Thermal stress of fruit and vegetables pickers: temporal analysis of the main indexes through "Predict Heat Strain" model

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Abstract

Working in agriculture behaves workers to be exposed to sundries risk factors e.g. chemical agents, noise, posture, loads heading etc. Among these the most peculiar and the least investigated is constituted by microclimatic conditions during the different work steps. Warm and cold thermal stresses are estimated by microclimatic index: in particular, in agriculture range a heat strain condition come strain high temperature presence during horto-fruit harvesting. In particular the variation of environmental parameters during the working day makes the evaluation very difficult. A software for the evaluation of the main indexes has been realized to calculate the "Predict heat strain" (P.H.S.) according to the UNI EN 7933:2005 [2]. The model has been applied to the work environment of fruit and vegetables pickers during august. Analysis factors were: 1) physiologic variation, expressed by body temperature increase, skin moisture, water loss, perspiration; 2) variation of the main indexes of P.H.S. during the working day. Furthermore, the most effective and negative factors that determine thermal stress conditions have been found out. Among them, the most important is the worker acclimation, so it's extremely important to locate proper areas for reducing any exceeding thermal excursions. The paper highlights the importance of acclimation for fruit and vegetables pickers in their work environment.

Keywords: analytic determination, mean skin temperature, hot environment, total water loss.

Introduction

The job in agriculture involves the exposure of workers to different factors of risk, like chemical agents, noise, the postures, the loads moving, etc.

Among these, one of the most peculiar and less investigated risk is constituted by the micro-climatic conditions, during the different phases of work (in the field, in greenhouses, etc.). The thermal (heat and cold) stresses are evaluated through the micro-climatic indexes: particularly, in agricultural environments, a condition of thermal stress for the presence of high temperatures is had during the fruit harvest in the orchard.

In fact this mainly takes effects in the summer periods with the presence of high temperatures (> 30°C) and it lasts for a lot of time during the day.

The micro-climatic conditions outdoors, as for the operators addicted to fruit harvesting, result also to be varying and standard conditions are not always introduced within the cycle of work and in the following days. It is therefore necessary to also consider the physiological aspects that can describe in a better detailed way the evolution of the thermal stress due to activity in severely warm environments. The standard ISO 7933: 2005 "Analytical Determination and Interpretation of heat stress using calculation of the predict heat strain" comparisons a particular set of data, concerned:

- the prediction of the skin temperature (ISO 9886) [5]
- the influence of clothing on convection, radiation and evaporation;
- the combined effect of clothing and movements;

- the increase in core temperature related to activity;
- the exposure limit criteria and in particular the alarms and danger levels;
- the allowed maximum water loss.

The points requiring a concerted research were consequently identified as being:

- the coefficients of heat exchange by convection, radiation and evaporation in extreme conditions;
- the modelling of the physiological behavior during work to heat and, in particular, of the average skin temperature, the core temperature (rectal) and sweat rate [2].

The criteria for the determination of the exposure duration limit take account of the interindividual differences between the workers.

The goal of this paper is to describe the evolution of the thermal uneasiness, in a context of "predict heat strain", to evaluate the thermal discomfort for the operators employed to the fruit harvest. Particularly we want to foresee the response of the operators to the possible temperatures, considering a range that could be present during the harvest season, through physiological indexes as the skin temperature (t_{sk}) e Body mass loss measurement, $D_{limloss50}$, $D_{limloss95}$, D_{max50} [grams] (maximum water loss to protect a mean subject), D_{max95} (maximum water loss to protect 95% of the working population [grams] [4].

Matherial and methods

Influence of Clothing on the Heat Transfers by Convection and Evaporation

The heat loss by convection is a main part of the heat loss of the human body, particularly in moderate climates. In hotter environments, the heat loss depends more on evaporation, itself function of the characteristics of clothing. An important aspect of the transfers of heat to convection and evaporation is the effect wind velocity and movements on the transfer coefficients on the surface layer of the clothes. A factor played by clothing in the heat transfer is that it increases the heat transfer surface between the body and the environment. This increase is larger as the clothing is thicker and more insulating. The relation between the average t_{sk}, the primary climatic parameters, the metabolic rate and the rectal temperature was represented by an additive model. For the subset of data relating to the naked subjects, a model of prediction excluding the non significant variable metabolic rate was obtained [4]:

$$t_{sk} = 7{,}19 + 0{,}064 + 0{,}061 t_r + 0{,}198 p_a - 0{,}348 V_a + 0{,}616 t_{re}$$

were: t_{sk} = temperature of the surface of the clothes; t_r = mean radiant temperature ; p_a = partial vapour pressure; V_a = air velocity; t_{re} = rectal temperature.
The multiple coefficient of correlation between the observed values and predicted was equal to 0,86 and 83,3% of the predicted skin temperatures were in the range of = 1 °C from the observed values.
The following model was obtained for the clothed subjects:

$$t_{sk} = 12{,}17 + 0{,}020 t_a + 0{,}044 t_r + 0{,}194 p_a - 0{,}253 V_a + 0{,}0297 M + 0{,}153 t_{re}$$

with M = the metabolic rate (Wm^{-2}).
The coefficient of correlation (0,77) was lower than for naked subjects, but 81,8% of the predicted values were in the range of $\pm$ 1 °C from the observed values.
While the *temperature of the clothing t_{cl}* is given from:

$$t_{cl} = t_{sk} - I_{cl}\left\{ f_{cl} * h_c (t_{cl} - t_a) + 3{,}96 * 10^{-8} f_{cl}\left[(t_{cl} + 273)^4 - (t_r + 273)^4 \right] \right\}$$

where: I_{cl} = clothing insulation , f_{cl} = clothing area factor, There are two different types of temperatures that influence the heat exchanges from the operator to the outside; one is the temperature of the skin and the other one it is the temperature of the external surface of the clothing. It is also possible to identify a layer of air and a layer constituted by the fabric of the same clothing between the surface of the skin and the external surface of the clothing (figure 2). The two layers oppose a resistance to the transfer of the sensitive heat coming from the body (H) measured in [m^2 k/W]. In situations of rest it can be hypothesized that the thermal sensitive exchange through clothing, H, equalizes the general thermal exchange for convection, C, and for radiation, R, that leaves the surface of the covered body.

$$H = C + R; \quad H = (t_{sk} - t_{cl}) / I_{cl}$$

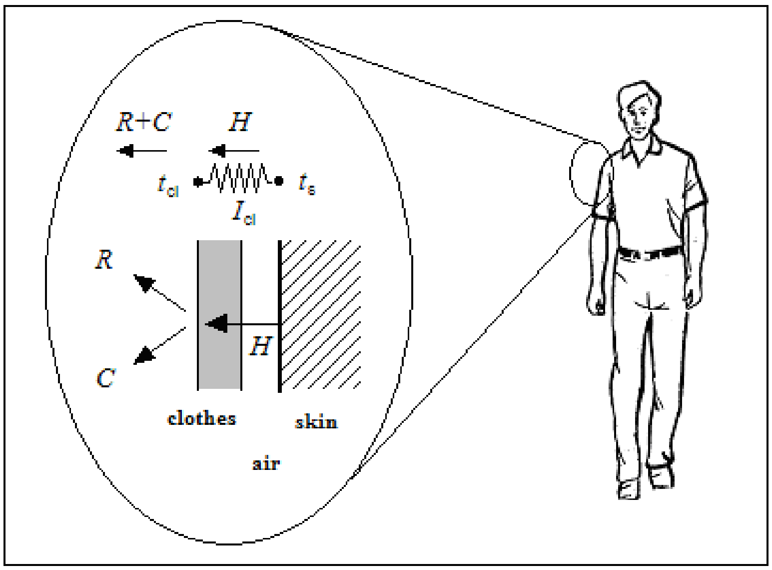

Figure 2: representation of the thermal sensitive exchange [2]

Instruments

To survey environment parameters, the unit LSI BABUC M with six inputs was used connected to 3 probes: a psychometric probe BSU102 with forced ventilation and a distilled water tank, used for measuring the air temperature (t_a) and the temperature of the damp bulb (t_w); an anemometric probe with hot wire BSV101, to measure the speed of the air (V_a); a global thermometric probe BST131 in black opaque copper (reflexion < 2% ASTM 97-55) for measuring the average radiating temperature (try) (probes in compliance with regulation ISO 7726) [1].
A farm situated on the Latium coastline was monitored, evaluating with the P.H.S. model the risk of excessive thermal load for workers harvesting fruit and vegetables in the fields. Monitoring have been done from July to August, during the whole day (a work day), during the harvest period.

PHS Model (Predict Heat Strain) and software realized

The P.H.S. "Predict Heat Strain", takes as input environmental parameters as air temperature t_a, the average radiating temperature t_r and the air velocity V_a.
Besides subjective parameters which are related to the operators, are considered: metabolic rate (Met), clothing insulation (I_{cl}), the duration of activity, weight and height of the operator, the speed with which the work is carried out in relation to the direction of the wind, and the acclimatization of the worker.

In exchange the P.H.S. model supplies us with some output which enable us to evaluate the probability of thermal collapse due to the environmental and personal conditions of operators working in severely hot environments.
The P.H.S. calculation is arduous; we can make it easy using a software Microsoft© Excel and Macro in Visual Basic programming language, inserting and modifying the analytic processes and the algorithm fixed by UNI EN ISO 7933:2005 [2].
In figure 2 you can see a data form, as well as the various instruments used for the experiment.
The software was developed by the department GEMINI – Laboratory of Ergonomics and Occupational Safety and Health– of the University of Tuscia - Viterbo, by Andrea Colantoni and Massimiliano Bernini.

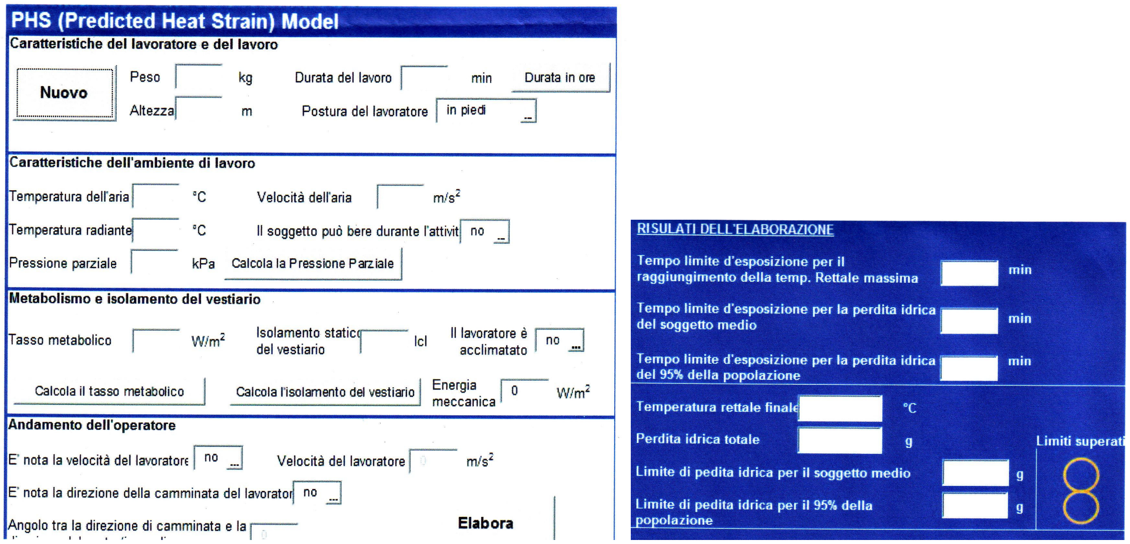

Figure 2. Software realized with Microsoft© Excel and Visual Basic's Macro

Results

__*Risk valued through P.H.S. method during harvest period on field*__

The tests were carried out on 6 workers taking into consideration their weight, height, type of work, insulation from clothes, their metabolic expenditure in relation to their work and lastly the state of acclimatization in relation to the environmental parameters.
The average values of environmental parameters, measured near workplaces, have been:
t_a = 30 °C (air temperature); t_r = 42,3 °C (mean radiative temperature); p_a = 3,48 kPa (partial vapor pressure), V_a = 3,0 m/s (air velocity); M = 150 met (metabolic rate); I_{cl} (clothing insulation) = 0,5 clo, on fields during the harvest [3-4].
The above described values, derive from the average of surveys made within a day; the environmental characteristics result notably variable and they negatively influence the micro-climatic evaluation. In the following tables is shown the response of these operators to a range of temperatures (28 - 38°C) that can be present within the same day, but also during different days of harvest. The evaluation in outdoor systems results to be complicated by the variability of the environmental parameters: therefore is useful to the goals to prevent the risks from heat stress to define a previsional model of the physiological response to the different and possible situations of thermal discomfort, caused by variations of temperature for severely warm environments.

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
A	[kg]	[m]	[m²]	[%]	Standing	[clo]	[W/m²]	Harvesting peppers
	58	1,70	1,67	0		0,5	150	

([1]) no drink

t_a °C	t_{sk} °C	t_{cl} °C	SW_{tot} [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50}$ (*) [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m² k/W
28	33,89	32,30	2290,00	480	288	480	3,2
29	34,59	33,21	2474,55	480	288	480	2,8
30	34,69	34,10	2873,40	480	288	480	1,2
31	34,70	34,45	2890,05	480	288	455	0,5
32	34,73	34,55	3080,35	480	272	427	0,4
33	34,75	35,10	3292,50	480	255	410	-0,7
34	34,86	35,89	3510,00	480	239	400	-2,1
35	34,86	35,89	3735,50	480	226	377	-2,1
36	34,91	36,33	3967,00	480	213	356	-2,8
37	35,01	36,78	4205,00	480	201	336	-3,5
38	35,10	37,22	4451,00	470	190	318	-4,2

Table 1 course of the physiological indexes in the range of temperature 28 ÷s 38° Cs for the operator A (limit values D_{max50} = 4350 grams; D_{max95} = 2900 grams)

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
B	[kg]	[m]	[m²]	[%]	Standing	[clo]	[W/m²]	Harvesting peppers
	80	1,75	1,95	0		0,5	150	

([1]) no drink

t_a °C	t_{sk} °C	t_{cl} °C	SW_{tot} [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50}$ (*) [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m² k/W
28	34,51	32,30	2679,0	480	288	480	4,4
29	34,60	32,55	3000,0	480	288	480	4,1
30	34,63	33,64	3139,0	480	288	480	2,0
31	34,65	34,08	3377,0	480	288	480	1,1
32	34,70	34,53	3621,2	480	272	427	0,3
33	34,73	34,90	3872,7	480	255	410	-0,3
34	34,77	35,42	4131,3	480	280	466	-1,3
35	34,81	35,86	4397,0	480	262	438	-2,1
36	34,85	36,31	4671,2	480	247	413	-2,9
37	34,90	36,75	4954,2	480	234	390	-3,7
38	34,94	37,20	5246,6	470	221	369	-4,5

Table 2 course of the physiological indexes in the range of temperature 28 ÷s 38° Cs for the operator B (limit values D_{max50} = 6000 grams; D_{max95} = 4000 grams)

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
C	[kg]	[m]	[m²]	[%]	Standing	[clo]	[W/m²]	Harvesting peppers
	78	1,80	1,97	0		0,5	150	

([1]) no drink

t_a °C	t_{sk} °C	t_{cl} °C	SW $_{tot}$ [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50\ (*)}$ [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m² k/W
28	34,54	32,76	2339,60	480	288	480	3,6
29	34,57	32,94	2560,20	480	288	480	3,3
30	34,63	33,65	2739,40	480	288	480	2,0
31	34,67	34,1	2946,70	480	288	480	1,1
32	34,73	34,54	3159,20	480	288	480	0,4
33	34,76	34,99	3377,09	480	288	480	-0,5
34	34,81	35,44	3601,40	480	270	451	-1,3
35	34,85	35,88	3832,24	480	254	424	-2,1
36	34,90	36,33	3890,58	480	240	400	-2,9
37	35,01	36,77	4315,34	480	226	378	-3,5
38	35,10	37,66	4830,49	470	214	357	-5,1

Table 3 course of the physiological indexes in the range of temperature 28 ÷ 38° C for the operator C (limit values D_{max50} = 5850 grams; D_{max95} = 3900 grams)

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
D	[kg]	[m]	[m²]	[%]	Standing	[clo]	[W/m²]	Harvesting peppers
	63	1,75	1,76	0		0,5	150	

([1]) no drink

t_a °C	t_{sk} °C	t_{cl} °C	SW $_{tot}$ [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50\ (*)}$ [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m² k/W
28	34,52	32,75	2704,26	480	288	480	3,5
29	34,56	33,20	2933,19	480	288	480	2,7
30	34,61	33,64	3167,53	480	288	480	1,9
31	34,65	34,09	3407,67	480	288	480	1,1
32	34,70	34,53	3654,07	480	279	465	0,3
33	34,74	35,01	3906,80	480	261	435	-0,5
34	34,78	35,42	4167,08	480	245	403	-1,3
35	34,82	35,87	4435,05	480	231	385	-2,1
36	34,87	36,31	4711,24	480	217	363	-2,9
37	34,91	36,76	4996,23	480	205	343	-3,7
38	34,95	37,20	5290,66	470	195	325	-4,5

Table 4 course of the physiological indexes in the range of temperature 28 ÷ 38° C for the operator D (limit values D_{max50} = 4725 grams; D_{max95} = 3150 grams)

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
E	[kg]	[m]	[m^2]	[%]	Standing	[clo]	[W/m^2]	Harvesting peppers
	90	1,70	2,00	0		0,5	150	

([1]) *no drink*

t_a °C	t_{sk} °C	t_{cl} °C	SW $_{tot}$ [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50\ (*)}$ [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m^2 k/W
28	34,49	32,74	2762,11	480	288	480	3,5
29	34,54	33,18	2996,63	480	288	480	2,7
30	34,58	33,63	3236,80	480	288	480	1,9
31	34,62	34,1	3483,02	480	288	480	1,0
32	34,66	34,52	3735,77	480	288	480	0,3
33	34,71	34,97	3995,15	480	288	480	-0,5
34	34,75	45,41	4262,42	480	288	480	-1,3
35	34,80	35,85	4537,75	480	286	477	-2,1
36	34,83	36,30	4821,69	480	270	450	-2,9
37	34,87	36,74	5114,86	480	254	424	-3,7
38	34,91	37,18	5417,93	480	240	400	-4,5

Table 5 course of the physiological indexes in the range of temperature 28 ÷ 38° C for the operator E (limit values D_{max50} = 6750 grams; D_{max95} = 4500 grams)

Worker[1]	Personal information		A_{Du}	Acclima-tization	Work position	I_{cl}	Met	Work
	weight	height						
F	[kg]	[m]	[m^2]	[%]	Standing	[clo]	[W/m^2]	Harvesting peppers
	85	1,75	2,00	0		0,5	150	

([1]) *no drink*

t_a °C	t_{sk} °C	t_{cl} °C	SW $_{tot}$ [g]	$D_{limloss\ 50}$ [minutes]	$D_{limloss\ 50\ (*)}$ [minutes]	$D_{limloss\ 95}$ [minutes]	*H* m^2 k/W
28	34,49	32,74	2751,11	480	288	480	3,5
29	34,54	33,18	2984,40	480	288	480	2,7
30	34,58	33,63	3223,25	480	288	480	1,9
31	34,62	34,1	3468,1	480	288	480	1,1
32	34,66	34,52	3719,37	480	288	480	0,3
33	34,71	34,97	3977,18	480	288	480	-0,5
34	34,75	35,41	4242,78	480	288	480	-1,3
35	34,80	35,85	4516,31	480	271	453	-2,1
36	34,83	36,30	4798,33	480	270	450	-2,9
37	34,87	36,74	5150,50	480	256	427	-4,4
38	34,91	37,18	5390,30	480	292	382	-4,5

Table 6 course of the physiological indexes in the range of temperature 28 ÷ 38° C for the operator F (limit values D_{max50} = 6350 grams; D_{max95} = 4250 grams)

Conclusions

The analyzed data in the charts, show the principal physiological indexes defined by the P.H.S. *predict heat strain model* in agreement to the ISO 7933:2005. The variations of the total loss water, reaching dangerous levels for the workers, have been analyzed particularly, considering a range of temperatures, that can be present during the season of harvest and mainly in the warmest hours (from 12.00 a.m. to 4.00 p.m.), and the minutes needed to arrive to possible critical situations, expressed in terms of:

- $D_{limloss50}$ (minutes): this is the maximum allowable exposure time for water loss, for a mean subject (weight 75 kg and height 1,80 m);
- $D_{limloss50}$(*) in water absence;
- $D_{limloss95}$ (minutes): this is the maximum allowable exposure time for water loss, for 95% of the working population.

Analyses have been developed considering the maximum values of air speed (3 m/s) and the partial pressure of vapor (3,8 kPa), as defined by the limits of applicability of the P.H.S. and only increasing the temperature of the air. It is possible to deduce from the tables that there are no risks to arrive to the total water loss if the worker can reinstate the lost liquids through an availability of water, versus the analysis in absence of water availability (Dlimloss50 $^{(*)}$) shows the attainments of critical levels, expressed in minutes, for all the workers in one determined temperature; these levels vary in operation of the subjective parameters of the works and particularly of weight and height (used for the calculation of the bodily surface A*Du* in m^2). The results are synthesized in table 7.

Worker	A	B	C	D	E	F
Dlimloss50(*) [min.]	288					
Dlimloss95 [min.]	455	427	451	465	477	453
SW tot [g]	3080,35	3621,2	3601,40	3654,07	4537,75	4516,31
t. criticism [°C]	**31**	**32**	**34**	**32**	**35**	**35**
ADu [m2]	**1,67**	1,95	1,97	1,76	**2,00**	**2,00**

Table 7 comparison among the total SW and the ADu and measure of the times for the attainment of critical levels and determination of the temperature limit

Also the Dlimloss50 $^{(*)}$ in absence of water availability has been valued: in fact in some cases there is no possibility for workers to access water because the harvest's areas are mostly isolated. An important aspect, is deduced by the comparison between ADu (Du Bois surface area) and the total water loss, for from table 7 is deduced that the greater is the bodily mass of the subject, the greater the critical temperature in which phenomena of excessive loss of perspiration are introduced. The results of the present work, therefore, seem to bring to the conclusion that, besides the evaluation of the risk founded on the P.H.S. model, it would be opportune to deepen the investigation with evaluations of the fatigue through, for instance, measurement of the cardiac frequency of the workers.

References

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The contribution to the programming and executing of this research must be equally divided by the authors.