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Developing a Feasible Integrated Framework for Occupational Heat Stress Protection: A Step Towards Safer Working Environments

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Abstract

Background: *Specialized occupational health and safety (OHS) issues are covered at the EU level through detailed legislation and guidelines. Unfortunately, this does not extend to occupational heat stress, not only in Greece but also (with few exceptions) internationally. One possible explanation could be the difficulty in accurately identifying the dangerous conditions, as many environmental and individualized elements are involved, and hundreds of "thermal stress indicators" are available. Another explanation could be the difficulty in adequately measuring hazardous conditions for workers affected more (i.e., outdoor and high intensity) since the biological protection framework is based on the human body's internal temperature.* **Methods:** *The Wet Bulb Globe Temperature (WBGT) has been proposed as the most efficacious thermal stress indicator. Since 2021, the Hellenic National Meteorological Service has provided 48-h WBGT forecast predictions to serve as a first level of alert. Real-time measurements and 48-h forecasts of WBGT are also available through a smartphone application. Additionally, as revealed when developing the occupational heat stress legislation in Cyprus and Qatar, crucial first steps are identifying the specific characteristics of worker exposure and the tripartite collaboration between employers, workers, and the State.* **Results:** *Evaluating the simplified WBGT forecasted values and the smartphone application estimates proved well-established. The sound scientific basis can be effectively combined with administrative measures based on the EU OHS legislative experience to produce practical solutions.* **Conclusions:** *As the climate crisis exacerbates, worker productivity and well-being will decline, underscoring the urgent need for an integrated protection framework. Such a framework is proposed here.*

1. Introduction

Occupational Health and Safety (OHS) is a large interdisciplinary field that deals with almost every human activity. In its recent strategic framework 2021-7 [1], the European Commission describes a set of key actions in the changing and challenging world of work. The previous strategic frameworks

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have brought significant progress in the last three decades concerning a 70% decrease of fatal accidents at work in the EU (from about 6 per 100,000 employed persons in 1994 to less than 2 in 2018), while the main focus remains on deaths from work-related illnesses that are many more (~200,000 in 2018) than the fatal accidents (3,300 fatal accidents and 3.1 million non-fatal accidents in the EU-27 in 2018). Besides health and well-being, there is also an enormous cost to the EU economy from work-related accidents and illnesses, amounting to over 3.3% of GDP annually (460 billion € in 2019) [1].

Thermal stress causes accidents as well as illnesses that can be fatal [2]. It's worth noting that, while there are Directives and/or Guidelines that cover most of the highly specialized OHS issues (i.e. vibrations, electromagnetic fields – EMF, artificial optical radiation – AOR, most of the chemical and biological hazardous agents, including SARS-CoV-2), occupational heat stress has not been adequately addressed not only in Greece but also internationally (with the exception of Cyprus, Qatar, China and Malaysia) and is covered only by relevant circulars published at the beginning of each summer. Technical (e.g. increased intake of water and electrolytes, clothing) and organizational (e.g. shifting work to cooler hours) best practices are employed [3-5], combined with risk assessment techniques [6-8]; all these can be also used for employee training. Not all workers are affected in the same way; outdoor, high intensity and intrinsic heat exposure are the main categories to deal with.

The above-mentioned discrepancies arise from the difficulties to accurately define the dangerous conditions, which is an aspect of uncertainty, since many environmental and individualized parameters are involved. For this reason, hundreds of relevant 'thermal stress indicators' exist, as revealed from a recent systematic review [9]. More specifically, a total of 340 thermal stress indicators have been developed, 153 of which are of no practical significance for large-scale guidance for occupational settings because they are nomograms, arcane instruments, and/or require detailed non-meteorological information (e.g. metabolic rate, clothing insulation, type of work). Concerning the remaining 187 indicators that are based only on meteorological data (i.e. air temperature, relative humidity, solar radiation, wind speed), 126 are primarily designed for sports and physical exercise, while the remaining 61 apply to workplaces and have been designed to detect occupational heat/cold stress [9].

The benchmark and simplest, meteorological index to apply is air temperature. Ten years ago in Greece, three different collective agreements existed (construction, couriers and ship repair), which included three different air temperature limits to protect workers against heat stress (36, 37 and 38°C). This non-scientific approach is no longer in use due to the cessation of collective agreements during the years of the recent economic crisis in Greece.

These 61 thermal stress indicators provide different approaches to estimate the 'perceived temperature' that is a combination of the environmental conditions with the biological parameters of thermoregulation, workload, clothing, acclimatization, etc. Human thermoregulation is a highly specialized survival mechanism, capable of coping with all the aforementioned issues through autonomic (i.e. implementing vasodilation, sweating, and increased respiratory rate in hot environments) and behavioral (i.e. by reducing clothing and physical activity) reactions [10]. While approaches such as the Physiological Heat Strain (PHS) model, described in ISO 7933, allow for detailed analysis of the physiological response of individuals exposed to thermal stress, their use in large-scale assessment and guidance remains limited [11, 12]. A recent multi-country field assessment concerning the 61 thermal stress indicators for occupational settings demonstrated that the empirical index of Wet Bulb Globe Temperature (WBGT) is the most efficacious thermal stress indicator in order to apply quick, large-scale assessment [9, 13, 14].

Another possible explanation of the limited adoption of legal frameworks to protect against occupational heat stress could be the difficulty to accurately measure the dangerous conditions, as the biological protection framework is based on the core temperature of the human body, allowing up to a 1°C increase [15]. Nevertheless, as previously mentioned, the choice of the proper occupational heat stress index is moving towards WBGT, while its measurement and/or prediction is now technically feasible as smartphone apps are an increasingly viable option to facilitate communication. Additionally, other models like the PHS model [11] allow much more detailed assessment. In this sense the most plausible explanation of the delay seems to be the lack of an integrated protection framework.

As the climate crisis continues to exacerbate environmental conditions [16], it is clear that its consequences involve not only the health but also the productivity of the workers [17]; an evaluation of recent European heat-waves determined an annual cost of €160 billion due to these causes [17]. At an EU level, the recent HEAT-SHIELD project funded by the European Commission proposed an early warning system which uses WBGT, vulnerability, and exposure information to produce short- and long-term advice on heat-management strategies [18]. In Greece, the active collaboration of the Hellenic Ministry of Labour and Social Affairs with the stakeholders (workers' and employers' organizations), the Hellenic National Meteorological Service (HNMS) and the Environmental Physiology FAME Lab of the University of Thessaly, has produced such an integrated protection framework that is briefly presented in the Discussion section.

2. Methods

2.1. The WBGT Index

The choice of the WBGT as a thermal stress indicator has been common for several decades [19], and it was further supported by a recent field assessment in occupational settings [9, 13, 14]. WBGT can be used both for outdoor and indoor assessments and is defined accordingly as follows (1):

$$WBGT_{outdoor} = 0.7\,T_{nwb} + 0.2\,T_g + 0.1\,T_a \text{ and}$$
$$WBGT_{indoor} = 0.7\,T_{nwb} + 0.3\,T_g \qquad (1)$$

where: T_{nwb} is the natural wet bulb temperature, measured by a thermometer yarn in distilled water and exposed to the thermal radiation and to the wind, T_g is the globe temperature, measured inside a black sphere and T_a is the air temperature (dry temperature). As mentioned above, T_a alone is not an effective thermal stress indicator, because it cannot account for conditions of low wind, high humidity, and/or high solar radiation [10]. The WBGT index implies various work-rest schemes considering environmental conditions, metabolic rate, clothing and acclimatization, in order to prevent occupational heat stress [15]. Moreover, it has been also used for the general public concerning climate change [20].

In a typical weather station, only the air temperature and the relative humidity are measured using shaded meteorological devices. In this sense, the T_{nwb} and T_g temperatures cannot be accurately specified, and approximations of the WBGT are used. In our work, the Liljegren approximation (WBGT-Lil) and the simplified methodology of the American College of Sports Medicine (WBGT-Sim) [21] have been chosen as the best options. Liljegren [22] developed an approximation independent of the applied location model, comprising the mass-energy equilibrium equations, where T_g includes direct and diffuse sunlight, making the method applicable in sunshine and heavy clouds. The mathematical formulation is complex and is supported by relevant software. In cases where only air temperature and relative humidity (RH) measurements are available, the simplified equation (2) is also applicable [21]. While this was initially developed for shaded indoor or outdoor locations, it has also been extensively used for outdoor locations exposed to direct sunlight (VP stands for vapor pressure, DW for dew point and RH for relative humidity, and T_a for air temperature):

$$WBGT\text{-}Sim = 0.567 \times T_a + 0.393 \times VP + 3.94 \qquad (2)$$

where: $VP = 6.11 \times 10^{(7.5 \times DW)/(237.3 + DW)}$ and

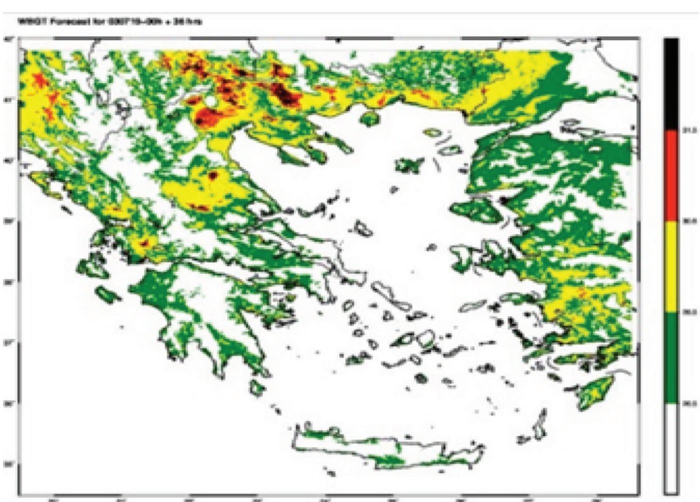
$$DW = 273.3\frac{\dfrac{\log\frac{RH}{100}}{17.27} + \dfrac{T_a}{273.3 + T_a}}{1 - \dfrac{\log\frac{RH}{100}}{17.27} - \dfrac{T_a}{273.3 + T_a}}$$

It is worth mentioning that the WBGT estimation accuracy is limited by measurement errors associated with the omission of global temperature in calculations as well as errors associated with instrumentation and calibration procedures. The WBGT measuring devices nowadays are fairly small and practical, since they implement a much smaller (than the standard) black globe, and they do not include a natural wet bulb temperature meter which is replaced by an anemometer that improves accuracy. The ISO 7726 and ISO 7243 set an acceptable accuracy of ±0.5°C when measuring WBGT [23, 24].

2.2. WBGT Prediction by the Hellenic National Meteorological Service

In order to predict WBGT values (Figure 1), forecasted values from the HNMS's Numerical Weather Prediction (NWP) model COSMO-GR1 for a number of weather parameters were used. COSMO-GR1 is a non-hydrostatic regional model that was developed by the COSMO consortium (COnsortium for Small-scale MOdeling, www.cosmo-model.org). The horizontal resolution used in this application is 0.01° (~ 1 km) and the grid covers horizontally the Hellenic region and includes 80 vertical layers. Boundary conditions are embedded on a daily basis from the ECMWF (European Center of Medium Range Forecast) and the corresponding dimension of the matrix for every forecasted parameter is 800x1000 points. On a daily basis, hourly predictions of various parameters (wind speed, 2m temperature, 2m dew point, solar radiation, etc.) are extracted for a 48h forecast horizon. Those values are used as input for the WBGT-Lil calculation algorithm, especially developed for this study that is based on the R libraries that were developed by Ana Casanueva of the Swiss Meteorological Service for the EU-funded HEAT-SHIELD project (www.heat-shield.eu).

As with any numerical product, WBGT forecasts are associated with errors. The accuracy of the calculations depends highly on the reliability of the forecasted parameters that are inserted in the algorithms that produce WBGT predictions. It should be noted that on average, the two main parameters in the calculations (2m temperature and dew point) are associated with errors of about 0.5 degrees with a clear diurnal cycle in error phase [25] which is inherited unavoidably to WBGT predictions. At the current stage, WBGT is not used to screen work activities but as an alert to set the OHS procedure. Given that this is a general guidance provided by the HNMS for the entire population, it does not provide details in relation to work intensity, clothing, and acclimatization.



Risk Level	WBG T (°C) Min	Max
1	<26.6	26.6
2	26.7	29.4
3	29.5	31.1
4	31.2	32.2
5	32.3	>32.3

Figure 1. Indicative WBGT predictions map produced by HNMS in 1km resolution, applying the Liljegren algorithm and adapted in color scale (left). Color scale of WBGT risk level (right) is a simplification approach, while detailed information is included in the circular.

2.3. The WBGT Prediction Application for Smartphones

FAME Lab has developed a WBGT prediction application for smartphones. It obtains precise geolocation through Application Programming Interfaces (APIs) to the OpenWeather web service (www.openweathermap.org), which offers weather data from satellite and weather stations for more than 200,000 cities worldwide. Solar radiation is calculated through mathematical models that consider the exact geographical and time location, while an estimation of the cloudiness percentage is also carried out based on relevant literature. Four meteorological parameters (air temperature, relative humidity, wind speed, and solar radiation) are used to estimate WBGT according to Liljegren's approach.

As the mathematical approach (WBGT-Lil) has been repeatedly validated, the accuracy and validity of the application depend on the proximity to the weather station and on the reliability of the available environmental data. To test this hypothesis by quantifying the relative error, the FAME Lab collected WBGT measurements all over Greece using portable weather stations (Kestrel 5400FW, Nielsen-Kellerman, Pennsylvania, USA), which were compared to the simultaneous use of the WBGT app at the point of assessment.

2.4. The Cases of Cyprus and Qatar

In Cyprus, an organized effort to mitigate workers' heat stress was launched over 10 years ago. An extensive code of practice (as well as a short one) was issued in 2014, with the parallel adoption of three indices (Corrected Active Temperature, Heat Stress Index, Sensible Temperature), which are calculated through measurements carried out by employers in the workplace with low-cost thermo-hygrometers [26]. Key parts of this effort were the cooperation of all productive entities and the pilot implementation phase until it reached the point of active legislation.

At the same time, in Qatar, known for its high temperatures, no extensive research had been conducted, as in any other Persian Gulf country, to assess whether and to what extent these high heat levels affect workers. Adopting countermeasures created for other countries (e.g., for the USA) may not be effective and, more importantly, may have disastrous consequences if used in significantly different settings. It was, therefore, vital to conduct a broad evaluation, in real field conditions, to test different countermeasures and provide specific guidance to the stakeholders. In 2019, the International Labour Organization and the Qatar Ministry of Labour commissioned FAME Lab to conduct a large study on occupational heat stress focusing on outdoor manual work (https://bit.ly/3JQzDGF). Data concerning mental and physical health, physiology, and work effort per second of the workers, were collected for more than 5,500 hours of work. The effectiveness of different coping strategies regarding environmental conditions was also compared. Although high heat levels were recorded, workers could perform their work safely when effective heat stress measures were in place, and very few experienced short-term high body temperatures. Some of the applied measures were:

- Workers were able to regulate work intensity and take frequent breaks;
- The importance of effective hydration strategies was highlighted as many workers were found to be dehydrated from the beginning of their shift;
- It was found that workers are more likely to avoid hyperthermia if they replace dark-colored overalls with loose, light-colored clothing made of breathable fabrics.

This research provided the scientific basis to propose adjustments to Qatar's existing relevant legislation and evaluated their effectiveness (https://bit.ly/3yGnyiY), so in May 2021 new legislation was announced that adopted all research proposals. The measures included, among others, adopting the WBGT index so that outdoor work must be stopped when 32.1°C is exceeded. As recently announced by the International Labor Organization [27], within the first year of its implementation, the package of measures led to a more than 50% reduction in workers' hospitalization for health problems related to heat stress, without limiting productivity.

3. Results - Evaluation

3.1. How Close are the HNMS Forecasted WBGT Values to the Observed Values?

Up to now, specialized WBGT instruments are not included in the standard equipment of meteorological stations, even worldwide. For this study, measurements were made in the framework of the collaboration of HNMS with the Hellenic Ministry of Labour and Social Affairs, while the equipment was provided by the FAME Lab. Specifically, WBGT instruments were placed near the meteorological stations at several airport locations. An experimental campaign took place during the summer of 2019, i.e. from the end of May through early September. The collected and analyzed data were used for the evaluation of WBGT forecasts derived from the HNMS that is, it was possible to have WBGT measurements, which can be compared to the predicted simplified values.

Before the operational use of any numerical forecast product, a statistical evaluation of its error range is necessary in order to quantify the deviations compared to the observations. Bias (prediction-observation) and Root Mean Square Error (RMSE) indices were used in the statistical analysis and their values are provided in Figure 2 [28].

The BIAS diagram (Figure 2), shows the difference between predicted and observed WBGT values for the three summer months. The mean BIAS is +1.87°C (overestimation) for WBGT-Sim predictions and −1.15°C (underestimation) for WBGT-Lil, when using the methodology developed. Accordingly, the average value of RMSE is 3.74 and 2.42, suggesting that the use of the more sophisticated formula (Liljgren) allows more reliable prediction of the index. While this magnitude of error in WBGT predictions is similar to that inherited from temperature errors in numerical predictions as mentioned in section 2.2, it exceeds the ±0.5°C recommendation set in ISO 7726 and ISO 7243 when measuring WBGT in situ [23, 24]. However, it is important to note that these are forecasts with a 48-hour horizon and not real-time observations. Based on this notion and considering that additional work in the future will increase our sample size and thus improve accuracy, WBGT forecasts are considered reliable for any use.

3.2. WBGT In-situ Measurements and the WBGT Application-Derived Values

The WBGT measurements performed by FAME Lab showed that the estimation of the WBGT index through the WBGT application shows a very strong

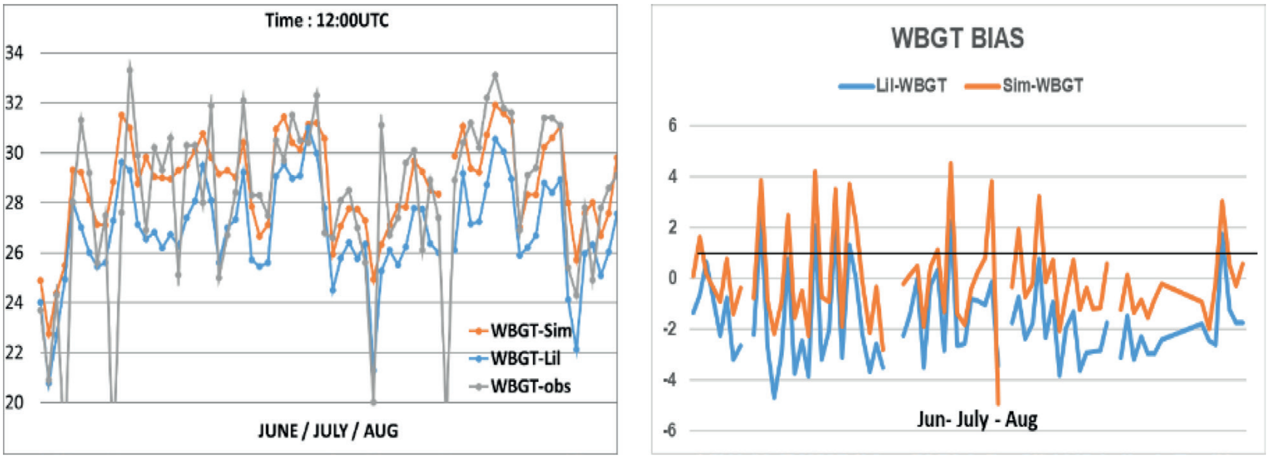


Figure 2. Time series of WBGT-Lil, WBGT-Sim forecasts and WBGT-obs observations (left) and plot of forecasted values Bias (right).

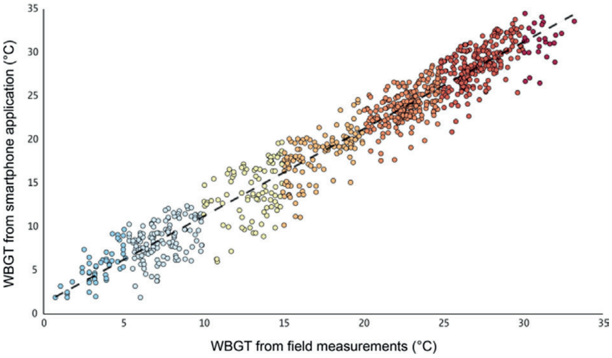


Figure 3. Differences between the estimation of the WBGT index through the WBGT application and the actual measured values, at the same geographical point. The prediction slightly underestimating (−1.2 °C) the actual readings. Each circle reflects a measurement at a different location. The colors indicate the six categories of thermal stress based on a 5-point scale from 1-5 (cold) to 31-35 (hot).

correlation (R^2=0.94, p<0.001) with the actual field measurements made using portable weather stations (Kestrel 5400FW, Nielsen-Kellerman, Pennsylvania, USA), slightly underestimating (−1.2°C) the actual readings (Figure 3). As above, given that these are estimations from the closest weather station as well as forecasts with a 48-hour horizon, this level of accuracy is considered acceptable. This is especially true considering that additional work in the future will increase our sample size and thus improve accuracy.

4. Discussion - An Integrated Protection Framework

As the cases of Qatar and Cyprus demonstrate, although vital, the forecasting and measurement procedures are only part of the overall management of occupational heat stress. A comprehensive protection framework should include the following steps and/or key points:

- The corresponding assessment of the general population does not effectively address the assessment of occupational thermal stress. Forecasts and/or warnings are used as guidance for workers, but the subsequent steps are different;

Table 1. Upper and lower action values (°C WBGT) in relation to metabolic rate in Watts [30]. The lower action value indicates the upper WBGT value that work can continue. The upper action value is the WBGT value where work stops.

Metabolic rate (W)	lower action values	upper action values
Low (180)[1]	31.0	32.5
Moderate (300)[1]	28.0	31.5
High (415)[2]	27.5	30.5
Very high (520)[3]	28.0	30.0

Note: [1] = work can continue without interruption; [2] = work can continue with 15 min break every hour; [3] = work can continue work can continue with 30 min break every hour.

- Occupational thermal stress is treated as a hazardous Occupational Health and Safety (OHS) agent, for which the employer must take a series of prescribed measures [29]. Therefore:
  1. Thermal stress must be considered in the written risk assessment;
  2. It must be certified that there is a relevant provision if measurements are required;
  3. It should be ensured that there is information, training, consultation, and participation of workers, as well as surveillance of their health and provision for sensitive groups. In general, typical office work does not require special measures, but for work performed outdoors, with inherent heat exposure, physical activity, and/or use of protective clothing, provisions should be made based on the following measures;
- The WBGT index is chosen as the bioclimatic indicator of foreseeable risks to model a forecasting system useful to identify alert and risk situations in advance. This type of approach cannot replace a risk assessment targeted at a specific occupational exposure situation;
- Following the rationale of EU Directives, it is proposed to adopt an exposure limit value and action exposure values (Table 1) for the

Table 2. Work-resting schemes in relation to metabolic rate [30, 31]. The lower action value indicates the upper WBGT value that work can continue without interruption.

Time every 60 min of work (min)		°C WBGT over the lower action value – metabolic rate			
Work	**Resting**	**Low**	**Moderate**	**High**	**Very High**
60	0	31	28	*	*
Up to 45	At least 15	31	29	27.5	*
Up to 30	At least 30	32	30	29	28
Up to 15	At least 45	32.5	31.5	30.5	30
Complete work interruption		>32.5	>31.5	>30.5	>30

** Accurate assessment of heat stress with core body temperature measurements is required.*

various heat exposure levels, based on the WBGT, as follows:

1. The exposure limit value is defined as the increase in the worker's core body temperature to 38°C, i.e. an increase of 1°C above normal [15].
2. In order to ensure compliance with the exposure limit value, which is difficult to control, directly measurable upper and lower action values are defined (Table 1) [30]. The lower action value indicates the upper WBGT value that work can continue without interruption. The upper action value is the WBGT value where work stops.
3. When heat exposure exceeds the lower action values, the employer sets the organization on alert, e.g. makes personal protective equipment (PPE) available to employees. When the exposure exceeds the upper action values, either the work stops, or additional measures are taken, or the area is marked with appropriate signs for access only by workers with appropriate training and/or PPE. Various work-resting schemes are applied for intermediate values (Table 2) [30, 31].

- Determining the actual workers' exposure considers the exposure limit value reduction due to a possible lack of acclimatization. Acclimatization is considered sufficient if, during the previous 15 days, 12 or more 8-hour shifts have been performed in the environmental conditions under investigation. Otherwise, a 2.5°C reduction is applied to the upper/lower action value. At the beginning of summer, all workers are considered non-acclimatized. Corresponding corrections are provided for the metabolic rate and the PPE (e.g., clothing) likely to be worn by the worker [15], i.e.:
- Upper/Lower action value = WBGT action value according to metabolic rate - WBGT according to personal protective equipment - WBGT according to acclimatization level (3)
- The simplified WBGT forecast, now provided by HNMS for 24/48h, can be used by the organizations to plan OHS measures;
- Calculation/prediction of WBGT, provided by the free WBGT application, can be valuable but cannot – at this point in time – act as an *in situ* assessment. If additional data in the future allow reduction of the bias to no more than 0.5°C WBGT, the free WBGT application could act as an in situ assessment;
- The prediction margins are of the order of 1° C (even a little more) that is sufficient to initiate the alert procedure; apart from the ± 0.5° C demand for the WBGT measurements there are many more uncertainty factors. Specialized in situ measurements are much more indicative.
- To calculate the WBGT, in addition to specialized measurements, the widely accepted simplified equation (2) can be used for indoor and outdoor locations, in cases where only air temperature and relative humidity measurements are available. Automatic calculation of the simplified index is provided at the link: www.famelab.gr/el/meteo. Those measurements/

calculations can be easily carried out by the employer and/or the Safety Officer;
- Registration of the above procedure shall facilitate the relevant compliance control by the competent Authorities.

A circular based on this approach was issued before the summer of 2022 by the Hellenic Ministry of Labour and Social Affairs [32], and a pilot phase was launched in the summer of 2021. The legal integration of the whole procedure is the next crucial step. The knowledge already gathered indicates that this final step mainly relies upon political will. A recently introduced legislation based on methodologies similar to those presented here demonstrated, within the first year of its implementation, a more than 50% reduction in worker hospitalization for health problems related to heat stress, without limiting productivity [27]. Future research in Greece will validate the prediction model accuracy and provide real heat exposure data and stop-down times from the implemented pilot phases.

5. Conclusions

The unresolved OHS issue of heat stress has taken on greater significance in light of the climate crisis. New ideas and solutions have been combined to promote an integrated framework. The scientific background is based on the well-established WBGT index, which was demonstrated to be able to support the general assessment. More specifically, the different formulas to calculate WBGT [the complete equation (1), the simplified equation (2), and Liljegren's approach], enable a 48 h forecast by the Hellenic National Meteorological Service, which is complemented by the smartphone application provided by FAME Lab. More specific occupational exposures can be performed using more detailed approaches if indicated by the written risk assessment. The administrative framework, based on the rationale of relevant OHS Directives, to support and unify the scientific background is briefly presented, which led to the Hellenic Ministry of Labour and Social Affairs issuing a circular based on this approach in the summer of 2022.

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Declaration of Interest: The authors declare no conflict of interest.

References

1. European Commission (EC), 'EU Strategic framework on health and safety at work 2021-2027', COM(2021) 323 final, Brussels.
2. Flouris AD, Dinas PC, Ioannou LG, et al. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *Lancet Planet Health*. 2018;2(12):521-31. Doi: 10.1016/S2542-5196(18)30237-7. PMID: 30526938
3. Hellenic Ministry of Labour and Social Affairs. 'Prevention of occupational heat stress during heatwave'. Circular 217464/6.7.2020 (reference in Greek).
4. Hellenic mining enterprises' association. 'Mining and quarry regulation', 2011 (reference in Greek).
5. Health & Safety Executive (HSE), 'Heat stress in the workplace, a brief guide', INDG451, 2013.
6. Association of Farmworker Opportunity Programs, 'TRAINER GUIDE AND WORK BOOK', 2010 Occupational Safety and Health Administration, U.S. Department of Labor.
7. Occupational Health and Safety Council of Ontario, 'HEAT STRESS AWARENESS GUIDE, 2007, 5252A CSAO (04/07), Ontario, Canada.
8. Malaysian Department of Occupational Safety and Health, 'GUIDELINES ON HEAT STRESS MANAGEMENT AT WORKPLACE', 2016, Ministry of Human Resources, Malaysia.
9. Ioannou LG, Dinas PC, Notley SR, et al. Indicators to assess physiological heat strain, part1: Systematic review, part2: Delphi exercise. *Temp*. 2022. Doi: doi.org/10.1080/23328940.2022.2044738.
10. Flouris AD. Human thermoregulation. In Heat Stress in Sport and Exercise; Périard J. and Racinais S., Eds.; Springer Nature, UK, 2019.
11. Ioannou LG, Tsoutsoubi L, Mantzios K, et al. A free software to predict heat strain according to the ISO 7933:2018. *Ind Health*. 2019;29;57(6):711-720. Doi: 10.2486/indhealth.2018-0216. Epub 2019 Mar 27. PMID: 30918161; PMCID: PMC6885605.
12. ISO 7933. 2004, Ergonomics of the thermal environment—Analytical determination and interpretation of heat stress using the predicted heat strain model. International Organization for Standardization, Geneva.

13. Ioannou LG, Tsoutsoubi L, Mantzios K, et al. Indicators to assess physiological heat strain – Part 3: Multi-country field evaluation and consensus recommendations. *Temperature* (Austin). 2022;9(3):274-291. Doi: 10.1080/23328940.2022.2044739. PMID: 36249710; PMCID: PMC9559325.
14. Ioannou LG, Dinas PC, Notley SR, et al. Indicators to assess physiological heat strain – Part 2: Delphi exercise. *Temperature* (Austin). 2022;9(3):263-273. Doi: 10.1080/23328940.2022.2044738. PMID: 36211947; PMCID: PMC9542877.
15. ISO 7243: 2017, 'Ergonomics of the thermal environment - Assessment of heat stress using the WBGT (wet bulb globe temperature) index'.
16. Georgoulias AK, Akritidis D, Kalisoras A, et al. Climate change projections for Greece in the 21st century from high-resolution EURO-CORDEX RCM simulations. *Atmos Res*. 2022;271.
17. Garcia-Leon D, Casanueva A, Standardi G, et al. Current and projected regional economic impacts of heatwaves in Europe. *Nat Commun*. 2021;5807(12). Doi: https://doi.org/10.1038/s41467-021-26050-z.
18. Morabito M, Messeri A, Noti P, et al. An Occupational Heat-Health Warning System for Europe: The HEAT-SHIELD Platform. *Int J Environ Res Public Health*. 2019:13;16(16):2890. Doi: 10.3390/ijerph16162890. PMID: 31412559; PMCID: PMC6718993.
19. Hellenic Ministry of Labour and Social Affairs. 'Handling occupational heat stress during summer'. Circular 130427/26.6.1990 (reference in Greek).
20. Lemke B and Kjellstrom T. Calculating workplace WBGT from meteorological data: a tool for climate change. *Ind Health*. 2012;50(4), 267-78.
21. American College of Sports Medicine. Prevention of thermal injuries. Position stand. *Med J Aust*. 1984; 141(12-13):876-9.
22. Liljegren JC, Carhart RA, Lawday P, et al. Modeling the wet bulb globe temperature using standard meteorological measurements. *J Occup Environ Hyg*. 2008;5: 645-655.
23. ISO 7726:1998. Ergonomics of the thermal environment—Instruments for measuring physical quantities. International Organization for Standardization, Geneva.
24. ISO 7243:2017. Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index. International Organization for Standardization, Geneva.
25. Gofa F, Pytharoulis I, Andreadis T, et al. Evaluation of the Operational Numerical Weather Forecasts of the Hellenic National Meteorological Service. 9th Conference of Meteorology, Climatology and Atmospheric Physics, 9th COMECAP, Thessaloniki, 28-31 May, 2008.
26. Ministry of Labour of Cyprus. Occupational Heat Stress. Nicosia 2014 (reference in Greek).
27. ILO. One is too many. The collection & analysis of data on occupational injuries in Qatar. Doha, Qatar 2021.
28. Gofa F, Nikas D, Gourzoulidis GA and Flouris AD. Measuring and predicting heat stress conditions with the WBGT index. 15th International Conference on Meteorology, Climatology and Atmospheric Physics - COMECAP 2021.
29. Directive 89/391/EEC, on the introduction of measures to encourage improvements in the safety and health of workers at work - "Framework Directive".
30. ACGIH. TLVs and BEIs based on the documentation of the threshold limit values for chemical substances and physical agents. 2020. ISBN: 978-1-607261-12-4.
31. ISO 7243: 1989, 'Hot environment – Estimation of the heat stress on working man, based on the WBGT (wet bulb globe temperature)'.
32. Hellenic Ministry of Labour and Social Affairs. 'Handling occupational heat stress during summer'. Circular 56163/15.6.2022 (reference in Greek).