rec}$.

The D_{SW} and D_W durations were predicted for the same combinations of the primary parameters (table 1). The lowest value (D_{PHS}) of the 2 was estimated: D_W is actually always smaller than D_{SW}.

Figure 4 shows the rectal temperature at time D_{PHS} in all combinations of the primary parameters.

This translates exactly the mathematical expression of $D_{PHS} = 1 - D_{rec}$ described above.

FIGURE 4 - Rectal temperature at time D_{PHS} in all combinations of the primary parameters.

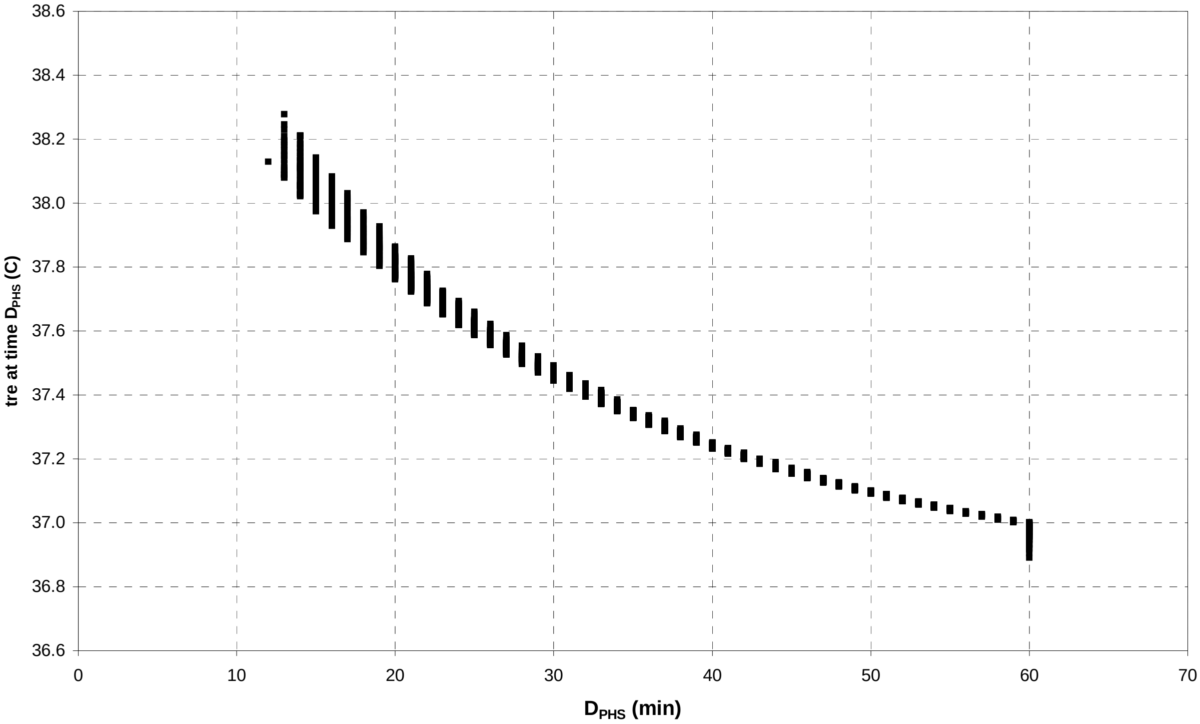
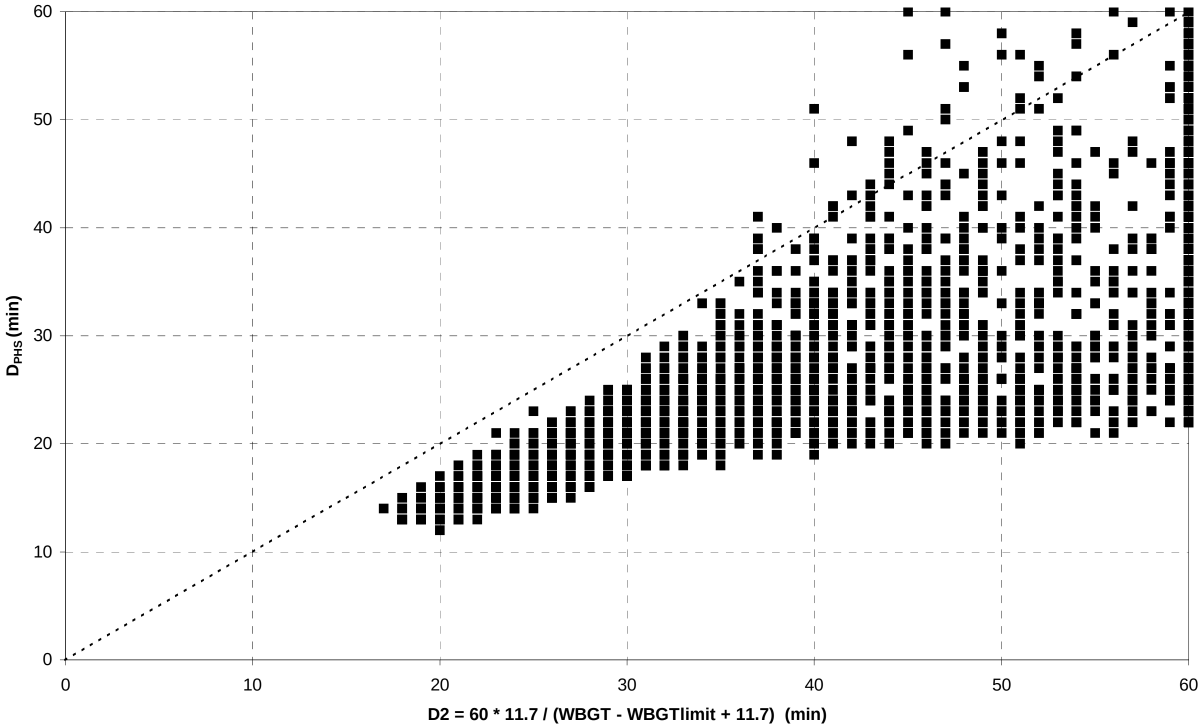


Figure 5 compares D_2 estimated from the WBGT and D_{PHS} estimated from the PHS model as described above.

This figure shows that the WBGT procedure systematically leads to hourly work duration longer than the PHS model. The conclusion is therefore that

- the WBGT index can be used to screen the conditions that might lead to a heat stress problem;
- it cannot be used to organise safely the work-rest regimen (with rest in a WBGT = 20.3 condition).

FIGURE 5 – Comparison between D_2 estimated from the WBGT ad D_{PHS} estimated from the PHS model in all combinations of the primary parameters.



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WET BULB GLOBE TEMPERATURE: IMPLICATIONS IN THE ANALYSIS OF HEAT STRESS

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The recognition, evaluation and control of heat stress in the workplace are a part of occupational hygiene. The Screening and Observation stages represent the recognition principle, which relies on the informed knowledge of workers and their management. Likewise, evaluation divides into two stages: Analysis and Expertise. The Analysis stage is the first step in quantifying heat stress and requires the training and experience of an occupational hygienist, who may not have specialised or expert knowledge of heat stress, but who works in concert with the workers and management. A very useful tool in the analysis stage of heat stress is the wet bulb globe temperature (WBGT).

The WBGT is an index of environmental conditions as they may contribute to heat stress. The globe temperature responds to radiant and convective heat exchange between its surface and the ambient environment. The natural wet bulb temperature is an indicator of the maximum rate of evaporative cooling that can be achieved. When the two temperatures are combined, they can form an index of both the dry and wet heat exchange between a person and the work environment. The proportions of 70% of the natural wet bulb temperature and 30% of the globe temperature were selected to match a thermal comfort index.

As investigators were attempting to understand the relationship between the risk for heat-related disorders and environmental conditions with work place demands, two notable findings were reported. One was the body core temperature limit of 38°C for sustained exposures to heat stress suggested by an expert panel for the World Health Organisation. The other was the concept of an Upper Limit of the Prescriptive Zone proposed by Lind. For a given person, the upper limit could be described by a combination of WBGT and metabolic rate. By limiting extended exposures to the Upper Limit of the Prescriptive Zone, a worker could easily maintain body core temperature below 38°C. With this observation, the upper limit was explored for a range of individuals and different rates of work. The U. S. National Institute for Occupational Safety and Health (NIOSH), the American Conference of Governmental Industrial Hygienists (ACGIH), and the International Organisation for Standardization used these data to prescribe thresholds for extended exposures that were protective of most workers.

In essence, the goal of present WBGT-based heat stress evaluation schemes is to describe a relationship between environmental conditions and work demands that represents the point at which the least heat-tolerant workers in ordinary summer work clothing can safely work for extended periods of time. The relationship is frequently plotted as WBGT versus metabolic rate. In practice, heat stress evaluations based on extended periods in summer work clothes are not common. For instance, many jobs are performed with heavier coveralls woven from treated cotton or man-made fibres, with non-woven particle-barrier fabrics, or with water- and vapour-barrier fabrics that contain films or coatings to achieve the desired properties. All of these affect the degree of heat stress. Often, the exposures are for shorter and irregular periods of time than the assumed 8 hours and a time-weighted average over one to two hours is employed.

Ultimately, the frequently used WBGT-based evaluation schemes are simple and simplistic models of heat stress. They help to determine if further evaluation is worthwhile. Following the public health model of prevention, a healthy, acclimatised person in summer work clothes exposed to environments and work demands below the WBGT limit will not experience excessive heat stress. The converse is not true. That is, a person exposed above the threshold may be working safely, but that decision requires an evaluation at the Expertise stage.

MEDICAL ASPECTS: SELECTION AND SURVEILLANCE OF PERSONNEL WORKING IN THE HEAT

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Introduction

The ergonomic design of workplaces aims at the harmonisation between a person and his/her work. Apart from the prevention of health hazards, the physiological costs shall be at a minimum thus allowing the workers to perform at their optimum.

Though many dangerous workplaces were sufficiently redesigned within the last decades, there are still numerous situations that impose a health risk due to the occupational activities per se and/or due to the environment at the respective workplace. To limit the risk three complimentary measures are possible. These are:

- technical measures, i.e. the provision of the workers with suitable personal protective equipment,
- organisational measures, i.e. the limitation of exposure,
- medical prevention, i.e. the selection and surveillance of the workers, and their adaptation to their work.

Medical prevention

This paper is restricted to the latter aspect and to work in the heat. The need for medical prevention is well accepted and realised in many countries. But there is a great uncertainty about the criteria to be applied. This concerns both, the thermal conditions where the workers are exposed to as well as the quantitative requirements of individual characteristics relevant for coping with heat.

Selection of personnel

The criteria for critical climatic conditions are not well defined. The actual draft of ISO 12894 (Medical supervision) suggests that body core temperature must not exceed 38.0 °C. But, field studies executed so far have clearly shown that this limit is rather often surpassed, even in well acclimated workers.

It is well understood that workplaces in the heat are due to individual characteristics not accessible for everybody. Suitable medical examinations prior to the start of the work aim therefore at the selection of only those persons who very likely can cope with the respective situation and at the exclusion of particularly vulnerable persons.

The criteria for excluding a person from heat exposure base on permanently existing features, i.e. on the health state and the individual's physiological capacity.

It is therefore commonly accepted to exclude persons with chronic diseases of the cardiovascular, the pulmonary, the gastro-intestinal, the urogenital, and the nervous system, those with disorders of metabolism, with obesity, with chronic skin diseases or abuse of alcohol and drugs from the respective stress.

Regarding physiological capacity, it is commonly accepted that the level of fitness should be matched to the respective exposure. Well-defined criteria, however, are again missing and the occupational physician has a great freedom for the decision on the capability of a person to perform the task in question.

Moreover, the method usually applied to determine physical capacity in terms of maximal oxygen uptake, namely the bicycle ergometry and the significance of the respective results are debated after it has been shown that e.g. the data determined in fire fighters were only weakly related to the results recorded during work-specific exercises.

Additionally, medical examination does not concern the fact that some persons are irrespective of their sufficient or even excellent physical condition essentially unable adapt to heat. The development and application of a suitable heat tolerance test that reliably predicts this inability is therefore recommended since long and would be particularly important for those occupational situations where acclimation does not occur due to rather rare exposures.

Surveillance

Once a person has started to work, it is advisable to keep him/her under surveillance by regularly repeated medical examinations and – dependent on the severity of the exposure – by monitoring during actual exposure which is particularly important for those persons who are not daily exposed to heat.

Medical examination: As long-term effects of heat, i.e. occupational diseases are not expected, medical examination aims at almost the same goal as the examination before work, namely the exclusion of persons with chronic diseases and insufficient physical performance. It is suggested to increase the frequency of these examinations with age.

Monitoring: It might be advisable in some cases to monitor the worker during exposure. Where it is in the most situations sufficient that the respective workers are visually checked by their colleagues the need of an organised monitoring increases with the severity of the exposure and is particularly relevant for persons who are not acclimated due to their irregular and rather rare exposures to heat.

For practical purposes exposures might be categorised into

— Regular exposures including work in protective clothing, very hard work in rather moderate conditions and training activities for emergency exposures, where a trained first aide should pay attention to subjective responses and clinical signs.

— Exceptional exposures such as maintenance or repair work, where a trained first aide, should observe the work and shall be entitled to withdraw the workers from exposure (the workers' decision making can be affected by the heat).

— Emergency exposures which cover the work of fire and rescue authorities, where the development and application of personal alarm devices based on physiological responses are advisable.

TRADITIONAL AND MODERN MONITORING METHODS OF HEAT STRAIN IN WORKERS EXPOSED TO EXTREME HEAT AT WORK .

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Heart rate, body core and skin temperatures, sweat rate and subjective sensations are widely accepted as suitable criteria to assess heat strain. The physiological literature is rich in human thermal data collected under various hot conditions, mostly in climatic chambers but also under real work conditions. The rapid development of low cost, miniaturised personal heat stress monitoring systems enables continuous and simultaneous monitoring of several physiological parameters and generates much needed information on prolonged heat strain under occupationally stressful hot conditions.

The limits for heat-related physical exhaustion and fatal heat stroke have already been appreciated for years (1). Also the first suggestions for limit values of permissible heart rate and body temperature elevation or sweat production for short-term exposures or per 8-h work shift have been published decades ago (8,10). More recent limit values are given e.g. in ISO standard 7933:1989 "Hot environments - Analytical determination and interpretation of thermal stress using calculation of required sweat rate" and in ISO 9886:1992 " Evaluation of thermal strain by physiological measurements". However, the ISO 7933 has only limited applicability to the clothed worker and it does not take adequately account individual variation in sweat sate. There are also informative limit values in ISO 9866, which describes methods for measuring and interpreting physiological parameters considered to reflect thermal strain caused by physical work and work environment.

ISO/DIS 12894:1997 Ergonomics of thermal environment – Medical supervision of individuals exposed to extreme hot or cold environments" gives advise on the acceptability of extreme hot environments for human exposure and provides guidance about health monitoring which may be appropriate prior to and during such exposures. However, there is a lack of systematical studies on the factors affecting the human tolerance to either high ambient temperature or heat strain associated with exercise. This kind of information would be extremely valuable in selection of candidates for hot work.

Good physical and mental health and a certain level of maximal oxygen consumption and muscle performance are suggested for primary requirements for hot workers in several countries. However, recent findings (2-6) have shown that good physical working capacity may only protect from excessive cardiovascular strain during the exercise in the hot environment, but oxygen consumption alone does not predict very well the individual heat tolerance.

The main components of cardiovascular strain are heart rate and blood pressure. During the simultaneous exposure to heat and exercise effective control mechanisms of circulatory adaptation are required. Monitoring of the blood pressure has three advantages. Systolic blood pressure reflects the pumping capacity of the heart. The decrease during the exercise is a significant sign of pump failure. The post-exercise hypotension in the heat is not an uncommon finding in subjects with hyperkinetic hemodynamics or low stroke volume. Orthostatic hypotension may have some predictive value in selecting candidates for the extreme heat exposing jobs.

In general the diastolic blood pressure decreases in heat. There are however subjects, who in contrast show increasing tendency of the diastolic blood pressure. It may be a sign of diastolic dysfunction of the hypertensive or cardiac patients and it is a risk factor for cardiac events in subjects with clinical or subclinical cardiac insufficiency.

The autonomic nervous system is an important part of the cardiovascular and thermoregulatory control mechanisms. The new techniques of cardiac autonomic reflex testing allow to monitor this system (9). The multifactorial analysis of heart rate, electrocardiogram and/or continuous blood pressure can be used in the physiological laboratories for the assessment of the autonomic control capacity e.g. in selection protocols. During the training programs they can be used as markers of the physical overstrain and/or stress reactions. After an extreme heat load they are better indices of recovering capacity than only a heart rate. Alterations in the cardiac autonomic control predict the vulnerability to serious cardiac events during the psychophysiological environmental stress.

Repeated heat and exercise bouts may also cause progressive muscle damage. The muscle enzymes, especially lactate dehydrogenase (LDH) and creatine kinase have both diagnostic and predictive value in case of the exercise induced heat illnesses. Creatine kinase is more suitable for the field measurements, although LDH is preferred in the emergency care units.

The recent findings of our studies on heat tolerance in different aged men and women (5), fire fighters (2-4) and young men with previous heat illness (6) support recommendation for further multifactorial studies, which provide needed information for better understanding of the factors affecting individual tolerance to heat strain.

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HEAT STRESS – WHAT TO DO IN PRACTICE - Selection, training and short and long-term surveillance of workers exposed to heat: The situation in Germany

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Work under heat stress even today is much more common than we might expect in our highly developed and frequently highly automated industry in our European countries. Melting iron and steel, forging and welding or the production of glassware or ceramics still require human work exposed to heat as we also can observe in working places in hot environments in the chemical industry or even more than thousand meters underground in coal or potash mines.

A lot of engineering work has been applied to reduce the heat impact and the health hazards for the workers, but there is still the need to improve working conditions in order to reduce the impact of heat or in cases the heat load can not be sufficiently reduced to improve the health surveillance for the workers involved. Due to the dual system of safety surveillance in Germany which dates back to the governmental safety inspectorates of the state of Prussia in the middle of the last century as well as to the accident prevention regulations issued by the Berufsgenossenschaften. These again date back to the year of 1884 when Bismarck presented the “Imperial Message” of emperor William I. that laid the basis for the formation of a general insurance system for work accidents. This insurance system was placed into the hands of the so-called Berufsgenossenschaften. In order to reduce the insured safety risks this institution was granted the formal right to inspect enterprises and to proclaim not only accident prevention rules but also to enforce lawfully their strict following. This system combined with the governmental inspectorate which enforces governmental accident prevention rules has been kept nearly unchanged up to these days.

The only exception to this procedure for the German industry can be found in the mining industry where it is the mine inspectorate which is responsible for the supervision of work safety and the miners’ health following a century old tradition dating back to the medieval mining royalties of the German emperor. So by tradition the single rulers of the German states introduced a mine inspectorate which was not only responsible for the supervision of the mining procedures but also for the health care of the miners and their families. The oldest regulations date back to 1225 in the Iglau Mining Law where night and shift work and also the work of women and children underground was regulated.

In today’s mining industry accident prevention and health care is regulated by the Federal Mining act of 1980 (Bundesberggesetz) combined with the Mine Regulation for Health Protection of 1984 (Gesundheitsschutz-Bergverordnung) and the Mine Regulation for Work under Heat Stress underground (Klima-Bergverordnung). Both regulations give precise criteria for the selection of miners, their health care and the climatic conditions under which underground mining is tolerable or illegal. Besides these regulations there is also a regulation for emergencies and mine rescue operations (Plan für das Grubenrettungswesen).

All other industrial working places under heat stress are regulated by the accident prevention regulation “Heat” as well as additionally by several individual accident prevention recommendations issued by individual branches of the work accident compensation system. These publications gives special advise in accident prevention for different industries, for instance for the chemical industry, for power stations, the steel industry etc.

The system of medical supervision and selection is again common for all parts of the industry. Here it is the central accident prevention regulation “VBG 100 Occupational Health Care” which forms the basis and the framework of the central regulations for the procedures of the specific occupational health medical testing.

This collection of different medical investigation procedures implies the specific heat stress surveillance program “G 30” which defines explicit rules to determine physical fitness for industrial work under heat stress. According to our German legislation a worker found to be unfit according to these rules is not supposed to work in these conditions, so the employer cannot legally send him to work. If he does so, nevertheless, he risks a high penalty or meets full responsibility in cause of an accident.

Following these regulations a worker can be declared fit, unfit or temporarily unfit for work under heat stress. The criteria are written down in these regulations giving some additional hints for the physician in charge of the occupational health supervision.

The general procedures and the content of these different regulations will be commented in the oral presentation much more in detail as well as the procedures of selection and the main experiences of the system applied.

HEAT STRAIN AND HEAT STRESS INDICES AND WHAT LIES BETWEEN THEM

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Man lives and works in a microenvironment that is jointly influenced by various factors. This includes the external environment: air temperature, humidity, air movement and radiation; the metabolic heat produced by activity, and the clothing that serves as a thermal barrier between the body and the environment. It follows that it is impossible to express the thermal burden on man as a function of a single factor. Although measurement of those parameters individually does not present much difficulty, the integration of all parameters into a single composite index that determines "heat stress" has been a matter of investigation for almost a century. The first index, suggested by Halden (1905), considered the wet bulb temperature as a suitable index of heat stress.

A suitable index of thermal stress should provide a yardstick against which one could assess the severity of the given exposure. It should also enable to predict safe and desirable limits of exposure without irreparable damage to the body. Hatch (1963) concluded that a heat stress index should meet the following criteria:

(One) it should be quantitative, with a defined zero-point and with scale intervals in direct proportion to increments of stress;

(b) stress values should be directly calculated from stated conditions of exposure and activity;

(c) the basis of calculation should be such that the various combinations that produce the same physiological response will be recognised and given equal stress values.

Heat stress indices can be grouped into 2 categories:

(One) indices based on subjective feelings of warmth;

(Two) objective indices based on physical laws of heat transfer.

The first category is presented by the "effective temperature" (ET) and its later derivatives; the second category is best represented by the "heat stress index" (HSI).

The change in response of a particular physiological parameter from its value in a comfortable environment is regarded as the corresponding physiological strain. In this respect heat strain is defined in terms of the physiological cost of those parameters which are involved in maintaining the thermal balance of the body. Whether a single parameter can assess the physiological strain is questionable. Not many heat strain indices were developed. Some of these indices are based on a combination of end point values of selected physiological variables. Such an approach bears intrinsic difficulties in the application of the index. Physiological strain is time dependent and non-linear in its nature; using end-point values does not count for the dynamic changes. Also, most of the variables that are used in these indices are interrelated and therefore affect each other.

Over the years, only few indices that determine the physiological strain in terms of the physiological cost were developed. The first was based on a single physiological variable – the "predicted 4 hrs sweat rate" (P4SR). Recently Frank et al suggested the "cumulative heat strain index" (CHSI) which evaluates the cardiovascular strain separately from the thermoregulatory strain and then combines them together into a single index.

In conclusion, the choice of an index of thermal stress/strain should be determined by the purpose for which the index is required. The indices of stress (heat load – external and internal) and strain (physiological response), based on the distinction between them, must be independent of each other, i.e. not derived from the same parameters.

EXAMPLE OF APPLICATION

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The programme includes 2 versions:

VERSION 1 is for untrained users wishing to get a first idea of the discomfort or the heat strain. It relies only on appreciation of the parameters and avoids systematically uncommon concepts and units.

- The user selects
    - the type of work load: rest, light, medium, heavy or from a list of examples
    - the type of clothing from a list of common outfits
    - the air temperature, in °C
    - the air humidity: low, normal, high, very high
    - the air velocity: nil, very low, low, medium, high, very high
    - the radiation: nil, negligible, low, medium, high, very high, or from a list of examples.
- At each of these qualitative descriptions of the primary parameters, corresponds a quantitative value from which the programme makes the interpretation
    - it describes the risk of discomfort or heat stress and, in the latter case, recommends a duration limit of exposure
    - it suggests the modifications to bring to the worse parameters and indicates what the situation will be if these modifications are implemented
    - in case of heat stress, it recommends the quantity of water the workers should drink.
- If the user wishes so, he can get the relevant interpretation parameters:
    - total water loss (g) over a 8 h period
    - rectal temperature at the end of 8 hours
    - DLE for water loss, DLE for t_{re} = 38
    - PMV, PPD
    - WBGT, WBGT limit

VERSION 2 is addressed to occupational health specialists.

1. Contrary to the simple version, it makes possible to introduce a sequence of workplaces characterised by
    - the duration, in minutes
    - the air temperature, in °C
    - the humidity in either
        - partial vapour pressure, in kPa
        - wet bulb temperature, in °C
        - relative humidity, in %
        - dew point temperature, in °C

      ◊ the 3 other parameters are recomputed as soon as one is changed

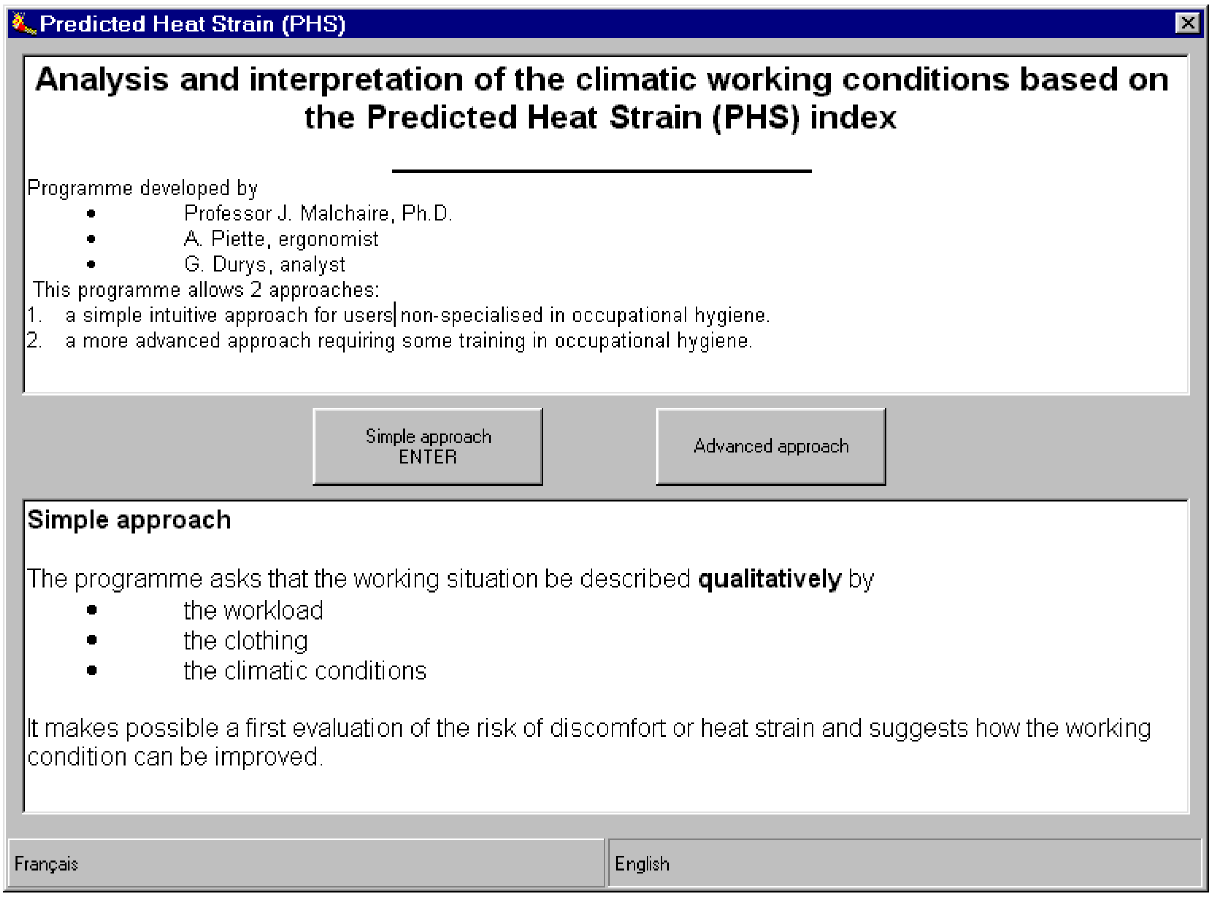
      ◊ if the air temperature is changed, the partial vapour pressure is kept constant and the other 3 parameters are recomputed
    - the radiation in either
        - the globe temperature, in °C
        - the mean radiant temperature, in °C

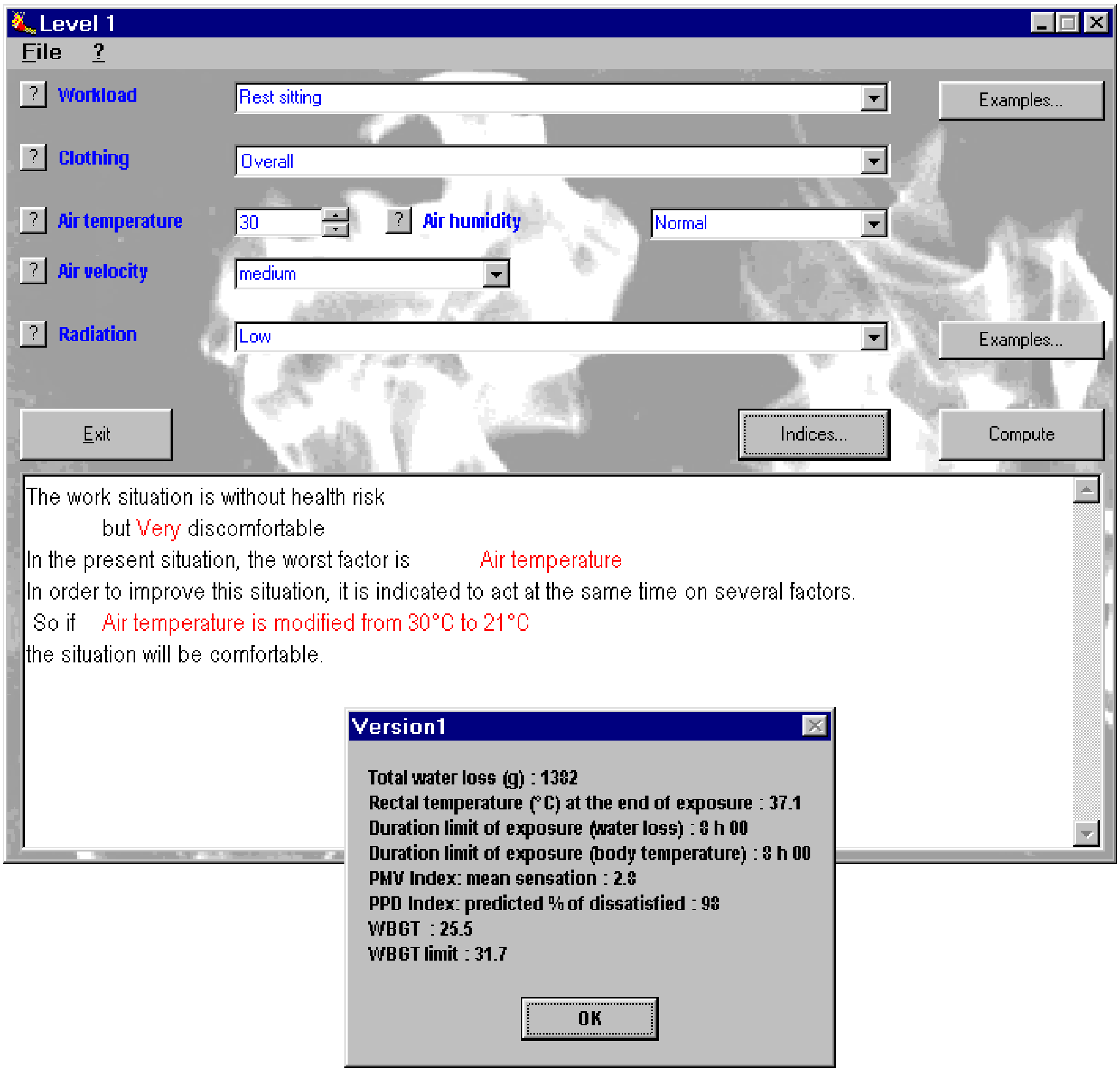
      ◊ the other parameter is recomputed as soon as one is changed

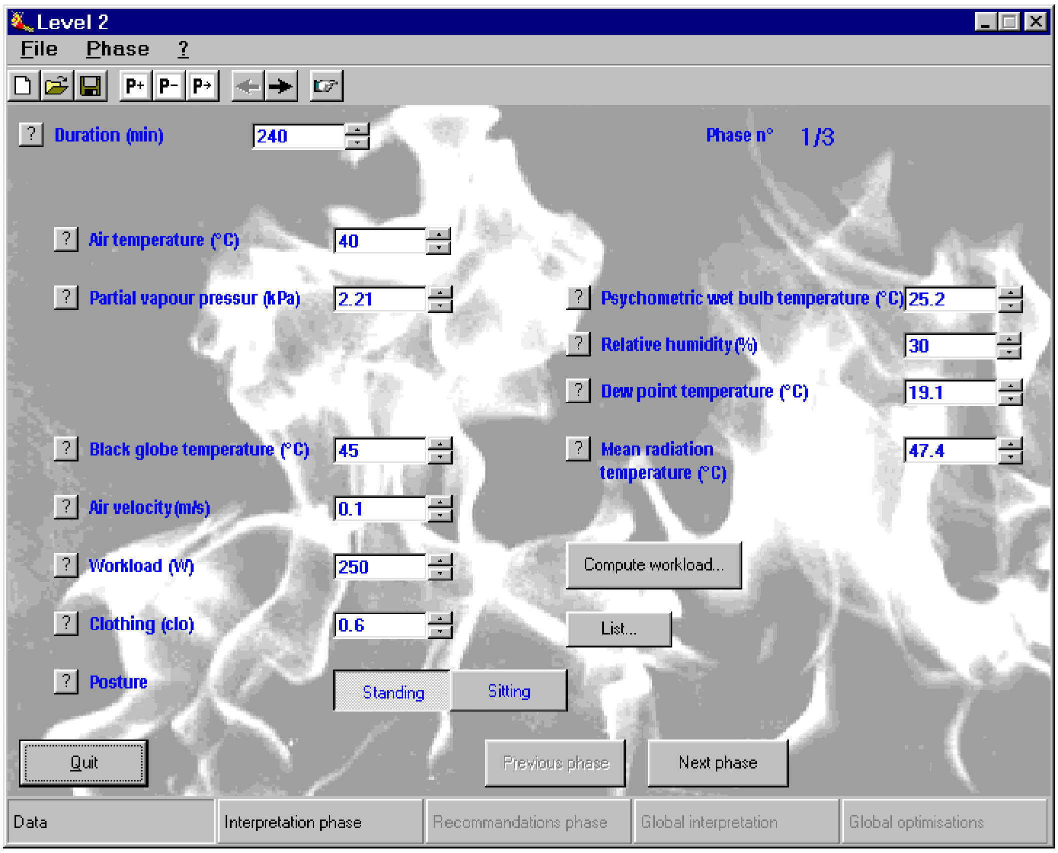
    - ◊ if the air temperature is changed, both parameters are reset at the air temperature.
  - air velocity, in m/s
  - workload in watts or from 3 methods
    - ◊ as a function of the body parts involved and the heaviness of the work
    - ◊ from a list of operations
    - ◊ from the mean heart rate, as a function of the maximum work capacity estimated as a function of age and weight
  - clothing insulation in clo or from a list of outfits
  - posture: standing or sitting.
2. The second step of the programme is the interpretation of each phase, without taking into account its duration. A table is proposed summarising the primary parameters and giving the following values:
   - PMV, PPD
   - WBGT, WBGT limit
   - Sweat rate , g/h
   - DLE (min)
   - a conclusion: discomfort or heat stress.
3. The third step of the programme makes suggestions concerning
   - the worst parameters
   - the modifications to bring to these factors.

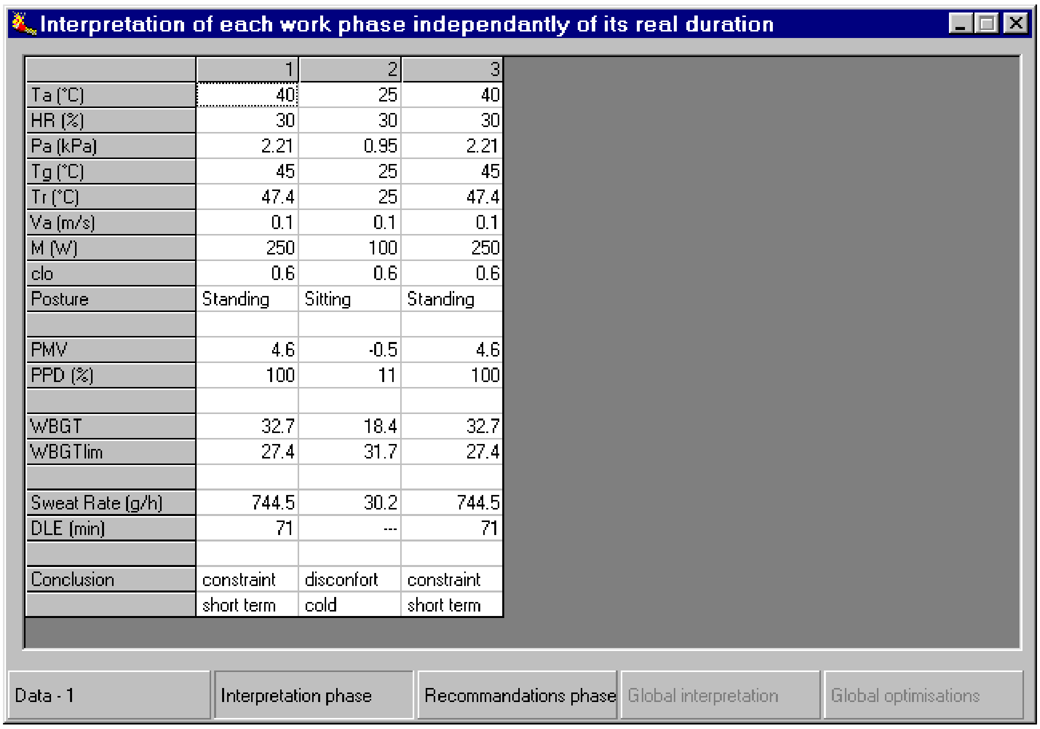
   It summarises what the situation would be if these modifications were implemented and makes the interpretation. The user can decide to accept or not these modifications.
4. The fourth step of the programme is the global interpretation of the sequence of phases taking into account their durations. The programme displays
   - the evolution of the sweat rate
   - the evolution of the cumulated sweat loss
   - the evolution of the rectal temperature
   - the PPD and WBGT indices in a coloured form indicating discomfort or not and heat stress or not.
   - the user has the possibility to modify any parameter of any phase and display directly the consequences on the graphs.
5. The fifth step of the programme is the global optimisation of the sequence.
   - if only discomfort is encountered, the programme offers to the user the possibility to modify the sequence
   - if heat stress is encountered, the programme itself makes suggestions in order to limit the duration of the heat stress phases and introduce rest periods.

The programme makes possible to go from one step to any other at any time.


Predicted Heat Strain (PHS)
Analysis and interpretation of the climatic working conditions based on the Predicted Heat Strain (PHS) index
Programme developed by
• Professor J. Malchaire, Ph.D.
• A. Piette, ergonomist
• G. Durys, analyst
This programme allows 2 approaches:
1. a simple intuitive approach for users non-specialised in occupational hygiene.
2. a more advanced approach requiring some training in occupational hygiene.
Simple approach ENTER
Advanced approach
Simple approach
The programme asks that the working situation be described qualitatively by
• the workload
• the clothing
• the climatic conditions
It makes possible a first evaluation of the risk of discomfort or heat strain and suggests how the working condition can be improved.
Français
English

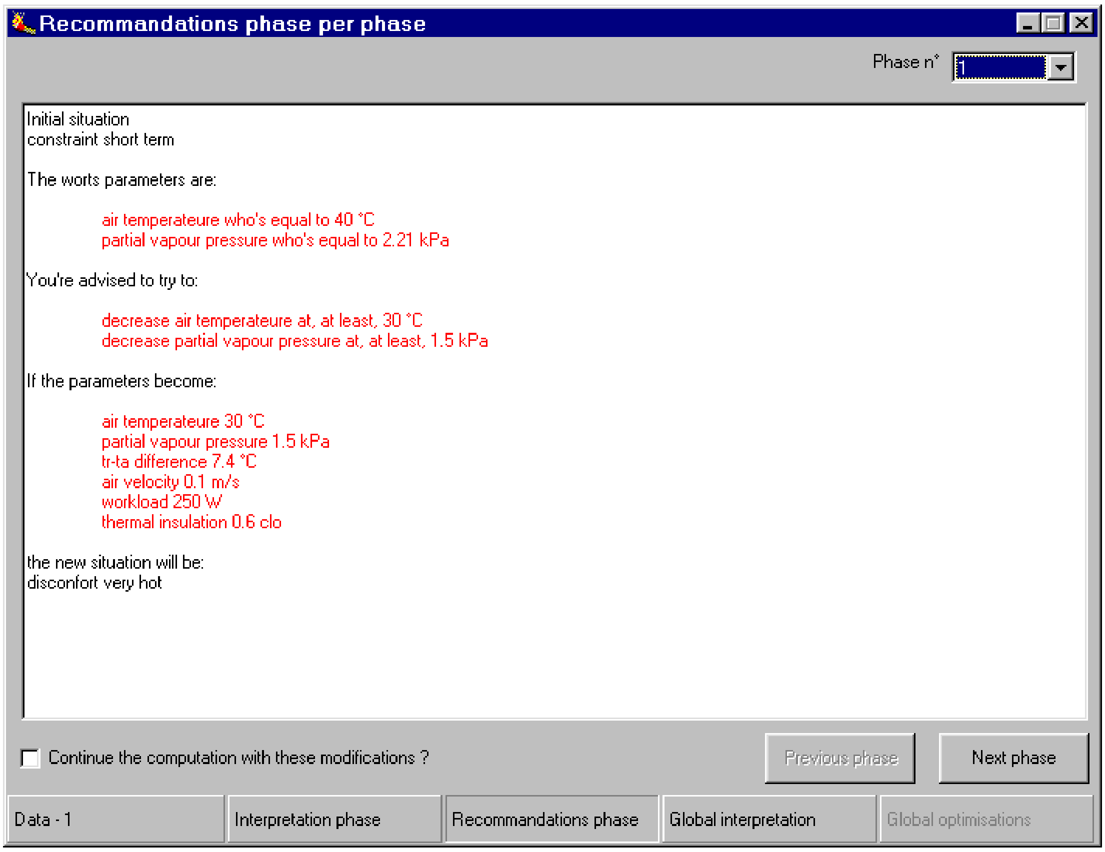

Level 1
File ?
Workload
Rest sitting
Examples...
Clothing
Overall
Air temperature
30
Air humidity
Normal
Air velocity
medium
Radiation
Low
Examples...
Exit
Indices...
Compute
The work situation is without health risk
but Very discomfortable
In the present situation, the worst factor is Air temperature
In order to improve this situation, it is indicated to act at the same time on several factors.
So if Air temperature is modified from 30°C to 21°C
the situation will be comfortable.
Version1
Total water loss (g) : 1382
Rectal temperature (°C) at the end of exposure : 37.1
Duration limit of exposure (water loss) : 8 h 00
Duration limit of exposure (body temperature) : 8 h 00
PMV Index: mean sensation : 2.8
PPD Index: predicted % of dissatisfied : 98
WBGT : 25.5
WBGT limit : 31.7
OK

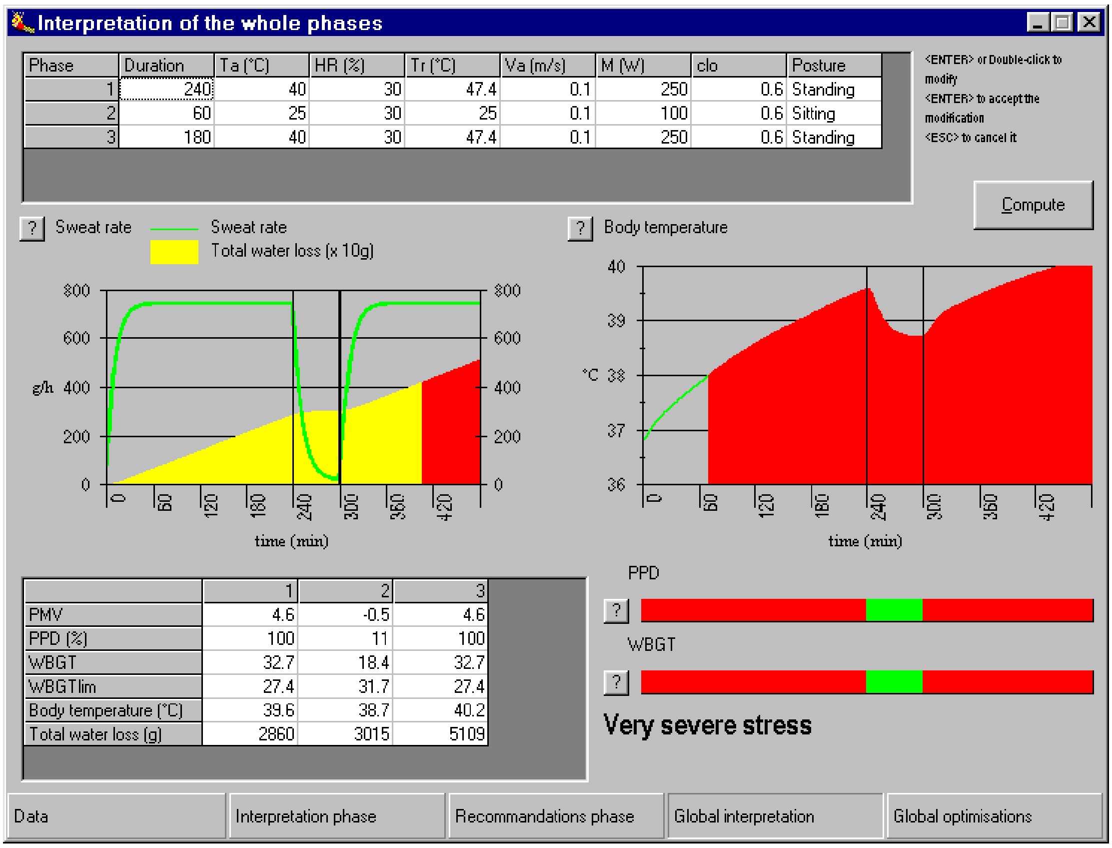


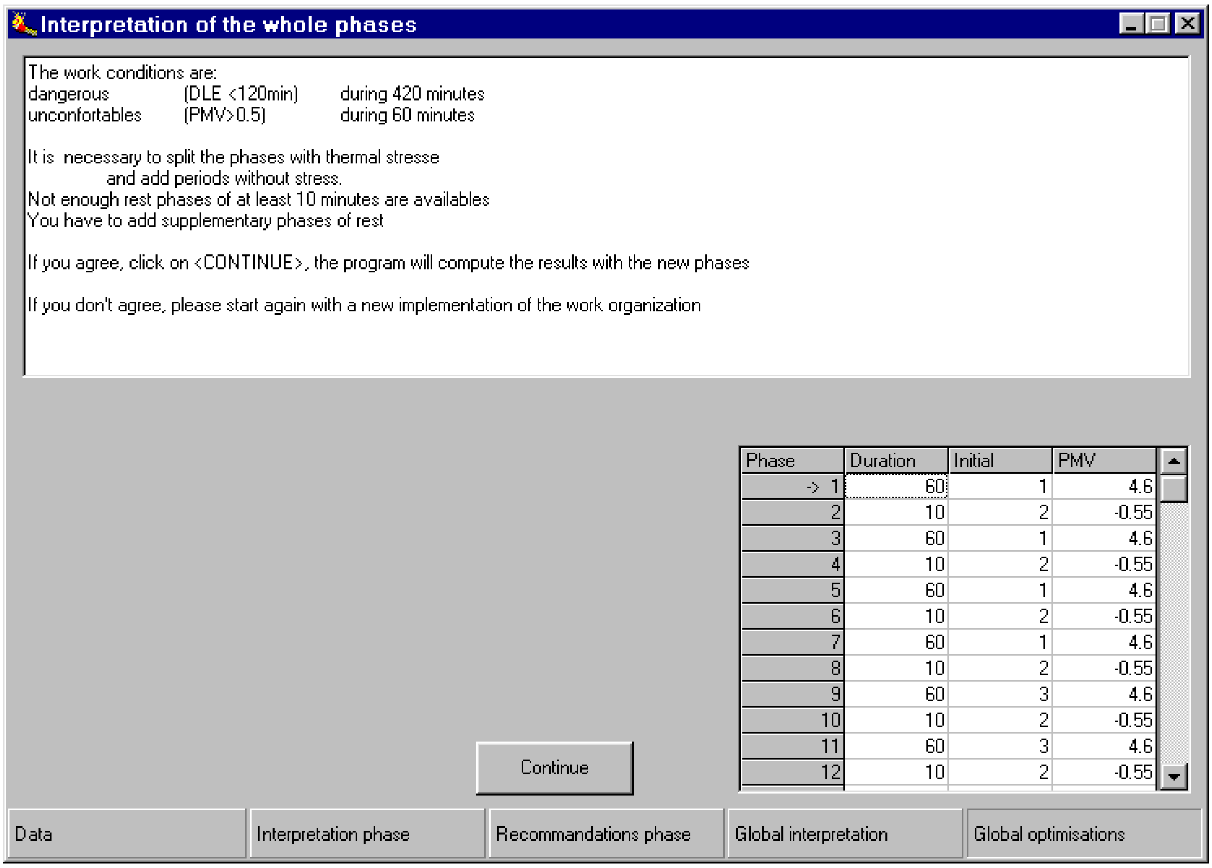

Interpretation of each work phase independantly of its real duration

	1	2	3
Ta (°C)	40	25	40
HR (%)	30	30	30
Pa (kPa)	2.21	0.95	2.21
Tg (°C)	45	25	45
Tr (°C)	47.4	25	47.4
Va (m/s)	0.1	0.1	0.1
M (W)	250	100	250
clo	0.6	0.6	0.6
Posture	Standing	Sitting	Standing
PMV	4.6	-0.5	4.6
PPD (%)	100	11	100
WBGT	32.7	18.4	32.7
WBGTlim	27.4	31.7	27.4
Sweat Rate (g/h)	744.5	30.2	744.5
DLE (min)	71	---	71
Conclusion	constraint	disconfort	constraint
	short term	cold	short term

Data - 1 | Interpretation phase | Recommandations phase | Global interpretation | Global optimisations


Recommandations phase per phase
Phase n°
1
Initial situation
constraint short term
The worts parameters are:
air temperateure who's equal to 40 °C
partial vapour pressure who's equal to 2.21 kPa
You're advised to try to:
decrease air temperateure at, at least, 30 °C
decrease partial vapour pressure at, at least, 1.5 kPa
If the parameters become:
air temperateure 30 °C
partial vapour pressure 1.5 kPa
tr-ta difference 7.4 °C
air velocity 0.1 m/s
workload 250 W
thermal insulation 0.6 clo
the new situation will be:
disconfort very hot
Continue the computation with these modifications ?
Previous phase
Next phase
Data - 1
Interpretation phase
Recommandations phase
Global interpretation
Global optimisations


Interpretation of the whole phases
Phase | Duration | Ta (°C) | HR (%) | Tr (°C) | Va (m/s) | M (W) | clo | Posture
1 | 240 | 40 | 30 | 47.4 | 0.1 | 250 | 0.6 | Standing
2 | 60 | 25 | 30 | 25 | 0.1 | 100 | 0.6 | Sitting
3 | 180 | 40 | 30 | 47.4 | 0.1 | 250 | 0.6 | Standing
<ENTER> or Double-click to modify
<ENTER> to accept the modification
<ESC> to cancel it
Compute
? Sweat rate
Sweat rate
Total water loss (x 10g)
g/h
time (min)
? Body temperature
°C
time (min)
| 1 | 2 | 3
PMV | 4.6 | -0.5 | 4.6
PPD (%) | 100 | 11 | 100
WBGT | 32.7 | 18.4 | 32.7
WBGTlim | 27.4 | 31.7 | 27.4
Body temperature (°C) | 39.6 | 38.7 | 40.2
Total water loss (g) | 2860 | 3015 | 5109
PPD
WBGT
Very severe stress
Data
Interpretation phase
Recommandations phase
Global interpretation
Global optimisations



Interpretation of the whole phases

The work conditions are:
dangerous (DLE <120min) during 420 minutes
unconfortables (PMV>0.5) during 60 minutes

It is necessary to split the phases with thermal stresse
and add periods without stress.
Not enough rest phases of at least 10 minutes are availables
You have to add supplementary phases of rest

If you agree, click on <CONTINUE>, the program will compute the results with the new phases

If you don't agree, please start again with a new implementation of the work organization

Phase	Duration	Initial	PMV
-> 1	60	1	4.6
2	10	2	-0.55
3	60	1	4.6
4	10	2	-0.55
5	60	1	4.6
6	10	2	-0.55
7	60	1	4.6
8	10	2	-0.55
9	60	3	4.6
10	10	2	-0.55
11	60	3	4.6
12	10	2	-0.55

Continue

Data | Interpretation phase | Recommandations phase | Global interpretation | Global optimisations

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