Control of the climate parameters inside greenhouses to defende workers health

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Abstract

Greenhouse cannot be considered a very suitable place for work operators specially in hot season. Operators are forced to work in unfavourable conditions and exposed to harmful effects. Working at not suitable temperature combined with stress to the body from heavy physical activity, and exposure to chemicals, can be very dangerous to man's health.

The research was carried out to highlight the risks in the workers' health by analyzing the climate data recorded inside and outside the greenhouse in the Experimental Farm of the Agricultural Faculty of Viterbo from 1992 to 2002 in all season.

In addition to the calculation of WBGT index and of the human heat balance at different body temperature under various work conditions and clothing, the research also analysed the skip heat between internal and external environment on workers when they leave their worksite.

At 20th week the average of indoor temperatures is always above the limit suitable to operators and the average of maximum temperatures may rise as high as 40 °C at the 36th week.

The average values per week of WBGT index at the 16th week rose over the limit of 28 °C, considered standard limit as heavy work by current legislation.

In thermal stress conditions (>25°C) the amount of latent energy given off by sweat increased markedly reaching 60% at 30°C, 70% al 35°C and rose over 80% above air temperature of 40°C.

The paper is offered as a contribution towards evaluating the risks from long period of heat exposure.

Keywords: greenhouses, working environment, health risk.

Introduction

Greenhouse are structures utilized as microclimate environment to make the plants grow well in un favourable climate.

They are extremely useful when plants, in particular period of the year, cannot be grown in open country or in areas where the climate never guarantees a good quality crop. Vegetables need very high levels of temperature with a peak of 30 °C and 80 % of relative humidity but these levels cannot be considered favourable to operators who work in this environment.

Particular emphasis is placed on the risks to people who live in Mediterranean countries where the sun radiation can go over 1000 W/m^2. It is very difficult, in these regions, to control the excess of heat.

To prevent operators from taking periodic breaks during warmest months, it is necessary to control the temperature utilizing shading and common or mechanical ventilation systems.

Yet these precautions are not so enough to guarantee the health of operators forced to work hard during the day.

Operators are exposed to two different kinds of stress: firstly the log time exposure to severe environmental conditions, according to the standards, secondly the thermal change, when they leave their work site

Prevention against chemicals disease has been the main focus of research but now climatic risks from exposure to heat environment is increasingly being recognised.

The paper is offered as a contribution towards evaluating the risks from long period of exposure at unfavourable environmental conditions into greenhouses that are bereft of artificial heating.

Legislative regulation

The first suggestions about microclimate in working environment date back to the legislative regulation n° 864 of September 19th 1970. In a generic way, the article n° 10 reports: "in the working places the temperature must be comfortable and stable as much as possible, according to the circumstances. The article n° 33 of the Legislative Decree n° 626 of September 19th 1994 and subsequent amendments (that substituted the article n° 11 of Presidential Decree n° 303/56) about the temperature in working places reports:

1) the temperature of inside environment must be suitable to operators during the work time according to their physical efforts and working methods.
2) A suitable and healthy climate must be well valued taking into account the influences of humidity and air movement.
3) The surrounding places such as, rest room, first aid room, surveillance room, canteens and toilets require a temperature suitable to their purposes.
4) Windows, skylight and glass walls must to prevent strong sun light from coming through specially during the working activity.
5) Specific protective measures and technical intervention reducing the level of risks are required as necessary when the temperature cannot be modified or when it is not cheap to modify the temperature..

The new unique legislative text about security and health of workers was issued on April 9th 2008 decree n° 81. The IV attachment "work place standards" taken, for the most part, from the legislative decree n° 626 of September 19th, lays down undetailed provisions about microclimate. In addition there is EU legislation utilized in Italy and synthetically laid down in the following table:

- UNI EN 27243: 1996 (ISO 7243) : Hot environnent. Estimation of heat stress on working man, based on the WBGT-index (wet bulb globe temperature).
- UNI EN ISO 7933: 2004: Ergonomics of the thermal environment - Analytical determination and interpretation of heat stress using calculation of the predicted heat strain.
- UNI EN ISO 10551:2002.: Ergonomics of the thermal. environment - Assessment of the influence of the thermal environment using subjective judgement scales
- UNI EN ISO 7726: 2002 :Ergonomics of the thermal environment - Instruments for measuring physical quantities.
- UNI EN ISO 15265 2005: Ergonomics of the thermal environment - Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions

Material and methods

The research was carried out in a tunnel structure in the experimental farm of Agricultural Science Faculty of University of Studies of Tuscia in Viterbo.

Figure 1. Experimental tunnel

The semi elliptical tunnel is m 8.00 wide, 30.00 m deep and 3.40 m high (Fig. 1).
The greenhouse structure is covered by a long life polythene film 0.18 mm thick.
An electro fan, placed at the head back of tunnel, works governed by a thermostat keeping the temperature at 25 °C.
The air (in taken from fan) entered the greenhouse through the window placed over the front door which is always opened in working time during the warmer months.
There was no shading system. The plants were grown in four experimental patches.
The instantaneous environmental parameters, on a 15 minute basis, was supplied by many sensors connected to a data logger Campbell CR 21, then stored in solid memories. Then, these data were gathered by a computer system for the next elaboration.
For this research were measured:

- the inside air temperatures at three levels (+50 cm, + 150 cm, +250 cm) in the centre of tunnel;
- the outside air temperatures into a meteorological station;
- the inside air relative humidity;
- the globe temperature.

Were taken into consideration the data recorded by 1992 to 2002.

The data measured by different sensors, on a year basis, were gathered weekly (from Monday to Sunday) to be compared with those registered by a thermoigromether. There were n° 672 measurements per sensor (one per 15 min) per week giving us the minimum, medium and maximum weekly values.

The inside reference temperature data were obtained by taking an arithmetical mean of the data from the three sensors placed at three different levels.

The main purpose of research was, however, to identify the environmental conditions within the greenhouse during daily working hours. So it was performed another data processing, identical to the first calculation but limited to the data recorded in the period between the hours 8.00 am to 5.00 pm per day and per week, including Sundays.

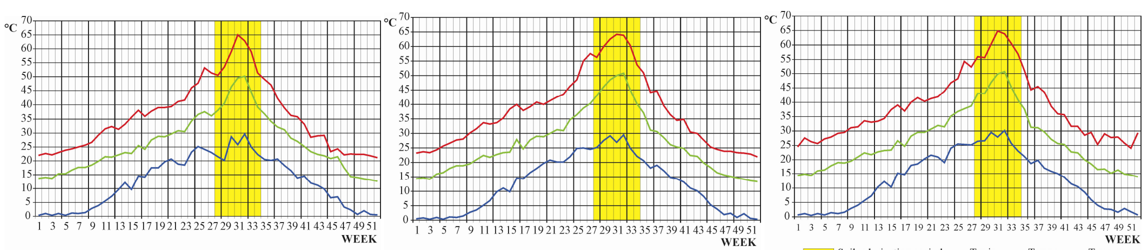

Figure 2. Inside air temperatures measured at + 50 cm, +150 cm and + 250 cm

The minimum, average and maximum values per week per each sensor so calculated were mediated with similar values of the years from 1992 to 2002 consequently we derived the weekly arithmetic means of minimum, medium and maximum inside temperatures at the various heights of detection and the internal temperature of reference (average of three sensors) (Fig. 2).The same data processing was carried on the inside air relative humidity, black globe temperature and outside air temperature.

A further elaboration was covered about the calculation of the jump heat between internal and external at three levels of height in working time. With the same procedure we

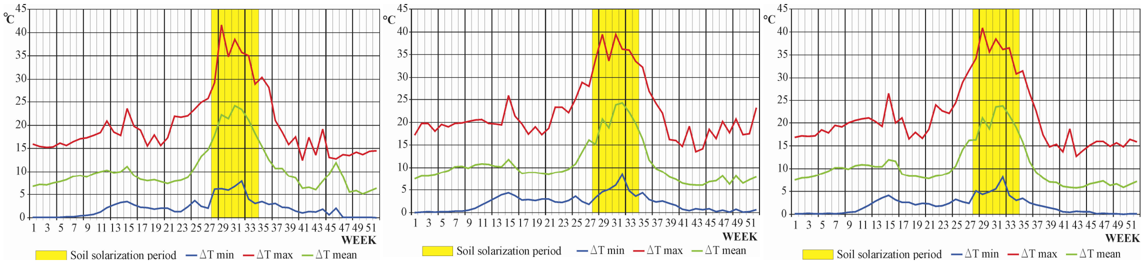

Figure 3. Jump between outside and inside temperature measured at + 50 cm, +150 cm and + 250 cm

have calculated the minimum, average and maximum thermal jump per week and per testing year.

The WGBT index was calculated using the inside reference temperature, the relative inside humidity and inside globe temperature on a 15 min. basis using this mathematical expression:

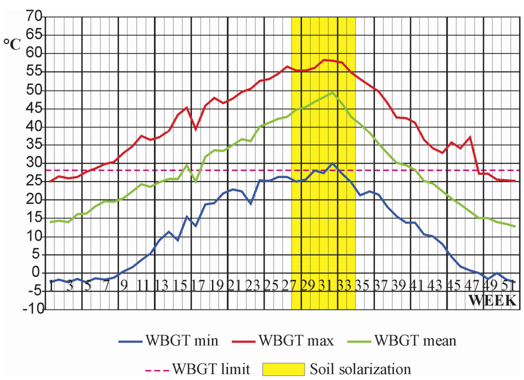

Figure 4. WBGT index

$$WBGT = 0{,}7 \cdot t_{wb} + 0{,}3 \cdot t_{bg}$$

where:

t_{wb} = wet bulb temperature [°C];

t_{bg} = black globe temperature [°C]

The work aims to have a detailed assessment of the greenhouse microclimate involving the characteristics of human body and its physiological implications.

In homeothermic condition, the energy given off by human body throught the metabolism and the man/environment energy exchange in the form of thermal and mechanical energy must have the same value.

This is showed by the following formula:

$$M - W - E_d - E_{sw} - E_{ve} - C_{ve} - C - R - C_k = 0$$

where:

M = thermal power given off by body for metabolism,

W = power exange between man and environment in the form of physical work,

E_d = latent thermal power given off by body surface,

E_{sw} = latent thermal power given off by perspiration;

E_{ve} = latent thermal power given off by respiration;

C_{ve} = sensible thermal power given off by respiration;

C = thermal power given off by convection;

$R =$ thermal power given off by irradiation,
$C_k =$ thermal power given off by conduction.

1. thermal power realised by the body for metabolism

$$M = 351 \cdot (0.23 \cdot RQ + 0.77) \cdot V_{O_2} \quad [\text{W/m}^{-2}]$$

2. power exchange between man and environment in the form of physical work

Mechanical power given off by work activity calculated considering the mechanical efficiency η=0.2

3. latent thermal power given off by body surface

$$E_d = 3.05 \cdot 10^{-3} \cdot f_d \cdot (1-\varpi) \cdot A_b \cdot (256 \cdot t_{sk} - 3373 - \phi \cdot p_{as}) \qquad [\text{W}]$$

4. latent thermal power given off by perspiration

$$E_{sw} = \lambda \cdot f_d \cdot k' \cdot \varpi \cdot A_b \cdot (x_{sk} - x_a) \qquad [\text{W}]$$

5. latent thermal power given off by respiration

$$E_{ve} = 1.72 \cdot 10^{-5} \cdot M \cdot (5867 - \phi \cdot p_{as}) \qquad [\text{W}]$$

6. sensible thermal power given off by respiration

$$C_{ve} = 0.0014 \cdot M \cdot (34 - t_a) \qquad [\text{W}]$$

7. thermal power given off by convection

$$C = f_{cl} \cdot h_c \cdot A_b \cdot (t_{cl} - t_a) \qquad [\text{W}]$$

8. thermal power given off by irradiation

$$R = 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot A_b \cdot \left[(t_{cl} + 273)^4 - (t_{mr} + 273)^4 \right] \qquad [\text{W}]$$

9. thermal power given off by conduction

C_k = not important for this balance

$RQ =$ *Respiration rate (between volume CO_2 given off and Vol O_2 given in)*	$h_c =$ *unit conductivity air/clothes [W/(m^2 K)]*
$V_{O2} =$ *Volume of oxygen consumption [l/min] a T=0° e P=1 atm*	$x_{sk} =$ *specific humidity insaturation condiction at skin temperature [kgwater/kgdry air]*
$f_d =$ *permeability factor of clothing*	$x_a =$ *specific humidity of the air [kgwater/kgdry air].*
$\omega =$ *body area covered by sweat perspiration (area of wet surfaces sweat/body surface area)*	$t_a =$ *air temperature [°C].*
$A_b =$ *body surface area [m^2]* $A_b = 0.202 \cdot m^{0.425} \cdot h^{0.725}$ *(Du Bois)* $m =$ *body weight [kg]* $h =$ *body high [m].*	$f_{cl} =$ *relationship between external surface area of clothes Acl [m^2] and surface area of the naked body Ab [m^2];*
$t_{sk} =$ *mean skin temperature [°C]*	$h_c =$ *convective unit conductivity clothes-air [W/(m^2 K)];*
$\phi =$ *relative humidity*	$t_{cl} =$ *mean temperature of external surface of dressed human body [°C]*
$p_{as} =$ *vapour pressure at air saturation [Pa]*	$t_{mr} =$ *mean radiant temperature of the environment [°C]*
$k' =$ *mass transfer coefficient [kg/(m^2 s)]* $k' = h_c/1.012$	

The human body heat balance was evaluated at 6 different air temperature: 20°C, 25°C, 30°C, 35°C, 40 °C and 45 °C.

Results

a) <u>Inside air temperature</u>

At the high of 150 cm (man height) in working time the inside air average temperatures always remained above 20 °C in the period between the 8th and the 45th week and in the period between the 19th and the 37th week reached 30 °C. Starting from the last weeks of June, this value exceeded 40 °C[1].

Though the standards do not lay down exact limits of the inside air temperature it has been assumed that the optimal temperature normally should not exceed 25 °C.

For a period of 20 weeks, the average of inside air temperature is always above the reasonable limit suitable to operators.

About the average of maximum inside air temperature, the period is n° 16 weeks longer than the just said period of the average temperature. In this period the temperatures may rise as high as 40 °C; these high values were recorded about midday when normally operators keep working.

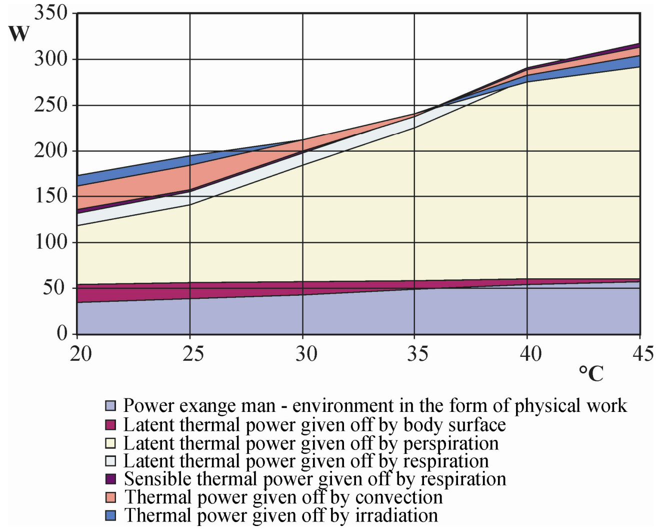

Figure 5. Power losses from human body

A long exposure to these high temperatures may cause thermal stress[2] with the following consequences:

- Heat Rash (prickly heat);
- Radiation Burns (Sunburn);
- Transient Heat Fatigue;
- Heat Syncope;
- Heat Cramps;
- Heat Exhaustion;
- Heat Stroke;
- Indirect Heat-Related Health Effects;

Or long term effect:

1. Reduced Work Performance: tired, fatigued workers perform with reduced accuracy, efficiency;
2. Increased Accidents**:** tired, fatigued workers are more susceptible to accident and injury;
3. Reproductive Problems: heat has been shown to reduce both male and female fertility and may be a problem for the fetus;
4. Heart/Lung Strain: if you already have heart, lung, kidney or circulatory problems; heat stress is an added strain on your body which in severe situation may precipitate serious episodes of acute problems.

On the contrary, the minimum values of the inside air temperature fells down as low as 0 °C in the first week of the year. This condition, thought uncomfortable, does not cause risks for health's operators who can wear heavy clothes to protect themselves from cold.

The graphs shows that the temperature values at a high of +50 cm (plants level) and at a high

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[1] It is not considered the period between the 28th and the 34th week because the greenhouse was closed for soil solarization.

[2] Heat Stress is defined as the physical and physiological reactions of the worker at temperatures that fall outside the normal comfort zone of workers.

+ 250 cm (near the cover film) don't seem have a significant difference from values measured at + 150 cm. This is due to mechanical ventilation that makes the temperature homogeneous.

b) Thermal jump between inside and outside air

About thermal jump, the figures showed that the average of the difference between inside (at + 150 cm) and outside temperature is constant about 10 °C in the first period of the year till the soil solarization and not worrying for operators who leave the worksite.
Also the maximum of thermal jump did non seem to give problems to health's man till the 21st week because the temperature remained on the average of 18°C. Starting from the June period the maximum of thermal jump rised as high as 30 °C. These high values could generate some problems about breathing to operators without same precaution (thermal filter room).

c) The WBGT

The WBGT, an index widely used for the assessment of indoor environment, was estimated taking in account the average of inside air temperature, the humidity rate and the temperature measured by black globe thermometer.
The average value per week, during the test period, at the 16th week rose over the limit of 28 °C, considered by current legislation as standard limit for moderate work.
Into the greenhouse operators' work is not supposed to be "heavy" according to labouring standards, yet the some positions of operators, as handwork at soil level, could be very dangerous. For this reason the greenhouse operation should be classified as the "heavy work".
Assuming, however, the limit of 28°C valid for acclimatized[3] workers with suitable summer clothes, it is observed that the average values of WBGT exceeds the standard limit from the 16th week up to the 41st week, except the soil solarization period. The highest of average values are above 40°C before the soil solarization period and the average of inside air temperatures goes over 35°C.
The inside environment, of course, becomes particularly dangerous around the central hours of the working day (Fig.2)
The minimum values, always remain below the standard limit therefore do not cause problems for the health of employees.

Table 1. Human heat balance [W]

Human heat balance	Inside greenhouse air temperature [°C] 20	25	30	35	40	45
Input: *M*	**172.4**	**194.4**	**216.7**	**246.0**	**269.2**	**286.1**
W	34.5	38.9	43.3	49.2	53.8	57.2
E_d	19.9	17.0	14.1	9.2	6.3	2.9
E_{sw}	64.1	84.9	126.5	167.0	218.6	247.7
E_{ve}	13.9	14.3	13.9	12.9	11.8	10.0
C_{ve}	3.4	2.4	1.2	-0.3	-2.3	-4.4
C	26.2	26.2	13.0	3.1	-6.2	-9.3
R	10.5	11.1	0.0	0.0	-7.3	-12.7
Total output	**172.5**	**194.8**	**212.0**	**241.0**	**274.8**	**291.4**

d) Human heat balance

Analyzing the results of human heat balance (table 1), in the different conditions (from 20 °C to 45 °C) it appears that whereas the thermal power given off by work activity remains

[3] Acclimatization requires up to 3 weeks to be fully established and is noticeably decreased after 4 days (for TLV® purposes: use 5 of last 7 days)

constant (mechanical efficiency η=0.2) the power given off by body, in different ways, varies in according to the air temperature variations.

In welfare conditions the most loss of energy occurs by perspiration (37 %), by convection (15%) and by diffusion from skin (11,5%). The energy loss in other way was about 10 %.

But about the higher limit of welfare parameters (25°C) the power given off by perspiration rises till 43.6% .

In thermal stress conditions (t_a > 25 °C) the amount of latent energy given off by perspiration increases markedly reaching 60 % at 30 °C, 70 % at 35 °C and rises over 80 % above the temperature of 40 °C.

Perspiration has a very important role to guarantee the human heat balance in stress conditions. Water given off in the form of perspiration or breathing rises with the increase of temperature (table 2).

Table 2. Water losses through perspiration and respiration [l/h]

Water	Inside greenhouse air temperature [°C]					
	20	25	30	35	40	45
Perspiration	0.091	0.120	0.178	0.234	0.305	0.344
Respiration	0.020	0.020	0.020	0.018	0.016	0.014

The amount of water given off by perspiration in-creases and is above 300 g/h when the air temperature is over 40 °C. Undoubtly the water loss produces an alteration of the body water equilibrium with a consequent loss of minerals, leading workers to severe health risks.

Conclusion

The analysis of different climatic parameters and the results of data processing of the WBGT and of the thermal human balance have shown that for a long period of year the inside climatic conditions are above a reasonable level of comfort for operators. Both the air temperature values and the WBGT show clearly that the human body is stressed in a non-appropriate mode even for subjects acclimatized.

Indeed, analysis of the thermal human balance of a standard person in average environmental conditions, calculated in terms of WBGT, shows a loss of thermal energy trough a remarkable perspiration and breathing with a consequent loss of water and mineral salts that could lead to the immediate and remote serious consequences as heat syncope.

The technological solution to avoid these dangers lies, in our opinion, in drastic reduction of solar energy during the hottest periods of the year. But this solution is not always possible to apply in the intermediate seasons when the solar energy constitutes the main sustainable source of energy for the greenhouse productions.

However, many heat related health problems can be prevented or the risk of developing them deduced by some precautions.

To take advantage of climatic conditions operators should work earlier in the morning or in the coolest times of the day.

Clothing should be appropriate, shifting the working time when heavy and uncomfortable dresses are unnecessary. Operators, during the hot working time should be forced to have fresh drinks bereft of glucose and rich in minerals to replace the loss of thermal energy.

Could be useful to minimize exposure to high temperature and sun but this is not always possible when sun is the main source to make the plants grow.

To take advantage of climatic conditions operators should work earlier in the morning or in the coolest times of the day.

It is understandable discomfort of a prolonged interruption but the advantage on the health of employees has a value much greater.

Thermal jump does not seem to be particularly dangerous for worker health when leaves worksite.

Even in the most serious jump temperature may be borne by workers with simple and elementary shrewdness as protection with dry clothing or going through areas filter at intermediate temperature (eg room appropriately shielded).

The greenhouse is an important source for Italian agriculture because it provides an environment conducive to plants production on a year-round basis or extend the growing season. Yet a greater overall knowledge and preventive measures would all help the operators to avoid risks of indoor work.

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