

Heat stress assessment in artistic glass units

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Abstract: Heat stress in glass industry is mainly studied in large and highly mechanized manufacturing Units. To the contrary, few studies were carried out in small factories specialized in hand-made products. To stress the need of combined objective and medical surveys in these environments, this paper deals with a simultaneous climatic and physiological investigation of working conditions in artistic crystal glass factories in Tuscany (Italy). The microclimatic monitoring, through a continuous survey has been carried out in early spring. The main physiological parameters (metabolic rate, heart rate, tympanic temperature and water loss) were measured over the whole shifts. The results show that, despite the arduousness of the working conditions, the heat stress levels are physiologically tolerable. The predictions made using the PHS model at the *Analysis* level described in ISO 15265 agree closely to the observed values, validating the use of PHS model in these conditions. This model was then used to analyse what is likely to be the situation during the summer. It is concluded that the heat constraint will be very high and that some steps must be taken from the spring to monitor closely the exposed workers in the summer and take measures to prevent any heat accident.

Key words: Heat exposure, Glass factories, Physiological heat stress, WBGT, PHS, Physical agents risk assessment, Ergonomics, Sustainability

Introduction

The physiological effects of climatic working conditions are well known by physiologists and experts in occupational health and ergonomics¹. High heat exposure increases the risks of heat exhaustion, heat stroke and loss of performance². The prevalence of these effects might increase significantly due to the present (and future) climate changes that result in more severe occupational heat stress levels at workplace in tropical or sub-tropical coun-

tries^{3–5}.

Glass factories^{6–13} pile up a great number of hazards: noise, airborne particles, lead, fumes, other chemicals, awkward postures, manual handling of loads and, finally, convective and radiative heat that can result in various heat stress disorders^{6, 10, 12, 13} and in cataract due to infrared radiation^{14, 15}.

The literature reports essentially data from large and highly mechanized manufacturing Units^{6, 9, 13, 16–20} where operations are automated, the exposition of workers to the molten material is reduced (as in the cases of hand-built factories reported by Valentini *et al.*⁷) and Banchi *et al.*¹⁰) and distances between heat sources and workspaces are large. In these cases, the thermal working conditions

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Table 1. WBGT values reported in different glass factories

Activity	Country and season	WBGT range (°C)	Reference
Forming machine		33–39	
Furnace operator	Summer (India)	37–40	(17)
Charger		37–39	
Glass forming machine operator	End of summer (Illinois, USA)	22.1–30.0	(18)
Glass forming	Season not declared (Iran)	39	(19)
Glass picker		19.7–32.0	
Glass forming	Beginning of fall (France)	20.5–28.9	(27)
Glass cooler		23.4–35.2	
Glass blower		20.9–25.0	
Glass picker (handmade crystal Unit)	Summer (Italy: 05.00 am – 12.00 pm)	27.5–31.4	
Glass former (handmade crystal Unit)	Summer (Italy 05.00 am – 12.00 pm)	23.6–27.2	
	Spring (Italy: 02.00 pm – 10.00 pm)	23.6–27.2	
Automatized glass Unit (near the pressing or the forming machine)	Summer (Italy: 10.00 pm – 06.00 am and 06.00 am – 02.00 pm)	24.9–31.4	(33)
	Summer (Italy: 02.00 pm – 12.00 am)	29.7–34.8	
	Spring (Italy: 02.00 pm – 10.00 pm)	23.6–27.2	
Automatized glass Unit (control panel)	Summer (Italy: 10.00 pm – 06.00 am and 06.00 am – 02.00 pm)	22.9–29.4	
	Spring (Italy: 02.00 pm – 10.00 pm)	28.9–34.1	
	April (Coimbra, Portugal)	20.1–35.5	
Not specified	July and September (Leiria, Portugal)	26.7–38.0	(34)
	November (Leiria, Portugal)	30.3–47.1	

were generally assessed using the *WBGT* index, despite the fact that this index is only recommended by ISO⁽²¹⁾ and ACGIH⁽²²⁾ as a first approach tool due to its limitations, as stressed in several recent papers^(23–25). One study⁽¹⁸⁾, although quite recent, reported assessments by means of rational methods (e.g. based upon the heat balance equation on the human body) such as the obsolete *HSI*⁽²⁶⁾ or other simple thermoregulation models^(27, 28). None used robust methods validated in situ based on the heat balance equation such as the PHS model^(29–32) and only few papers reported physiological parameters such as heart rate and oesophageal or rectal temperatures⁽¹⁶⁾. The results of these investigations in large glass factories do not appear to be consistent (Table 1), mainly due to the production specificities, the locations where climatic measurement were made, and, finally, geographical and seasonal aspects. In particular, Srivastava *et al.*⁽¹⁷⁾ reported in a glass factory in India *WBGT* values systematically exceeding the ACGIH limits and suggested continuous medical supervision of the workers, whereas a NIOSH survey in the US⁽¹⁸⁾ in similar manufacturing Units, reported *WBGT* values well below these limits.

It must be noticed that the metabolic rate was never quantified in any study and was simply assumed to be light or moderate to determine the *WBGT* limit values.

Apart from the very recent in field report in Portuguese glass units by Oliveira *et al.*⁽³⁴⁾, few studies were carried out in small factories specialized in hand-made products, such as the artistic crystal manufacturing Units common in France and in Italy near Venice (Murano's glass) and in Tuscany⁽³⁵⁾. In these Units, microclimatic conditions and working activities are extremely specific, heterogeneous and variable⁽⁷⁾. Investigations carried out in the 90's⁽³³⁾ in semi-automatic Units reported that the *WBGT* and *HSI* values exceeded the limit values, especially during summer, but that physiological strain levels remained acceptable. Further comprehensive studies addressing physical and physiological issues are clearly needed in these environments and others similarly heterogeneous such as small foundries, handmade ceramic industry and bakeries.

With the assistance of the internal occupational health departments, we carried out such a study in two artistic glass factories of Tuscany (Italy). As we were not allowed to carry it during the summer (probably due to logistical and manufacturing needs), we chose to make measurement during the mid-season, hoping to be able to extrapolate the findings toward the hot season.

The investigation covered both the physical and physiological aspects in monitoring continuously the main physiological variables on the exposed workers and the climatic

Table 2. Outdoors climatic data during the study period

	Average	Extreme
Minimum air temperature, °C	3.4	−4.0
Maximum air temperature, °C	14.6	21.0
Relative Humidity, %	51	—

parameters at the most representative working locations. Both sets of data were then integrated as recommended in ISO 15265^{36, 37)} at the analysis level.

Methods

Description of the workplaces

The study was carried out in two manufacturing Units in Tuscany, Italy, at the end of March 2014. External climatic conditions at early morning hours were cold with air temperatures near 0°C (Table 2).

Unit 1

This small Unit (less than 10 workers) uses only one traditional crucible furnace where the temperature of the molten glass is about 950°C. Production is made only from 5.00 to 12.00 in the morning with a break of 30 min at 8:30. Only the workers most exposed to heat were monitored: a press operator and a glass-picker.

The glass-picker takes from the crucible a certain amount of molten glass (from a few grams to some kilograms) by means of a metallic stick (about 2 m long) and moves it to a press. The sequence of operations is as follows:

- about 5 s for taking the molten glass while standing in front of the furnace hole;
- about 10 s to reach the press machine, drop the glass in the mould and come back to the furnace;
- about 10 s waiting near the furnace before a new taking.

The press operator activates the press as soon as the molten glass is in the mould. A third worker transfers the moulded parts to the tempering oven (this operator was not monitored as his working conditions are similar to those of the press operator).

The working conditions were assessed at the 2 main locations occupied by these 2 workers: A) near the press machine (worker 1) and B) between the press and the furnace mouth (worker 2).

Unit 2

This Unit is semi-automated and uses a basin furnace.

The overall number of workers is about 30. Production is made in 4 shifts of 6 h per day. In this paper, only the 6:00 to 12:00 am shift is considered. The process consists in the automatic sampling of molten glass from the basin and its transfer by gravity to a forming machine.

One worker (worker 3) blows compressed air in the molten glass to pre-form the piece and a second (worker 4) completes the process. The pieces are then placed on a transport belt and sent to the tempering furnace. The frequency is about 3 pieces per minute.

The conditions were assessed for both operators at the main working position.

Measurement protocols

In both Units, the measurement points were chosen as close as possible to the work position while not disturbing the operations. The climatic parameters (air temperature, relative humidity, plane radiant temperature, air velocity and natural wet bulb temperature) were recorded using INNOVA 1221 data loggers equipped with probes by the same manufacturer for measurements under stress conditions (class S according to ISO Standard 7726³⁸⁾). The continuous monitoring of the mean radiant and globe temperatures was impossible using 150 mm globe thermometers due to their large response times³⁸⁾ (30–40 min). In addition, low diameter sensors (e.g. 50 mm) do not offer high advantages neither in terms of response time^{39, 40)} nor in accuracy of the mean radiant temperature measurement³⁹⁾. Therefore, these parameters were derived from the plane radiant temperature values in the six directions using the projected area factors in these directions^{38, 41)}.

Outdoor climatic data (e.g. air temperature and relative humidity) were recorded with the same devices.

The physiological parameters (body mass loss, heart rate, oxygen consumption and tympanic temperature) were measured according to the specifications of ISO Standards 9886⁴²⁾ and 8996⁴³⁾.

A portable device (Morgan Oxylog) recorded each minute the ventilation rate and the difference of oxygen partial pressure in expired and inspired air: the workers carried the 2.6 kg device with a shoulder strap and wore a face-mask with two valves (for inspired and expired air).

The total water loss (respiration included) was estimated by weighing the worker at the beginning and at the end of the work shift by means of a Soehnle scale 50 g in accuracy, and controlling the mass of food and drinks consumed (with another Soehnle scale 25 g in accuracy), as well as the mass of urine and faeces excreted during the shift (urine mass measured by using graduated contain-

Table 3. Classes of risk reported in ISO 15265³⁷⁾

Class		Criteria
1	Immediate constraint	$D_{lim} < 30 \text{ min}$
2	Constraint in the short term	$I_{clr} < IREQ_{min}$ $DLE < 120 \text{ min}$
3	Constraint in the long term	$PMV < -2$ $IREQ_{min} \leq I_{clr} \leq IREQ_{neutral}$
4	Cold discomfort	$-2 \leq PMV < -0.5$
5	Comfort	$-0.5 \leq PMV \leq +0.5$
6	Warm discomfort	$+0.5 < PMV \leq +2$
7	Constraint in the long term*	$D_{lim} < 480 \text{ min}$
8	Constraint in the short term*	$D_{lim} < 120 \text{ min}$
9	Immediate constraint*	$D_{lim} < 30 \text{ min}$

*in these situations the water loss for 8-h of continuous work and the predicted risk of increase of the internal temperature of the body according to ISO 7933 Standard are required.

ers and faeces mass obtained by measuring the body mass before and after the peristalsis) and the sweating trapped in the clothing. The reference mass balance equation is the following⁴²⁾:

$$\Delta m_{sw} = \Delta m_g - (\Delta m_{res} + \Delta m_0 + \Delta m_{wat} + \Delta m_{sol} + \Delta m_{clo}) \quad (1)$$

Heart rate was continuously monitored by means of a POLAR PE 3000 Sport tester and the tympanic temperature was measured at the beginning, at mid-time and at the end of the work shift by means of an infrared thermometer (BRAUN ThermoScan IRT1020).

Data processing protocols

Microclimatic measurements

The climatic parameters were treated as described at level 2, Analysis, of the strategy described in ISO 15265³⁷⁾. The *PMV-PPD*^{44–47)}, *WBGT*²¹⁾ and *PHS*^{29–32)} model were calculated^{24, 46)} and the class of risk was determined (Table 3).

The criteria at the basis of the classification in Table 3 are presently under discussion at ISO level: particularly, the need to harmonize ISO 15265 with ISO 7730^{44, 49)} will require to move the comfort-discomfort transition from $PMV = \pm 0.5$ to ± 0.7 and an additional condition ($D_{lim} \geq 480 \text{ min}$) should be added to the warm discomfort class to allow continuity between ‘warm discomfort’ and ‘constraint in the long term’.

The predicted sweat rate, rectal temperature and Duration Limit of Exposure (*DLE*) were calculated from the *PHS* model using as input data the min per min values of the microclimatic variables⁵⁰⁾ and the mean, maximum and minimum metabolic rate values recorded for each worker.

Physiological measurements

The metabolic rate was calculated from the measured oxygen consumption as described in ISO 8996 Standard⁴³⁾. The results were normalized by the body surface area of each subject. The maximum working capacity (*MWC*) of each worker was estimated using the expression given in ISO 8996 Standard and the work load was estimated from the ratio between the actual metabolic rate and the *MWC*.

From the heart rate recordings, were determined^{42, 51)}:

- The resting heart rate HR_0 ;
- The heart rate after 5 min of rest HR_r , after the heart rate components due to static exertion and dynamic muscular work had disappeared;
- The increase in heart rate ΔHR_T linked with the thermal strain experienced by the subject calculated as follows:

$$\Delta HR_T = HR_r - HR_0 \quad (2)$$

Finally, both the heart rate limit HR_L and the sustained heart rate limit over a work period $HR_{L,sustained}$ were calculated by means of the equations given in ISO 9886⁴²⁾ as a function of the age of the subjects (expressed in years):

$$HR_L = 185 - 0.65age \quad (3)$$

$$HR_{L,sustained} = 180 - age \quad (4)$$

Clothing thermophysical properties

The basic thermal insulation values of the clothing ensembles were estimated according to ISO 9920 Standard^{52, 53)} based on the single garments worn by the workers as summarized in Table 4. The reference value of 0.38 was adopted for the moisture permeability index i_m ^{29, 52, 53)}.

Results and Discussion

This section will present and discuss firstly the results from the microclimatic and physiological monitoring separately and afterwards the stress and strain indicators according to the *Analysis* stage of ISO 15265.

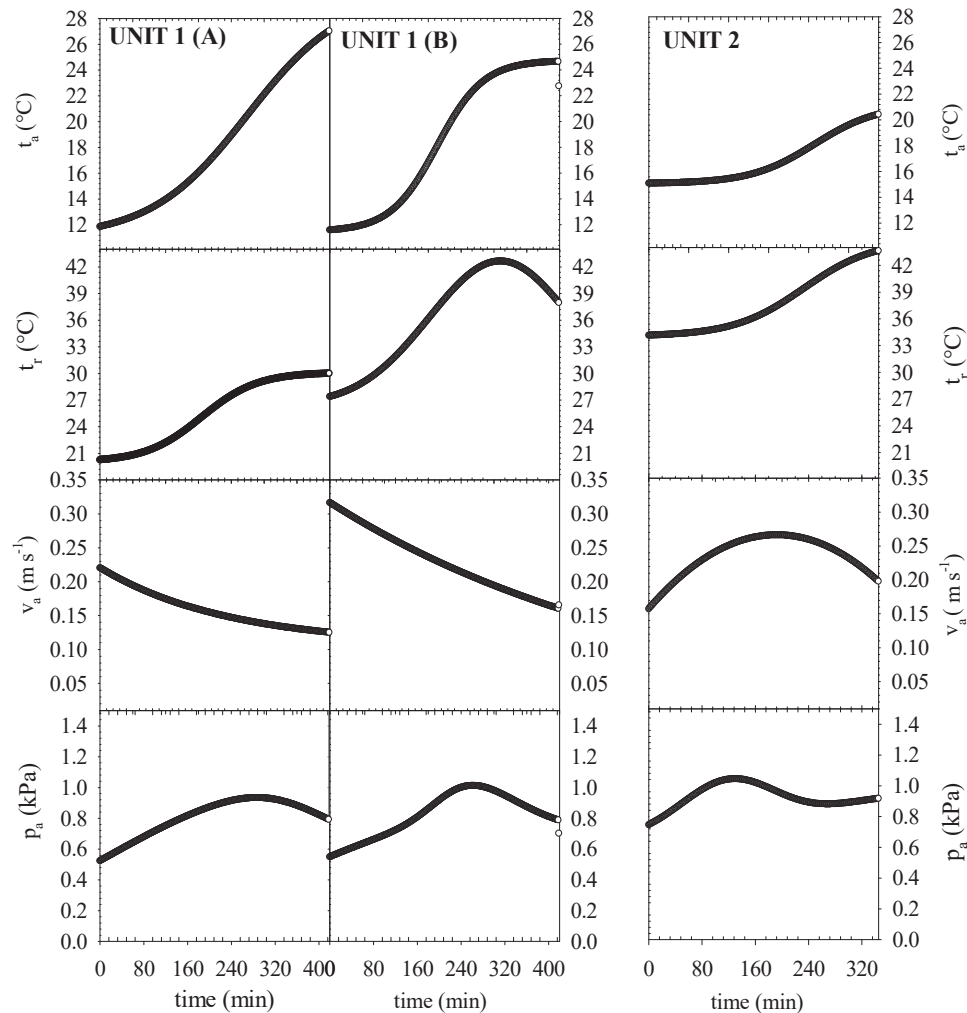
Microclimatic measurements

Figure 1 illustrates the evolution of microclimatic parameters at the working places in the course of the day, evolution simultaneous to the outdoor weather conditions (the outdoor air temperature rose from 0°C to 18°C in both Units).

The two manufacturing Units are quite different, with differences between mean radiant and air temperatures

Table 4. Clothing insulation values of the garments worn by workers of the two investigated manufacturing units according to ISO 9920⁽⁵²⁾

Manufacturing unit 1				Manufacturing unit 2	
Worker 1: Press machine		Worker 2: glass picker		Workers 3 and 4: press machine	
Garment	I_{clu} (clo)	Garment	I_{clu} (clo)	Garment	I_{clu} (clo)
underpants	0.03	underpants short leg	0.03	underpants short leg	0.03
t-shirt	0.08			t-shirt	0.08
heavy socks	0.06	socks	0.03	socks	0.03
long sleeves, shirt collar	0.26	undershirt	0.25	undershirt	0.25
coverall	0.52	Work pants	0.24	Work pants	0.24
shoes	0.05	shoes	0.05	shoes	0.05
<i>Overall</i>	<i>1.00</i>	<i>Overall</i>	<i>0.60</i>	<i>Overall</i>	<i>0.68</i>

**Fig. 1.** Time course changes in climatic parameters (air temperature, mean radiant temperature, air velocity and partial vapour pressure) during the work shift in Unit 1 and in Unit 2.

greater than 20°C. Due to their proximity to the molten glass, the most critical workplaces are B in Unit 1 and the Unit 2.

The observed air and mean radiant temperatures are

lower from those reported in the literature (Table 5) for essentially factories in tropical or subtropical countries during the summer. The lower air temperatures are mainly due to outdoors climatic and production differences^{6, 16, 17, 19)}

Table 5. Values of microclimatic parameters reported in different glass factories

Unit and/or activity	t _a (°C)	t _r (°C)	t _g (°C)	p _a (kPa)	v _a (m s ⁻¹)	Reference	
Glass picker	22.5	65	—	0.9	0.9	(27) and (28)	
Glass moulder	23	69.5	—	1.1	2		
Glass forming (summer)	38.9	104.5	—	1.8	1.1		
Glass forming (winter)	26.7	86.7	—	0.7	0.6		
Glass forming (summer)	24.2	—	34.8	1.4		(18)	
Glass bangle Unit	38.2	—	46.2	3.3	—	(16)	
Pressing and forming Units	46.1	—	31.8	3.7	1.0	(13)	
Bottle Units near furnace	46	—	48	5.0	—	(17)	
Unit 1 (A)	at 5.00 am	11.5	21.6	16.1	0.5	0.3	In this paper
	at 9.00 am	25.1	26.0	25.5	0.8	0.3	
	at 12.00 am	25.1	31.0	28.3	0.7	0.2	
Unit 1 (B)	at 5.00 am	11.7	28.4	19.4	0.6	0.3	
	at 9.00 am	22.9	43.3	33.1	0.9	0.3	
	at 12.00 am	22.9	38.4	31.4	0.7	0.2	
Unit 2 (A)	at 6.00 am	15.6	35.5	26.4	0.8	0.2	
	at 9.00 am	20.8	35.5	27.9	1.1	0.3	
	at 12.00 am	20.8	43.1	33.3	0.9	0.2	

Table 6. Results from physiological measurement for the 4 workers

Quantity	Units	Measured value			
Worker		1	2	3	4
Activity		press machine	glass picker	press machine	press machine
Age	yr	40	39	27	47
Height	cm	172	170	180	181
Weight	kg	79.4	81.4	85.2	91.8
Metabolic rate (percentage of the MWC)					
Minimum	W m ⁻² (%)	67.3 (11.1%)	84.8 (13.7%)	56.5 (8.2%)	56.1 (8.8%)
Average		83.7 (13.8%)	114.2 (18.4%)	73.6 (10.7%)	70.3 (11.0%)
Maximum		90.3 (14.9%)	132.5 (21.4%)	78.1 (11.3%)	78.6 (12.4%)
Heart rate					
HR ₀	bpm	61	85	64	50
Maximum		117	129	118	126
HR _m		81	109	86	68
ΔHR _T		19	18	5	3
HR _L		159	159	167	154
HR _{L,sustained}		140	141	153	133
Tympanic temperature					
Start	°C	36	36.7	36.7	36.8
Middle		37.2	37.9	37	37.2
End		36.6	37.4	37.2	37.2
Water loss	kg	1.1	2.1	0.74	0.95
Maximum admissible water loss		4.0	4.1	4.3	4.6

while the mean radiant temperatures may be lower due to the characteristics of the Units (small factories and small size of the Unit 1 furnace opening).

Physiological measurements

The metabolic rate and heart rate values are reported in Table 6. The work load can definitely be considered to be light, as the highest average value is 18.4% of the *MWC*

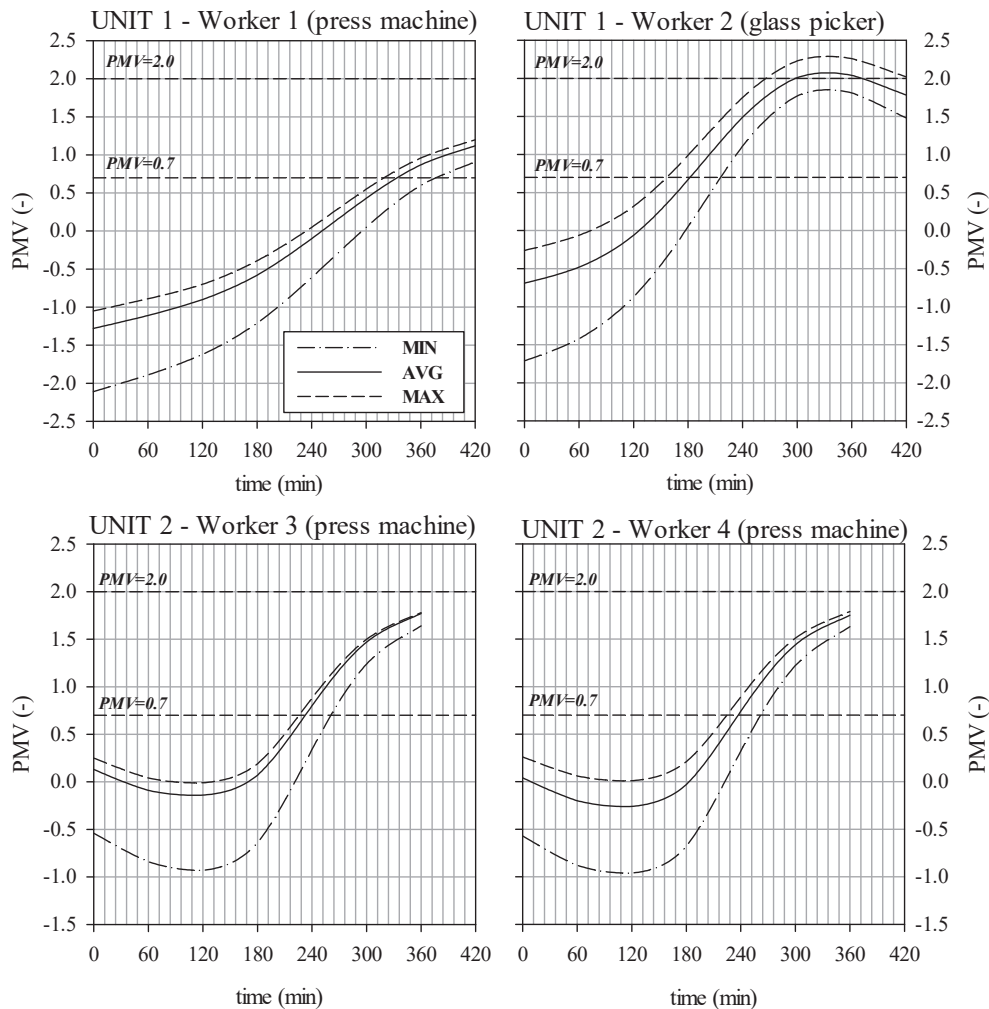


Fig. 2. Time variation of the PMV values during the work shift for the minimum (MIN), average (AVG) and maximum (MAX) metabolic rate values for the 4 workers in the 3 Units.

for the glass-picker in Unit 1 (this being in agreement with most values reported in the literature for similar working activities⁶⁾) and neither the heart rate limit HR_L nor the sustained heart rate $HR_{L,sustained}$ were exceeded. Additionally, for all workers the increases of heart rate due to heat strain ΔHR_T remain well below the limit value of 33 beats per minute which, according to Annex C of ISO 9886, is in average the increase of heart rate associated with an increase of 1°C in core temperature.

The body temperatures stayed well below the 38°C value set by WHO⁵⁴⁾ as the critical value for the onset of heat related disorders. Only in the case of the glass-picker who has the greater energy expenditure, did it approach (37.9°C) this limit value at the middle of the shift.

The reduction of tympanic temperature values observed at the end of the shift in Unit 1 for both the press operator (−0.6°C with respect to mid-shift) and glass picker

(−0.5°C) can be related to two particularities of hand-built glass factories:

- Due to the reduction of the amount of molten glass into the furnace, the mean radiant temperature decreases by about 4°C at the end of the shift (see Fig. 1–Unit 1(B));
- To avoid prolonged physical exertions, small pieces are usually produced at the end of the shift.

The total sweat losses over the whole shift were quite moderate and well below the limits of 5% of the body mass set to protect 95% of the working population from dehydration³²⁾. Also here, the highest value was recorded for the glass picker, confirming a greater—but still moderate—heat strain than for the other workers.

Table 7. WBGT values for each hour of exposure and limit values corresponding to the maximum metabolic rate for acclimatised and unacclimatised subjects^{21, 22)}

Time from the beginning of the work shift (h)	WBGT (°C)			
	Unit 1		Unit 2	
	1(A)	2(B)	3(A)	4(A)
1	10.5	12.1	17.3	17.2
2	11.5	13.7	17.5	17.4
3	12.8	16.3	18.1	17.6
4	14.5	19.2	19.8	19.0
5	16.4	20.8	20.9	20.5
6	17.8	20.7	22.0	21.2
7	18.5	19.9	—	—
Limit value	27.2	24.7	27.2	27.2
Limit value (acclimatised)	31.0	29.0	31.3	31.0
Limit value (not acclimatised)	28.3	26.0	28.8	28.6

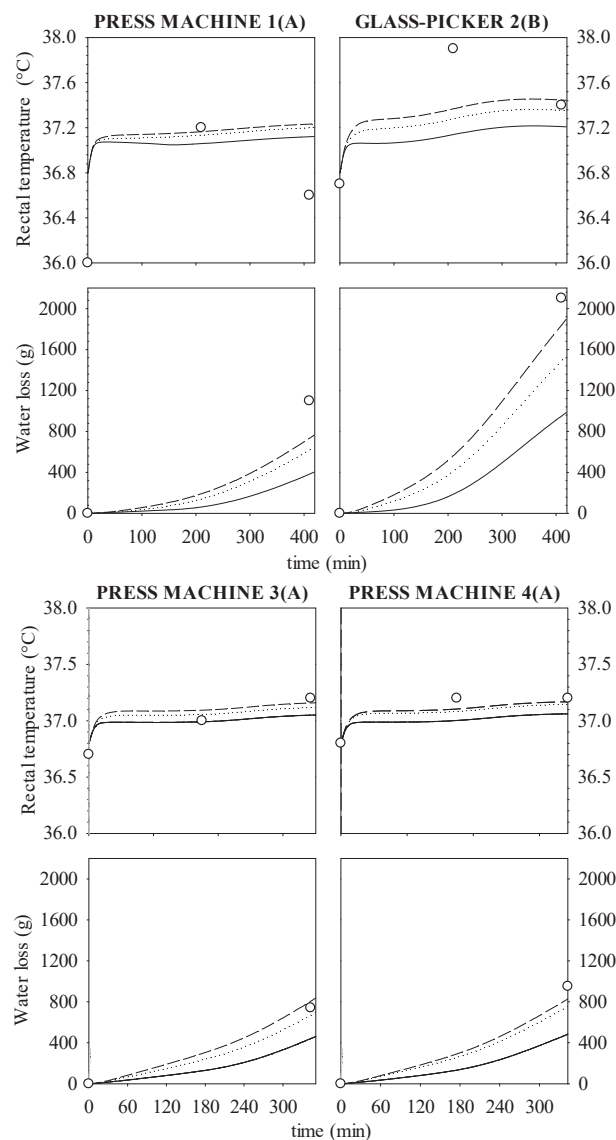
Comparison between predicted and observed values of main strain indicators

The working conditions were analysed as suggested by the SOBANE strategy³⁶⁾ and adopted in ISO Standard 15265³⁷⁾ (Table 3). To this aim, the PMV values were calculated according to time in each Unit (see Fig. 2).

The variation of the outdoor air temperature during work-shifts combined with the startup of manufacturing operations (ovens require some hours for reaching steady-state conditions) results in a strong variability of the PMV in both factories. In particular, PMV values fall within the ranges of discomfort conditions (Class 6 in Table 3) for many hours and, in case of the press-machine worker in Unit 1, reveal cold discomfort conditions (Class 4) at the beginning of the shift. This is due to the light metabolic rate of this worker and the rather low values of air and mean radiant temperatures recorded in the first three hours.

Table 7 gives the WBGT values calculated from the mean values during each hour of exposure: all values are well below the limit values corresponding to the maximum metabolic rate for both acclimatised and unacclimatised subjects^{21, 22)} indicating that these conditions are acceptable. This is in agreement with investigation carried out in some automated factories in intermediate seasons as summarized in Table 1. However, according to ISO 15265 Standard³⁷⁾, the measurement of WBGT index is useful only for evaluating the working conditions and not for assessing the class of risk, as this requires the calculation of the maximum D_{lim} according to ISO 7933³²⁾ (see Table 3).

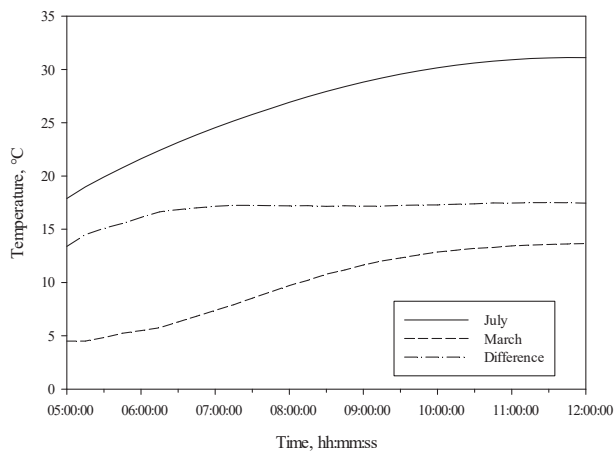
Figure 3 shows the trends of the rectal temperature and the water loss predicted by the *PHS* model for workers 1 and 2 of Unit 1 assuming the highest metabolic rate values,

**Fig. 3.** Rectal temperatures and water losses predicted according to ISO 7933 Standard³³⁾ for the 4 workers at minimum (continuous lines), average (dotted lines) and maximum (dashed lines) metabolic rate and comparison with observed values (○). No difference where predicted for acclimatised and unacclimatised subjects.**Table 8.** Comparison between total water losses (in kilograms) measured and those predicted by the *PHS* model³²⁾ for the minimum (MIN), average (AVG) and maximum (MAX) metabolic rate values of the 4 subjects investigated

		Unit 1		Unit 2	
		1(A)	2(B)	3	4
PHS	MIN	0.40	0.99	0.47	0.48
	AVG	0.65	1.54	0.70	0.75
	MAX	0.77	1.90	0.84	0.80
Observed		1.10	2.10	0.74	0.95

Table 9. Outdoor air temperature and water partial pressure measured by the Regional Agency for the Environmental Protection of Toscana on the 15 July 2016

Time	Air temperature (°C)	Water vapor partial pressure (Pa)
05:00 am	19.3	2,127
06:00 am	23.0	2,106
07:00 am	26.2	2,193
08:00 am	29.0	2,342
09:00 am	31.2	2,453
10:00 am	32.9	2,525
11:00 am	33.6	2,558
12:00 pm	34.0	2,531

**Fig. 4. Predicted mean internal surface temperature as a function of the time for the two manufacturing Units.**

whereas Table 8 compares the predicted and observed total sweat losses.

In all cases, the total water losses over the whole shift predicted and observed are quite lower than the limit value for incipient dehydration (5% of the body weight corresponding to about 4 kg for all workers³³). However, except for the worker 3 in the Unit 2, the predicted values are lower than the observed values, even when adopting the maximum value of the metabolic rate.

Based on Figs. 2 and 3, it can be concluded that, during this work shift, in early spring, the class of thermal risk increases from 4 (cold discomfort) or 5 (comfort) in early morning to 6 (warm discomfort) in later hours and reaches 7 (constraint in the long term) only for the glass picker (worker 2 in Unit 1) at the second part of the shift.

Extrapolation of the results toward the summer season

To provide useful information for summer conditions, we have reconstructed the likely climatic scenarios based on climatic data provided by the Regional Agency for

the Environmental Protection of Toscana (ARPAT) for a typical summer day (see Table 9) and global irradiance values for horizontal and vertical surfaces provided by EUMETSAT⁵⁵.

In order to estimate the likely mean radiant temperature during the summer, we first estimated the mean internal surface temperatures inside the two manufacturing Units in the absence of indoor radiative sources in March and in July by assuming pseudo-stationary conditions (Fig. 4). This hypothesis is consistent with the characteristics of the walls (made in concrete with low thermal inertia and a high thermal transmittance of $1.0 \text{ W m}^{-2} \text{ K}^{-1}$) and allowed to consider negligible delays between internal and external temperature variations.

Figure 4 shows that the difference between the mean surface temperature predicted in July and in March ranges between 13°C and 17°C . This means that the mean radiant temperature in July can reasonably be assumed to be the value recorded in March (as in Fig. 1) increased by 15°C . The inside air temperatures were assumed to be greater than the outdoor values reported in Table 9 by 5°C . The inside water vapour partial pressures were assumed the same as outside (Table 9) and the air velocities recorded in March were used for the calculation of discomfort and stress indices as no additional ventilation system is installed in neither Unit in the summer.

Figure 5 illustrates the time course changes in the PMV and WBGT indices, and the strain indicators calculated using the PHS model for the workers 1, 2 and 3 (the worker 4 is exposed to the same conditions as worker 3).

The results clearly show that, despite the relatively light activity of the 3 workers, the variations of the microclimatic scenario induced by outdoor conditions make the working conditions close to the limits of acceptability. The PMV is predicted greater than 2 for the entire working shift at each investigated metabolic rate (for the worker 1 the limit has been exceeded after 60 min) and it exceeds 3 for workers 3 and 4 due to the additional indoor radiative loads of the Unit 2.

Based on the PHS model, the rectal temperature might reach 38°C before the end of the work shift for all workers even at the lowest metabolic rate. Moreover, in case of workers 2, 3 and 4, work should be interrupted after less than 4 h at the highest metabolic rate. However, in all cases, the total water loss remains within the limit of 5% of the total body mass. Concerning the analysis of working condition by means of the WBGT index, a certain qualitative agreement with PHS model has been found. Particularly, the WBGT is always beyond the limit value consis-

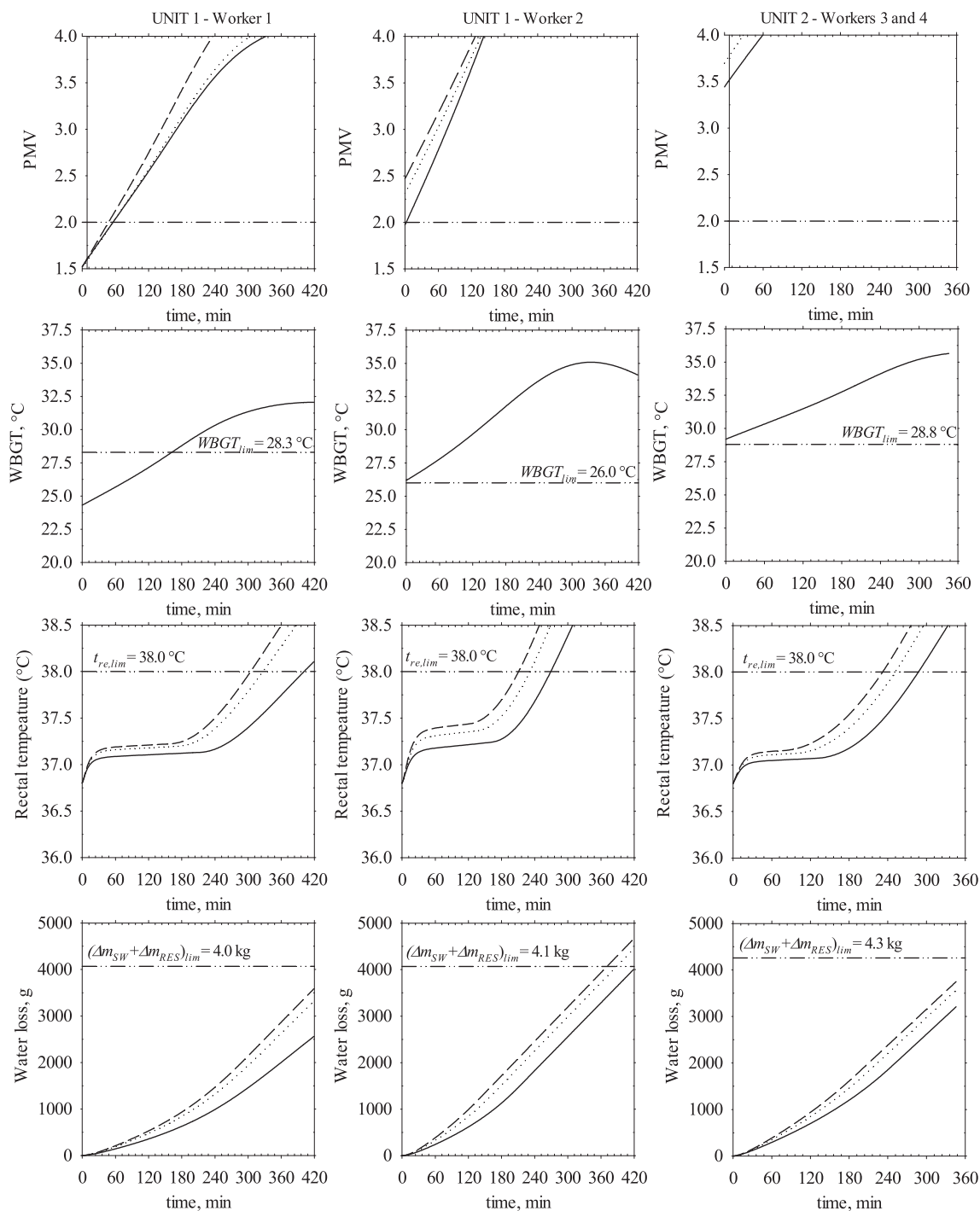


Fig. 5. PMV, WBGT and rectal temperatures and water losses predicted for all the workers at minimum (continuous lines), average (dotted lines) and maximum (dashed lines) metabolic rate for the summer scenario by means of the PHS model (unacclimatized workers).

tent with the highest metabolic rate for workers 2, 3 and 4, whereas it is below its limit values only for three hours of work shift in case of worker 1.

Figure 5 allows to say that it is highly feasible that, in the summer, during the day shift, the class of thermal risk

will be class 7 (constraint in the long term) during the almost the entire day, but that a risk of increase of the core temperature above 38°C might exist after 4 to 6 h in all cases. It can then be expected that the class of thermal risk will increase from class 6 in the spring to 7 in the sum-

mer, and measures are to be taken in consequences. However, results as above should be considered (reasonable) extrapolations and require to be confirmed by a combined physiological and microclimatic monitoring in the warmer period.

Conclusions

The main and primary objective of occupational health practitioners is not, as it is sometimes the case, to observe and quantify the health risk in a given harmful working condition, but to avoid its occurrence. And prevention means anticipation, especially when the occurrence of such situations depends on unpredictable factors. This is the case for heat stress as it is not unusual that companies have suddenly to confront heat waves early in the hot season. Anticipation means that, from observations made in less noxious circumstances, the risk during more severe conditions can be estimated and preventive measures are defined and implemented accordingly. The study reported here illustrates this in industrial working conditions potentially very harmful, in artistic glass units.

Working conditions in artistic crystal glass factories are indeed very unusual and might vary from light to severe, mainly due to the extremely variable climatic conditions and the constant variations in working activities and therefore in metabolic rates. The review of the literature showed that the few available investigations in this field led to contrasting results due to specificities of the workplaces and seasonal and geographical differences.

The results from our study carried out in two Italian Units can be summarized as follows:

- The PHS model described in the ISO 7933 standard gives results in very good agreement to the observed values and can thus be used to validly anticipate future conditions.
- The climatic conditions range from class 5 (comfort) to 6 (slightly warm) at early spring and from 05:00 to 12:00 am. In these conditions, the thermal strains expressed in terms of rectal temperature and water loss may be considered to be mild, especially for the press workers.
- The heat strain levels can be predicted in the summer using likely climatic scenarios. The class of risk rises to 7 (constraint in the long run) and the most critical situations are those characterized by high radiative loads as in the case of Unit 2 or high activity levels as in the Unit 1.

As suggested in ISO 15265, the control measures to be

taken do not depend on the exact values of temperatures or humidity but essentially upon the severity of the risk. The prediction of the class of risk is enough then to preventively reorganise the work schedules, foresee the distribution of appropriate beverages, optimise an extra ventilation system, temporally reduce some heat sources and, if need be, monitor some workers particularly exposed.

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Symbols

<i>age</i>	Age of the subject, years
<i>BSA</i>	Body surface area, m ²
<i>D_{lim}</i>	Maximum allowable exposure time, min
<i>HR₀</i>	Resting HR, taken as the HR value overtaken during 1% of the duration of the recording, bpm
<i>HR_L</i>	Highest HR, taken as the HR value overtaken during 1% of the duration of the recording, bpm
<i>HR_{L,sustained}</i>	Sustained heart rate over a work period, bpm
<i>HR_m</i>	Average HR value, bpm
<i>HR_r</i>	Heart rate during a break in work after heart rate components due to static exertion and dynamic muscular work have disappeared, bpm
<i>HSI</i>	Heat Stress Index, 1
<i>I_{cl}</i>	Basic clothing insulation, m ² K W ⁻¹ or clo
<i>I_{clu}</i>	Thermal insulation of the individual garment, m ² K W ⁻¹ or clo
<i>i_m</i>	Moisture permeability index, 1
<i>M</i>	Metabolic rate, W m ⁻²
<i>MWC</i>	Maximum working capacity, W m ⁻²
<i>p_a</i>	Water vapour partial pressure, Pa
<i>PHS</i>	Predicted Heat Strain, 1
<i>PMV</i>	Predicted Mean Vote, 1

<i>PPD</i>	Predicted Percentage of Dissatisfied, %
<i>RH</i>	Relative humidity, %
t_a	Air temperature, °C
t_d	Dew temperature, °C
t_{pr}	Plane radiant temperature, °C
t_r	Mean radiant temperature, °C
v_a	Air velocity, m s ⁻¹
<i>WBGT</i>	Wet Bulb Globe Temperature, °C

Greek symbols

ΔHR_T	increase in heart rate connected with the thermal strain experienced by the subject, bpm
Δm_0	mass loss due to the mass difference between carbon dioxide and oxygen, kg
Δm_{clo}	mass variation due to change of clothing or sweat accumulation in the clothing, kg
Δm_g	gross body-mass loss, kg
Δm_{sol}	mass variation of the body due to intake (food) and excretions (stools) of solids, kg
Δm_{res}	mass loss due to evaporation in the respiratory tract, kg
Δm_{SW}	mass loss due to sweat loss during the time interval, kg
Δm_{wat}	mass variation of the body due to intake and excretion (urine) of water, kg

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