The effects of climate change on the health and safety of pasta industry workers: assessment of heat stress using WBGT index

Domenico Giuseppe Costabile[1]; Vincenzo Fuccillo[2]; Cosimo De Marco[3]*

1. *Freelance*
2. *European Association for Prevention*
3. *ASL Napoli 1 Centro - Prevention Department - Occupational Hygiene and Medicine Service "UOSD Work 24-28-73"*

**Corresponding author taldem@inwind.it*

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Abstract

Protection of workers from environmental heat stress, especially the risks to which individuals are exposed due to the microclimatic conditions of the summer season characterized by particularly high temperatures, requires a careful assessment of working conditions and the implementation of preventive actions. The sectors most affected by such exposure are related to construction and road works, agriculture, and maritime fishing. This contribution presents the practical assessment and study of some work environments belonging to the pasta production sector, focusing on thermal stress in hot working environments, based on the use of the Wet Bulb Globe Temperature (WBGT) index, easily determinable with the use of simple portable instruments. The impact of climate change on the health and safety of workers in the pasta sector is a topic of growing importance. Climate variations adversely affect the health of workers throughout the entire pasta supply chain. This article explores the tangible effects of global warming on the well-being of sector workers, with a particular focus on heat stress and its related impact on productivity. The challenges faced by workers in the pasta sector due to extreme heat weather conditions and appropriate strategies aimed at mitigating the associated economic impacts were analyzed. Furthermore, precautionary measures were examined to define, prevent, and protect the health and safety of workers, thereby contributing to the long-term sustainability of this vital food industry.

This case study delves into the analysis of temperatures in the workplaces of three pasta factories during two distinct periods of the year, using the WBGT index. This index provides a more accurate assessment of the thermal conditions perceived by workers, considering the complexity of the variables involved. The decision to examine three different pasta factories aims to provide a comparative analysis of the thermal conditions, taking into account the specificities of each structure. The chosen investigation period, spanning summer and early autumn, is motivated by the desire to understand seasonal variations and evaluate the impact of climate change on microclimatic conditions in workplaces. The main objective of the study was to identify any significant differences in thermal conditions between the two periods considered and to analyze how climate change could influence workers' health.

The comparative analysis of the data collected during the months of July and October aims to provide a detailed overview of the thermal conditions in pasta factories, highlighting any trends or fluctuations. Through this investigation, we aimed to outline the potential impacts of climate change on the microclimate of workplaces, contributing to greater awareness and the formulation of adaptation strategies. The information emerging from this study is useful for managing the safety and well-being of workers in the specific pasta factories examined. However, it could also constitute a broader contribution in the context of discussions related to the adaptation of working conditions to climate change. The ultimate objective was to promote safe, comfortable, and resilient working environments capable of facing the challenges imposed by climate variations.

Introduction

According to the "State of the Global Climate 2022" report published by the World Meteorological Organization (WMO), compiled by experts from around the world, it follows the publication of the State of the Climate in Europe by the Copernicus Climate Change Service and integrates the Sixth Assessment report of the Intergovernmental Panel on Climate Change (IPCC), which includes data up to 2020. The report reveals global-scale changes on land, in the ocean, and in the atmosphere caused by record levels of greenhouse gases. It confirms that, concerning global temperature, in 2022 it was 1.15°C [from 1.02 to 1.28] above the 1850-1900 average. The years from 2015 to 2022 have been the eight warmest in instrumental records dating back to 1850, with 2022 being the 5th or 6th warmest. Record heatwaves have impacted Europe during the summer, with some areas experiencing extreme heat accompanied by exceptionally dry conditions. According to a recent report from the United Nations agency, 60,000 people died due to extreme heat in Europe last summer, despite strong

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early warning and health plans for the continent.
The health emergency caused by the pandemic and the increasing average age of workers only exacerbate this risk. Additionally, intense heat conditions are becoming more frequent not only during the summer but also in the intermediate seasons, particularly in many European countries, especially those bordering the Mediterranean basin.
According to the National Oceanic and Atmospheric Administration (NOAA), 2021 was the second warmest year in the last 140 years, and 2022 was one of the three hottest years ever recorded globally. Consequently, there is a growing number of studies analyzing the impact of heat stress on workers' health and productivity, resulting in reduced cognitive and physical performance at the workplace and an increased frequency of accidents.
The rise in temperature can lead to acute effects such as dehydration, heat syncope, heat stress, and heatstroke, especially in non-acclimatized workers performing heavy tasks in heavy clothing (e.g., personal protective equipment) without adequate protective measures (breaks in cooled areas, frequent hydration, etc.). Heat can also trigger acute cardiovascular and cerebrovascular events through increased blood viscosity, plasma cholesterol, and platelets, exacerbating chronic conditions such as chronic obstructive pulmonary disease. Furthermore, workers chronically exposed to heat may experience medium- and long-term damage, such as kidney function alterations.
In workers, heat can also increase the risk of workplace accidents and injuries due to cognitive impairments, particularly affecting attention, concentration, and reaction time.
The health impacts associated with heat correspond to social and economic costs primarily for the workers and their companies but also for the healthcare and insurance systems. According to a global study, the economic damage resulting from deaths, injuries, and occupational diseases accounts for 3.9% of the global GDP, with a similar estimate (3.3%) available at the European level.
In a general sense, the term "microclimate" refers to a range of physical parameters that characterize living and working environments, determining the thermal comfort of individuals.
The increasing frequency and intensity of heatwaves are among the most relevant aspects of climate change, and weather-climate prediction scenarios indicate it as a public health priority. The impact on workers' health and safety is a crucial research area for defining intervention and mitigation policies, and the pasta industry is certainly one of the occupational sectors most affected by exposure to high indoor temperatures. This sector has always been a symbol of Italian cuisine and the Made in Italy brand worldwide.
In Italy, the pasta sector generates 3.5% of the national turnover of the food industry and is a global reference for the sector. This study aims to present solutions to occupational exposure to extreme heat, increasing awareness and attention to associated risks in the pasta industry (and, by extension, other more involved occupational contexts). It also aims to implement fundamental adaptation strategies to protect workers' health, thereby containing the significant economic effects related to productivity loss due to heat stress-induced injuries and reducing the various social costs associated with this issue.
Environmental Parameters and Metabolic Energy: Under baseline conditions, the human body loses about 44% of heat through radiation, 31% through convection, 21% through sweat evaporation, and 4% through other causes such as body water heating, diuresis, and conduction loss. The percentages of heat dissipation vary depending on factors such as the type of work, ambient temperature, and clothing. The body's thermal balance is fundamentally expressed by the formula: $S = M \pm C \pm R - E$, where S is the thermal balance, M is the metabolic heat produced by the body, C is the heat exchanged by convection, R is the heat exchanged by radiation, and E is the heat dissipated through sweat evaporation. Since the value of M is always positive and that of E is always negative, when $S = 0$, the thermal balance brings the body to ideal conditions; when $S > 0$, the thermal balance leads to an increase in body temperature, and when $S < 0$, the thermal balance leads to a decrease in body temperature. In hot environments, S should not reach excessively positive values that pose a risk to human health. To determine heat stress, it is necessary to measure the parameters of the environment in which the body is immersed and evaluate the metabolic energy resulting from the activity performed.

Measurement of Natural Ventilation Wet Bulb Temperature:

The natural ventilation wet bulb temperature (tnw, in °C) is the value indicated by a temperature sensor covered by a naturally ventilated wet sheath, located in the environment under examination without forced ventilation. The temperature sensor must comply with the following characteristics (UNI EN 27243 standard): a) shape of the sensitive part of the sensor: cylindrical; b) outer diameter of the sensitive part of the sensor: 6 mm ± 1 mm; c) sensor length: 30 mm ± 5 mm; d) measurement range: from 5 °C to 40 °C; e) measurement accuracy: ± 0.5 °C; f) the sensitive part of the sensor must be entirely covered by a white sheath made of highly hydro-absorbent material (e.g., cotton); g) the sensor support must have a diameter of 6 mm and extend for 20 mm, covered by the sheath to reduce conduction from the support to the sensor; h) the sheath must be woven in a sleeve shape and accurately placed on the sensor; too tight or too loose fixing compromises measurement accuracy; i) the sheath must be kept clean; j) the lower part of the sheath must be immersed in a tank of distilled water; the free length of the sheath in the air must be between 20 mm and 30 mm; k) the tank must be designed so that the water temperature inside does not rise due to radiation from the environment.

Measurement of Globe Thermometer Temperature:

The globe thermometer temperature (tg, in °C) is the temperature indicated by a temperature sensor placed at the center of a globe with the following characteristics (UNI EN 27243 standard): a) diameter: 150 mm; b) average emissivity: 0.95 (globe painted in opaque black); c) thickness: as thin as possible; d) measurement range: from 20 °C to 120 °C; e) measurement accuracy: for the range from 20 °C to 50 °C: ± 0.5 °C; for the range from 50 °C to 120 °C: ± 1 °C.

Measurement of Air Temperature:

Air temperature (ta, in °C), also known as dry bulb temperature, can be measured using any suitable method, regardless of the shape of the sensor used. However, it is necessary to observe measurement precautions related to air temperature measurement. The air temperature sensor must be protected from radiation by a device that does not impede air circulation around the sensor. The air temperature measurement range is between 10 °C and 60 °C, and the accuracy must be ± 1 °C (UNI EN 27243 standard). If there is a significant difference between air temperature ta and globe thermometer temperature tg, it means there is a high level of radiant heat, for example, due to direct sunlight. The wet bulb temperature tnw differs from air temperature ta because the tnw value is influenced by the natural movement of the air. Due to evaporative cooling, the wet bulb temperature is lower than the air temperature.

Valuation of Metabolic Energy:

Assessing metabolic energy, i.e., the amount of thermal energy produced within the body, requires some practice. In the absence of an evaluation using precise reference tables, activities can be classified into five broad categories: rest, low metabolic rate, moderate metabolic rate, high metabolic rate, and very high metabolic rate. Table 1, with established values for continuous activities, facilitates such classification.

Evaluation of Heat Stress with the WBGT Index: The heat stress experienced by an individual in a hot environment is, as mentioned, a function of the production of thermal energy within the body resulting from physical activity and the characteristics of the environment regulating the heat exchange between the environment and the body. Internal thermal load is the result of metabolic energy due to activity. A detailed analysis of the environment's influence on heat stress would require knowledge of the following four fundamental quantities: air temperature, mean radiant temperature, air velocity, and absolute humidity. A comprehensive assessment of the environment's influence can be performed by measuring quantities derived from the fundamentals, which are a function of the physical characteristics of the space used.

The WBGT index combines the measurement of two derived quantities, the natural ventilation wet-bulb temperature (tnw) and the globe thermometer temperature (tg), and, in some situations, the measurement of a fundamental quantity, the air temperature (ta) (dry-bulb temperature). The relationships between these different quantities are as follows:

- Indoors and outdoors in the absence of solar radiation: WBGT = 0.7 x tnw + 0.3 x tg
- Outdoors in the presence of solar radiation: WBGT = 0.7 x tnw + 0.2 x tg + 0.1 x ta

This method of assessing thermal stress (WBGT index, UNI UN 27343 standard) is based on the measurement of these different parameters and the calculation of average values (including metabolic activity) that take into account any spatiotemporal variations. The collected and utilized data must be compared with limit values, and when exceeded, it is necessary to directly reduce thermal stress or physiological stress in the workplace using appropriate methods. The limit values correspond to exposure levels at which almost all individuals can be habitually exposed without any harmful effects, provided there are no pre-existing pathological conditions.

Method specifications: When any of the environmental parameters does not have a constant value in the space surrounding the worker, it is necessary to determine the WBGT index at three positions corresponding to the height, relative to the floor, of the head, abdomen, and ankles. When the worker is standing, measurements should be taken at 0.1 m, 1.1 m, and 1.7 m above the floor; when the worker is sitting, measurements should be taken at 0.1 m, 0.6 m, and 1.1 m above the floor. The measurements should be taken simultaneously. The average value of the WBGT index is obtained from the three index values, weighted using the following formula: WBGT = (WBGT_head + 2 x WBGT_abdomen + WBGT_ankles) / 4

If the environment is practically homogeneous (heterogeneity less than or equal to 5%) in the examined or similar places, a simplified procedure can be adopted by determining the WBGT index at the abdomen level only. For a quick determination of the WBGT index, a single measurement at the level where thermal stress is maximum is sufficient. The use of this procedure provides greater safety, as it overestimates thermal stress. The use of this procedure should be highlighted in the assessment. If the environmental parameters do not have a constant value over time for the workplace and work activity, a representative average value must be determined. The most accurate method is to measure the trend of this parameter over time and deduce the average value for integration. Since in many cases this method can be used only with some difficulty, the trend of each considered parameter is divided into segments at almost constant levels. The average value of the considered parameter is then obtained by weighing the levels of the different categories over the total time during which each of these levels was obtained. The time basis T for calculating average values is a work/rest period of 1 hour, representative of the maximum thermal stress. It must be calculated from the beginning of a work period.

The average value of a parameter p (e.g., globe thermometer temperature) for which the trend over time has been divided into "n" levels is therefore

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expressed by the following formula: p_average = [(p1 x t1) + (p2 x t2) + ... + (pn x tn)] / (t1 + t2 + ... + tn), where p1, p2, ... pn are the levels of the parameter obtained during the times t1, t2, ... tn, with t1 + t2 + ... + tn = T = 1 hour. The number of measurements to be taken depends on the rate of variation of the parameters, the response characteristics of the sensors used, and the desired accuracy for the measurement.

The previous considerations on temporal variations also apply to determine the average value of the metabolic rate. If the metabolic rate is simply classified into one of the five main classes, the average value of the metabolic rate is determined by taking the average value for each elementary activity given in Table 1.

The determination of the WBGT index allows for the evaluation of the thermal stress to which the worker is subjected at the time of measurement. Consequently, it is recommended that these measurements be carried out during the period corresponding to the maximum thermal stresses, usually during the hottest period of the summer season and at midday or when the thermal energy generation system/source is in operation. The duration of each measurement depends on the response time of the sensor used, which, in some cases, can be considerable (especially for the globe thermometer temperature). It will be possible to perform a single measurement or evaluation for each of the levels used for each parameter. The duration of the measurements is therefore distinct from the duration of the analysis itself (base time) T = 1 hour.

Limit Values:

Table 2 provides the limit values of the WBGT index. They are based on data available in the scientific literature. If these values are exceeded, it is necessary, as mentioned, to directly reduce thermal stress in the considered workplace using suitable methods, such as environmental control, activity level management, time spent in the environment, and the use of personal protective equipment. The specified limit corresponds to a given situation for

***Table* 1** - *Classification of metabolic rate levels*

Class	Average metabolic rate value		Examples
	Relative to the skin surface area unit W/m^2	For an avetate equal to skin area 1,8 m^{2}W	
At rest	65	117	**Rest**
Low metabolic rate	100	180	Sitting at ease: light manual work (writing, typing, drawing. cutting, accounting); work with hands and arms (small tools, inspection, assembly or sorting of light materials); work with arms and legs (driving a vehicle in normal conditions, maneuvering a pedal or foot switch). Standing: drill work (small pieces); milling machine (small pieces); coil winding, winding small armor, work with low- powered machines; walking (speed up to 3,5 km/h)
Moderate metabolic rate	165	297	Supported work with hands and arms: (hammering nails, filing); working with arms and legs (driving off-road trucks, tractors or construction equipment); work with arms and trunk (work with a jackhammer, assembling tractors, plastering, intermittent handling of moderately heavy material, weeding, hoeing, picking fruit or vegetables), push or pull light carts or wheelbarrows, walk at a speed between 3.5 and 5.5 km/h, forge
High metabolic rate	230	414	Intense work with arms and trunk, carry heavy material, dig with shovel, work with hammer, sawing, planing or chiselling hard wood, mow the grass by hand, dig, walk at a speed between 5,5 and 7 km/h. Push or pull carts and wheelbarrows with heavy loads, deburring castings; arrange concrete blocks
Very high metabolic rate	290	522	Very intense activity at a fast to maximum pace; work with the axe, dig intensely, climb large stairs, walk quickly with small steps, run, walk at a speed exceeding 7 km/h

an individual normally dressed (thermal insulation index Icl = 0.6 clo), physically fit for the activity considered, in good health, and with a maximum rectal temperature of 38 °C as a reference. These limit values represent the average effect of thermal energy on humans over a sufficiently long working period. They do not take into account peak values of thermal stress to which individuals may be exposed during short periods (a few minutes), either in a particularly hot environment or following momentarily intense physical activity. In such cases, thermal stress can indeed exceed the permitted values without surpassing the representative limit values for average activity or a moderate environment.

When there is uncertainty about the adopted metabolic rate value, the limit value corresponding to the highest metabolic rate should be used. If no assessment is possible, refer to class 4. If the clothing worn is not normal work clothing (air and vapor-permeable with a thermal insulation index Icl = 0.6 clo), the limit values must be adjusted considering the specific characteristics of the clothing and the environment. Generally, wearing vapor-impermeable clothing results in a decrease in limit values, while wearing reflective clothing may lead to an increase in these limit values. Table 3 presents some limit values for WBGT, established for different work/rest cycles, based on the assumption that the WBGT value at the designated rest area is equal to or very close to the WBGT value at the workplace.

Use of Table 3:

The use of Table 3 can simplify the reorganization of work by modifying work/rest cycles based on the activity performed, to adhere to the limit values. Regarding acclimatization, it is a condition resulting from a physiological adaptation process that enhances an individual's tolerance when exposed to a specific environment for a sufficient period. Compared to a non-acclimatized individual, an acclimatized individual exhibits fewer physiological reactions under the same thermal stress. This type

Table 2- Limit values relating to a given situation

Metabolic rate class	WBGT limit value	
	Person acclimatized to heat “C	Person not acclimatized to he heat “C
0 At rest	33	32
1 Low metabolic rate	30	29
2 Metabolic rate moderate	28	26
	Stagnant air/Non-stagnant air	Stagnant air/Non-stagnant
3 High metabolic rate	25/26	22/23
4 Very high metabolic rate high	23/25	18/20

Table 3-WBGT limit values, in “C. for different work/rest cycles and workloads

Work cycle	Metabolic workload		
	Light	Medium	Heavy
25% work-75% rest	32,2	31,1	30
50% work -50% rest	31,4	29,4	27,9
75% work-25% rest	30,6	28	25,9
Continuous work	30	26,7	25

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of acclimatization can be achieved either artificially through repeated and controlled exposures in a climatic chamber or naturally through the individual gradually performing their work for short periods initially and then for gradually increasing durations.

Work/rest cycles for acclimatized and non-acclimatized individuals are determined by assessing the WBGT based on the specified limit values. The increase in the duration of the work period when transitioning from a non-acclimatized state to an acclimatized state should occur gradually over a seven-day period. Individuals who have not been exposed to daily heat during the previous workweek are considered non-acclimatized.

Description of the Studied Sector:

The pasta factories considered in this study fall within the production and packaging area of the Protected Geographical Indication (PGI) "Pasta di Gragnano," which includes the entire territory of the Municipality of Gragnano in the Province of Naples. According to the specifications, this pasta is produced with only two ingredients: durum wheat semolina and water from the local aquifer. It is available in various formats and diverse shapes, all typical and the result of the creativity of Gragnano pasta makers. Thanks to its established tradition in pasta production, the city of Gragnano is universally recognized today as the "City of Pasta."

Materials and Methods

For the measurements, a Delta Ohm HD32.3° datalogger (Figure 1) was used, a small and handheld portable microclimate station. This instrument proves particularly useful for measuring the main microclimatic parameters necessary for evaluating thermal stress in work environments, as required by Legislative Decree 81/2008 based on the empirical WBGT (Wet Bulb Globe Temperature) index.

Figure 1. Datalogger Delta Ohm HD32.3°

This empirical index takes into account three main components:

1. Wet Bulb Temperature: This measurement represents the temperature that would be recorded on a thermometer covered with a wet cloth, similar to the cooling sensation when the skin is moist. Wet Bulb Temperature takes into account the humidity in the air and is measured with a naturally ventilated wet-bulb temperature probe (Figure 2).

Figure 2.Naturally ventilated wet-bulb temperature probe

2. Globe Temperature: Measured with a globe thermometer probe (Figure 3), this component reflects the temperature of the black sphere, similar to the heat absorption by the human body. The globe thermometer is sensitive to both solar radiation and ambient temperature.

Figure 3. Globe thermometer probe

3. Dry Bulb Temperature: Represents the temperature of the surrounding air, indicating the perceived heat by the body when in motion. It is

measured with a dry-bulb temperature probe (Figure 4).

Figure 4. Dry Bulb Temperature Probe

Before installation in the pasta factories, the datalogger was carefully calibrated to ensure measurement accuracy. Sensors were placed near key work areas, such as drying cells, pre-drying rooms, and the dosing and pressing group, to capture data representative of different phases of the production process.

The surveys were conducted in two different periods of the year: the first survey was carried out from July 20 to July 27, 2023, with an average external temperature of about 36.0°C (6°C above the period average). The second survey took place from October 20 to October 27, 2023, with an average external temperature of 28.9°C. Each measurement had a minimum period of 15 minutes, given that the workplaces had relatively stable environmental conditions.

table 4 presents the Wet Bulb Globe Temperature (WBGT) indices of the three production facilities under analysis in this study during the two observation periods from July 20 to July 27, 2023, and from October 20 to October 27, 2023.

	WBGT	WBGT
	(July 20-27)	(Oct 20-27)
Pasta factory 1	42,4°C	32,8°C
Pasta factory 2	41,8°C	33,1°C
Pasta factory 3	42,8°C	32,9°C

Table 4. Result of the WBGT empirical index in the two establishments under study from July 20 to July 27, 2023.

In the first observation period from July 20 to July 27, 2023, the first pasta factory recorded an index of 42.4°C, the second pasta factory 41.8°C, and the third pasta factory 42.8°C. These data reflect summer conditions characterized by high temperatures. These temperatures may have been influenced in part by climate change, which has led to a gradual increase in temperatures during the summer season (approximately +6°C).

Climate change has become increasingly evident over the years, leading to hotter and prolonged seasons in many regions. This has created conditions of severe heat not only outdoors but also within production facilities, directly affecting the well-being and health of workers.

In the second period, from October 20 to October 27, 2023, temperatures significantly decreased: the first pasta factory recorded 32.8°C, the second pasta factory 33.1°C, and the third pasta factory 32.9°C, indicating a significant climate change towards cooler autumn conditions.

Discussion: This comparison reveals significant variations in temperatures between the two periods of the year in all three production locations, with a notable impact on the well-being of workers and production. It is evident that the rise in temperature due to climate change is contributing to increased climate variability, with hotter summers and milder autumns, necessitating new strategies to manage thermal conditions in food industries and protect workers from the challenges posed by these climate fluctuations. Legislative Decree 81/2008, in its Title VIII, recognizes microclimate as a physical risk factor that can influence the health and safety of workers. Although it does not contain a specific temperature limit for workplaces, it provides general provisions regarding environmental conditions and the need to ensure the safety and well-being of workers.

Relevant articles addressing environmental conditions in workplaces include Article 180, which suggests that the employer should take necessary measures to ensure that environmental conditions are suitable for the protection of the health and safety of workers. These environmental conditions include aspects such as temperature, humidity, air velocity, and other variables.

In the context of managing climatic conditions in pasta factories, it is essential to consider ambient temperatures and thermal limits to which workers are exposed. Temperatures in pasta factories can vary significantly depending on the different phases of the production process. For example, drying areas can reach high temperatures, while storage and packaging areas may be cooler. During this period, the pasta factories recorded average temperatures ranging from 41.8°C to 42.8°C. These temperatures were monitored and evaluated based on the thermal risk indicators provided by the UNI EN ISO 7243:2017 standard for the Assessment of heat stress for humans in the workplace, based on the WBGT index, which came into effect on November 9, 2017. The standard replaces the UNI EN 27243:1996 Hot environments - Assessment of heat stress for humans in the workplace, based on the WBGT index, which is repealed. This new standard imposes specific WBGT limits for different activities and exposure levels. It applies to the assessment of heat-induced effects on an individual during a working day (up to 8 hours) and cannot be used in situations where heat exposure is of short duration.

The standard is indicated for assessing the level of heat stress present in occupational environments, both indoor and outdoor or of another type, to which adult workers of both sexes may be exposed. For a work activity like that of pasta factories, WBGT limits range from 28°C to 33°C. However, the thermal risk assessment revealed that during this period, some phases of the production process exceeded these limits. In Pasta Factory 1, the WBGT index detected from July 20 to July 27 was 42.4°C, consistently exceeding the WBGT limits of the UNI EN ISO 7243:2017 standard by +9.4°C. This discrepancy indicates exposure to severe heat beyond the prescribed limits, highlighting an evident thermal risk for workers. Regarding the observation period from October 20 to October 27, the detected WBGT index was 32.8°C, staying within the standard limits.

In Pasta Factory 2, the WBGT index detected during the same period was 42.8°C, exceeding the WBGT limits of the UNI EN ISO 7243:2017 standard by approximately +8.8°C. This temperature index suggests thermal risk for workers. During the observation period from October 20 to October 27, the detected WBGT index was 33.1°C, slightly surpassing the WBGT limits of the UNI EN ISO 7243:2017 standard by +0.1°C.

In Pasta Factory 3, the WBGT index from July 20 to July 27 was 42.8°C, approaching the WBGT limits of the UNI EN ISO 7243:2017 standard but still remaining above those limits by +9.8°C. In this situation as well, there is a thermal risk due to extreme heat. From October 20 to October 27, the WBGT index was 32.9°C, staying below the WBGT limits of the UNI EN ISO 7243:2017 standard, although very close to the limit.

In summary, all three pasta factories present WBGT indices that exceed the limits imposed by the UNI EN ISO 7243:2017 standard for work activity during the July monitoring period. This comparison reveals exposure to extreme heat, representing a clear thermal risk for workers in all three pasta factories. Therefore, it is necessary to attempt to adopt some of the additional measures described earlier, depending on the cases, to protect the health and safety of workers in these adverse climatic conditions, with subsequent measurement of the microclimate attesting to the achievement of the thermal well-being pursued and allowed by current regulations.

Conclusions

Climate change and extreme temperatures can pose significant challenges for food industries such as pasta factories, as they impact both the well-being and health of workers and the production process. In general, to address the challenge of severe heat in pasta factories, it is essential to implement a series of systems and measures to protect the health and safety of workers while ensuring the maintenance of production and product quality. Some key systems to mitigate this issue include:

1. **Installation of Cooling Systems:** One of the most effective solutions is the installation of cooling systems in production areas. These systems can include the use of air conditioners, industrial fans, misting systems, or other devices to maintain an acceptable internal temperature. These systems help stabilize thermal conditions during the summer, reducing the risk of excessive heat for workers.
2. **Improvement of Thermal Insulation of Structures:** Investing in better thermal insulation of pasta factory structures can contribute to maintaining more stable temperatures inside, reducing the impact of extreme heat.
3. **Flexible Scheduling of Working Hours:** A flexible scheduling approach can allow pasta factories to adapt production schedules or timing based on weather forecasts. This way, production can be planned to avoid periods of extreme heat while ensuring operational efficiency.
4. **Provision of Personal Protective Equipment:** It is crucial to provide workers with appropriate personal protective equipment to cope with extreme weather conditions. This may include lightweight and breathable clothing for heat resistance, as well as access to drinking water.
5. **Continuous Monitoring of Thermal Conditions:** Regularly measuring climatic conditions inside the pasta factory and work areas is crucial. This monitoring allows verification that temperatures and humidity do not exceed predefined safety levels and enables anticipation of periods of extreme heat based on weather forecasts.
6. **Education and Training:** Providing workers with safety training courses related to extreme weather conditions, such as heatstroke prevention, can help prevent accidents and promote awareness of workplace safety.
7. **Worker Involvement in Safety Planning:** Involving workers in planning safety measures related to heat and seeking their input in identifying potential issues is crucial. This collaboration can lead to practical solutions and improvements in working conditions.

However, for a more comprehensive understanding of the implications for worker well-being, it is essential to also consider the metabolic energy derived from the tasks performed, as well as factors specific to the type of job and clothing worn. Metabolic energy represents a fundamental component to assess as it directly influences the perceived thermal load on workers.

The introduction of a detailed assessment of metabolic energy, considering different tasks and specific clothing worn by workers, can provide a more accurate perspective on the real tolerability of thermal conditions. This integrated approach would help identify potential criticalities related to work activities and clothing, offering practical insights for human resource management and the design of targeted strategies to improve working conditions. Furthermore, the correlation between metabolic energy and the WBGT index could reveal significant insights into the need to implement specific adaptation measures for each task, thereby contributing to a safer and more comfortable working environment. In the future, further research could delve into this integrated perspective, incorporating metabolic energy data for an even more comprehensive assessment of environmental and working conditions.

Below is an overview of the approach to assessing the metabolic energy of workers in pasta factories:

1. **Identification of Tasks:** Categorize work activities in pasta factories into specific categories, such as mixing, rolling, cutting, drying, and packaging. Assign each task to a specific profile, considering the type of movements, physical intensity, and duration of activities.
2. **Measurement of Heart Rate:** Use wearable heart rate monitors to detect heart rate during the performance of tasks. Record heart rate data for each worker in different thermal conditions and periods of the year.
3. **Application of Metabolic Equations:** Use appropriate metabolic equations for each task to estimate oxygen consumption and the associated MET, considering individual variables such as body weight and age for more accurate estimates of the metabolic load.
4. **Assessment of Environmental Conditions:** Measure the Wet Bulb Globe Temperature (WBGT) index in different sections of pasta factories and correlate the relationship between thermal conditions and variations in the perceived metabolic load on workers.
5. **Consideration of Clothing Type:** Evaluate the influence of specific clothing for each task on thermal regulation and, consequently, the required metabolic energy. From these considerations, a corrected WBGT value for clothing effects is derived. The thermal resistance of clothing is indicated by Icl, the "Local Thermal Conductance Index." The unit of measurement is CLO (1 CLO = 0.155 m^2K/W). This parameter is crucial for well-being, although defining clothing rigorously for individuals is challenging. Therefore, values are tabulated for numerous clothing combinations and individual garments. 1 CLO corresponds to the thermal resistance of a European mid-season suit.

Therefore, environmental WBGT is considered when the actual clothing worn is equivalent to that in which standard work clothes are worn (thermal insulation index Icl = 0.6 clo, im = 0.38) (See ISO 9920). The Clothing Adjustment Values (CAV) are introduced to adjust the WBGT value, taking into account the effects of clothing with thermal properties different from standard work clothes.

At this stage, possible improvements in clothing are identified to optimize working conditions. The thermal resistance of some combinations of workers' clothing in the three production facilities according to the thermal insulation values provided by the UNI EN ISO 9920 standard is presented in Table 5.

	Type of Work Clothing	CLO
Pasta factory 1	Underwear, Shirt, Apron, Pants, Shoes	0,90
Pasta factory 2	Underwear, Shirt, Apron, Pants, Shoes	0,90
Pasta factory 3	Underwear, Shirt, Apron, Pants, Shoes	0,90

Table 5. UNI EN ISO 9920 standard

Comparative Analysis:

Comparison of estimates of metabolic load among different tasks and among workers with different roles, with identification of any inequalities in working conditions and suggestions for targeted interventions. This integrated methodology allows for a detailed understanding of the specific energy requirements for each task in pasta factories. The comparative analysis of various activities and environmental conditions helps identify potential areas for improvement to promote the well-being and safety of workers in pasta factories.

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