Strategy of intervention on heat problems

Predicted Heat Strain index (PHS) MODEL

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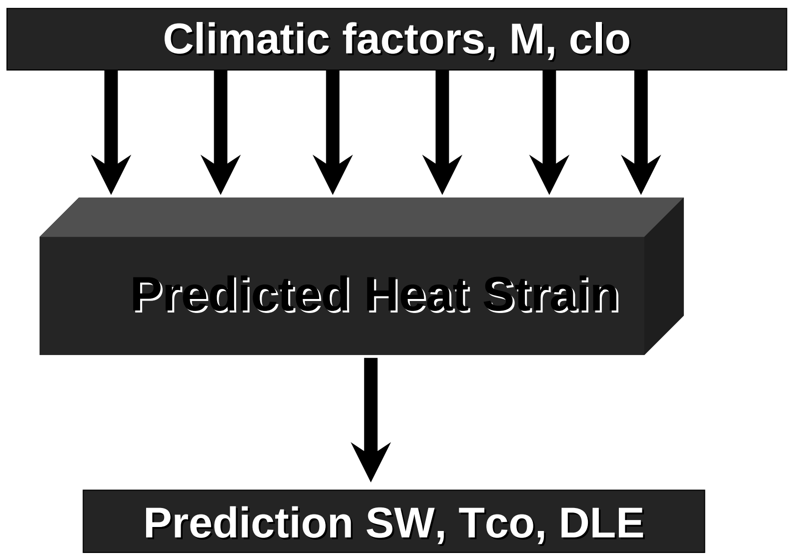
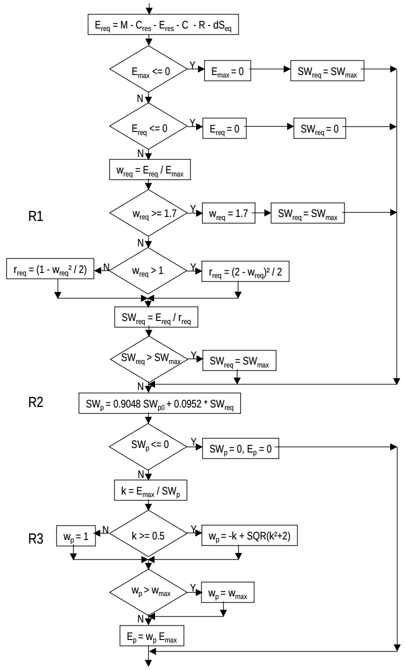
PLAN:

- Strategy of management of the problems
- BIOMED Research
  - Development of PHS
    - Algorithms
    - Limit criteria
  - Validation
  - Demo of the programme

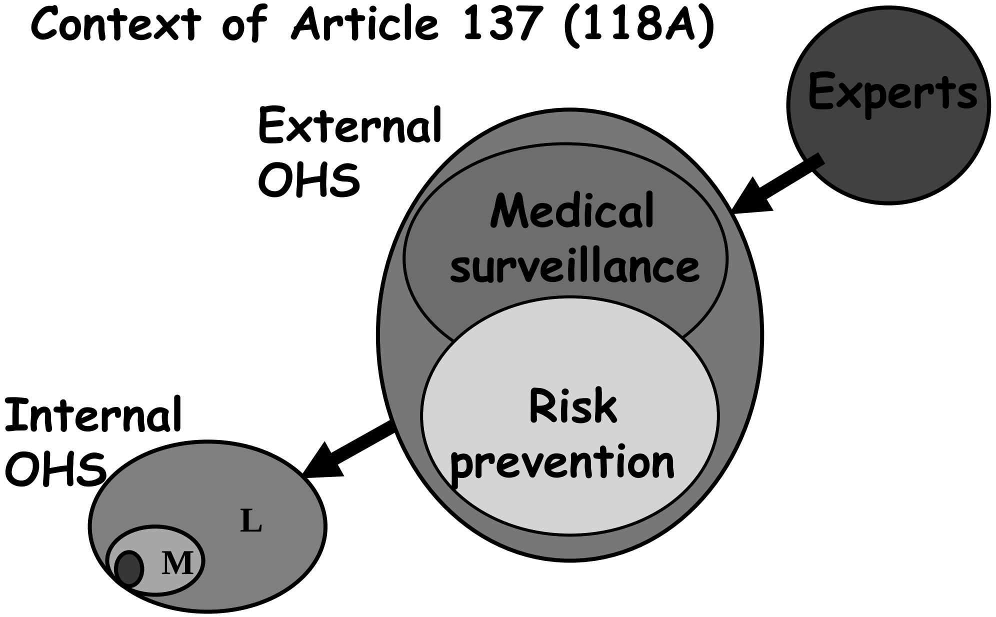
Strategy for the management of the thermal working conditions



Symbol	Term	Unit	Symbol in the program
-	code =1 if walking speed entered, 0 otherwise	-	defspeed
-	code =1 if walking direction entered, 0 otherwise	-	defdir
α	fraction of the body mass at the skin temperature	dimensionless	-
α_i	skin-core weighting at time i	dimensionless	TskTcrwg
α_{i-1}	skin-core weighting at time (i-1)	dimensionless	TskTcrwg0
ε	emissivity of the bare skin	dimensionless	-
τ	time constant	min	-
θ	angle between walking direction and wind direction	degrees	Theta
A_{Du}	Dubois body surface area	square metre	Adu
A_p	fraction of the body surface covered by the clothing	dimensionless	Ap
A_r	effective radiating area of the body	dimensionless	Ardu
C	heat flow by convection at the skin surface	Watts per square metre	Conv
c_e	water latent heat of evaporation	Joules per kilogram	-
$C_{orr,cl}$	correction for the dynamic clothing insulation for totally clothed subjects	dimensionless	CORcl
$C_{orr,Ia}$	correction for the dynamic boundary layer insulation	dimensionless	CORia
$C_{orr,tot}$	correction for the dynamic clothing insulation as a function of the actual clothing	dimensionless	CORtot
$C_{orr\ E}$	correction for the dynamic permeation rate	dimensionless	CORe
c_p	specific heat of dry air at constant pressure	Joules per kilogram of dry air	-
C_{res}	heat flow by respiratory convection	Watts per square metre	Cres
c_{sp}	specific heat of the body	Watts per square meter per degree celsius	spHeat
D_{lim}	allowable exposure duration	min	Dlim
$D_{lim\ tre}$	allowable exposure duration for heat storage	min	Dlimtre
$D_{limloss50}$	allowable exposure duration for water loss, mean subject	min	Dlimloss50
$D_{limloss95}$	allowable exposure duration for water loss, 95% of the working population	min	Dlimloss95
D_{max}	maximum water loss	grams	Dmax
D_{max50}	maximum water loss to protect a mean subject	grams	Dmax50
D_{max95}	maximum water loss to protect 95% of the working population	grams	Dmax95
dS_i	heat stored during the last time increment	Watts per square metre	dStorage
dS_{eq}	body heat storage rate for increase of core temperature associated with the metabolic rate	Watts per square meter	dStoreq



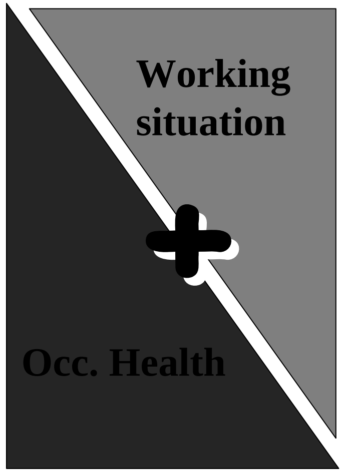
Context of Article 137 (118A)



Occupational Health Services structure

OH partners

- Employees
- Management
- Safety officers
- Occ. physicians
- Occ. hygienists
- Ergonomists
- Experts



Objectives

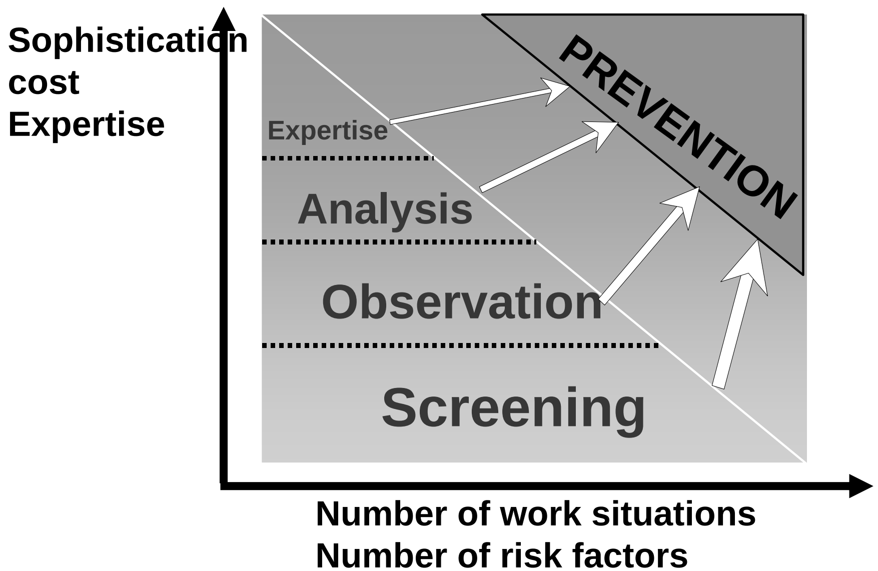
- Coordination of all partners
- Qualitative vs quantitative
- « Evaluation » vs « Measurements »
- Prevention vs assessment
- Cost-effectiveness
- Methods applicable by SMEs

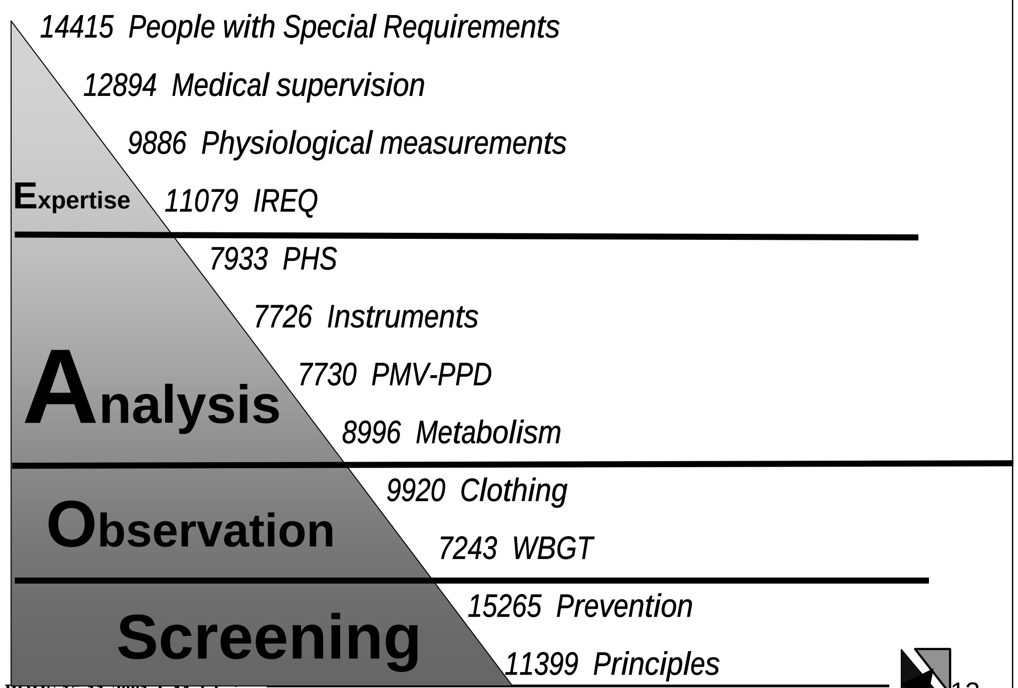
	Stage 1 "Screening"	Stage 2 "Observation"	Stage 3 "Analysis"	Stage 4 "Expertise"
• When?	Systematically	When a "problem" is detected	More complicated Cases	Very complex cases
• How?	Opinions	Qualitative observations	Ordinary measurements	Specialised measurements
• Cost?	Very low	Low	Average	High
• Duration (order of magnitude)	10 min	2 hours	1 day	A few days
• By whom?	Workers + company management	Workers + company management	Same + specialists	Same + specialists + experts
• Knowledge - working conditions - ergonomics	Very high Low	High Average	Average High	Low Specialised

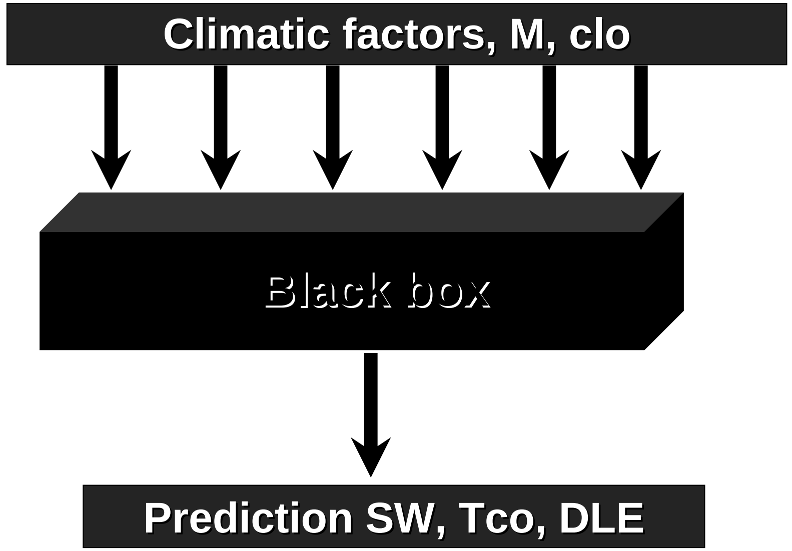
Characteristics

- Participative
  - Workers play the essential role in the dynamics of improvement
  - Occupational health specialists and experts are helping
- Structured in 4 complementary stages
  - Requiring complementary knowledge and competencies

Prevention Strategy SOBANE







Methodology

Stage 1: SCREENING

First stage: SCREENING

- To get an overview of the working conditions
  - for the main factors related to safety, health and well being
- Conclusions:
  - Are there complaints related to the climatic conditions?

Stage 1: SCREENING

Collect information about the work situation, in general:

- the working conditions
- the physical conditions: heat, noise, pollution,...
- the psychosocial factors
- ....

Define what is determinant for the workers health and well being

Stage 2 : OBSERVATION

OBSERVATION designed to:

- Identify particular circumstances, specific tasks, unusual working conditions where a "problem" exists
- Determine what to do to reduce or eliminate these problems: straightforward solutions
- By or with the help of the workers themselves.

Conclusion:

- Is the "problem" satisfactorily controlled or not?
- If not, the assistance of specialists is needed.

Criteria for OBSERVATION

Designed for the workers and their management

- Simple to understand by untrained people
- Avoiding concepts or terms not readily understood
- Easy to use, maximum 1 hour for a specific circumstance of work
- Based on simple OBSERVATIONS (no measurement)
- Oriented towards prevention

Stage 2: OBSERVATION

Procedure

Discussion of

- The working conditions
- The technical process
- The characteristics of the heat or cold sources
- The possibilities of control measures.

- Describe the working condition known to or likely to raise a thermal problem
- Evaluate the situation for each of the six parameters separately:

Stage 2: Air temperature

Actual situation
Causes and sources
Actions of prevention – improvement
Future situation

-3	• Generally freezing
-2	• Generally between 0 and 10°C.
-1	• Generally between 10 and 18°C
0	• Generally between 18 and 25°C
1	• Generally between 25 and 32°C
2	• Generally between 32 and 40°C
3	• Generally greater than 40°C

Air temperature: Solutions

- Locate the sources of heat or cold in the periphery
- Eliminate the sources of hot or cold air
- Insulate the hot surfaces
- Exhaust hot or cold air locally
- Ventilate without draughts
- Use clothes with lower or higher insulation

Stage 2: Humidity

Actual situation

Causes and sources

- -1 - Dry throat/eyes after 2-3 hours
- 0 - Normal
- 1 - Moist skin
- 2 - Skin completely wet

Actions of prevention – improvement

- Eliminate the leaks of vapour and water
- Enclose all evaporating surface
- Use clothes waterproof but permeable to vapour
- ...

Future situation

Stage 2: Thermal radiation

Actual situation

Causes and sources

- -1 - Cold on the face after 2-3 minutes
- 0 - No radiation discernible
- 1 - Warm on the face after 2-3 minutes
- 2 - Unbearable on the face after > 2 minutes
- 3 - Immediate burning sensation

Actions of prevention – improvement

- Reduce the radiating surfaces
- Use reflecting screens
- Insulate or treat the radiating surface
- Locate workstations away from radiating surfaces
- Use special protective clothes reflecting radiation
- ...

Future situation

Stage 2: air movements

Actual situation

Causes and sources

- -2 . cold strong air movements
- -1 . cold light air movements
- 0 . no air movements
- 1 . warm light air movements
- 2 . warm strong air movements

Actions of prevention – improvement

Reduce or eliminate air draughts
Use screens to protect locally against draughts
Locate workstations away from air draughts
...

Future situation

Stage 2: workload

Actual situation

Causes and sources

- 0 . office work: easy low muscular constraints,
- 1 occasional movements at normal speed.
- 2 . Moderate work with arms or legs
- . Intense work with arms and trunk
- 3 . very intense work at high speed: stairs, ladders

Actions of prevention – improvement

Reduce the movements during work
Reduce displacements
Reduce the speed of movements
Reduce the efforts, use mechanical assistance…
Improve the postures…

Future situation

Stage 2: clothing

Actual situation

Causes and sources

0 - light, flexible, not interfering with the work
1 - long, heavier, interfering slightly with the work
2 - clumsy, heavy, special for radiation, humidity
3 - special overalls with gloves, hoods, shoes

Actions of prevention – improvement

- Improve the design of the clothing
- Select more suitable materials
- Look for lighter materials
- ...

Future situation

Stage 2: Opinion of the workers

Actual situation

-3 - shivering, strong discomfort for the whole body
-2 - strong local discomfort overall sensation coolness
-1 - slight local cool discomfort
0 - no discomfort
1 - slight sweating and discomfort thirst
2 - heavy sweating, work pace modified
3 - excessive sweating, special clothing

Future situation

OBSERVATION: Synthesis

Characteristics of the actual situation

	-3	-2	-1	0	1	2	3
Air temperature							O
Humidity						O	
Radiation					O		
Air movements				O			
Work Load						O	
Clothing							O

OBSERVATION: Synthesis

Comparison before and after improvements

	-3	-2	-1	0	1	2	3
Air temperature						X	O
Humidity					X	O	
Radiation					=		
Air movements				=			
Work Load					X	O	
Clothing					X		O

OBSERVATION: Conclusions

- Decide whether a more detailed ANALYSIS is needed to quantify and to solve the problem.
- Determine the measures to be taken in the short-term if needed:
  - Drinks
  - Recovery periods
  - Work organisation
  - Clothing....

Stage 3: ANALYSIS

ANALYSIS: Objectives

- For the conditions selected during stage 2: OBSERVATION
  - To quantify the risk of thermal discomfort or
  - To Identify more elaborated solutions
  - To determine the optimum work organisation.
  - To determine whether an EXPERTISE (stage 4) is needed.

Stage 3: ANALYSIS

- Deal with specific conditions
- Usually involve measurements

Conducted with the assistance of OH practitioner with adequate training

- To find technical solutions
- To define organisational solutions and short-term protection measures

Conclusions

- Is the assistance of an Expert required?

Criteria for ANALYSIS

Designed for OH practitioner

- Use common concepts and techniques
- If necessary, simple measurements to identify
  - the causes of the problems
  - the solutions
- Useable in less than one day
- Oriented towards prevention

ANALYSIS: Procedure

Analyse the sequence of activities:

- Description of the activities.
- Mean and maximum durations.
- Period concerned by the working situation.
- Exposed workers

ANALYSIS: Procedure

ANALYSIS of the working situation during representative period(s) of time

- Measurement or estimation of the mean and maximum values
- Computation of the indices PMV - PPD, PHS

ANALYSIS: Synthesis

	Activity ...		Activity ...	
	mean	Max	mean	max
t_a				
RH				
t_g				
v_a				
M				
Clo				
PMV				
PPD				
WBGT				
PHS / DLE				

ANALYSIS:Interpretation

Risk in the present situation

cold constraint	PMV < -2
cold discomfort	-2 < PMV < -0,5
comfort	-0,5 < PMV < 0,5
warm discomfort	0,5 < PMV < 2
constraint in the long term	DLE < 480 min
constraint in the short term	DLE < 120 min
immediate constraint	DLE < 30 min

ANALYSIS: Procedure

- Determine the acceptability of the working condition by comparing:
  - mean-maximum duration of each activity
  - the DLEs.
- Define prevention/control techniques
- Define the optimum work organisation.
- Determine the residual risk after implementation of these prevention/control measures.

ANALYSIS: synthesis

	Activity ...	Activity

3. RISK
• Class of risk
• If heat stress
  • Sweating rate
  • Water loss per day
  • DLE		

4. ACCEPTABILITY		
5. PREVENTION/CONTROL MEASURES		
6. RESIDUAL RISK		
7. NEED FOR AN EXPERTISE		
8. SHORT TERM MEASURES		
9. MEDICAL SURVEILLANCE		

Stage 4: EXPERTISE

Stage 4: EXPERTISE

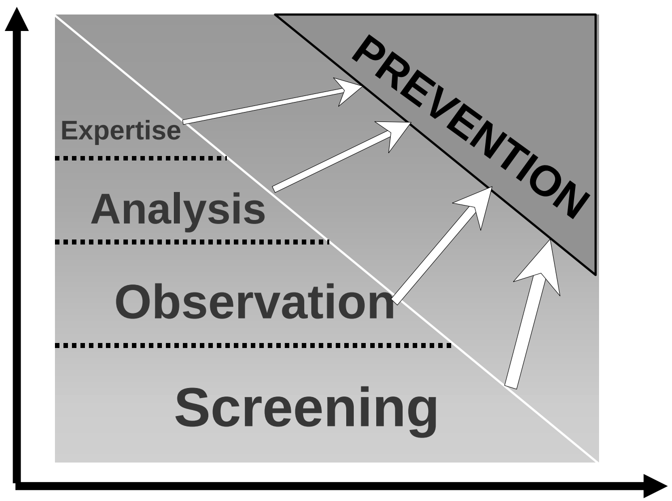
- Better characterise some heat or cold sources and/or some unusual circumstances
  - Specific measurements
  - Specific investigation techniques
- Characterize the overall exposure of the workers
- Look for sophisticated prevention/control measures

Stage 4: EXPERTISE

- Sequence of activities:
- Specialised measurements:
  - Radiation, air circulation,…
  - Metabolic rate: Oxygen consumption, HR
  - Clothing insulation
  - Time variations
- Computation of indices according to time:

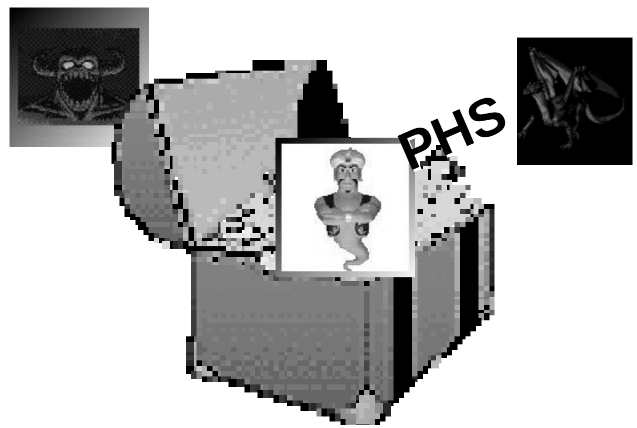
  PMV - PPD, Predicted Heat Strain

Prevention Strategy



The Biomed research

Predicted Heat Strain



ISO 7933 "Required Sweat Rate"

- *Main criticisms concerned:*
  - *The prediction of the skin temperature*
  - *The influence of the clothing on convection, radiation and evaporation*
  - *The increase of core temperature linked to the activity*
  - *The prediction of the sweat rate in very humid conditions*
  - *The limiting criteria and in particular the "alarm" and "danger" level*
  - *The maximum water loss allowed.*

Partners in the BIOMED research:

- **8 European labs**
  - **J. Malchaire, catholic university of Louvain, Belgium**
  - **H. Gebhardt, ASER, Germany**
  - **B. Griefahn, P. Mehnert, IFADO, Germany**
  - **B. Kampmann, institut für arbeitswissenschaften, G.**
  - **G. Alfano, universita di Napoli, Italy**
  - **G. Havenith, E. Den Hartog, TNO, The Netherlands**
  - **I. Holmér, Arbetsmiljöinstitutet, Sweden**
  - **K. Parsons, Loughborough university, UK**

Predicted skin temperature (1/4)

- ***ISO 7933 algorithm***
  - ***Based on a limited set of data***
  - ***For mainly nude subjects.***
  - ***Skin temperature decreases with the clothing***

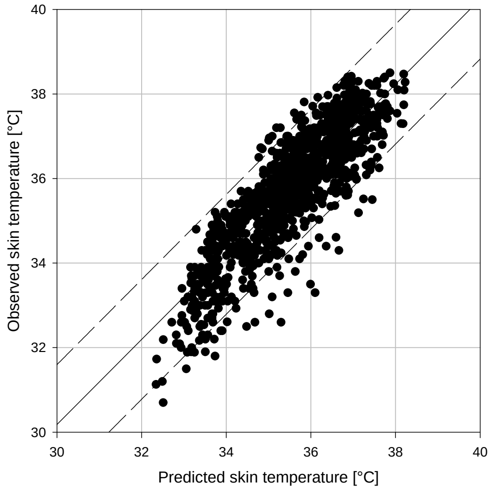
Predicted skin temperature (2/4)

- **Material and Methods**
  - **HEAT database**
  - **Selection of data points in steady state conditions**
  - **Only data from MALE subjects**
- **T_{SK} database: 1999 data points (from 1399 conditions with 377 male subjects)**
  - **Separate analysis for nude (≤ 0.2 clo) and clothed (0.6 ≤ Icl ≤ 1.0) subjects**
  - **Multiple linear regression technique (with re-sampling: non-parametric bootstrap)**

Predicted skin temperature (3/4)

Prediction model: nude subjects

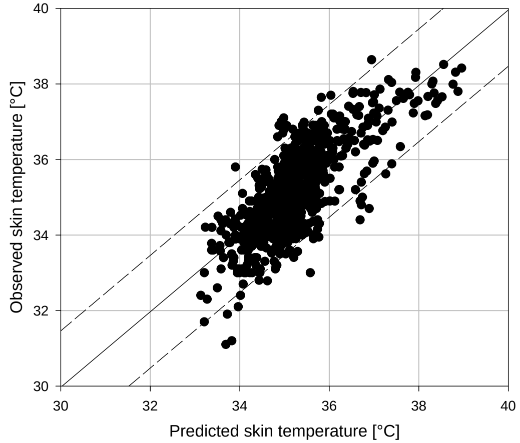
$$t_{sk} = 7.19+0.064\ t_a+ 0.061t_r+ 0.198p_a- 0.348v_a+ 0.616t_{re}$$



Predicted skin temperature (4/4)

Prediction model: clothed subjects

$$t_{sk} = 12.17+0.020\ t_a+0.044\ t_r+0.194\ p_a- 0.253\ v_a +0.003\ M+0.513\ t_{re}$$



Skin - core temperature weighting

◆ ***SW_{req} assumes weighting 30% – 70%***

- **$\alpha = 0.3$ for $t_{re} \leq 36.8°C$**
- **$\alpha = 0.1$ for $t_{re} \geq 39°C$**
- **α varies between 0.3 and 0.1 according to**

$$\alpha = 0.3 - 0.09\ (t_{re} - 36.8)$$

Prediction of the rectal temperature

◆ ***Rectal temperature remains, with heart rate, the easiest physiological parameter to record at the work place***

- **The core temperature t_{co} is the mean of**
  - **the rectal temperature: characteristic of the muscle mass**
  - **the oesophageal temperature: characteristic of the blood and influencing the hypothalamus.**

$$t_{oe} = 1.31 + 0.962\ t_{re} + 7.03\ dt_{re}$$

Increase in t_{co} associated with M

- ◆ *SWreq does not take into account the normal increase in core temperature due to activity even in moderate and neutral climate.*
- Saltin (1966), in a neutral condition:

  t_{cor} = 0.002M + 36.6 (M in watts)
- The body does not attempt to loose this stored heat

Evolution of t_{sk} and SW with time (1/3)

- ◆ *Main limitation of the ISO 7933 standard:*
  - *Assume that a steady state is reached instantaneously.*
  - *Impossible to predict the situation in case of intermittent exposure*
  - *Heat accumulation assumed to remain the same during the WHOLE exposure*

Evolution of t_{sk} and SW with time (3/3)

$$V(t) = V_{max} (1 - \exp(t / \tau))$$

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

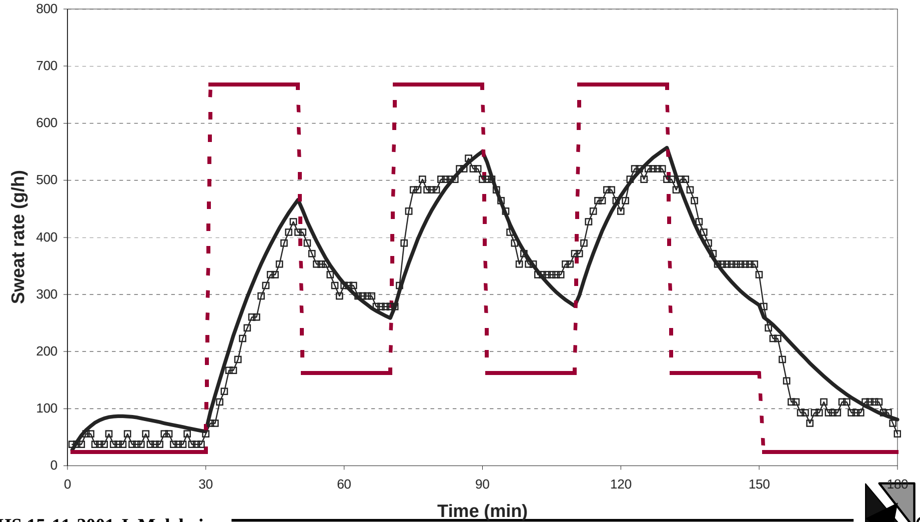
where

- 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
- $k = \exp(-\Delta t / \tau)$
- τ is the time constant (in minutes)
  - 3 minutes for the skin temperature
  - 10 minutes for the sweat rate

Evolution of t_{sk} and SW with time (2/3)

- Observed and predicted SW

  (using ISO 7933 and PHS)



Maximum sweat rate: SW_{max}

- ◆ *ISO 7933 assumes constant values of maximum sweat rate for acclimatised and unacclimatised subjects*
- **SW_{max} = 2.6 (M - 58) g/h**
  - **for M < 300 watts : 650 g/h**
  - **limited to 1000 g/h for unacclimatised subjects**
- **For acclimatised subjects:**
  - **maximum capacity increase by 25%**
  - **sweating in a given environment can be greater by a factor 2**

Max dehydration and water loss (1/2)

- ◆ *ISO 7933 limit values questioned in the field, and particularly in mines*
- **Maximum tolerable <u>dehydration</u> to be considered only in less severe conditions**
  - **2% body mass: threshold for thirst stimulation**
  - **3% body mass: increase in heart rate and sweating**

Max dehydration and water loss (2/2)

- **with exposure 4 to 8 hour**
  - **average rehydration rate of 60%**
  - **rehydration rate greater than 40% for 95% of the subjects**
- **Maximum <u>water loss</u>**
  - **7.5% of the body mass for an average subject**
  - **5% of the body mass for 95% of the working population**

Limit criteria: ISO7933 (1/3)

ISO 7933 limits for acclimatised and unacclimatised subjects

2 levels of protection:

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

Criteria too vague and too stringent.

- ***Prediction***
  - ◆ *for the "average" subject*
  - ◆ *for percentile 95%*

Limit of internal temperature (1/3)

- *WHO document 1969: Limit of 38°C*
  - **"It is inadvisable for deep body temperature to exceed 38°C in prolonged daily exposure to heavy work."**
  - ***commonly adopted and implicitly adopted in ISO 7933***
  - ***Document often quoted and altered***

Limit of internal temperature (2/3)

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

Limit of internal temperature (3/3)

- **Maximum probabilities:**
  - **for 42°: $< 10^{-6}$: <1 heat stroke every 4 years among 1000 workers (250 days/year)**
  - **for 39.2°: $< 10^{-3}$: <1 person at risk among 1000 shifts.**

Main modifications ...PHS

1. **Prediction of t_{sk}**
2. **Prediction of heat exchanges**
3. **Prediction of heat storage**
4. **Prediction of t_{re} taking into account the heat storage in the skin layer**
5. **Prediction of DLE:**

   total water loss 7.5 and 5%

   t_{re} = 38°C

➡ **Predicted Heat Strain PHS**

VALIDATION

Database: 1113 experiments

- the primary parameters (t_a, p_a…)
- the physiological factors (t_{re}, sweat rate…)

	Number of experiments
Lab experiments	747
Subset 1	369
Subset 2	378
Field experiments	366
Men	1020
Women	93
Not acclimatised	452
Acclimatised	661
Nude experiments	244
Clothed experiments	869

BIOMED database

- Means, standard deviations and 95% confidence interval for the 6 parameters, 672 lab experiments, 95689 points

		m	s	95% confidence interval
air temperature	t_a (°C)	30.85	9.14	12.94 - 48.75
humidity	p_a (kPa)	1.95	1.26	0 - 4.42
radiation	t_r-t_a(°C)	15.42	21.80	0 - 58.15
air velocity	v_a (m/s)	0.40	0.25	0 - 0.90
metabolic rate	M (W)	243	114	20 - 467
clothing insulation	(clo)	0.38	0.34	0 - 1.05

Ranges of validation

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

Data selection for the validation

	SW	t_{re}
Lab experiments	672	1927
Field experiments	237	1028

Validation in lab experiments: SW

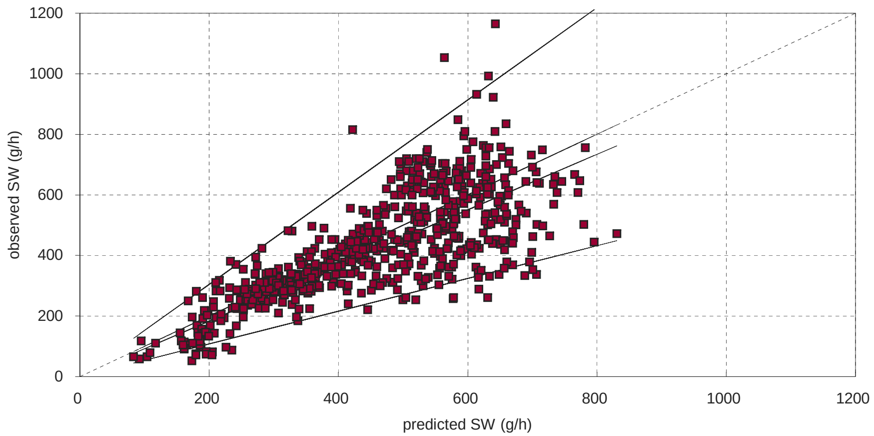
SW	Lab experiments
N	672
Observed (m±s)	424 ± 172
Predicted (m±s)	451 ± 154
Slope	0.848
Intersection	41
R	0.7601

- **Predicted values: in average 27 g/h greater**
- **Standard deviation smaller**

- **$SW_{obs} = 0.848 * SW_p + 41$ R=0.76**
- **$SW_{obs} = 0.918 * SW_p$**

Validation in lab experiments: SW

- **Observed and predicted sweat rates**
- **95% confidence interval**



Validation in lab experiments : t_{re}

t_{re}	Lab experiments
N	1937
Observed (m±s)	37.45 ± 0.47
Predicted (m±s)	37.46 ± 0.47
Slope	0.664
Intersection	12.57
r	0.6585

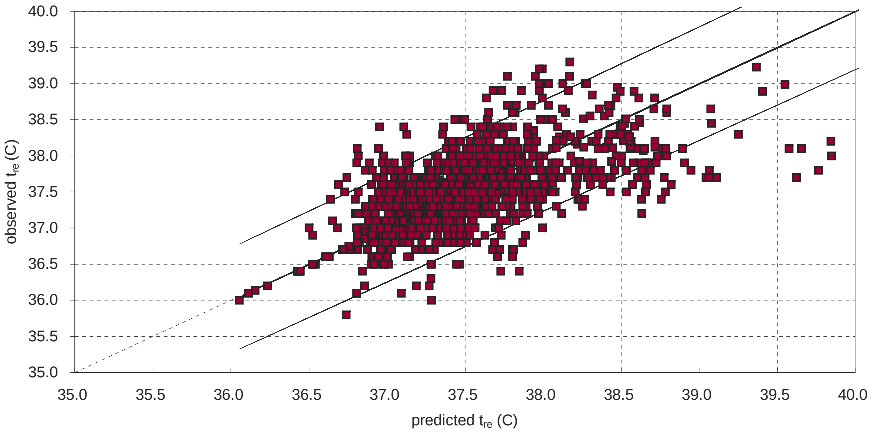
- **Means and standard deviations of observed and predicted values about equal.**

$t_{re\ obs} = 0.664\ t_{re\ p} + 12.57$ R = 0.66

$t_{re\ obs} = 1.000 * t_{re\ p}$

Validation in lab experiments: t_{re}

- Observed and predicted rectal temperature
- 95% confidence interval



Validation in field experiments:SW

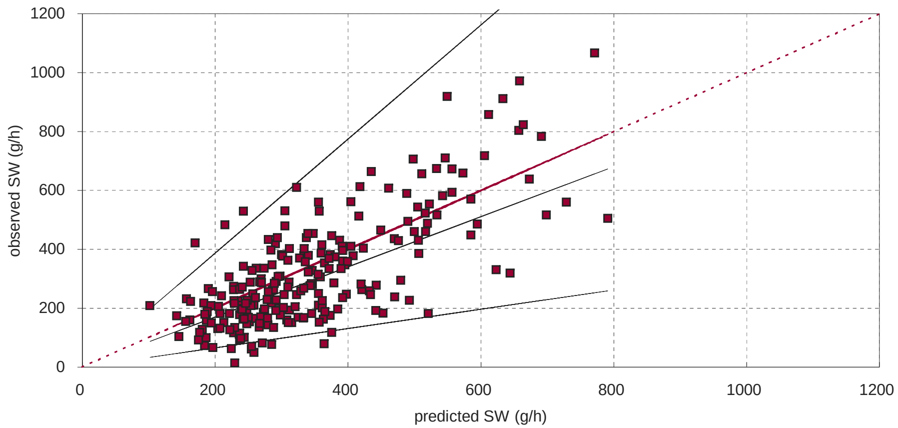
N	237
Observed (m ± s)	317 ± 187
Predicted (m ± s)	344 ± 132
Slope	1.056
Intersection	-46
r	0.7448

$SW_{obs} = 1.056 \quad SW_p - 46 \qquad R = 0.74$

$SW_{obs} = 0.851 * SW_p$

Validation in field experiments:SW

- Observed and predicted sweat rates
- 95% confidence interval



Validation in field experiments: t_{re}

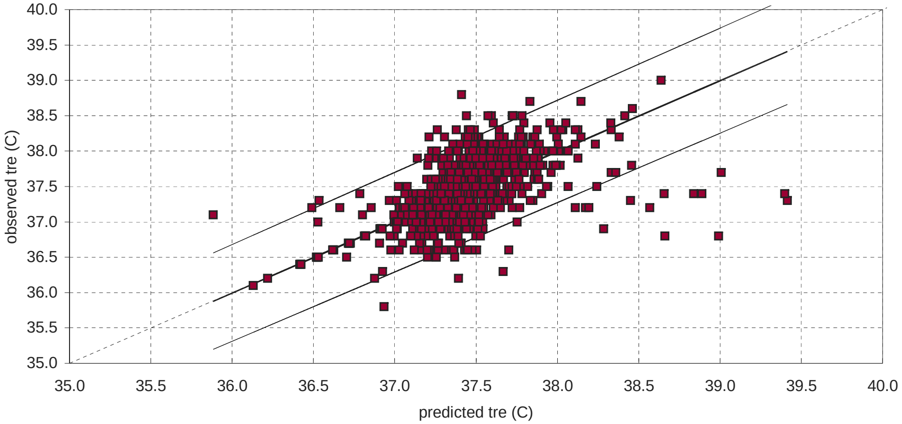
N	1028
Observed (m ± s)	37.40 ± 0.44
Predicted (m ± s)	37.40 ± 0.34
Slope	0.770
Intersection	8.60
r	0.5940

$t_{re\,obs} = 0.770 \quad t_{re\,p} + 8.60 \qquad R = 0.59$

$t_{re\,obs} = 1.000 * t_{re\,p}$

Validation in field experiments: t_{re}

- Observed and predicted rectal temperature
- 95% confidence interval



PHS model validation: conclusions

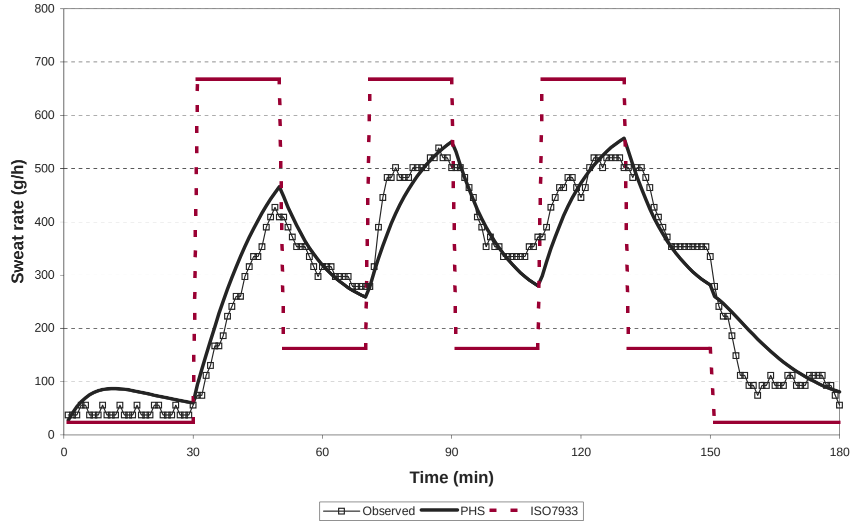
- good correlation between observed and predicted
- In view of the inter-individual differences

COMPARISON BETWEEN PHS MODEL AND ISO7933

Predicted sweat rate

	LAB EXPERIMENTS (n = 672)			FIELD EXPERIMENTS (n = 237)		
	Slope	Inters	r	Slope	Inters	r
SW_{ISO}	0.757	75	0.744	0.663	52	0.523
PHS model	0.848	41	0.760	1.056	-46	0.745

Comparison of PHS and ISO 7933



COMPARISON BETWEEN PHS MODEL AND WBGT INDEX

DLE_{PHS} Vs WBGT

- **DLE computed in 3680 sets of conditions:**

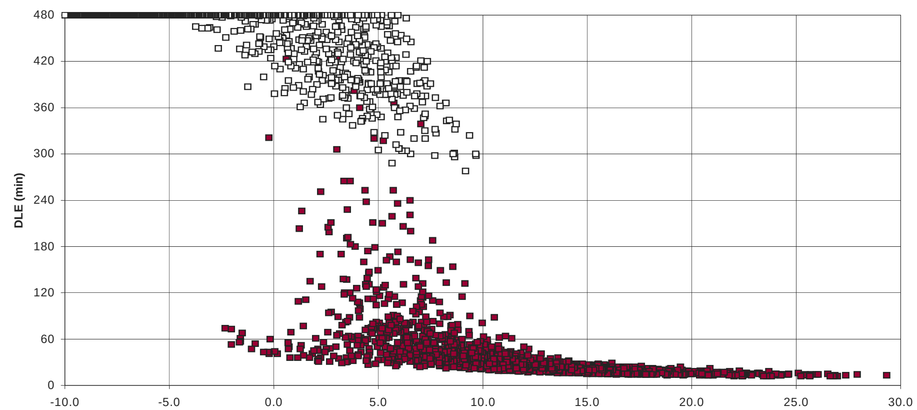
	Range	Step	Number of values
Air temperature (°C)	20 - 50	5	7
Relative humidity (%)	20 - 80	20	4
$(t_r - t_a)$ (°C) (but t_r limited at 60°C)	0 - 40	10	<5
Air velocity (ms^{-1})	0.01 - 2	0.5	5
Metabolic rate (W)	100 - 450	50	7
Clothing insulation (clo)	0.6	-	1

- **WBGT according to ISO 7243**
- **$WBGT_{limit}$ = 34.3 - M / 35.5 (with M in W).**

DLE_{PHS} Vs (WBGT - $WBGT_{limit}$)

DLE_{PHS} (min)

■ Heat storage
□ Dehydration



WBGT - $WBGT_{limit}$

DLE_{PHS} Vs (WBGT - $WBGT_{limit}$)

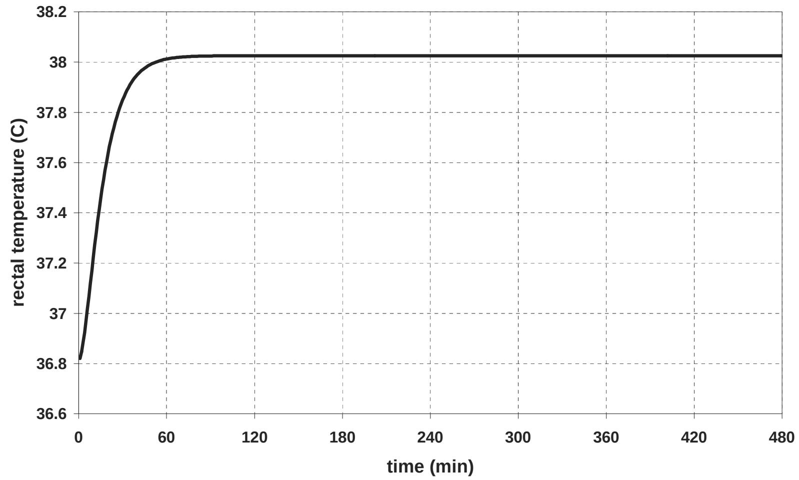
- **3 conditions with the same WBGT difference:**

t_a °C	RH %	t_r °C	v_a ms^{-1}	M W	clo	WBGT	$WBGT_{lim}$
40	20	40	1.0	450	0.6	27.6	21.6
25	60	45	0	350	0.6	30.4	24.4
30	80	60	1.5	300	0.6	31.7	25.8

- **According to the PHS model:**
- **DLE respectively 30, 236 and 425 minutes.**
- **⇒ WBGT plays role of screening method**

DLE_{PHS} Vs (WBGT - $WBGT_{limit}$)

- **Evolution of the rectal temperature predicted by PHS**



Conclusion

- **WBGT imposes work duration limitations even in cases where, according to the PHS model, work would still be permitted for 8 hours continuously.**

- **OK: WBGT screening method**

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Thank you