

# The heat stress for workers employed in a dairy farm

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## Abstract

The Italian dairy production is characterized by high heterogeneity. The typology quantitatively more important (80% of national production) is represented by cow's milk cheeses (*Grana Padano* cheese, string cheese, Parmesan cheese, etc.), while the cheese from buffalo's milk (especially string cheese such as *mozzarella*) and cheese from sheep and goats represents respectively 4% and 8% of the national dairy production, and are linked to specific regional contexts. Some phases of the cycle of milk processing occur at certain temperatures that are not comfortable for the workers also in relation to possible problems due to thermal shock. The aim of this study was to evaluate the risk of heat stress on workers operating in a dairy for processing of buffalo milk. The research was conducted at a dairy farm located in the province of Viterbo, Italy, during the spring-summer period. To carry out the research were detected major climatic parameters (air temperature, relative humidity, mean radiant temperature, air velocity) and the main parameters of the individual operators (clothing thermal insulation and the energy expenditure required from the work done by employees). Subsequently, main indices of heat stress assessment provided by the main technical standards were calculated. In particular have been calculated predicted mean vote and predicted percentage of dissatisfied in moderate thermal environments (environments in which the objective, in the design and management phases, is to achieve the thermal comfort), provided by the UNI EN ISO 7730 and the wet bulb globe temperature in severe hot environments (environments in which you must protect the health of workers) required by UNI EN ISO 27243. The results show some phases of risk from heat stress especially during times of test in which the internal air temper-

ature exceeds the threshold of 30°C and possible solutions to improve the safety of the operators.

## Introduction

During the summer Mediterranean areas are characterized by high values of solar radiation, coming to 1000 W m<sup>-2</sup>, and consequently high values of air temperature that can reach 40°C (Marucci *et al.*, 2013).

The issues related to the microclimate in the workplace are connected to the environmental factors that affect the thermal exchanges between man and the environment. In many agricultural and agro-industrial workplaces, the thermal comfort is difficult to achieve. In fact, the man is often found to operate outdoors or in the presence of animals, or in high temperature conditions (greenhouses) or very low (cold storage) or in situations where climatic parameters must be kept within specific microclimatic intervals, to ensure products conform to the standards of preparation, ripening and storage of products.

The main factors that influence these exchanges are: the weather conditions outside, the structural characteristics of the building, the characteristics of air conditioning (cold, hot), the number of occupants in environment to be examined and the type of activity. Of particular importance is also, especially in the agro-food industries, the presence of thermal excursions such as to endanger the health of workers (Monarca *et al.*, 2012).

In dairy farms remain, even where the level automation is high, many risk conditions for health of workers (Di Giacinto *et al.*, 2012). Among these, it includes the feeling of thermal discomfort perceived by employees, due to the microclimatic conditions (Marras *et al.*, 2005).

The milk processing within a dairy varies according to the type of product to be obtained with a consequent variation of the optimal microclimatic conditions, which are often in contrast with those relating to the feeling of thermal comfort of workers. In particular, in the case of the buffalo's *mozzarella* processing (Figure 1), the phase greatest risk with regard to heat stress is that relating to the spinning.

Therefore, it is necessary to analyze such working conditions and the impact on the worker's health and be taken appropriate measures to improve the staff working conditions (Marucci *et al.*, 2012).

The risk assessment of thermal stress is evaluated using microclimatic indices (Alfano *et al.*, 1998; Moran *et al.*, 2001; Pérez-Alonso *et al.*, 2011; Callejon-Ferre *et al.*, 2011) based on the safety legislations that take into account climatic factors, the activities carried out by operators and clothing used (Budd, 2008). The goal of this research is to assess the risk of heat stress for workers that operate within a dairy farm used as processing of buffalo's milk.

The research was conducted in a dairy farm located in the municipality of Alto Lazio during the spring-summer period and were subsequently determined the assessment heat stress indices provided by the main technical standards: UNI EN ISO 7730 (ISO, 2006) for the determination of the predicted mean vote index (PMV) and predicted per-

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centage of dissatisfied index (PPD) in moderate environments and UNI EN ISO 27243 (ISO, 1996) for the calculation of the wet bulb globe temperature index (WBGT) in hot severe environments.

## Materials and methods

The technical standards used for the risk assessment of thermal stress are those represented by the International Organization for Standardization (ISO) standard, implemented in Italy as UNI. In particular, the following standards were applied:

- EN ISO 7730:2006 - Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO, 2006);
- EN ISO 27243:1996 - Hot environments. Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature) (ISO, 1996);
- EN ISO 8996:2005 - Ergonomics of the thermal environment. Determination of metabolic rate (ISO, 2005);
- EN ISO 9920:2009 - Ergonomics of the thermal environment. Estimation of thermal insulation and water vapour resistance of a clothing ensemble (ISO, 2009);
- EN ISO 7726:2002 - Ergonomics of the thermal environment. Instruments for measuring physical quantities (ISO, 2002).

In order to determine the indices proposed by the reference standards were detected microclimatic parameters (temperature and relative humidity inside and outside) of a dairy farm (Figure 2) located in a municipality of Alto Lazio (altitude: 464 m; latitude: 42°32'17" N; longitude: 12°03'19"E) during the spring-summer period. The measurements were performed during the production process of *mozzarella* (3-4 p.m.) in the phases of: milk curdling, cutting and bleeding of curd, spinning and forming of *mozzarella*, and three employees working within the dairy during these phases.

The measurement system used is the following (Figure 3): i) multi-acquiring LSI BABUC M instrument with 6 inputs; ii) probes for measuring micro-climatic parameters (thermometer, psychrometer, anemometer and globe thermometer); iii) prop for probes; iv) tripod.

The probes were put into position on a tripod at a height of 1.50 m from the ground. The PMV index is the average rating from a large sample of people present in the same environment and is a mathematical

function (1) that depends on several factors:

$$PMV = [0.303 \cdot \exp(-0.036 \cdot M) + 0.028] \cdot \left\{ \begin{aligned} & (M - W) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M - W) - p_a] - 0.42 \cdot [(M - W) - 58.15] \\ & - 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) \\ & - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^2 - (t_a + 273)^2] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \right\} \quad (1)$$

where:

- M = metabolic rate (Wm<sup>-2</sup>);
- W = effective mechanical power (Wm<sup>-2</sup>);
- f<sub>cl</sub> = clothing surface area factor;
- t<sub>a</sub> = air temperature (°C) (parameter acquired);
- t<sub>r</sub> = mean radiant temperature (°C) (parameter acquired);
- p<sub>a</sub> = water vapour partial pressure (Pa);
- h<sub>c</sub> = convective heat transfer coefficient (W m<sup>-2</sup> K<sup>-1</sup>);
- t<sub>cl</sub> = clothing surface temperature (°C).

Climatic parameters have been calculated using climate data collected on the farm during the days April 10<sup>th</sup>, May 3<sup>rd</sup>, May 30<sup>th</sup>, June 11<sup>th</sup> and June 17<sup>th</sup>, 2013, while the metabolism rate (M) and clothing insulation (I<sub>cl</sub>) of workers have been determined on the basis of existing legislation and the conditions of workload and of clothing detected in trial days. It was taken on value of metabolic rate (M) equal to 116 W m<sup>-2</sup> (2.0 met), as reported in legislation that corresponds to a medium activity and standing. The clothing used by workers is underpants, boiler suit, socks, shoes that corresponds to an I<sub>cl</sub> equal to 0.75 clo (0.11 m<sup>2</sup> K W<sup>-1</sup>).

ISO 7730 defines the scale of values of the PMV (Table 1) in range +3 (very hot) to -3 (very cold) (ISO, 2006). There are intermediate situations where the 0 corresponds to thermal neutrality; the range between -0.5 and +0.5 corresponds to the thermal comfort. When -2 < PMV < -0.5 and +0.5 < PMV < +2 the thermal environment is moderate while the PMV values less than -2 and greater than +2 the thermal environment is severe.

The same standard defines PPD as the percentage of thermally dissatisfied people and is calculated according to the following function (2):

$$PPD = 100 - 95 \cdot e^{-\left(0.03353 PMV^4 - 0.2179 PMV^2\right)} \quad (2)$$

The PPD is equal to 10% in the case where the PMV is within the

**Table 1. Thermal sensation scale.**

PMV	Seven-point thermal sensation scale	Classification working environment
+3	<i>Hot</i>	Severe hot environment
+2.5		
+2	<i>Warm</i>	Moderate warm environment
+1.5		
+1	<i>Slightly warm</i>	
+0.5		Thermal comfort
0	<i>Neutral (thermal neutrality)</i>	
-0.5		
-1	<i>Slightly cool</i>	Moderate cool environment
-1.5		
-2	<i>Cool</i>	
-2.5		Severe cold environment
-3	<i>Cold</i>	

PMV, predicted mean vote.

range of thermal comfort ( $-0.5 < PMV < +0.5$ ), while for severe environments the PPD assumes values higher than 80%.

PMV has allowed to classify the thermal environment considered as hot. Consequently, it was necessary to calculate another index proposed legislation for harsh hot thermal environments: WBGT.

Wet bulbe globe temperature is used to determine the thermal stress for individuals acclimated. The current legislation proposes two equations for calculating the WBGT as a function of the presence or absence of sunshine. In this farm, the indoor lighting is completely artificial and therefore without the entry of sunlight. Therefore, the equation that has been applied is that relating to environments not sunny (3):

$$WBGT = 0.7t_{nw} + 0.3t_g \tag{3}$$

for internal and external exposition without exposure to sun, where:

- $t_{nw}$  is Natural wet-bulb temperature ( $^{\circ}C$ );
- $t_g$  is globe thermometer temperature ( $^{\circ}C$ ).

## Results and discussion

The measured values of temperature and relative humidity of the air and the calculated values of PMV and PPD during the processing of milk, in the test period, have given the mean values reported in Table 2. From the measurements performed in this period, the indoor air temperature is always higher than  $20^{\circ}C$ . In the last two measurement periods, which fall in June, the indoor air temperature was higher than  $25^{\circ}C$ . The high values of the internal air temperature in the dairy farm are due to the processing of milk and they can cause serious health problems of the operators especially in the event of prolonged exposure. The relative humidity measured inside the dairy farm is between 50% and 80%, has not been reached the saturation of the air and this has allowed to reduce the risks associated with the high air temperature.

Figure 4 shows the mean values of the PMV and PPD, calculated with the climate data collected from 3 p.m. to 4 p.m. for each day of measurement inside the dairy, and the limit (+2) beyond which the environment changes from moderate to severe hot. On the first day of the experimental period (April, 10<sup>th</sup>), taking into account the thermal energy produced during metabolic activity by workers and thermal insulation of the clothing, the PMV is equal to +1.32 placing itself in the middle between *slightly warm* and *warm* in the seven-point thermal sensation scale reported by the legislation. The PPD associated with this PMV value was equal to 41.2%. In the other days of measurements instead PMV index always exceeds the limit of +2 due to the high indoor values of air temperature and relative humidity measured, and other conditions being equal. Exceeding this limit allows to classify the

processing environment as severe hot.

On June 17<sup>th</sup>, the PMV was not calculated because the air temperature has exceeded the value of  $30^{\circ}C$ . Where the PMV index exceeds the threshold of +2, and thus the work environment becomes *severe hot*, and the indoor air temperature exceeds  $30^{\circ}C$  is necessary to calculate another index proposed by microclimate safety regulations: the WBGT, through which it is possible to verify if operators are subjected to heat stress.

Figure 5 shows the mean values of WBGT index for the periods of experimentation and the limit for acclimated subjects ( $26.7^{\circ}C$ ).

In the first day of observation (April, 10<sup>th</sup>) has not been calculated the WBGT index because the working environment was found to be moderate ( $+0.5 < PMV < +2$ ). Only in the last day (June, 17<sup>th</sup>), WBGT values are higher than the limit established by law for acclimated subjects ( $26.7^{\circ}C$ ). During these reliefs the WBGT was found to be equal to  $32.7^{\circ}C$  showing how the workers were subjected to a real thermal stress. In general, the search results allow to affirm that, under the climatic conditions in which the dairy farm is located, during the second part of the spring season (late April-mid June) the workers are in the presence of a situation of thermal discomfort but they are not subjected to thermal stress since the WBGT was found to be always lower than the limit established by law. In order to reduce the  $I_{cl}$  index, and so the thermal discomfort, it is possible modify operator's clothing. A significant improvement of the conditions would be obtained to passing a clothing

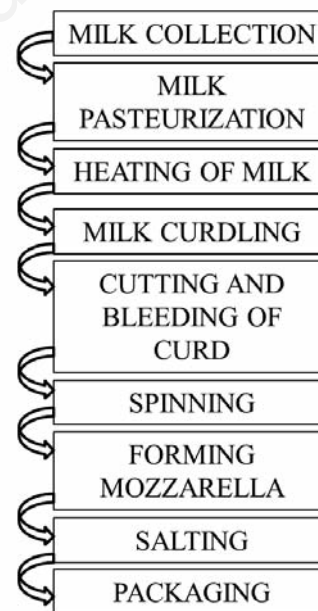


Figure 1. Buffalo's mozzarella production process.

Table 2. Mean values of indoor and outdoor air temperature and relative humidity, clothing insulation and metabolic rate.

Date of measurement	Indoor air temperature [ $^{\circ}C$ ]	Indoor relative humidity [%]	Outdoor air temperature [ $^{\circ}C$ ]	Outdoor relative humidity [%]	$I_{cl}$ [clo]	M [ $W m^{-2}$ ]
April, 10 <sup>th</sup>	20.9	65.3	16.6	51.4	0.7	116
May, 03 <sup>rd</sup>	22.9	64.8	21.1	59.2	0.7	116
May, 30 <sup>th</sup>	22.7	78.4	17.1	56.6	0.7	116
June, 11 <sup>th</sup>	26.3	61.5	23.1	54.3	0.7	116
June, 17 <sup>th</sup>	32.7	53.5	31.4	29.7	-	-

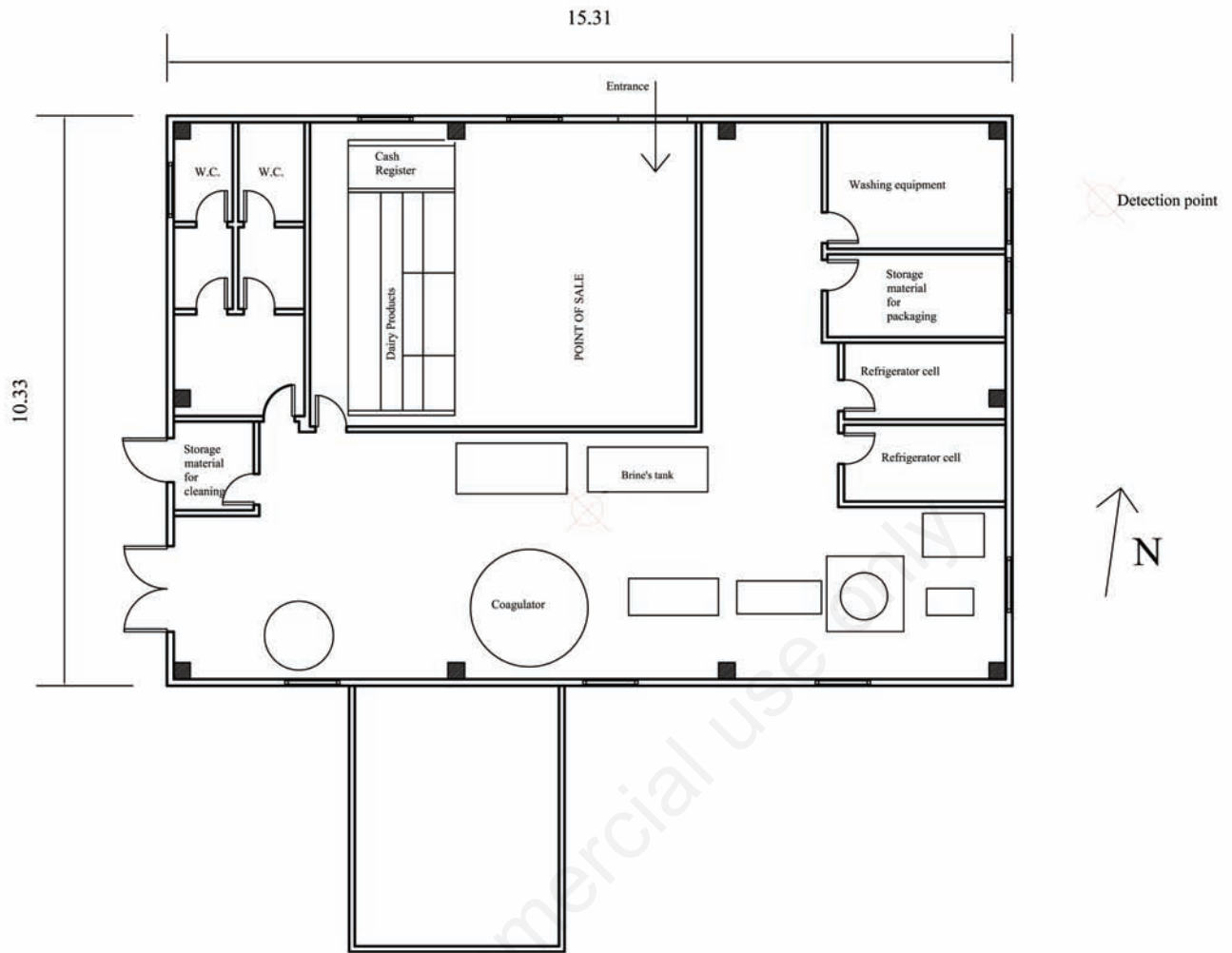


Figure 2. Plan of the dairy farm studied.



Figure 3. Measurement system used for the research.

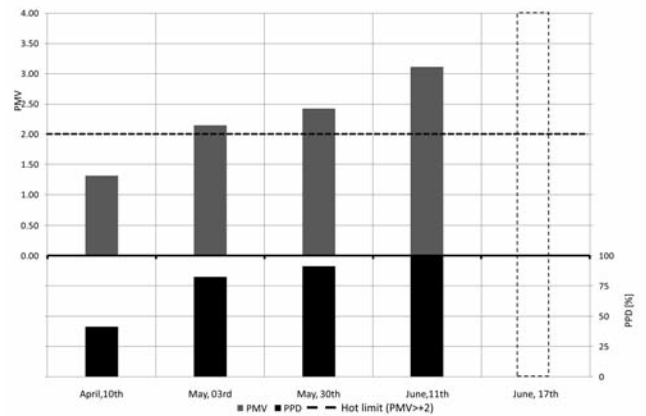


Figure 4. Predicted mean vote (PMV), predicted percentage of dissatisfied (PPD) and PMV limit established by the respective reference standards.

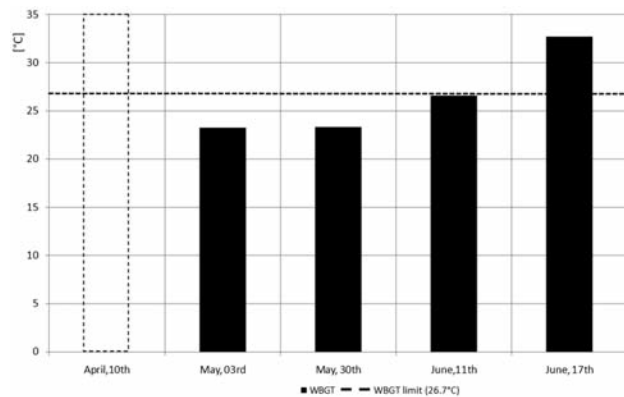


Figure 5. Mean values of wet-bulb globe temperature (WBGT) index for the periods of experimentation.

with  $I_{cl}=0.70$  clo to another with  $I_{cl}=0.50$  clo. This would allow reducing the operator's acclimatization and would reduce the PMV index of 33%.

In the first half of June, the WBGT exceeds the limit set for acclimated workers and the employees find themselves operating under thermal stress conditions. Since the WBGT index, unlike the PMV, is closely related to the air temperature you could intervene further reducing the value, whose control is generally entrusted only to the forced ventilation through fume hood. It is possible to reduce the indoor air temperature through a cooling system or, in the design phase of the building, to foresee the use of materials or construction techniques that improve the thermal insulation. Additional actions may be even the clothing of the operators described above and the programming of one or more breaks during the working shift to spend in areas of acclimatization.

## Conclusions

The calculation of the indices, brought in accordance with the safety standards, has allowed us to assess the degree of risk of heat stress they are subjected to the operators involved in the preparation of buffalo's *mozzarella* in a dairy farm. The survey data showed the presence of different situations of heat stress risk.

During the second part of the spring season (late April to mid June) the Steelworkers of buffalo's *mozzarella*, under the climatic conditions in which it is located the dairy farm, are in the presence of a situation of thermal discomfort because the calculated WBGT index not exceeds the threshold established by the legislation but at the same time the relative values of PMV calculated classify the workplace as a moderate warm environment. In the last study period (mid-June) in the vicinity of the summer and in presence of significantly higher air temperatures, it is possible to affirm that operators are in presence of heat stress conditions. In order to reduce this risk situation, the employer is required to: i) provide appropriate clothing in order to reduce the  $I_{cl}$  index; ii) check the exposure times with programming breaks to spend in areas of acclimatization; iii) reduce the internal air temperature of the workplace through an adequate air conditioning system.

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