Analysis of heat stress at the workplace

Glass manufacturer

Workplace: “furnace”

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I. Definitions

Hot workplace

When working in hot environments, the combined burden of heat, physical work, and, if applicable, clothing leads to warming of the body and therefore a rise in body temperature. An increase of 1-2° C in body temperature can already result in fever-like temperature of 38-39° C*. As a result, the regulation of body temperature is of the utmost importance. As a result of vigorous and frequent work in hot environments, damage to health can occur. Even brief activity in hot environments can be a health risk.

By producing sweat on the skin, the body tries to cool itself, but this process requires energy too. This energy is then no longer available for work anymore. Scientific studies have shown (sports) 5-10% performance reserves by cooling. The Kiel Institute for the World Economy (IfW) also predicts loss in performance of up to 12% during hot days.

Thermal image

The technique of making images using a thermal imaging camera is called thermography. Being invisible to the human eye, thermal radiation (medium infrared) of an object or body is made visible by the thermography imaging technique. Temperature distributions on surfaces and objects are recorded and displayed by thermography. Thermography is a non-contact measurement method, i.e. far away objects can be displayed too. The sun's radiation as well as artificial light sources do not interfere.

When working in hot environments, the body's core temperature and skin temperature** are important indications of the body's thermoregulation. Both temperatures influence one another. The thermal imaging camera just has to capture the surface temperature of the body, while the stored images can be analyzed afterwards***.

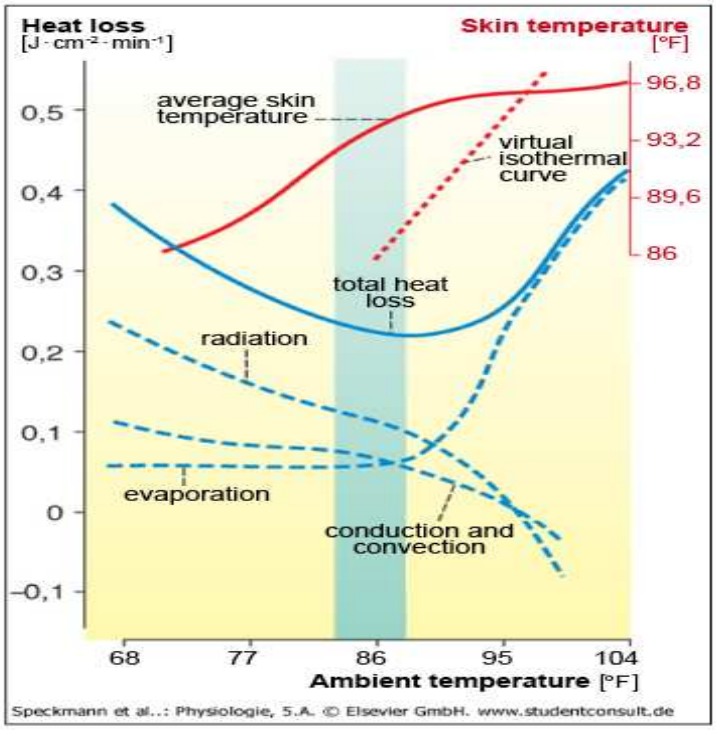


Figure 1: Unimpaired effect of outdoor temperature on energy and skin temperature, of which the latter influences body temperature via thermo receptors. High evaporation rate influences skin temperature positively and increases energy demand.

WBGT value

The WBGT index according to DIN EN 27243 (European Standard; US reference OSHA Technical Manual; Section III, Chapter 4: Heat Stress) is a guiding measure for the evaluation of heat stress and is recommended in BGI (information of the German Institution for Statutory Accident Insurance and Prevention on safety and health at work) 579 for evaluation of heat stress in case of increased thermal radiation (for sources see BGI 579, page 18). The WBGT index combines the basic climate factors air temperature, air humidity, velocity of ambient air stream, and thermal radiation to a unified parameter (climate index).
Reference values for WBGT values apply to various cycles of working and resting periods based on the adaptation of average muscular activity (energy turnover). The assumption is made that the WBGT value at the resting facility is more or less the same as at the workplace.

Energy turnover Level	**Reference values for maximal value of WBGT index in °C**			
	For acclimatized employees		For non-acclimatized employees	
0 1**** 2	33 30 28		32 29 26	
	No noticable air movement	Noticable air movement	No noticable air movement	Noticable air movement
3 4	25 23	26 25	22 18	23 20

When WBGT values are exceeded, continuous exposure must be avoided or suitable measures implemented. It must be examined whether technical or organizational measures are capable of reducing exposure. Based on the labor protection act dangers must be avoided by technical, organizational, or personal precautionary measures.
In most of the extremely hot workplaces the WBGT value is already exceeded by temperature alone.

** Human average body temperature: 37 °C*
*** Human average skin temperature: 32/33°C (depending on the part of the body)*
****Note: The numbering of the figures (IR XX) does not correspond to the order in which the images were taken, but are based on the order in which they were retrieved/edited from the server*
*****CLASS1: Sitting comfortably, light manual work, light tasks involving arms, hands, legs, driving a vehicle under normal conditions, standing, mechanical work with machine tools of low performance*

II. Situation

Description of workplace:
The glass manufacturer is an international technology company, developing and manufacturing special glass, special materials, components and systems for more than 125 years.
When making glass, very high temperatures occur especially near the “glass furnace”.

During an inspection of a factory of the glass manufacturer the work conditions at the furnace were to be assessed.
Temperatures of 304,1°C radiation temperature were measured with the thermal imaging camera in a passage next to the furnace, which is an integral part of the facility.

The facility is checked regularly. For this, the employees must inspect and conduct maintenance work in the passage as well as around the entire facility. Surveillance work and sometimes minor maintenance work are performed. Immense heat stress is the result. The furnace is located in the middle of the factory. The ambient temperature of the entire area was 28-31° C. The factory building was built in the thirties, is not air-conditioned and has lateral windows that can be opened.

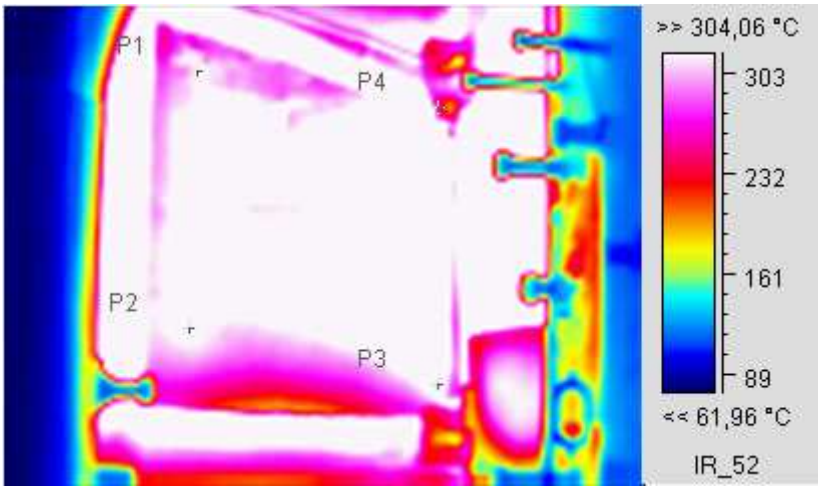


IMAGE1 Passage IMAGE 2 Passage as seen with thermal imaging camera

Chart 1	Value
P1: Temp.	304.10°C
P2: Temp.	304.10 °C
P3: Temp.	304.10 °C
P4: Temp.	251.60 °C

Work clothing:
Work clothing for rent, heavy cotton material, not flame-retardant.
Outfit consisted of pants and jacket. Underneath a normal T-shirt made of cotton.
Due to heat stress the subject was wearing a protective hood and a “silver jacket” over his normal clothes together with gloves.



Image 2: Subject with clothing

Bandana was worn underneath the protective hood. The vest was worn over the working jacket, but underneath the silver jacket.

Classification of subject:
Employee (called subject from now on)
Man, ca. 180 cm tall, in his mid-forties, muscular physique, former strength athlete, not acclimatized.

Determining WBGT value at workplace
Conducted on: 04.16.2010, 11:49 am - 12:54 pm
Place: facility location
Type of work:
Assumed energy turnover class 1 when working in the room

Identification of potential dangers (special situations/locations/machines, etc.):
Increased heat stress in the passage because of thermal radiation of the furnace.

Deviations of measurement during seasonal changes, especially in summer (in case they exist):
Yes.

III. Utilization of COOLINE products during test

Vest	☒
Bandana	☒
Helmet inlay	☐

Comment:
Vest (clothing) and bandana (head covering) were loaded with tap water according to the instructions for each product.

IV. WBGT measurement

In the area encompassing the facility the WBGT measurements were conducted next to the furnace alongside the passage. This is an investigational measurement, and its only purpose is the characterization of the chosen location within the room.

In reference to DIN EN 27 243 (EU Standard), the measurement was conducted over a period of about 65 minutes.

1. Measurement

Time: Begin: 11:49 am End: 12:54 pm
Measuring time: 65 minutes

Table 1

WBGT heat stress overview

Review file:	C:\Programme\Casella Group Ltd\WinHSM\HSM-(2010-04-16) [11;49;13].hsm
Begin:	11:49:13 am 04.16.2010
End:	12:54:13 pm 04.16.2010
Ventilation:	Suction (air current is 1 meter per second or above)

Parameter	Minimum	Mean value	Maximum
Tg	40,1° C	43,1° C	44,9° C
Tnw	25,0° C	27,4° C	29,4° C
Ta	33,9° C	38,8° C	40,4° C
WBGT TWAin	32,0° C		32,3° C
WBGT in		32,1° C	
WBGT TWAout	31,6° C		31,9° C
WBGT out		31,7° C	
Dew point	19,1° C	22,6° C	24,8° C
RH	34.4%	40.0%	56.3%

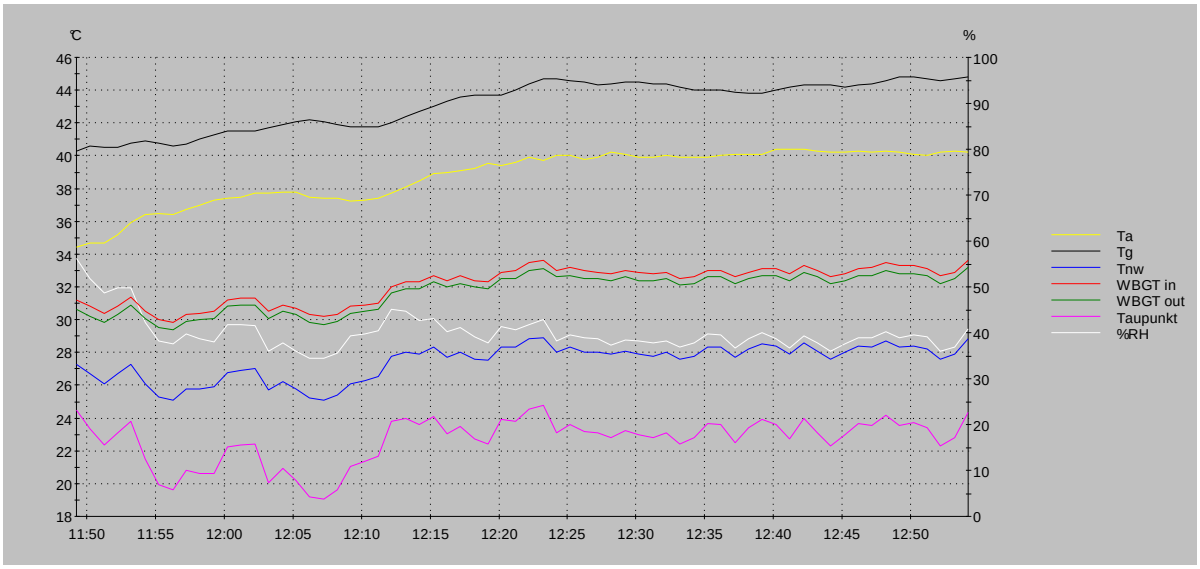
ISO reference value

Energy turnover class 1 (minor energy turnover).
Used average energy turnover 100 W/m^2.
For person not acclimatized to heat.
WBGT reference value 29°C.
WBGT TWAin exceeded reference value.
WBGT TWAout exceeded reference value.

Calculation formula WBGT:

WBGT 1 = 0.7 x t_{wet} + 0.3 x t_{glob} = 32,11°C

Diagram 1:



The subject discontinued the second attempt, during which he stayed in the passage without cooling clothing, after 7.25 minutes. Reason: heat stress was too high.

Because of the surrounding conditions within the room, the value of the radiation temperature (t_g) of max. 44,9° C (mean value: 43,1° C) was as high as expected, with an average relative air humidity of 40%.

As a consequence, the calculation of the climate index within buildings $WBGT_{in}$ leads to a value of 32,11° C on average across measuring time. The latest $WBGT_{in}$ value at discontinuation of measurement after 65 minutes is 32,3° C and correlates with the real conditions at this point of time.

In reference to DIN EN 27 243 (EU Standard) and based on the described activities performed in this workplace, the energy turnover during work was set as class 1 and included in the calculation of the permissible WBGT value. Due to shifting assignment no employees were being alleged of acclimatization, i.e. no daily periodically recurring activity in the rooms. Clothing was assumed to be normal clothing with an insulation value of I_{cl}=0.6 clo.

ISO reference value for $WBGT_{in}$ – reference value class 1: 29° C

WBGT value in measuring area: 32,1° C

NOTE: As the measuring device was located in the area in front of the passage and not inside, the values are of course higher inside the passage.

All values determined in this way clearly lie above the ISO reference value for $WBGT_{in}$ – reference value class 1 and therefore point towards an obviously higher heat stress at the workplace than recommended by the standard.
(see above: measuring table and standard value table)

Conclusion:
Based on the determined values and the employee‘s statements, the utilization of cooling clothing is recommended in both cases, as the values exceed the corresponding standard values in the classes affected.

V. Thermal images

Background of the images taken by the thermal imaging camera: door leading to adjoining room (ca. 26° C).

Thermal images with temperature data for measuring surface temperature:
During the test, the subject’s upper body was photographed with the thermal imaging camera at the location before and after work assignments, before and after entering the passage and the images were compared with one another. Images are compared on the next pages.

ORDER OF SEQUENCE:

1. Thermal image before usage
2. Thermal image after usage
3. Thermal image after usage and after having taken off the vest (only when vest was included in test)

1. First run with cooling

- Subject **is wearing** E.Cooline cooling vest/bandana
- Subject stays in the passage for 10 minutes, performing minor activity
- Subject: photographed with the thermal imaging camera right after leaving the passage

A. Image taken before entering the passage, without heat stress, without cooling vest:
Image 1, subject

Chart	Value
P1: Temp.	33.40 °C
P2 :Temp.	30.70 °C
P3: Temp.	35.00 °C
P4: Temp.	31.10 °C
Average temp. BS*	**31.7 °C**

*BS = Average temperature body surface

CONCLUSION: The temperature on the subject's body surface was 31,7° C before first measurement.

B. Implementation of test: 10 minute stay in the passage with cooling

Image 1.2, subject

Image with vest/bandana:

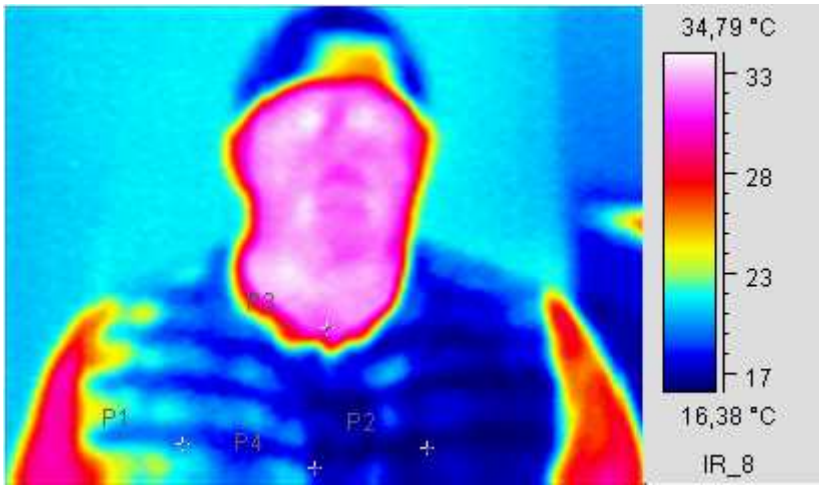


Chart	Value
P1: Temp.	20.00 °C
P2 :Temp.	16.80 °C
P3: Temp.	32.50 °C
P4: Temp.	18.20 °C
Average temp. BS*	**18.3 °C**

The thermal image shows the effectiveness of cooling vest and bandana. Because of the enormous radiation heat of the passage's environment, the surface of the cooling clothing reaches a temperature of 18,3° C .

C. Image after leaving the passage and taking off the vest

After having taken off the cooling vest, the subject was measured thermographically once more.
- Subject: after having taken off the cooling vest

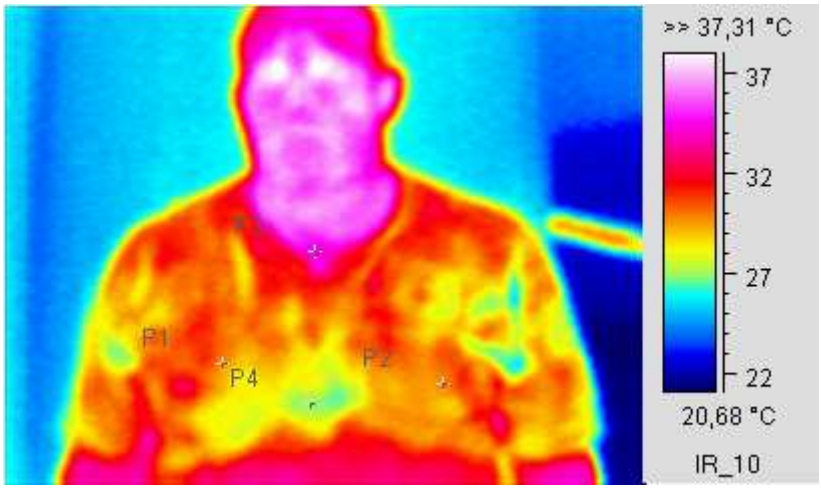


Chart	Value
P1: Temp.	30.20 °C
P2 :Temp.	30.40 °C
P3: Temp.	34.20 °C
P4: Temp.	27.20 °C
Average temp. BS*	**29.30 °C (-2.4 °C))**

Result:
After taking off vest/bandana, the temperature of the body surface was 29,3° C and therefore even lower than without cooling vest before the test.
Relief of the body by cooling is thereby clearly illustrated.

A rest period followed:
- Duration of recovery: 20 minutes

2. Second run
Subject without cooling

- Subject stays for 7.25 minutes (due to heat-related discontinuation), performing minor activity.
- Subject: photographed with thermal imaging camera right after leaving the passage

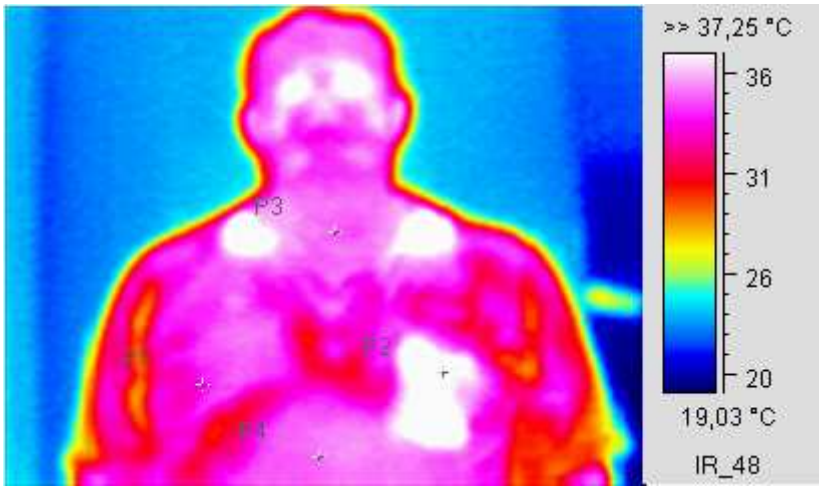


Chart	Value
P1: Temp.	34.20 °C
P2 :Temp.	37.90 °C
P3: Temp.	35.50 °C
P4: Temp.	35.50 °C
Average temp. BS*	**35.9 °C (+ 4,2° C)**

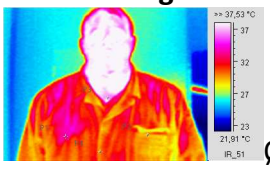
Without cooling, the body surface temperature in the chest area was +4,2° C higher than during measurement before heat stress

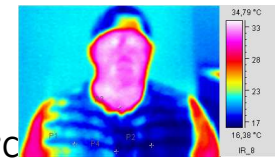
Summary of measurements:

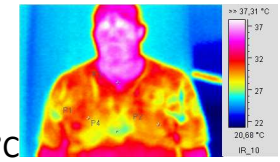
	Subject	
Before measurement **without** cooling vest (T_1)	ca. 31,7° C	
First run BS after leaving the passage **wearing** cooling vest (T_2)	ca. 18,3° C	-13,4° C cooler on vest
BS after leaving the passage **without** cooling vest (T_3)	ca. 29,3° C	-2,4° C cooler than before
Second run BS after leaving the passage **without** cooling vest (T_4)	ca. 35,9° C	+4,2° C warmer than before

Decrease of body surface temperature (BS) with cooling vest compared to no cooling (T_4 / T_3)	**ca. - 6,6° C cooler**	**than without cooling**

With cooling



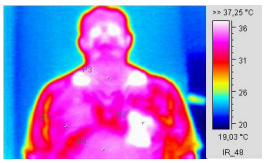
Ø31,7°C


Ø18,3°C


Ø29,3°C(-2,4°C)

Subject at test begin with cooling vest/bandana after taking off cooling vest/bandana

Without cooling

Ø 31,7°C


Ø35,9°C (+4,2°C)

Subject at test begin without cooling

By using the cooling vest, the temperature of the body surface in the chest and head area (cardiovascular system) did not increase, despite an increased WBGT value.
By using the cooling vest and the bandana, the temperature of the body surface in the chest area (cardiovascular system) was even kept below the baseline values, despite the very high temperature, without causing any heat stress.

In comparison, the temperature of the body surface clearly increased by 4° C without cooling, which was confirmed by the subject's reports regarding heat stress and discontinuation of the test after 7 minutes.

Therefore, the E.COOLINE cooling vest is capable of considerably relieving the employee and contributes to the performance preservation within the measured temperature range.

VI. Overall assessment of workplace

In this case, the result of the investigational measurement regarding heat stress in rooms showed an exceeding of the WBGT reference value according to DIN EN 27 243 (EU Standard).

In this case, the standard requires that a continuous exposition of employees must be avoided or other appropriate measures be taken. Independent of the WBGT values, it must be examined whether technical or organizational measures are capable of reducing exposure. Usually these measures are already exhausted due to the unique work situation.

The current studies show that a simple and very effective relief of employees can be the utilization of cooling clothing (vest, bandana).

The temperature on the subjects' body surface increased by 4° C without cooling.

When using the cooling products, the increase in temperature in the chest area was kept at physiological levels and even decreased slightly, resulting in considerably relieving the employee.

Sports sciences studies involving cooling vests of the E.COOLINE brand show that cooling the body increases the ability to call upon physical performance as well as endurance considerably when compared to subjects without cooling. During rest periods at work, a faster regeneration using cooling products is achieved between work assignments.

These results can be applied to the current work situation as the rest period intervals at work are comparable to the sports sciences study.

Using the cooling clothing at the workplace investigated is therefore recommended at WBGT values above 29° C.

“At last I can enjoy my free time after work again”

(Employee quoted at hot workplace after being relieved by E.COOLINE cooling vest)