TECHNICAL REPORT

D6.1: Final report for each industrial sector incorporating the final recommendations/conclusions

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The HEAT-SHIELD project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement No 668786.

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D 6.1 – Regional and sector specific vulnerability to occupational heat-stress – industry specific observations, recommendations and guidance for effective mitigation

Introduction

In this report, you will find an overview of regional, industry specific and individual vulnerability to current and future occupational heat-stress. Vulnerability is considered and evaluated as productivity impact [loss] or increased heat-related health risk. The document includes regional effect analyses identifying inequalities across EU and case studies with further specification of sub-groups of workers particularly vulnerable to environmental heat-stress effects. In section 2, an outline is given on the overall approach leading to the adjusted industry-specific guidance documents (provided for each industry in sections 3.1-3.5). This process based on feedback [general questionnaires], sparring with stakeholders across industries in addition to the specific “WP 6 case studies”. Part 3 is divided into sub-sections per industry and the specific case studies with testing of selected relevant strategies and solutions for reducing the impact of heat on workers’ risk of occupational heat strain. The industry specific sections includes link to infographics and videos (see also https://www.heat-shield.eu -> “public guidance”) targeting either the employee (individual worker or group of “end-users”) or employers (managers - private or public “work organisers”) with the combined info of relevance for the local health-safety advisor or policy-makers. Overall aiming at facilitating that “end-users” [workers at risk] are provided with relevant options (i.e. effective, feasible and sustainable solutions), knowhow on how to implement and basic comprehension of the importance to mitigate heat-stress for maintained health and performance.

1. Inequality aspects across EU – regional and industry-specific impacts.

1.1. Overall effects per industry and region

To identify how current and projected future heat stress levels impact productivity, and thus economic output across EU (regional analyses for 274 European regions into a regionalised general equilibrium economic model), we have analysed present and future economic damages due to reduced labour productivity caused by extreme heat in Europe (Garcia-Leon et al., 2021). Current impacts, analysed for hot years (2003, 2010, 2015, and 2018) were compared to the average historical period 1981–2010. In the selected years, the total estimated damages attributed to heatwaves amounted to 0.3–0.5% of European gross domestic product (GDP). However, as illustrated on Figure 1, the identified losses were highly heterogeneous across EU-regions, consistently showing GDP impacts beyond 2% in the most vulnerable regions and with outdoor industries (in particularly construction and agriculture) highly affected (see Garcia-Leon et al., 2021 for details and sectoral effects).

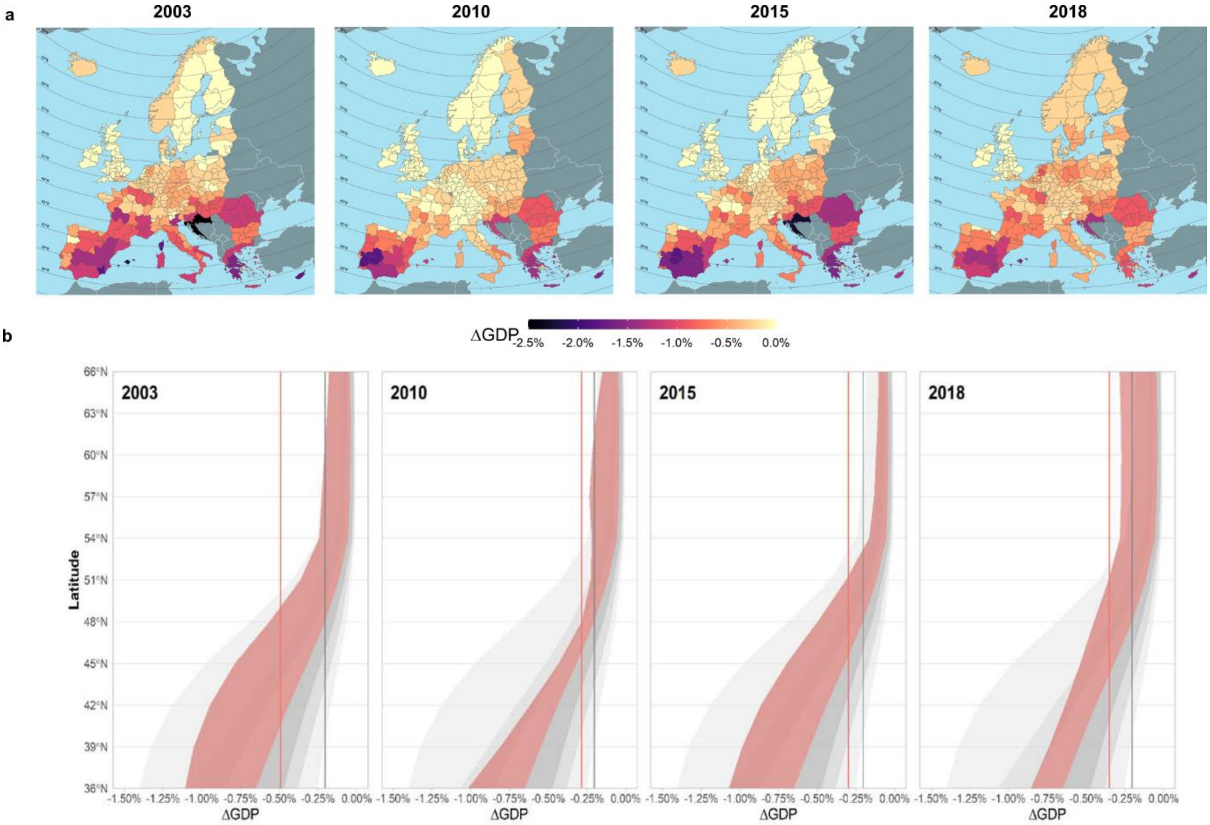


Figure 1: **a**) Regional-level cost of heatwaves (as a share of regional GDP) in the four years analysed. **b**) Regional impacts of heatwaves at different latitudes. Vertical lines show the average, cross-regional, annual GDP impacts of heatwaves (solid red line) and the corresponding effect over the historical period 1981–2010 (solid grey line).

We also analysed future projections for direct heat-impacts (in terms of economic losses) per region and industry (see Figure 2 below) towards the mid-century and identified how these might increase in Europe by a factor of almost five compared to the historical period 1981–2010 if no further mitigation or adaptation actions are taken. These analyses clearly emphasizing the importance of identifying and implementing effective counter actions, especially in regions and industries where damages are already acute.

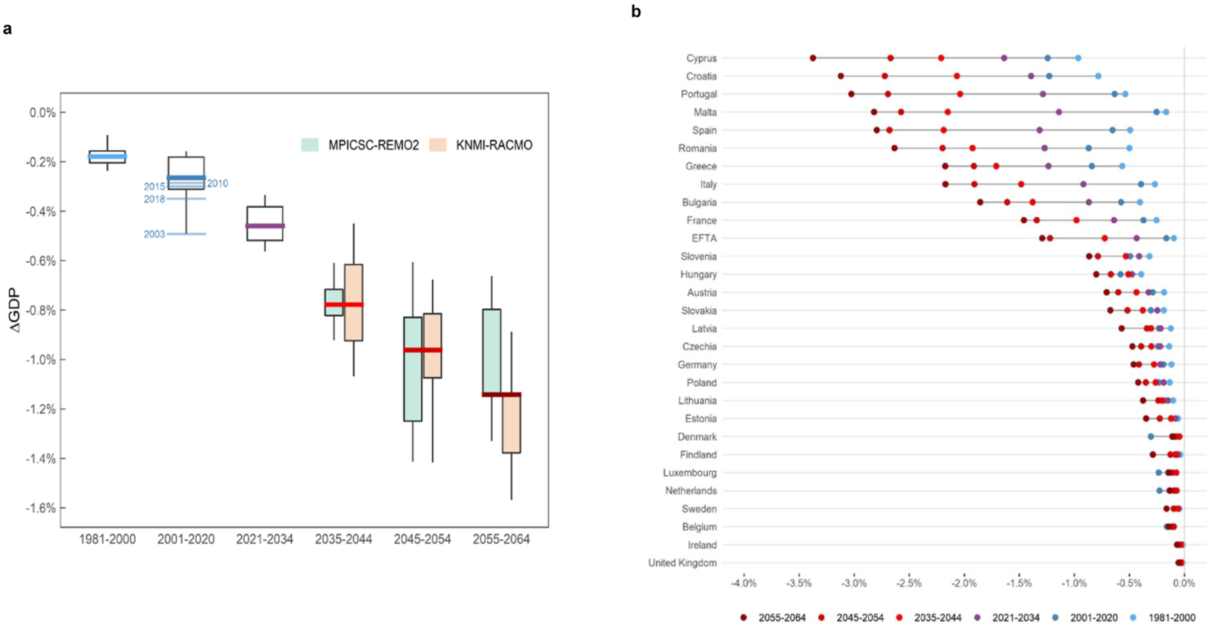


Figure 2: **a)** Estimates indicate that heatwave-induced total aggregated damages will grow steadily at the European level during the next four decades, peaking in the 2055–64 decade with annually expected GDP losses below −1.1%. This represents approximately a five-fold increase in losses, compared to what has been observed in the period 1981-2010. Each boxplot shows the inter-annual distribution of total European, annually estimated impacts over different time periods. In-depth analysed years (2003, 2010, 2015, and 2018) are highlighted. Boxes cover the interquartile range (IQR, 25th–75th percentiles) of the damage distribution and whiskers show the values contained within ±1.5·IQR. Thick solid lines denote the estimated median (multi-model median in the climate change analysis) GDP impact over each time period. Observations for the period 2001–2020 correspond to the annual simulations carried out over the period 2001–2010 together with the analysis of years 2015 and 2018. To simulate the economic model over the period 2021–2034, regional-level time series of labour productivity shocks were obtained by linearly interpolating average results over the historical period (1981–2010) and projected multi-model averages over the decade 2035–2044. **b)** Holding fixed the current economic sectoral composition, heat damages will grow in all areas, especially in southern countries, more vulnerable to heatwaves due to their high heat and economic exposure

The above analyses point to particularly vulnerable industries (providing policy-relevant information for action in the affected areas and industries) and workers at risk. How this in combination, may generate inequalities, geographically and with specific industries, hence groups of workers that are at higher heat-health risk compared to the average. These issues are further analysed and explored in section 1.2 as additional background for identifying the need for specific solutions to workers in specific industries.

1.2. Vulnerable sub-groups of workers and within industry inequality effects

Risk factors for morbidity and mortality related to occupational heat stress include lack of heat acclimatization, low physical fitness, dehydration, increasing age, high body mass index, underlying health conditions, and certain medications (Flouris et al., 2018;

Kenny et al., 2016; Leon & Kenefick, 2017; Notley et al., 2019; Sawka & O'Connor, 2020; Sawka et al., 2011; USDAAF, 2003). Table 1 provides individual (personal physiological), health, medication and environmental factors predisposing persons to severe diseases and health problems related to occupational heat stress (Sawka & O'Connor, 2020). Importantly, these health outcomes can develop even in low-risk individuals (young healthy adults with no history of heat-related pathologies) who are practicing sound heat mitigation procedures. For example, performing successive days of strenuous work under occupational heat stress can impair an individual's capacity to dissipate heat (even in heat-acclimatized workers) placing them at greater risk of heat-related pathologies (Notley et al., 2018a; Notley et al., 2018b).

Table 1: Factors predisposing individuals to severe heat-induced/related disease during work under occupational heat stress.

Environmental factors	High temperature, high humidity, little air movement, sources of radiant heat (sun and / or machinery), heat wave, physical work, heavy / impermeable clothing
Individual factors	Lack of heat acclimatization, low physical fitness, high body mass index, dehydration, advanced age, female sex
Health conditions	Inflammation and fever, cardiovascular disease, diabetes mellitus, gastroenteritis, skin rash, sunburn and / or prior burns to large areas of the skin, malignant hyperthermia, sickle cell trait
Medications	Anticholinergics properties (e.g., atropine), antiepileptic (e.g., topiramate), antihistamines, glutethimide, phenothiazines (a class of antipsychotic drugs), tricyclic antidepressants (e.g., imipramine, anitriptyline), amphetamines, cocaine, "ecstasy", ergogenic stimulants (e.g., ephedrine / ephedra), diuretics, beta-blockers (e.g., propranolol, atenolol)

Exertional heat stroke often occurs under conditions that the individual has experienced before or while colleagues concurrently are exposed to the same conditions without incident. This suggests that individuals experiencing heat-related pathologies may be inherently more vulnerable on that day and/or some unique event triggered the pathophysiological mechanism(s) involved (Carter et al., 2007). For example, several sources of evidence suggest that some victims of exertional heat stroke were sick on the before the incident (Laitano et al., 2019; Leon & Bouchama, 2015; Sawka & O'Connor, 2020; Sawka et al., 2011). Also, exertional heat stroke often occurs very early during a period of physical work, suggesting that the individual began work in a compromised state on that particular day (Carter et al., 2007; Laitano et al., 2019; Leon & Bouchama, 2015; Sawka et al., 2011). The common observation of rapid development of hyperthermia suggests that fever from a pre-existing illness or inflammation may increase the normal immune/hyperthermic response to physical work or impair molecular protection mechanisms (Dineen et al., 2020; Laitano et al., 2019; Sawka et al., 2011).

1.2.1. Heat-Shield observations on vulnerable workers across EU

Table 2.1-2.3**:** Data from online survey with (self-) reported heat-stress issues during work, at home, during outdoor activities and during night (sleeping) time.

Table 2.1: Overall and Gender

Reported (score from 1 low to 5 very high) heat stress	During work	At home (during the hottest periods of the day-time)	During outdoor recreational/leisure time activities	During night time (affecting sleep)
All (mean ± SEM; *n=455*)	2,6 ± 0,1	3,0 ± 0,1	3,4 ± 0,0	3,2 ± 0,1
Female (*n=221*)	2,5 ± 0,1	3,0 ± 0,1	3,5 ± 0,1	3,2 ± 0,1
Males (*n=234*)	2,6 ± 0,1	2,8 ± 0,1	3,3 ± 0,1	3,2 ± 0,1

Table 2.2: Age

Reported (from 1 low to 5 very high) heat stress	During work	At home (during the hottest periods of the day-time)	During outdoor recreational/leisure time activities	During night time (affecting sleep)
Elderly (above 60 y; *n=65*)	2,5 ± 0,2	2,7 ± 0,2	3,1 ± 0,2	2,9 ± 0,2
Younger (20-40 y; *n=285*)	2,6 ± 0,1	2,8 ± 0,1	3,5 ± 0,1 *	3,4 ± 0,1 *

* Significantly higher than the “compared” group of younger workers (P<0.05)

Table 2.3: Body Mass Index (BMI)

Reported (from 1 low to 5 very high) heat stress	During work	At home (during the hottest periods of the day-time)	During outdoor recreational/leisure time activities	During night time (affecting sleep)
High (above 30; *n=85*)	2,9 ± 0,2 *	3,0 ± 0,2	3,7 ± 0,2 *	3,1 ± 0,2
Normal BMI (20-25; *n=196*)	2,5 ± 0,1	2,9 ± 0,1	3,4 ± 0,1	3,2 ± 0,1

* Significantly higher than the “compared” group with normal BMI (P<0.05)

The above survey covered 455 European workers spread over all industries (from manual to desk work) responding to (self-evaluated rating) questions related to “How much heat-stress affected them during work, at home, during outdoor activities and during night (sleeping) time”. Overall, this survey indicated that “outside working-hour” exposure (including night-time/sleeping) are issues very relevant to consider – and combined with our observations on day-to-day hydration across 5 European industries (Piil et al., 2018) and delayed effect of a heat-wave on productivity in the manufacturing sector (Ciuha et al., 2019), we have included the “outside work exposure” and importance of heat- and hydration recovery from one work shift to another in our general and industry specific guidance documents. The survey also confirmed BMI (indicative of overweight) as a risk factor, but no gender differences and not increased work related issues for elderly workers. However, both the gender and age aspect should be considered in the light of the survey covering a mix of occupations and it is relevant to consider industry-specific issues (where workers across gender and age may be exposed to similar tasks and physical stress; see e.g. issues specific for manufacturing and agriculture below).

Another occupational group that warrants special attention is migrant workers (Flouris et al., 2021; Onarheim et al., 2021). Although, these individuals tend to be younger than the native workforce (Antecol & Bedard, 2006), they have less work experience and, often, poorer perception of health risks (Messeri et al., 2019). Also, migrant workers are more likely to work in manual labour occupations that require work outdoors and exposure to environmental hazards (Flouris et al., 2021; Onarheim et al., 2021; Orrenius & Zavodny, 2009), they consistently show a higher prevalence of work injuries, and they experience poorer occupational health than do native workers (Flouris et al., 2021; Onarheim et al., 2021; Sterud et al., 2018). However, the physical and chemical exposure working environment of this occupational group had not been extensively studied which limits the ability to draw generalized conclusions across different occupational settings and hazards (Sterud et al., 2018). With regards to heat exposure, the few studies on the topic suggest that migrant workers are more likely to be exposed to occupational heat stress, particularly in the agriculture and construction industries, as they are typically engaged in more physically demanding tasks and work more outdoors than the native workforce (Alahmad et al., 2020; Boschetto et al., 2016; Flouris et al., 2021; Flouris et al., 2019; Messeri et al., 2019; Orrenius & Zavodny, 2009; Sterud et al., 2018).

The above-mentioned results have been confirmed by extensive studies performed within the HEAT-SHIELD project (with observations in both agriculture and construction industry – see Messeri et al., 2019). In a recent study we have also analysed the full work shifts in 17 farms spread across Cyprus, including 124 experienced (i.e., agriculture is their main source of income) and acclimatized (i.e., continuously living in the area and performing agriculture jobs on a daily basis for ≥2 months) agriculture workers. Participants were divided into three groups based on the economic development of their country of origin: (1) high-income countries (HICs), (2) upper-middle-income countries (UMICs), as well as (3) lower-middle- and low-income countries (LMICs). The monitored workers performed their duties in warm environments (24.8 ± 4.2 °C WBGT; range: 14.6 to 32.5 °C WBGT). Our analyses demonstrated that migrant workers originating from LMICs experience higher levels of occupational heat strain, as compared to migrant workers from UMICs and native workers from HICs. This is caused by four factors: (1) a smaller body surface area, (2) fewer unplanned breaks taken during work, (3) higher work intensity, and (4) more clothing worn. As shown in Figure 3, these four factors result in migrant workers originating from LMICs having a higher core body temperature compared to migrant workers from UMICs and native workers from HICs. In total, this HEAT-SHIELD study reveals that cultural differences together with the lack of education on occupational heat stress increase the physiological heat strain experienced by migrant workers, widening the chasm of inequalities.

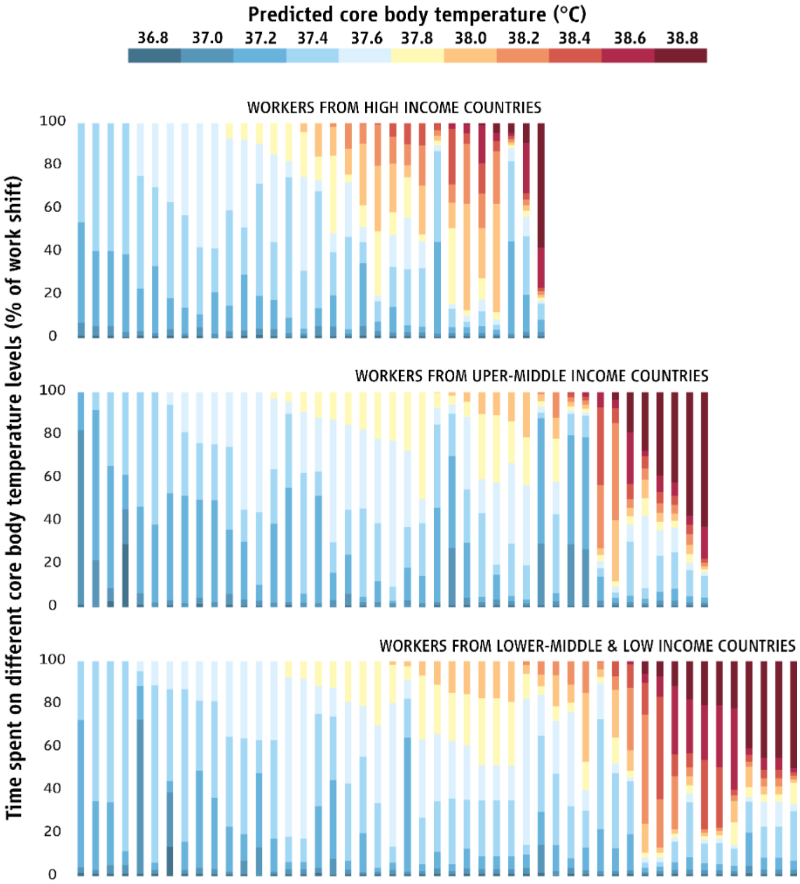


Figure 3: Time spent at different levels of predicted core body temperature during the work shift for workers originating from high-income, upper-middle-income, as well as lower-middle- and low-income countries. Each bar represents a different worker.

2. General assessment of HEAT-SHIELD strategies, dissemination materials and the weather warning platform

On the basis from specific case studies across the five representative industries and our ongoing "general testing" of guidelines/strategies to reduce [prevent or minimise] the impact of heat on the workers' risk of occupational heat strain, we have evaluated and adjusted the industry-specific guidance documents (provided in Sections 3.1-3.5 provided for each industry). This includes infographics and videos aimed at either the individual worker or the employer, with the combined information relevant to the local health and safety advisor or policy maker.

In the following sub-section, we provide the overall input obtained from feedback provided by three main "stakeholders" 1) employers, 2) workers, 3) workplace health-safety representatives - including occupational hygienists, policy makers, and other "local decision makers". This feedback was extracted from cross-country questionnaires and general feedback across industries. After WP4, it became clear that it would benefit guidance if we developed different types of infographics and videos specifically targeted at workers/managers/health advisors as they need a very different type of information and background knowledge. While section 1 provided information at continental and regional levels, targeting national and international policy makers the below recommendations have been developed to disseminate the lessons learned to specific sectors in order to improve understanding of the negative effects of heat in the workplace and to encourage employers, local managers and workers to adapt the policies. In addition to the very different and important worker-manager perspective, there are also some differences between sectors that have been considered (but mainly elaborated in section 3). E.g. in agriculture there were significant differences among age groups in relation to excessive sweating and thirst, and there were more females experiencing tiredness and dizziness, a headache, exhaustion, nausea or vomiting, and even fainting (see Pogačar et al., 2017 for details).

Therefore strategies were designed in the way to as much as possible take in account all observed differences and contribute to diminishing them. Disseminated HEAT-SHIELD strategies and information were in the form of:

- A general guidance document for development of a Work Heat Action Plan (WHAP) for keeping workers safe and productive in the heat is available on the project's webpage (see also Appendix 1).
- A ready-made heat-defence plan checklist for keeping workers safe and productive is also available on the project's webpage (or Appendix 2).
- Nine infographics in English, French, German, Greek, Italian, Dutch, Portuguese, Slovenian, Spanish and Swedish are available on the project's webpage, addressing five sectors, workers, employers, safety and health engineers, and the topic of hydration (see specific Sectors in Section 3 and Appendix 3).
- HEAT-SHIELD weather platform is available on the link and can be used in English, Greek, Slovenian, German, Italian, French and Portuguese.
- Additionally there are videos available on the topics of HEAT-SHIELD introduction, Creating individualized heat action plans and Clothing and occupational heat stress.

2.1. General assessment of HEAT-SHIELD guidance and measures to minimize negative heat effects

One of the specific objectives in the present period (WP6) was collection of feedback on the strategies offered, coming from different levels (groups of workers and other relevant stakeholders). More specifically, how did workers and policy makers (local managers, etc.) or health and safety advisors adopt or respond to our recommendations.

From online responses collected across EU, it is the overall interpretation that Health and safety engineers and occupational hygienists in Slovenia, Greece, the Netherlands and Spain are in general aware of heat stress and have informed workers/employers on how to behave in hot weather. They rate awareness of heat-related health risks as low, moderate and high in equal proportions. Ways to raise awareness appear to be training, workshops, hydration testing, clear policies, regular communication, creating a heat action plan, and cost-benefit analysis. They have already taken some measures to reduce the negative effects of heat stress, such as hydration testing, mandatory training, knowledge sharing and PPE changes, additional hydration, modified work hours and additional breaks, ventilation, creating a heat action plan, redistributing work so that more physically demanding tasks are done in the morning, and adequate clean restrooms. They believe that the use of **HEAT-SHIELD strategies** would **improve the well-being or health** of workers because **education** and **awareness** are of great importance and **prevention** is also very important and the materials are simple and easy to understand and provide a **clear guide**. They also believe that the strategies would **improve productivity**, especially if they helped to **prevent incidents** or **reduce risks**. Planning and rescheduling activities during heat waves, combined with technical solutions, allows for continuity of workload. On the other hand, it is very difficult to assess how the strategies would reduce inequalities. The heat action plan resulting from the HEAT-SHIELD strategies treats all employees equally, but takes personal conditions into account. They do not really believe that it is possible to talk about deliberate discrimination based on personal circumstances in the context of heat stress.

They rated the proposed HEAT-SHIELD measures as **very important**
(score higher than 4.4 out of 5):

- Increased water intake during working hours
- Rehydration after work
- Rescheduling work
- Reduced work intensity (to reduce physical exertion during the hottest hours).

Followed by (score 3.9 to 4.2):

- Longer or more frequent breaks
- Increased intake of electrolytes

And less important to them (score 3.5-3.6):

- Changed clothing (some workers saw no improvement).
- Solutions for cooling my body

All trade unions in the EU report that they get the most questions about safety and health at work precisely because of the high temperatures in the workplace. Sometimes things are dramatic - for example, workers faint due to a combination of heat and humidity. Of course they send an inspection there, but they do not have the right recommendations for technical solutions for cooling. The employer takes what is already offered in the market.

In evaluating the **Heat Shield HAP** (Heat Action Plan) for workers, all agreed that it was very **useful** and good. While basic, it **addresses all the issues** of protecting yourself from heat stress. A general heat plan **checklist** can **help address all actions and risks** and is **practical**, but still needs to be adapted to each company's conditions. They miss some guidance on assessing the risks. In some countries, the labour inspectorate has been recommending some of the measures for many years. The HEAT-SHIELD platform, infographics and other advice seem useful for almost all companies. However, some find it difficult to register on the platform and some would like to see the infographics simplified.

The research in Italy found that 30-40% of respondents see the **HEAT-SHIELD measures** implemented as having a **positive effect** on personal impact, overall, socially and on productivity. The least effect they see is in reducing inequalities. It seems that the respondents perceive heat stress as related to different aspects, but all belonging to a single problem. Almost two out of three companies had informed their employees about the risks associated with heat. All the measures implemented were in line with HEAT-SHIELD's recommendations: availability of water, short and frequent breaks, awareness of the heat risk, specific work schedules providing for less work during the hottest hours, time off for weaker workers, provision of shaded/cooled areas, etc. These responses are quite reassuring and show that the general message about heat risk and how to avoid it is known to at least some companies.

The survey in Spain found that the effectiveness of using PPE was mainly rated by workers as 4 out of 5. The impact on improving productivity was rated 3-4. About half of the workers said that the measure **improved their interaction** with colleagues, but none of them commented on the impact on reducing inequalities. Managers considered the HEAT-SHIELD strategies to be **practical and effective** in helping **to reduce worker absenteeism**.

Further on, a laboratory study focused on the evaluation of physiological responses during exposure to a heat wave and investigated the potential cumulative effects on labour productivity (see Ioannou et al., 2021 for more details). Namely, despite this plethora of studies confirming the impact of short-term heat stress on workers' health and productivity, no controlled studies have been performed to investigate the cumulative effect of a prolonged heat wave on the labour productivity and physiological strain experienced by workers. The aim of this study was to transfer the working conditions within the odelo manufacturing factory to a more controlled environment, where also other measurements could be obtained (i.e. skin and core temperature measurements, subjective interpretation of the environment, work performance etc.). Despite following the current guidelines which seem to have a protective role in the physiological strain experienced by workers who work in such conditions, we found that the simulated heat wave increased the number of mistakes committed, the time spent on unplanned breaks, and the physiological strain experienced by workers. The economic fallout of an identified 17% increase in the number of mistakes made by participants throughout the heat wave compared to the neutral conditions might be devastating for small enterprises, with possible spill over effects and irreparable damage to the reputation of the company. The identified heat-induced labour loss involves several physiological mechanisms. Firstly, a heat-induced increase in the deep body temperature is an important contributing factor able to impair human cognitive performance and decision-making. Furthermore, hydration state is undoubtedly one of the most important pillars for healthy and productive work. This becomes even more apparent during work under heat stress, where water loss in the form of sweat often exceeds water consumption. Very important is also the fact that workers report higher labour productivity when their individual thermal satisfaction is greater.

Based on the results of the study, clearly demonstrating the effect of heat waves on work performance, the management of the odelo manufacturing company expressed an interest to explore the option of implementing personal cooling strategies in their production halls. It is well known that such strategies, including cooling vests, can provide an efficient and economically viable solution, especially since in many working scenarios air-conditioning might not be feasible, as it either provides insufficient cooling or presents a substantial financial burden (such as in the case of manufacturing industry with large industrial halls). However, choosing an appropriate vest for a specific condition can be challenging, as there is a wide variety of cooling vest types available and the choice relies mainly on manufacturers' descriptions of the products. Managers responsible for the safety and wellbeing of workers have no methods available with which to objectively compare cooling vests and thus be able to decide which would be the optimal solution for a specific type of work and working environment. Void of their cooling capacity, the material and design of a vest has an inherent resistance to the transfer of heat from the skin to the environment (thermal resistance), and represents a barrier for evaporation of sweat from the skin surface (evaporative resistance). Thus, an inefficient cooling vest can become a burden by adding an additional layer of insulation and a barrier for evaporation of sweat from the body. All vests will contribute such a burden once their cooling capacity is exhausted or impaired. Therefore, we evaluated the cooling capacity of various commercially available vests of different cooling concepts (see Ciuha et al., 2020 for more detail on the study).

Under the given ambient conditions (temperature: 35°C, relative humidity: 35%) with a thermal manikin, the cooling capacities differed significantly among different vests and cooling concepts. For instance, some vests with frozen phase-change material inserts provided more aggressive cooling for a shorter period of time whereas evaporative vests provided milder cooling, but for longer periods. Thus, the former might not be suitable for industry workers during an 8-h shift.

When tested on participants, the vests in general provided shorter cooling duration than specified by manufacturer. If used in the working settings, this would mean that the majority of the vests (excluding the active-air-cooled vest, connected to unlimited source of power) would need to be reactivated. For some of the vests, this would require pre-planning, such as freezing of the inserts or preparing of the ice, whereas others, specifically evaporative vests, could be reactivated easily by saturating them with water. Therefore, the decision on the type of the cooling vest should be based on practicality, efficiency, comfort and affordability for a specific working scenario.

2.2. Assessment of the HEAT-SHIELD warning platform

One of the activities conducted to achieve the goals of the HEAT-SHIELD was the development of Occupational Heat-Health Warning System capable of providing individualized heat wave predictions and recommendations to prevent the negative health effects of heat stress for workers. This tool provides each user with a personalized heat risk forecast with specific recommendations for the next 5 days (and, with lower reliability, up to 45 days). Personalization is achieved by using personal anthropometric characteristics, information about clothing, work intensity, acclimatization, and characteristics of the environment in which the work takes place. Moreover, the forecast is accompanied by specific guidelines to mitigate the effects of the heat.

244 Italian users of the platform were asked to evaluate them, but only 36 did so (see Appendix 4 for more details). Less than two-thirds of respondents said they used the HEAT-SHIELD platform to receive a personalized heat forecast, with alerts and recommended actions to mitigate the effects of heat. Personalized heat forecasts and recommendations are the main goals of the platform. Therefore, there is still work to be done in the future to promote the platform and improve its ability to reach the users it was designed for.

In 2020, the HEAT-SHIELD website statistics showed a daily average of 34 visitors (with 57 visits), with large fluctuations from month to month (from 5 in December to 77 in February). The number of visitors was quite high in the first three months and then dropped significantly in the second quarter. In July, the number of visitors was again similar to the beginning of the year and the number of visits was the highest of the year (41,569 with a total of 8,084 pages visited). In the second half of the year, the number of visitors dropped steadily to a few hundred or even dozen. This did not change after we sent out the invitation and reminder. In the July-September period, visits totalled 6,123, of which one-fifth were among the most important contacts by length of visit. However, interpreting these results is not straightforward given that frequent visitors only take a few seconds to check the weather forecast regularly (as recommended). A relevant proportion of participants were involved in prevention services. It is therefore reasonable to assume that they would also share the specific information with their colleagues at work.

At least part of these results may be due to the Covid-19 pandemic, which dramatically affected the personal and professional lives of the entire population, including a total lockdown that lasted from March 9 to May 19 (in Italy) and additional lockdowns in the fall and winter. The general impression is that the web platform is a valuable resource for the majority of participants.

2.3. The main barriers identified by health and safety managers

The main **reasons against the use HEAT-SHIELD measures** in a company are evaluated as follows:

- Other issues are more important - in combination with lack of resources.
- No knowledge, no awareness (maybe they do not even want to make workers aware of OHS!).
- The main obstacle is the profit motive of the business owner.

- There are no known technical solutions for cooling. Currently, employees prefer not to use uncomfortable solutions (air conditioning over the head/neck).
- Leadership is falsely afraid of lost productivity - a misconception of leadership. An outdated mind-set that job performance depends only on hours worked (e.g., 8 hours) and not on productivity over a period of time.

Other reasons for the lack of a systematic approach – i.e. development of a “true” heat action plan in companies are mainly improvisation by the leadership, the belief that there is no actual need (companies or workers are not aware of the risk), they consider other risks more important or they do not have resources or knowhow to implement the HAP or specific solutions. The general work HAP (Appendix 1) is intended to cover overall issue and may work for health-safe representatives or some managers to run through the list/areas of importance, however below and with adjusted guidance per industry employers and employees will find industry-specific guidance.

3 Lessons from specific sectors and cases across countries

It should from the above (but as a motivational aspect still important to highlight for the individual worker and organizations) that occupational heat stress is detrimental for human health and performance with associated significant economic costs (Mora et al., 2017; Nybo et al., 2017; Zander et al., 2015).

3.1 Manufacturing

In manufacturing HEAT-SHIELD research there was a statistically significant difference ($p < 0.001$) in the number of women compared to men that perceived the working conditions as “very hot,” suggesting that they had a higher sensitivity to the hot conditions when performing the same work. 35% of the workers reported that their situation regarding perceived temperature was worse on the way to work than at work, with a greater percentage in women than men. Tiredness ($p < 0.001$), confusion ($p < 0.001$), and dizziness ($p < 0.05$) are more commonly perceived by women (81, 19, and 39%, respectively) than men (56, 12, and 9%, respectively). Gender differences are also evident among the reported heat-induced health problems; 39% of the male workers did not report any health problems, whereas 37% were affected by a headache and 47% by exhaustion. These percentages were much higher for female workers, with 73% ($p < 0.001$) and 64% ($p < 0.01$), respectively. Furthermore, 33% of the women have experienced nausea or vomiting ($p < 0.001$) and 16% prickly heat ($p < 0.01$), while only 6% of the male group reported the occurrence of these symptoms. All these gender differences may be attributed to greater susceptibility of women (smaller persons) to heat stress or/and to the traditional gender roles, which is a greater contribution of the tasks at home being conducted by females, preventing the same magnitude of recovery from heat strain as in men (see Pogačar et al., 2018 for more details).

Figure 4: The HEAT-SHIELD infographic on heat stress mitigation in manufacturing

The main finding of the field study in manufacturing sector in Slovenia (see Ciuha et al., 2019 for more details and Appendix A5.1) is that industrial productivity was affected in periods following heat waves rather than being directly affected during the heatwave periods. In the periods following two of the four documented heat waves there was a significant drop in OEE, suggesting that insufficient recovery and interaction between occupational exposure and overall daily heat strain (outside working hours) are of importance for the integrated impact on indoor workers. Namely, during normal weather conditions, the outdoor air temperatures are significantly lower than those at the work stations. As a result, the workers can recover from any level of heat strain developed during the 8-h shift, due to the 16-h exposure to normal ambient conditions at home and at activities outside of work. This is reflected in an unchanged OEE score during normal weather conditions. During periods of heat waves, the workers may not be able to recover completely from the heat strain, experienced at work as well as home. As a consequence, a longer period of heat exposure may affect OEE because of a cumulative effect that results from an inability of the workers to recover properly after leaving work. This cumulative effect of heat waves may result in fatigue and thus a drop of OEE after a certain period.

3.1.1. Case study odelo - Slovenia

During the course of the project, the Jozef Stefan Institute and Biotechnical faculty worked closely with Slovene manufacturing company odelo, which produces automobile rear lights (described in Appendix 7, under “Manufacturing industry in Slovenia”). Briefly, the company operates 24 hours a day for 7 days a week (‘‘24/7’’) with similar steady production process throughout the day. The heat from the machinery is constantly generated and can only be partly removed by the existing ventilation systems. This becomes an issue during summer time and especially during heat waves, when heat accumulation becomes too severe (~30–32°C at the injection-molding stations throughout the day). According to results of our study (see Ciuha et al., 2019 for details), this affects productivity in periods after the heat waves, suggesting insufficient recovery of the workers, exposed to heat during the 8-h work shift as well as during the 16-h period away from work. As a consequence, a longer period of heat exposure may affect work productivity because of a cumulative effect that results from an inability of the workers to recover properly after leaving work. As the company operates 24/7, the production cannot be performed during cooler parts of the day (during night). Therefore, the company implemented several other actions to reduce the problem with productivity loss and improve the well-being of workers. The company started implementing these actions soon after the HEAT-SHIELD project started, before the heat action plan within the project work frame was established. Nevertheless, the odelo company has been using these actions for several years, supported by positive results and feedback from workers. The main actions that have been implemented (also shown in Figure 4), include:

- The installation of ventilation system, which is effective in removing the excess heat in cooler parts of the year, whereas during summer months the heat accumulation becomes too severe to be handled by the ventilation systems, with temperature gradient between the indoor and outdoor conditions too low to notably affect the temperature within the factory.

- Water supply within reach with notes encouraging people to drink (extra) water, especially during warmer parts of the year.
- Diet, including light and water-reach meals.
- More frequent breaks which allow people to recover during working hours.
- Air-conditioned rooms during the breaks.
- Ventilators at individual work stations.
- Free ice-cream and drinks rich in electrolytes during lunch time on random days.
- Free swimming-pool tickets which can be used after work. This strategy in somehow unique, as to our knowledge it is not commonly used. However, it is of great importance as it deals with time spent outside the work, which can significantly add to heat accumulation and lack of recovery for the next working day. An activity which can reduce the heat stress of an individual is therefore a good strategy.

Figure 5. Manufacturing process in odelo d.o.o. (Slovenia)

3.1.2. Case study Prevent-Deloza - Slovenia

Over the last two years, the Jozef Stefan Institute has also collaborated with Prevent-Deloza d.o.o. company, which is a fabric manufacturing company (Celje, Slovenia), specialised in design of protective work clothing (police, army, fireman, medical personnel etc.) as well as smart and leisure clothing. The companies` manufacturing halls also deal with heat related issues, caused by the ironing process of the newly produced clothing, which cannot be eliminated by air-conditioning. Together with the Biotechnical faculty, we have provided the company with our heat action plan with general recommendations when working is such conditions. Moreover, the company and the members of the Jozef Stefan Institute have joined forces in development of a smart ventilation vest. The development of the vest is based on the measurement of the microclimate temperature and relative humidity, which trigger the activation of the ventilation once they reach a pre-set threshold, determined by an algorithm. When the microclimate temperature and relative humidity stabilise and drop, the ventilation is switched off. This preserves the battery life and optimises comfort of the wearer. Ventilation is designed to suck the air out from the microclimate, which allows the sampling of the microclimate parameters but has also been shown to perform as good or even better that the air blowing into the microclimate. Interestingly, there are very few ventilation vests available on the market, even though it is apparent that evaporation of one of the main mechanisms for dissipating heat from the body.

The tests on a newly designed smart ventilation vest have shown that the vest is very effective in removing the sweat away from the body, with the evaporative rate similar to one observed on a nude torso. The company therefore implemented several heat-related modifications in the last year, including:

- Moving working shifts to cooler parts of the day (early morning)
- Easy-access water supply
- Frequent breaks
- The usage of smart ventilation vest, which has improved the thermal state of the workers significantly (shown in Figure 6)

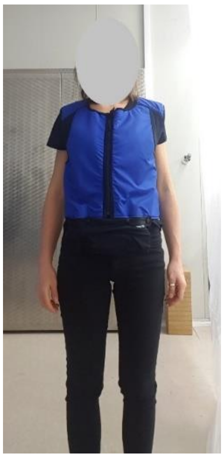


Figure 6. Smart ventilation vest, developed in collaboration with Jozef Stefan Institute and Prevent-Deloza d.o.o. (Slovenia)

3.1.3. Case study on Aluminium production (HYDRO) – Denmark

Heat stress issues in this manufacturing company were highly affected by heat from the industrial production (very high in this aluminium factory) in combination with environmental/climatic factors (with absolute air temperature and humidity as the predominant stressors for indoor heat load) and the workers' metabolic heat production (hence highest heat load for the workers engaged in packing/manual tasks) and clothing limiting heat dissipation (helmets and other safety requirements).

The air temperatures at production/work-sites were very heterogeneously distributed, but they were usually higher than the outdoor (shade) temperature, as industrial machinery adds heat to the outdoor heat load (in this case heat from ALU-melting was convective – NOT radiant heat). There was a limited ability to get rid of industrial heat at specific production sites is a challenge that requires attention at the planning stage as well as implementation stage of manufacturing processes.

The workers heat stress was highly dependent on individual work intensity: (for HYDRO-DK: on avg. the workers engaged with packing have ~ 2 times higher endogenous heat production [~ 400 watt] than the engineers handling/supervising the machinery [~ 200 watt]) and heat-dissipation possibilities (see below for specific boundary effects provided by special clothing/helmets/safety shoes).

Hence, higher heat stress than prescribed/interpreted from climatic/environmental data is often observed among manufacturing workers. Our sampling of data across occupations and work sites at Hydro-DK demonstrate that workers engaged in manual tasks and required to wear protective clothing are especially affected by heat during a large part of the year (from one-third to half of the year). Fatigue, thirst, and notably high head temperatures (for those wearing safety-helmets) were the most frequent issues/symptoms reported. Many workers appear to commence work in a hypo-hydrated state or fail to maintain hydration during the work-shift and dehydration will aggravate heat-issues such as dizziness, fatigue and concentration problems.

To minimize heat-health problems we suggested the following actions that subsequently were tested (and for hydration + clothing adopted):

- Allow workers to have scheduled (brief) breaks with “active resting” e.g. planned hydration and cooling (e.g. by one of the below mentioned methods) – overall this will benefit productivity and prevent excessive fatigue or lost work time due to illness. (the ability to take breaks was already possible at Hydro – but now formalized/emphasized at the onset of high heat periods)

- Access to cold drinking water (during severe periods crushed ice to maximize cooling) and advice workers to drink on a regular basis – and drink before getting thirsty. (Hydro-workers had and have very good access to drinks during work – but increased awareness on day-to-day rehydration was provided and benefitted those tending to fail initiating work sufficiently hydrated

- Make it possible to adjust airflow at individual workstations to facilitate heat dissipation. (many workers do not utilize this, but have the option at individual work stations)

- When heat loads are very high, and especially for elderly workers, encourage spreading water on exposed skin to support evaporative cooling. (not necessary for DK- but could be relevant in very high-heat scenarios – especially with developed arm-cooler/protectors is may be easier to implement)

- Optimization of clothing – although protective clothing was/is required, it was possible to find (scenario-specific) solutions that allowed for maintained protection but with breathable material that allows for airflow and evaporation (Figure 7)

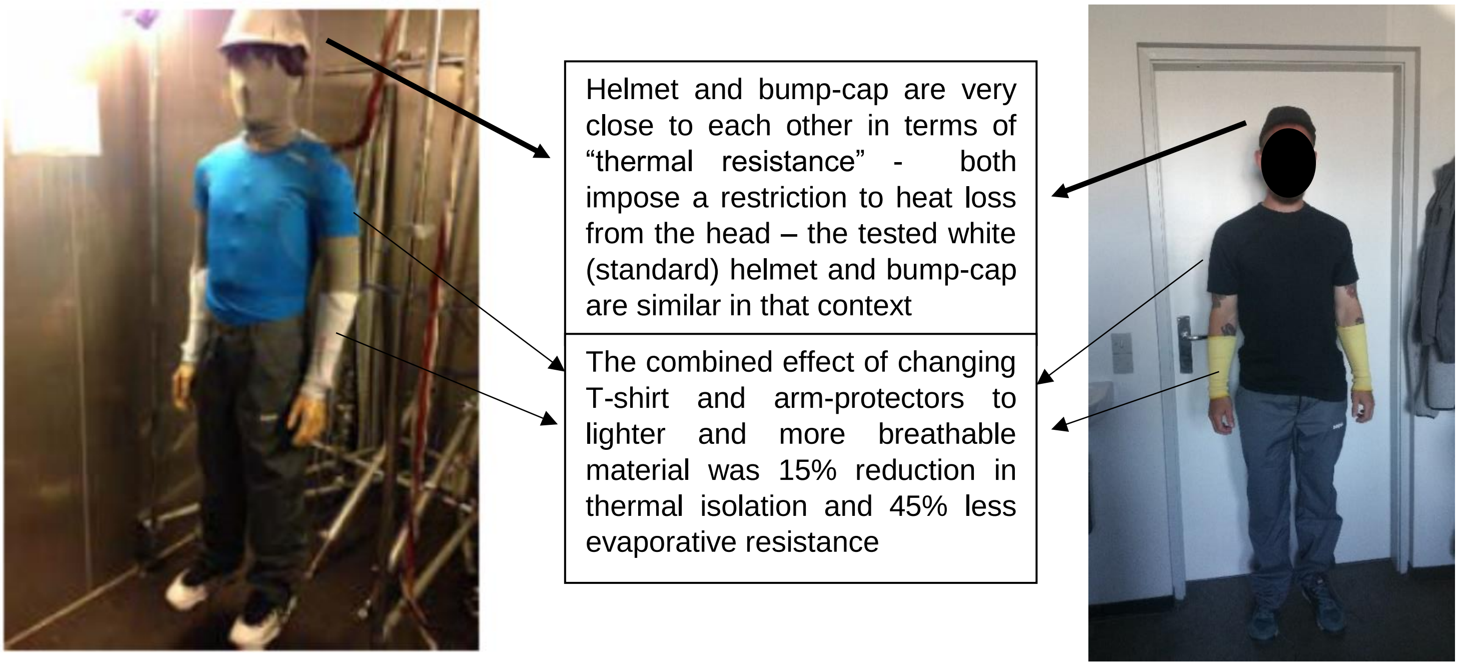


Figure 7: Effects of clothing inventions: – (change from traditional T-shirt and “arm-protectors” to high breathable fabricate) and helmet vs. “protective cap” – standard Hydro work-wear. All workers now offered (and using) the optimized clothing.

HEAT-SHIELD - guidance to mitigate or minimise heat stress in the manufacturing sector

In a manufacturing industry, air-conditioning is not always feasible, as it either provides insufficient cooling or presents a substantial financial burden (such as in the case of manufacturing industry with large industrial halls). Therefore, other actions also need to be considered.

Workers should particularly pay attention to the following recommendations:

- Frequent, shorter breaks during the work time.
- Fluid replacement (water + electrolytes) which has to frequent but moderate to hydrate the body.
- The usage of cooling vests, which can significantly reduce the thermal burden of a wearer.
- All the recommendations should also be followed once at home, as it is apparent that the influence of heat stress, experienced either at work or at home, can have a cumulative effect which results in increased fatigue and poor performance in a long run.

HEAT SHIELD - recommendations for employers (managers of manufacturing companies) and policy-makers to mitigate heat stress in the manufacturing sector

Policymakers and manufacturers should consider the following:

- Schedule frequent breaks for workers.
- Insure air-conditioned rooms during breaks.
- Provide short and clear guidelines on visible places.
- Ensure easy access to liquids and lavatories.
- If possible, working shifts should be moved to cooler parts of the day (night, early morning).
- Provide the workers with appropriate garments, and personal cooling systems

3.2 Agriculture

Representing an industry with many manual task and outdoor (direct) exposure, agriculture is (as highlighted in section 1) indeed a vulnerable industry in terms of productivity loss, however the ability to mitigate heat-related health and productivity problem remains somewhat unclear (Ioannou et al., 2017; Nybo et al., 2017). Workers involved in moderate or high-intensity agriculture outdoor activities during the warm season are especially prone to heat-related health problems (Figure 8). Physical work activities create endogenous heat production, which adds to the environmental heat stress, and the workplace accident risk is also affected. Temperature extremes may lead to diminished occupational performance capacity and general performance degradation with a consequent increase of accidents and occupational injuries.

Figure 8: The HEAT-SHIELD infographic on heat stress mitigation in agriculture.

3.2.1. Case studies in the wine industry – Cyprus and Greece

In a series of studies performed in Cyprus and Greece, we evaluated ~900 work hours via time-motion analysis on a second-by-second basis (3,159,034 data points) collected from 128 workers while performing different jobs in the wine industry. The workers' characteristics were as follows: 80 males [age: 40.9±14.3 years (range: 18-77 years); height: 172.3±11.7 cm; weight: 85.9±15.7 kg] and 48 females [age: 41.9±8.2 years (range: 26-68 years); height: 158.2±7.5 cm; weight: 54.6±10.3 kg]. Time-motion analysis identified 11 different activities occurring in varying frequency throughout the study period. Eight of these activities were directly related to the job tasks of the workers, two activities involved work breaks (i.e., unprescribed irregular work breaks determined by workers' own judgment) and were considered as labour loss indicators, while one activity involved a ~30-min lunch break that was administered by management. The work intensity of the different activities ranged from 1.3 metabolic equivalents (75.7 W/m^2; equal to very low metabolic rate (International Standard, 2004)) during break in the shade to 7.5 metabolic equivalents (436.5 W/m^2; equal to very high metabolic rate (Tudor-Locke et al., 2011)) during carrying boxes full of crop. Our results show that labour loss escalates from 4%, during low occupational heat stress (16-21°C), to about 10% during moderate occupational heat stress (22-29°C; an increase of 136%), to 14% during high occupational heat stress (29-34°C; an increase of 48%), increasing on average by 0.75% for every 1°C increase in workplace temperature (from 16°C to 34°C; see Figure 9).

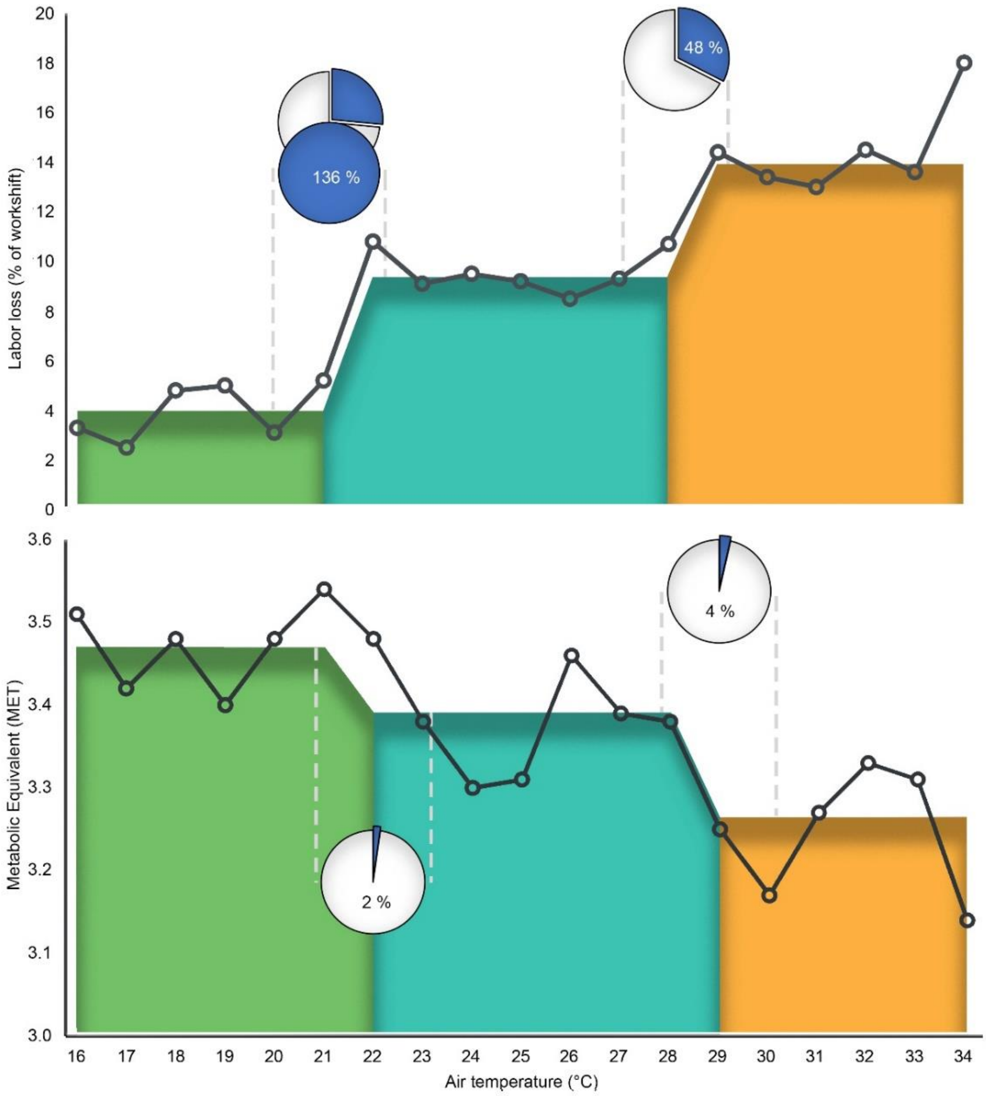


Figure 9: Relationship between air temperature and either loss of labour effort due to irregular work breaks (top graph) or work intensity (bottom graph). The three bars in each graph represent the average value recorded during low (green; 16-21°C), moderate (turquoise; 22-28°C), and high (yellow; 29-34°C) occupational heat stress. Pie charts represent percentage change between two adjacent occupational heat stress categories. Differences were statistically significant at p<0.001 for all comparisons between categories in the top graph, and between low and high occupational heat stress in the bottom graph.

The results from these time-motion experiments were combined with economic, climate, population, and labour data to model current and future global economic costs of agricultural heat-induced labour loss (Figure 10). During 2017, the global economic cost associated with this heat-induced labour loss was 228.8 billion USD (171 USD/worker), representing 6% of the “gross value added” from the agriculture industry. This cost will rise due to climate change and, by the end of the 21st century, the annual global cost of heat-induced labour loss in agriculture will range from 237.7 to 294.2 billion USD. Importantly, labour loss due to occupational heat stress is exacerbated in poorer countries ($r = 0.45$, $p < 0.001$). These findings underscore the current and the rising future impact of occupational heat stress on the labour effort of agriculture workers. Although the majority of the work shift in this industry is spent outdoors and, often, in hot conditions, appropriate strategies (work-rest ratios, hydration, clothing, shading, etc.) can mitigate, at least partly, the heat strain experienced by workers (Nybo et al., 2017). For instance, the annual savings in Colombia (characterized by high occupational heat stress) of reducing the projected labour loss from 8.9% to 6.9% amount to 622 million USD. Similarly, the annual savings in India (characterized by moderate occupational heat stress) of reducing the projected labour loss from 10.7% to 8.7% amount to 8 billion USD. Importantly, these estimates do not include the savings to the healthcare system from the occupational heat illness (Bonauto et al., 2007), absenteeism (Zander et al., 2015), and mortality (Gubernot et al., 2015) associated with heat strain. To reverse this situation, concerted international action encompassing different scientific, health and safety, as well as labour-related disciplines is needed to mitigate the impacts of occupational heat stress on agriculture workers, particularly in light of the occurring climate change and the anticipated rise in environmental heat stress.

Figure 10: Labour loss for different categories of environmental factors and heat stress indices. Each full coloured body figure represents one work shift lost per 10 work shifts due to labour loss. T_{air} represents the air temperature; WBGT represents the wet bulb globe temperature; UTCI represents the universal thermal climate index; ${}_{sol}R$ represents the solar radiation.

3.2.2. Case studies in the Tuscany agriculture sector

Three farms participated in a series of case studies in the Tuscany region, Italy (Figure 11). The 1st was a flower-nursery farm engaged in the production of citrus fruits in greenhouses, in the province of Pistoia (Tuscany). The province of Pistoia is one of the Italian areas with the highest concentration of flower-nursery companies and the plants produced by these companies are exported throughout Europe. The production of citrus fruits, due to the winter cold, is carried out exclusively in the greenhouse where, during the summer period, the thermal conditions in which the workers are engaged, are characterized by intense heat (high temperature and very high humidity inside the greenhouses). More than 10 workers of this farm participated in the case studies. The 2nd farm was a winery farm engaged in the production of Vernaccia wine in in the province of Siena (Tuscany). The province of Siena, as well as that of Florence, is well known for the production of high-quality wines which are exported all over the world. The wine sector in Tuscany represents one of the most important economic sectors, certainly the most important as regards the agricultural sector. During the summer, workers are engaged in outdoor activities and in particular in the green pruning and in the tying of the shoots, fundamental operations to guarantee a good production and ripening of the grapes. Such workers can therefore be exposed to extremely hot conditions in June, July and August. About 10 workers of this farm participated in the HEAT-SHIELD case studies. The 3rd farm was also a winery farm engaged in the production of Chianti wine in the province of Florence (Tuscany). Over 10 workers were also monitored in this farm.

Figure 11: Photos from the farms in Tuscany included in the case studies.

<u>For evaluation of HEAT-SHIELD strategies, the following methodology was adopted:</u>

In the 1st step, we identified potential work-sites. Then, we selected work-sites where the HEAT-SHIELD strategies could be implemented and evaluated. In a 3rd step, we contacted the work-sites and informed them about the project. In a 4th step, we installed weather stations at the selected farms in order to continuously monitor the main meteorological parameters during the summer period. Finally, in a 5th step, we identified at-risk days to also exploit the prototype of the hot warning system created as part of WP5. During these days, tests were realized in the selected farms. In particular, a hot risk assessment questionnaire, a thermal sensation assessment questionnaire was administered at three moments of the working day. In addition, physiological measures on workers were taken (heart rate, oxygen saturation, urine sampling, body weight). During the observation an analysis of the activity was carried out with particular attention to the description of the activities, the average and maximum duration, the period affected by the work situation, the number of workers exposed and the factors to be accurately quantified (air temperature, humidity, radiation, air movements, workload, clothing characteristics).

During the studies, we collected useful information to train and inform employers and workers, providing appropriate examples on how this kind of risk should be assessed. The microclimatic data collected by the instrumentation installed at the farms were used to calculate the WBGT and to estimate the hourly productivity loss and the economic cost during the typical working time (from 8 a.m. to 5 p.m.) and by advancing of 1 h and 2 h the working time. The hourly productivity loss and the related economic cost significantly decreased by working in the shade and by work-time shifting. Based on this information, we generated useful information to plan suitable heat-related prevention strategies to counteract the effects of heat in the workplace. These findings are essential to quantify the beneficial effects due to the implementation of specific heat-related adaptation measures to counter the impending effects of climate change.

Using data collected from questionnaires, we collected important information for raising awareness on the importance of hot risk assessment in the occupational field and particularly in the agricultural sector. Heat stress was identified as a problem by all farm managers. They also stated that heat stress affected workers' productivity and the risk for heat related illness. The selected farms were already using measures to counter the effects of heat on workers' health and productivity, such as a change in working hours during the summer season. All the farms also organized specific training days to inform workers about the risks associated with heat exposure.

With regards to evaluating the effectiveness of the HEAT-SHIELD Occupational Heat-Health Warning System and the specific recommendations developed within the HEAT-SHIELD project, 36 individuals [30 men (83.3%), 6 women (16.7%)], aged 29 to 65 years participated in a survey. The HEAT-SHIELD recommendations were considered a valid resource for the majority of the participants, although less than two thirds (61.1%) of the responders declared to regularly use these guidelines and the heat-warning system to get personalized heat risk, with alarms and guidance on actions to take to mitigate heat stress effects. Almost two companies out of three had informed their employees about the health risks connected with heat. Only one out of the respondents declared that in his/her company no measure was put in place to mitigate the negative effects of heat stress. Mitigation measures implemented by the companies corresponded to the HEAT-SHIELD recommended ones, i.e., availability of water, short and frequent breaks, awareness about the heat risk, specific schedules of the work involving less the hottest hours, exemption of more fragile workers, provision of shaded/cooled areas, etc. Almost two participants out of five considered the measures implemented in their companies positive overall, and 30.6% considered them positive for the safeguard of productivity. Only 16.7% recognized their value in tackling inequalities.

In combination, the above observations and evidence led to the below (adjusted) guidance for workers and mangers.

HEAT-SHIELD - guidance to mitigate or minimise heat stress in the agriculture sector

In the agriculture industry, air-conditioning and shade are typically not feasible given that many of the jobs are performed outdoors. Therefore, other actions also need to be considered.

Workers should particularly pay attention to the following recommendations:

- Frequent, shorter breaks during the work time.
- Fluid replacement (water + electrolytes) to hydrate the body.
- The usage of appropriate garments and/or cooling vests, which can significantly reduce the thermal burden of a wearer.
- All the recommendations should also be followed once at home, as it is apparent that the influence of heat stress, experienced either at work or at home, can have a cumulative effect which results in increased fatigue and poor performance in a long run.

HEAT-SHIELD - recommendations for employers (managers of agriculture companies) and policy-makers to mitigate heat stress in the agriculture sector

Policymakers and managers should consider the following:

- Schedule frequent breaks for workers.
- Insure air-conditioned rooms during breaks.
- Provide short and clear guidelines on visible places.
- Ensure easy access to liquids and lavatories.
- If possible, working shifts should be moved to cooler parts of the day (night, early morning).
- Provide the workers with appropriate garments, and personal cooling systems

3.3 Construction

When considering solutions to lower heat stress any practice that may either lower workers internal heat production (e.g. optimizing the work procedures) or facilitate heat dissipation (including lessening of the constraining effects that e.g. clothing may impose) or directly cool the body (e.g. ingestion of cold drinks or ice) can be beneficial (Figure 12). This can range from behavioural and biological interventions/adaptations to technical solutions that may assist heat dissipation (e.g. increasing air flow, cooling vests or air conditioning) or lower the environmental heat load (e.g. reducing solar radiation). In accordance with this overall context, the following sections present the consortium's work on the specific solutions screened and identified as both effective and feasible to implement for workers in the construction sector.

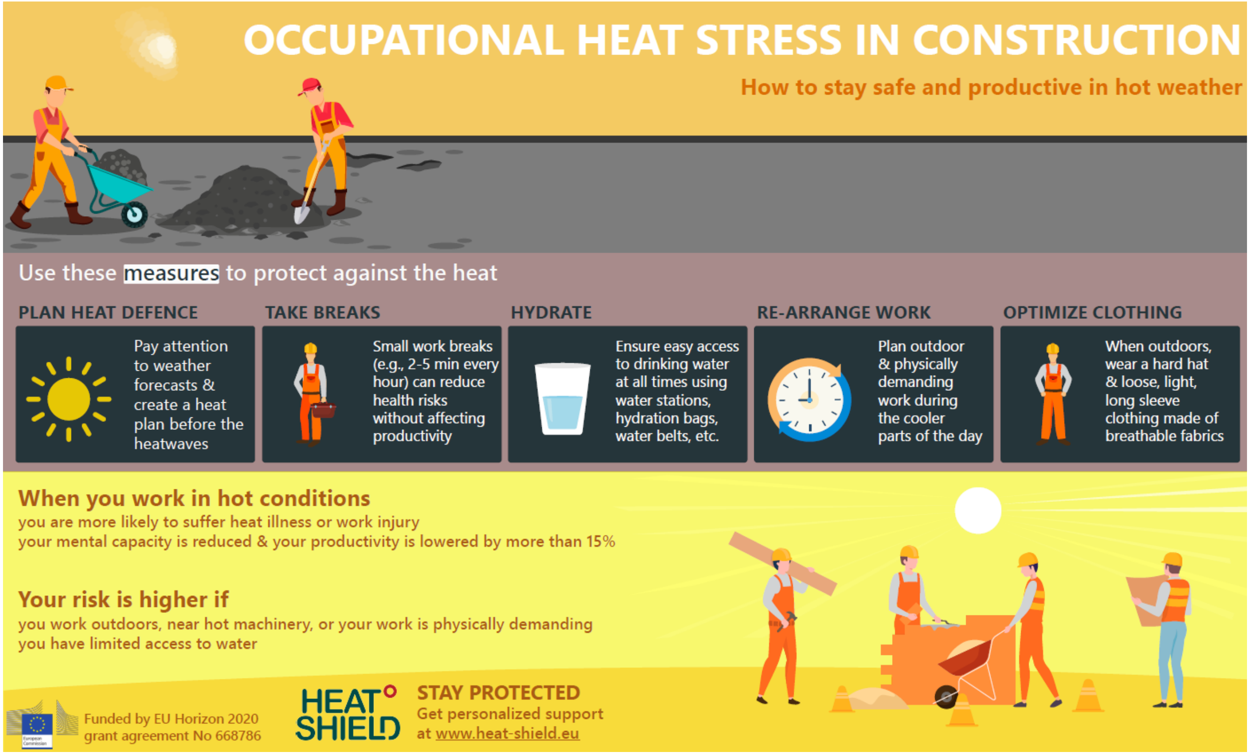


Figure 12: The HEAT-SHIELD infographic on heat stress mitigation in construction.

3.3.1. Case study series 1 in the construction industry – Spain

In a series of studies performed in Zaragosa and Murcia, Spain, we evaluated ~109 work hours via time-motion analysis on a second-by-second basis collected from 16 workers while performing different construction jobs. The study in Zaragoza, was conducted on two different days where we used time-motion analysis of a total of ~109 work hours on a second-by-second basis collected from 16 workers while performing different construction jobs. Day 1 was a hot day (temperature range: 21.8-37.3°C) with high levels of solar radiation (sunlight), whereas Day 2 was a cool day (temperature range: 21.9-31.6°C) with low levels of solar radiation due to increased cloud coverage. Sixteen male workers participated in the study: 10 frame workers, 4 brick layers, 2 drivers (1 forklift driver; 1 crane driver). The reported work experience ranged from 1 to 21 years, with a mean of 14 years. Workers' age ranged from 21 to 56 years, with a mean of 43 years.

As reported by the workers, 15% of the work done in a year (i.e. 55 days) is affected by heat (Figure 13). During these hot days, 50% of the workers feel that the intensity of the heat effect is moderate or high. Almost 2/3 of the workers reported working less during a hot day (Figure 14). Almost 2/3 of the workers reported working less during a hot day, with nearly 80% reporting feeling thirsty, and >2/3 feeling fatigued, uncomfortable, and with low concentration. Also, about 60% of the workers reported feeling breathlessness and dizziness, while about 40% reported having been ill due to the heat. Despite these reported symptoms, a total of 92% of the workers started their work shift in a dehydrated state, with 82% of the workers remained dehydrated at the end of the work shift.

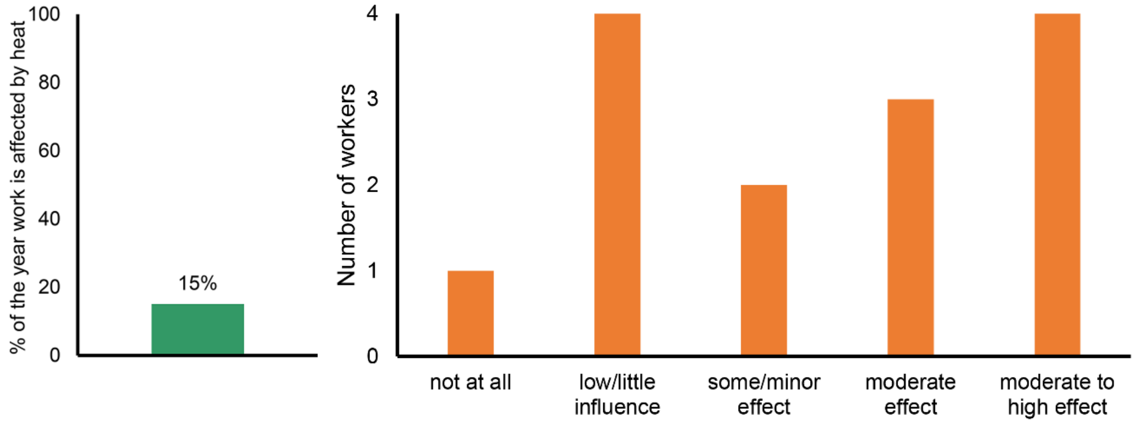


Figure 13: Average percentage of yearly work that is affected by the heat (left panel) and intensity of the heat effect during those hot days (right panel), as reported by the workers.

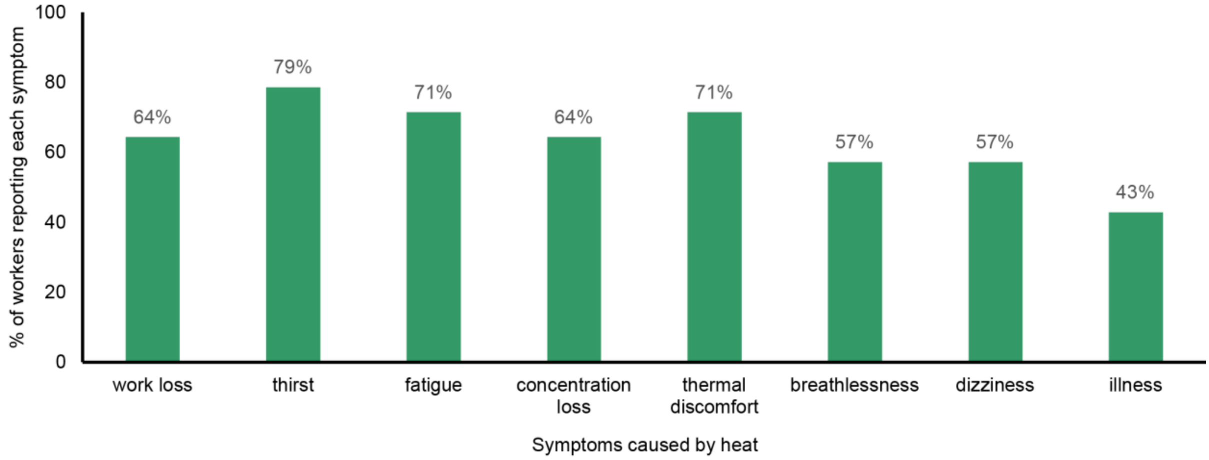


Figure 14: Percentage of workers reporting different symptoms caused by heat in the workplace.

The above results impacted the workers' productivity. In total, across the 2-day study, 7.1% of the total evaluated work shift time was lost on irregular breaks (i.e., spontaneous work cessation determined by workers' own judgment). More importantly, however, there was an additional 7.4 percentage points (4.7-fold difference) of work shift time lost on irregular breaks during Day 1 (a hot day) compared to Day 2 (a cool day).

Based on the results from the study in Zaragosa, we identified/screened solutions to address the identified problems and performed a 2nd study in Murcia. Our approach was to evaluate ~247 work hours via time-motion analysis on a second-by-second basis collected from 11 workers while performing different construction jobs and assess the effectiveness of different adaptation measures to alleviate the impact of workplace heat on labour effort. Three adaptation measures were tested in a random order (Figure 15):

- Planned breaks: during this intervention, the workers were provided with two 7-min breaks scheduled at 12:30 and at 16:30. During these breaks, the workers were free do as they pleased though an advisory was given to rest and hydrate in the shade.
- Ice slushy: during this intervention, the workers were provided with a 300 ml mixture of crashed ice and water every hour from 10:00 until the end of the work shift (18:00).
- Hydration: during this intervention, the workers were provided with a 750 ml of water every hour from 09:00 until the end of the work shift (18:00). Also, their arms (if wearing a t-shirt), neck, and face were sprinkled with water on an hourly basis.

During the study, the core temperature of the workers ranged from 36.7°C to 38.3°C with an average of 37.4 ± 0.4°C, indicating mild hyperthermia (Figure 15). During the Baseline condition, the core temperature of the workers ranged from 36.7°C to 38.1°C with an average of 37.4 ± 0.3°C. During the Planned breaks condition, the core temperature of the workers ranged from 36.7°C to 38.2°C with an average of 37.5 ± 0.3°C. During the Ice slushy condition, the core temperature of the workers ranged from 36.7°C to 38.3°C with an average of 37.4 ± 0.5°C. Finally, during the Hydration condition, the core temperature of the workers ranged from 36.7°C to 37.9°C with an average of 37.1 ± 0.3°C.

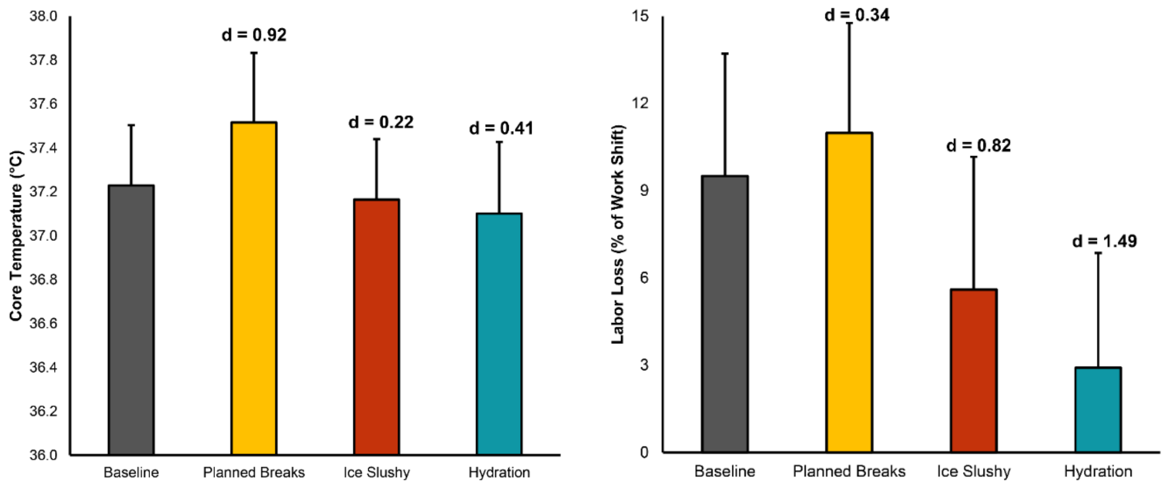


Figure 15: Average core temperatures (left graph) and labour loss (i.e., percentage of work shift time lost due to irregular work breaks) (right graph) during the baseline assessment and the three interventions used to test different adaptation measures.

The loss of labour effort escalated from 5%, during low occupational heat stress (23-25°C air temperature), to 15.8% during high occupational heat stress (26-34°C air temperature). The air temperature during work was positively correlated with labour loss ($r = 0.686$, $p < 0.05$). As shown in Figure 15, during the baseline assessment of the study, 9.4 ± 4.2% of the total evaluated work shift time was lost on irregular breaks (i.e., spontaneous work cessation determined by workers' own judgment). This was increased to 10.9 ± 3.8% when the workers were provided with planned breaks (when adding the time required to take those breaks). When the workers were provided with ice slushies, the labour loss was reduced to 5.6 ± 4.5%. Finally, when the workers were provided with additional water through the hydration and sprinkling strategy, the labour loss was further reduced to 2.9 ± 3.9%.

Based on the above results, construction workers should drink at least 750 ml (three cups of water) before starting work in the morning to mitigate arriving to work in a dehydrated state. During their work shift, they should consume 750 ml of water per hour. When working under heat stress, this strategy demonstrates the best results for maintaining hydration (reducing the risk for kidney disease or acute kidney injury) and for reducing labour loss due to irregular work breaks. For this reason, it is important that strategies are put in place for workers to have access to cold/cool water throughout the day, even when working on different floors or remote areas of a construction site. During periods where workers are sweating profusely, healthy workers should add a larger amount of salt (electrolytes) to their diet. However, workers with heart, blood pressure, or other medical conditions should adopt this advice only when confirmed by their physician. If possible – and, particularly, during breaks – cooling the water by refrigeration, or better yet, by the addition of shaved/crushed ice will help lower the discomfort and heat stress experienced by the workers and improve work performance. Additionally, spreading water on the skin either during breaks or during work (if there is an abundance of water) can help increase evaporative cooling and help limit the rate of dehydration.

3.3.2. Case study series 2 in the construction industry – Spain

In a series of studies performed across four work-sites located in Madrid and Toledo, Spain, we evaluated the recommendations developed within the HEAT-SHIELD project. The 1st work-site (Figure 16, top left) was located in Madrid and the main task was assembly of a tunnel boring machine. In this task on an average 70% of the work was performed outdoors, while 30% of the task was performed indoors (under a covered area). The 2nd work-site (Figure 16, top right) was located in Madrid and the main tasks are maintenance of the different machines used in construction for example asphalt extenders, dumpers, tunnel boring machines, compacters, etc. In this task on an average 50% of the work was performed outdoors in an uncovered area and, the remaining 50% was performed indoors. The 3rd work-site (Figure 16, bottom left) was located in Toledo and the main task was construction of a road and all the work was performed outdoors in an uncovered area. The 4th work-site was located in Madrid (Figure 16, bottom right) and the main task was construction of a residential building.

Here, 40% of the activities were performed outdoors in an uncovered area (before the construction of walls and slabs) and 60% indoors (under covered area).

Figure 16: Photos from the work-sites in Spain included in the case studies.

For evaluating the efficacy of the HEAT-SHIELD strategies, we interviewed managers and workers from each work-site. Managers were responsible for the successful operation of the work-site while ensuring workers' health and safety. Workers were actually performing day-to-day work-sites activities. The total number of participants were 31: 13% managers and 87% workers (including machine operators, fitters, brick layers, etc.).

Workers in the construction sector work mainly outdoor in uncovered areas. In this case 50 to 100% of work was performed outside. All workers considered heat stress as a problem. Construction activities requires lot of physically demanding work in heat and hence they are exposed to external condition, which in Spain during the summer means very high heat load due to natural conditions and ground conditions like asphalt that works as an additional heat source. They sweat a lot and the surrounding temperature seem hot for the majority. Therefore they are tired or even exhausted during and after the work.

They mainly wear "cotton and synthetic" cloths (light-reflecting jackets are mostly made up pf synthetic material). The most significant negative impact of heat is productivity decrease due to "worker absenteeism".

To reduce negative impact of heat, they already before tried to

- reduces working hour schedule (to an 8am-2pm strategy), and use work-rest ratios
- provide appropriate PPEs to the workers
- re-schedule the activities by changing shifts so that the same worker is not exposed to the same work environment
- perform real-time monitoring of heat-stress, based on air temperature and worker inputs
- prepare heat action plan (led by health-safety and/or company’s medical staff, but in dialogue with workers as outlined in Heat-Shield HAP guidance)
- Provide timely relevant information to workers – periodically and through face-to-face workshops and open-discussions.

To minimize heat-health problems, we also suggested the following actions that subsequently were tested and adopted at many work sites or individual stations:

- having fresh-water drinking facility at different locations in their work-sites as it is very important and emphasized by project results to maintain the hydration and to keep water close to all workers with this intention
- allowing workers to have scheduled (brief) breaks with “active resting” as it was shown during the project that these are less time-consuming than slower rate of work due to tiredness of workers or unregular breaks that they take due to exhaustion

All new HEAT-SHIELD strategies resulted in increased productivity (as measured through reduced absenteeism of workers from work). The HEAT-SHIELD platform and materials have also given a good impression on the users as they provided a useful source of information in mitigating heat-stress. However, 70% of the workers did not use HEAT-SHIELD platform due to the fact that they did not have access to desk-top in work-sites (possibility to use the platform as an app or even with smart watch).

Unfortunately, due to the unprecedented situation created by Covid-19 pandemic, strategies were not able to be exploited to the fullest. Overall, managers considered the HEAT-SHIELD strategies handy and effective. Additionally, we suggested a training program for managing heat-stress or heat-related illness, but it was not established yet, especially due to Covid-19 situation.

All managers recognized that heat stress is a problem for workers in their occupation. Half of the managers indicated that their work-site had recorded heat related problems, restricted duty, or accidents related to heat stress. Finally, all managers indicated that an established program for heat stress management was implemented at their work-site. Air temperature and worker input were the criteria that were used in all the assessed work-sites. All work-sites had a heat action plan that was managed by health and safety and medical staff. Front-line supervisors conducted pre-job evaluation to assess the level of heat-stress and based on written guidance they implemented necessary precautions. However, there was no training program for managing heat-stress or heat-related illness. Finally, all work-sites used local media to evaluate environmental conditions, while one work-site also used dry bulb temperature and wet bulb globe temperature. All the work-sites used PPEs, hydration regimes and work-rest ratios as preventive action, however, one work-site in addition also used central or local air-conditioning.

All workers considered that heat stress is a problem in their occupation. They also reported that construction work requires significant amounts of time (up to 100%) working in high heat conditions. However, 90% of them had not taken days off due to heat stress in last 10 years. More than half (55%) of the workers indicated that the temperature at their work-site was “very warm”. Seventy percent of the workers reported that their level of sweat was so high that their clothes were sticking to the skin surface. When asked about where do they do most of their work, 70% stated it was outdoor, 11% indoor, and 19% was combined outdoor and indoor.

Half of the managers confirmed that they have used HEAT-SHIELD platform, while the other half indicated that they were not able to do use due to urgent and unavoidable need to implement workers’ health and safety strategies to combat covid-19 pandemic. Moreover, half of the managers responded that, they have reduced working hour during the summer time, i.e. during summer they work from 8am till 14am, they also installed water facilities at different locations in their work-sites, and they gave short-breaks to the workers (especially, if the activity is outdoor) and provided heat protective clothes to all workers irrespective of whether they are working out- or in-door. All managers indicated that the HEAT-SHIELD platform and infographics resulted in improvement in workers’ wellbeing as measured by reduction in absenteeism.

Seventy percent of the workers reported that they did not use the HEAT-SHIELD platform during the study period, owing to the fact that they did not have access to a computer at their work-site. When asked about measures to reduce heat impact, the most popular answer was “usage of PPEs”.

3.3.3. Case study large-scale construction site – UK

Through a partnership with the British Occupational Hygiene Society (BOHS), we assessed the feasibility for implementation of HEAT-SHIELD strategies within a major construction site. The construction site (Hinkley Point C, HPC) employs over 5,000 people and its purpose is the development of a nuclear power station in Somerset, UK (Figure 17). The power station will hold two nuclear reactors. We conducted an onsite assessment aiming to 1) to document current risk of occupational heat stress in HPC’s workforce, 2) document current strategies used to alleviate heat strain, and 3) document challenges and opportunities in implementation of HEAT-SHIELD guidelines.

An on-site visit to HPC construction site (Somerset, UK) was conducted on 07/08/2020. On this day, the peak temperature in Somerset was ~30°C. HPC is a project to construct a 3,200 MWe nuclear power station with two reactors in Somerset, England. The site is approximately 400 acres in size, equivalent to over 1.5 million square meters (Figure 17). Our researchers were escorted around the site by the site safety advisor for EDF energy. The tour lasted approximately 2 hours and during which time we took an audit of the current working practices, areas where risk of heat strain is high, current methods used to alleviate the risk, and areas which heat safety can be improved. Following the tour, we interviewed the site safety advisor to document his (point-by-point where applicable) feedback on the guidelines developed by HEAT-SHIELD.

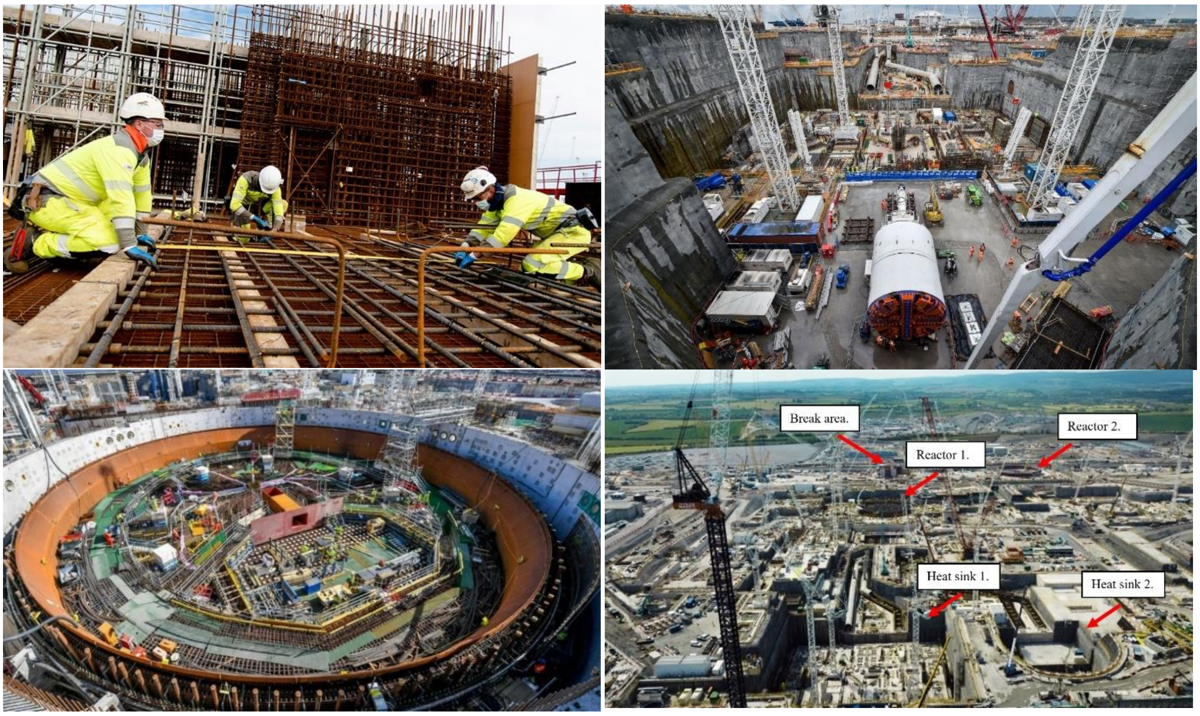


Figure 17: Photos from the Hinkley Point C work-site in the UK.

There were several factors rendering workers at risk of heat strain at HPC. The issues are related to:

- Heavy personal protective equipment/clothing which limits dry and evaporative heat losses. Shown in Figure 17.
- Topological factors which limit natural air movement and increase reflective solar influx to the worker. Shown in Figure 17.
- Logistical difficulties in providing water to workers. Particularly those engaged in work within the nuclear reactors. Shown in Figure 17.
- The site is large (400 acres) and distinctly three-dimensional i.e, workers often have to climb up and down to access work areas, as well as walk relatively large distances.
- No heat defense plan based on weather alerts.

- Primarily older work force (age > 50 years typical). Physiologically, this population is considered more at risk compared with younger workers. But more work experience in the older workforce may contribute to improved self-regulation/pacing, which is protective against heat stress.

Current heat defense practices

The current methods employed to avoid occupational heat stress issues are:

- A strong encouragement for workers to self-pace. Work productivity loss due to such pacing is recognized but is considered acceptable from a health and safety perspective. Hinkley Point C has not had a serious health and safety incident due to workplace heat. The perspectives of the workers are unknown.
- Water stations are positioned throughout the site. In some areas these are not easily accessible i.e, working in the reactors or in heat sinks, where heat stress severity is likely to be the greatest.
- An informal buddy system is utilized with regards to monitoring fellow workers in hot conditions.
- ‘Toolbox talks’ are daily, regular guidance given to small groups regarding hydration advice, urine colour etc. Notices on site, regularly changed. Guidance on hydration pre- and post-work is unclear.
- Workers have a health check every 6 months to assess blood pressure, lung function, and hearing. If test results are returned as problematic, workers are advised to visit their Doctor.

Feedback on the HEATSHIELD heat defense plan

UK workers (and citizens) only experience transient heat episodes, which typically last 1 – 2 weeks or less. That heat is not a daily consideration for the workers at HPC renders it less likely that time and finances will be invested in heat avoidance strategies. Despite areas where heat stress is significant, coupled with limited water availability, heat stress is not considered a problem because of the lack of individuals who present with signs of heat exhaustion. For health and safety operatives, more of their time is required for managing more common hazards such as trips and falls, manual handling issues, and working at height.

HEAT-SHIELD - guidance to mitigate or minimise heat stress in the construction sector

In the construction industry, air-conditioning and shade are typically not feasible given that many of the jobs are performed outdoors. Therefore, other actions also need to be considered.

Workers should particularly pay attention to the following recommendations:

- Frequent, shorter breaks during the work time.
- Fluid replacement (water + electrolytes) to hydrate the body.
- The usage of appropriate garments and/or cooling vests, which can significantly reduce the thermal burden of a wearer.
- All the recommendations should also be followed once at home, as it is apparent that the influence of heat stress, experienced either at work or at home, can have a cumulative effect which results in increased fatigue and poor performance in a long run.

HEAT-SHIELD - recommendations for employers (managers of construction companies) and policy-makers to mitigate heat stress in the construction sector

Policymakers and managers should consider the following:

- Schedule frequent breaks for workers.
- Insure air-conditioned rooms during breaks.
- Provide short and clear guidelines on visible places.
- Ensure easy access to liquids and lavatories.
- If possible, working shifts should be moved to cooler parts of the day (night, early morning).
- Provide the workers with appropriate garments, and personal cooling systems

3.4 Tourism

European workers in the tourism sector are seasonally exposed to heat stress levels that undermines individual health (mild hyperthermia and dehydration) (Figure 18). Occupational heat stress is very relevant in the tourism industry because many tasks rely on manual work as the prevailing and, sometimes, only feasible method for performing complex tasks. Importantly, occupational heat stress is difficult to mitigate in tourism, as there is a wide range of jobs – with vastly different physiological and environmental specifications – included in this industrial sector.

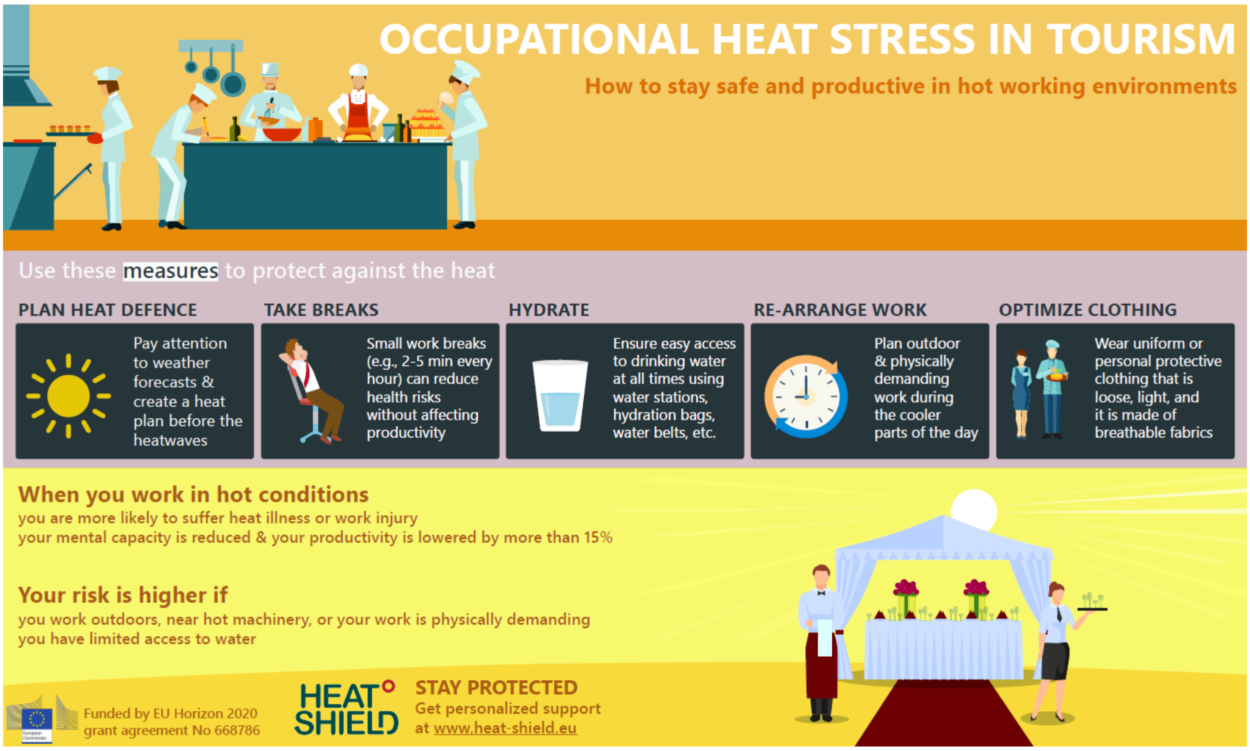


Figure 18: The HEAT-SHIELD infographic on heat stress mitigation in tourism.

3.4. Case studies in the tourism industry – Greece

In a series of studies performed in Greece, we evaluated ~380 work hours via time-motion analysis on a second-by-second basis collected from 47 workers (age: 34.5 ± 9.5 years) while performing different jobs in the tourism industry [12 waiters/ waitresses, 10 cooks, 7 barista staff, 5 bus drivers, 2 dish washing staff, 2 hotel maids, 2 outdoor manual workers (i.e. gardener, painter), 2 snack bar workers, 5 other workers (i.e. butcher, pool boy, hotel retail store employee, hotel manager, valet parking employee)].

Three different heat mitigation strategies were tested. Specifically, tourism workers were provided with (1) 90 sec of a planned break every 30 min of continuous work, (2) ice slurries (3.5 mL per body mass kilogram) every hour of continuous work, and (3) two minutes of a planned break combined with ice slurry consumption (2.4 g per body mass kilogram) every hour of continuous work.

A strong relationship was identified between WBGT and the mean skin temperature of workers ($r = 0.595$, $p = 0.032$). Similarly, linear regression analysis demonstrated that there was a 0.09 °C increase in mean skin temperature for every 1 °C increase in WBGT ($R^2 = 0.354$; $F_{(1,11)} = 6.029$, $p = 0.032$).

A strong relationship was identified between WBGT and core body temperature ($r = 0.646$, $p = 0.017$). A biphasic regression ($R^2 = 0.852$; $F_{(2,10)} = 28.678$, $p < 0.001$) demonstrated that there is an increase of ~0.4 °C in the core body temperature of tourism workers for every 1 °C increase in WBGT above 30 °C.

The tested heat mitigation strategies in the tourism workers did not impact their core body temperature (planned breaks: $p = 0.430$; ice slurry: $p = 0.094$; and combined: $p = 0.135$), mean skin temperature (planned breaks: $p = 0.909$; ice slurry: $p = 0.628$; and combined: $p = 0.326$), heart rate (planned breaks: $p = 0.384$; ice slurry: $p = 0.491$; and combined: $p = 0.536$), or labour effort (planned breaks: $p = 0.170$; ice slurry: $p = 0.992$; and combined: $p = 0.423$) (Figure 19). Despite the lack of statistically significant differences based on p values, it is important to note that we found large effect sizes when comparing the core body temperature of workers between the “business as usual” scenario and either the “ice slurry” ($d = 0.83$) or the “combined” ($d = 0.89$) strategies, indicating that a larger sample size might have revealed a statistically significant difference (Figure 19).

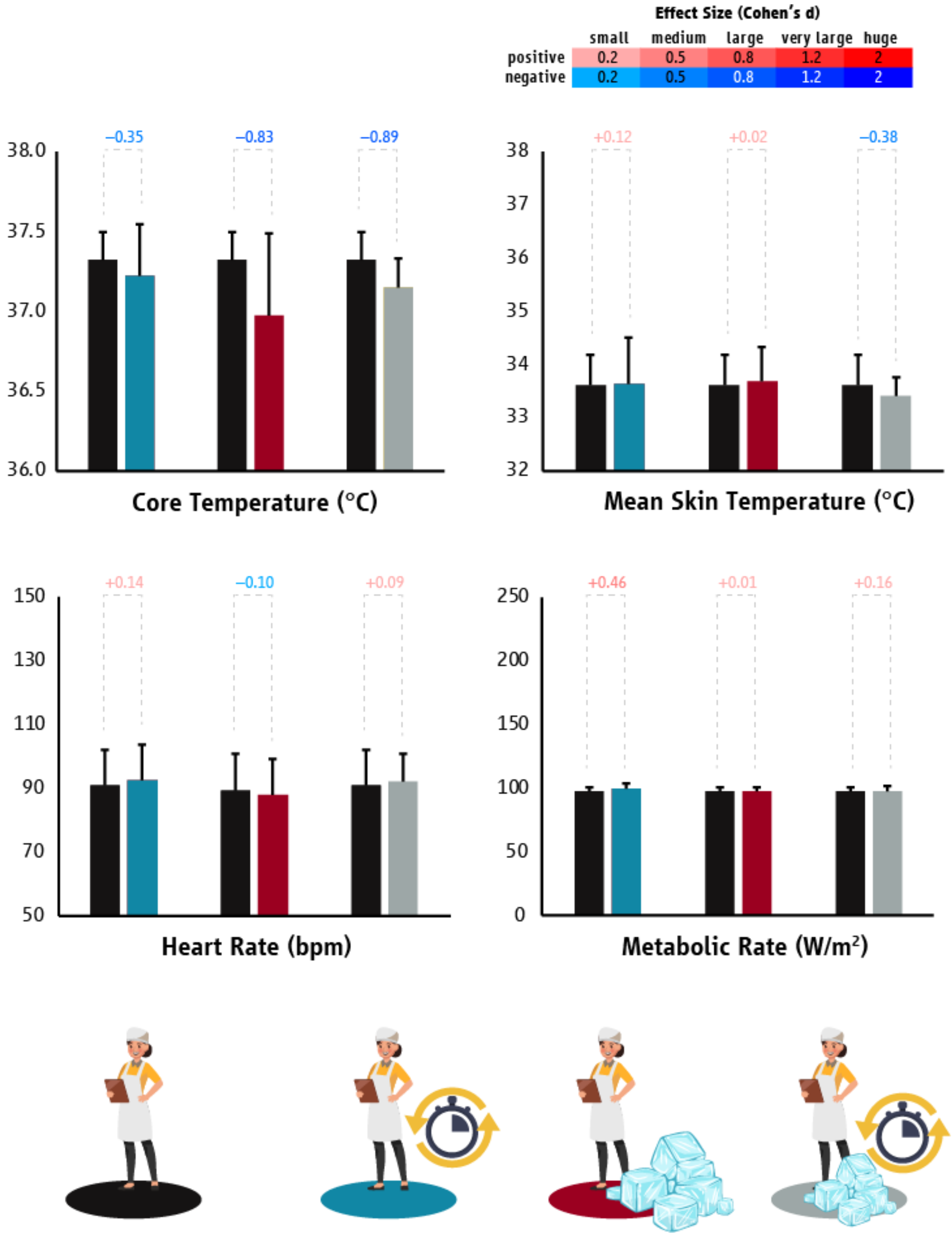


Figure 19: Differences (mean ± SD) in core temperature, mean skin temperature, heart rate, and metabolic rate/work intensity between "business as usual" and the tested heat mitigation strategies in the tourism sector. Black, light blue, red, and grey colours represent "business as usual", planned breaks, ice slurry, and "combined" (two minutes of planned break combined with ice slurry consumption (2.4 g per body mass kilo) every hour of continuous work) scenarios, respectively. Cohen's d effect sizes show the magnitude (small: 0.2; medium: 0.5; large: 0.8; very large: 1.2; huge: 2.0) and direction (positive: shades of red; negative: shades of blue) of the differences between "business as usual" and the tested heat mitigation strategies.

Based on the above findings, it is advisable that tourism companies, from large multinational corporations to small local businesses, consider/develop an appropriate heat adaptation plan to protect workers' health. This plan may be qualified by a designated person and benefit from consulting advanced warning weather systems to warn in advance when a period of hot weather is expected. Single or combined heat resilience methods appropriate/applicable for the specific work setting should be identified and translated into feasible actions and habits that workers can adopt during hot periods – with timely information at the beginning of the summer and regular follow-up reminders.

Staying hydrated is critical for maintained health in the tourism industry. Unfortunately, workers forget or fail to rehydrate from day-to-day. Thus, almost all tourism workers arrive at work at a dehydrated state. This means they start the day at an elevated risk for hyperthermia and acute kidney injury as well as low probability for performing at their best during their work shift. Tourism workers should drink 500-750 ml (2-3 cups of water) before starting work in the morning. During their work shift, they should drink 500-750 ml of water per hour. When working under heat stress, this strategy demonstrates the best results for maintaining hydration (reducing the risk for kidney disease or acute kidney injury). For this reason, it is important that strategies are put in place for workers to have access to cold/cool water throughout the day, even when working on different floors or remote areas. If such a strategy is followed regularly, day-to-day rehydration would be optimized and 500 ml per hour (2 cups of water) may be adequate for maintaining workers' hydration status to appropriate levels. During periods where workers are sweating profusely, healthy workers should add a larger amount of salt (electrolytes) to their diet. However, workers with heart, blood pressure, or other medical conditions should adopt this advice only when confirmed by their physician. If possible – and, particularly, during breaks – cooling the water by refrigeration will help lower the discomfort and heat stress experienced by the workers.

Clothing is important for tourism workers because it can lower the worker's thermal stress. Some tourism workers require special protective clothing (gloves, helmet, boots, etc.), while clothing is also beneficial for protecting the tourism workers from excessive sun exposure. However, clothing can also restrict heat loss as it provides a boundary layer that limits evaporation and convective/dry heat loss. To facilitate heat loss, clothing worn during the work shift should be selected based upon promoting air flow across the skin and improving sweat evaporation (reducing clothing evaporative resistance). This can be accomplished by reducing the total amount of skin covered by clothing by wearing a t-shirt vs long sleeve (if indoors), wearing looser fitting clothing which allows for greater air flow underneath the clothing, and wearing clothing with a wider knitting pattern which allows for more air flow to pass through the clothing. Additionally, lighter colours should be selected on sunny days in outdoor environments to increase the reflection of solar radiation. In situations where long, rigid clothing must be worn (e.g. coveralls), ventilation patches can be incorporated into more protected areas such as under the arms and between the legs to help promote air flow through the garment.

The monitored construction and tourism workers had limited capacity for self-pacing which predisposed them to occupational heat strain. Therefore, it is crucial to plan the workflow to allow workers time to adapt. Workers will acclimatize to heat during the first days of hot weather, however depending on the initial fitness and previous exposure it will take at least one week before workers get used (physiologically adapted) to the increased heat.

HEAT-SHIELD - guidance to mitigate or minimise heat stress in the tourism sector

In the tourism industry, self-pacing is not always feasible, as work is often driven by immediate customer demand for services. Therefore, other actions also need to be considered.

Workers should particularly pay attention to the following recommendations:

- Frequent, shorter breaks when possible.
- Fluid replacement (water + electrolytes) which has to frequent but moderate to hydrate the body.
- The usage of appropriate garments and/or cooling vests, which can significantly reduce the thermal burden of a wearer.
- All the recommendations should also be followed once at home, as it is apparent that the influence of heat stress, experienced either at work or at home, can have a cumulative effect which results in increased fatigue and poor performance in a long run.

HEAT-SHIELD - recommendations for employers (managers of tourism companies) and policy-makers to mitigate heat stress in the tourism sector

Policymakers and manufacturers should consider the following:

- Schedule frequent breaks for workers when tasks/workflow allows.
- Insure air-conditioned rooms during breaks (cooling oasis).
- Provide short and clear guidelines on visible places.
- Ensure easy access to liquids and lavatories.
- Where possible, working shifts should be moved to cooler parts of the day (night, early morning).
- Provide the workers with appropriate garments, and personal cooling systems

3.5 Transport

Workers in the transportation sector reveal heterogeneous exposures to heat, both when considering different professions and individual jobs. The heterogeneity was studied in depth in work package 3 (see technical report D3.2: Report on solutions to mitigate heat stress for workers of the transportation sector). The critical points that are affected mainly by hot environments and heatwaves were identified. Based on these points, we developed mitigation measures to avoid excessive heating of the driver's cabin and prevent adverse effects on cognitive performance and productivity, as a result of limited capacity to reduce environmental heat exposure, frequent dehydration, sleep deprivation, fatigue, and monotonous working periods.

As a next step, the mitigation measures were presented to stakeholders in work package 4 to receive feedback about their relevance and practicability. For this purpose, the German Social Accident Insurance (DGUV) expert group was contacted, having expressed some concerns about the cooling options recommended. They indicated that, in their opinion, the air-conditioning is the most effective strategy to cool vehicles cabins but they use a considerable amount of energy. Also, the suggestion to change the working hours for cooler periods of the day was received with some resistance, because of the tight and often inflexible schedules with which the transportation industries have to cope with. On the other hand, the expert group stressed the importance of the temperature to which trucks are exposed during the day or during the night, when stored in concrete bays or on the side of highways, which may raise the cabin temperature, increasing the heat stress on the driver.

A survey conducted on workers in the transportation sector confirmed the heterogeneity of heat exposure and, thus, the relevance of heat stress at work. While some reported no issues, others indicated a high impact of heat exposure on their work performance. Workers mentioned a high impact in conjunction with clothing not allowing for appropriate heat dissipation, leading to strong sweating and related dehydration.

We used the input received from the expert group and the conducted surveys to refine the guidelines for workers in the transportation sector and the recommendations for employers, policy-makers and vehicle manufacturers. The resulting guidelines and recommendations are given below and in Figure 20.

Feedback on the HEAT SHIELD guidance to mitigate or minimize heat stress in the transportation sector

We discussed the final recommendations with representatives from policymakers, vehicle producers and employers (managers of transportation companies). They considered the recommendations as very useful and understandable. The information included in the guidance was assessed as very relevant and essential. Both drivers and employers seem not to be fully aware of the negative impacts of heat exposures. For this reason, the information should be communicated most straightforwardly, avoiding as much as possible the use of technical terminology that may hamper understanding and/or assimilation.

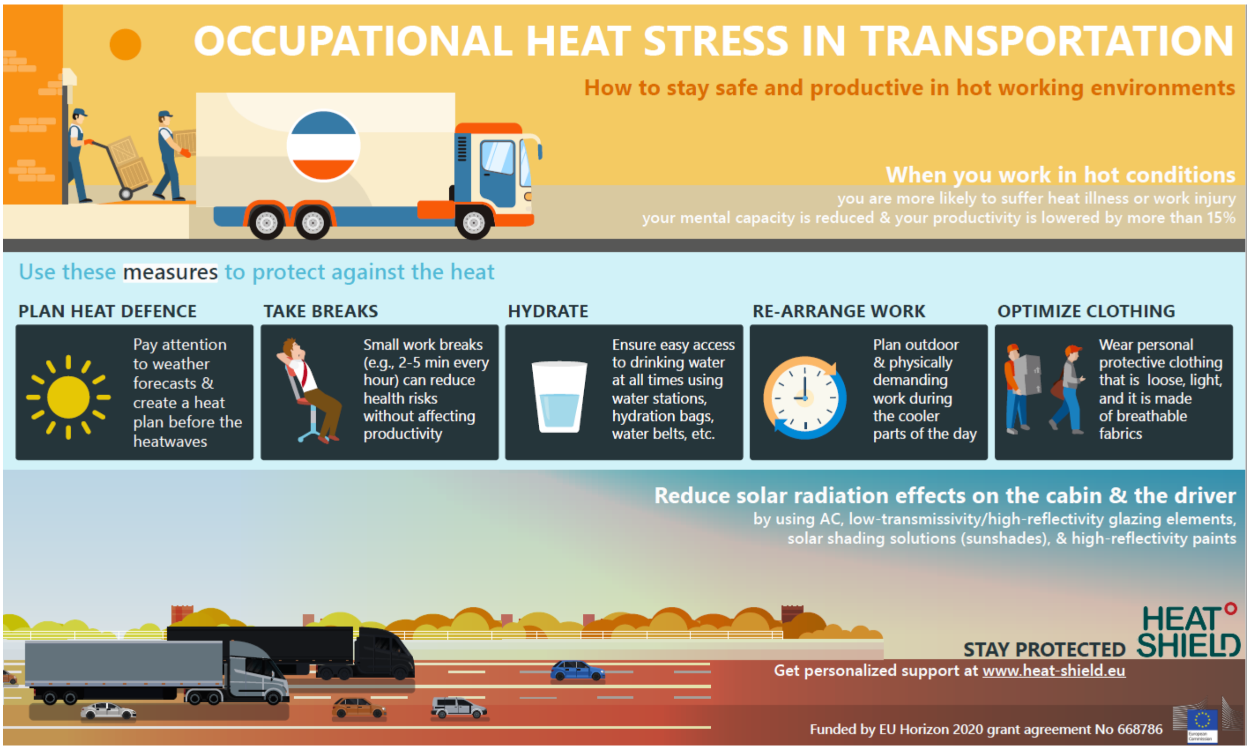


Figure 20: The HEAT-SHIELD infographic on heat stress mitigation in the transportation sector.

The representatives evaluated the practicability of the mitigation measures as very high. However, some concerns were expressed with costs that would be associated with the technical implementation of the recommendations and the instruction and training of the workers (e.g. security and safety training days for workers, including regular repetition of the courses to ensure a high level of assimilation and adoption). This aspect was mentioned as a primary barrier for the implementation of the recommendations. Therefore, it was suggested for these investments to be considered together with the reduction in costs associated with heat-related incidences (so that the mentioned reductions in costs can work as an incentive for the implement the recommendations). In this context, it was suggested for the cost implications (e.g. of the reductions in fuel costs due to lower use of air-conditioning, or the increased risk of accidents due to heat exposures) to be estimated/provided, so as to increase the managers' willingness/readiness to consider heat mitigation measures.

In general, the transportation workers (drivers) indicated that the implementation of heat mitigation measures would show appreciation for their work, and thus would have their support. The contact with the workers/drivers showed also that it will be important to consider the main nationalities (and thus the native languages) of the drivers in the different regions, as that will influence the understanding and assimilation/adoption of the guidelines. For instance, in Germany, most drivers are Polish and Ukrainian, and therefore, campaigns designed to address that region would require the translation of the guidelines/recommendation into those languages. This would be important to gather the support from the workers to the heat mitigation measures, which would increase pressure for companies and legislators.

HEAT-SHIELD guidance to mitigate or minimize heat stress in the transportation sector

Air Conditioning (AC) markedly reduces heat stress in car or truck cabins while driving. However, we propose additional aspects for a more healthy and sustainable protection against harmful effects of heat stress. Below, you will find a list of issues relevant for employees (drivers) and recommendations for employers (managers of transportation companies), policymakers and vehicle manufacturers.

Periods with elevated environmental heat stress may negatively affect driving skills and reduce safety. In addition, heat exposure during manual tasks, such as loading and unloading trucks and "outside working hours" exposures, may further aggravate heat load. Limited driving abilities are associated with direct effects of heat stress on attention, mental processes and the execution of movements. Indirect effects related to poor hydration and potential impact on sleeping quality may further deteriorate driving abilities.

Drivers should particularly pay attention to the following issues:

Keep your cabin cool - during driving under warm conditions, it is essential to:

- Use sunshades and glazing elements to reduce direct/diffuse thermal loads.
- Keep windows fully closed when AC is ON if the ambient is warmer than the cabin.
- Avoid setting the AC temperature too low and choose vehicles with darker windshields & windows and lighter cabin colours to reduce tailpipe emissions.
- Reduce heat load by increasing the airflow to support or substitute AC to facilitate evaporation of sweat.
- Choose covered parking places whenever possible to minimize the heating of the cabin – if not possible, keep windows slightly open when parked under the sun.

Help your body recover from physically intensive work

While driving, your body heat production is low. However, manual tasks (e.g. during the preparation of the drive or while delivering goods) increase metabolic heat production, so sweating and the heat accumulated in your body might affect subsequent tasks.
Help your body recover from such tasks by cooling and re-hydrating, as indicated below.

Stay hydrated

There is a marked interaction between heat stress and inadequate hydration – in terms of physical performance and ability to remain concentrated. It is important to:

- Remain hydrated during work shifts (see infographic for facts about hydration when exposed to heat).

- Rehydrate from day to day – and immediately after manual tasks.
- Remember to keep your electrolyte balance in addition to increasing your water intake.
- Ensure access to lavatory facilities

Recover/restitution from one work shift to next

Sleep deprivation, and fatigue due to irregular working hours can be aggravated by heat stress. Especially sleeping in the heat is a concern, as it may contribute to a decline in the driver's cognitive performance and decision-making. Therefore, pay extra attention to:

- Have access to a cool sleeping room.
- Reduce light and heat exposure of the sleeping facility.
- Reduce noise and other sleep-disturbing factors.

HEAT-SHIELD recommendations for employers (managers of transportation companies), policy-makers and vehicle manufacturers to mitigate heat stress in the transportation sector

Policymakers and vehicle manufacturers should consider the following:

The importance of optical properties of the cabin materials of the European transportation fleets to reduce AC use and, hence, the overall fuel consumption and tailpipe emissions.

- In the heavy-duty transportation sector, the use of high-reflectivity paints in the trucks' cabin external surfaces together with low-transmissivity windshields and side-windows can reduce the fuel costs by ~ €195 million/year across Europe and decrease CO2 emissions by 0.2 percentage due to reduced AC needs (see guidance on optimal AC use in the recommendations for drivers)
- Considering the above recommendations for the light-duty European fleet, which is ~5 times larger than the heavy-duty fleet, may further reduce CO2 emissions, given its ~ 8 times higher proportion of AC related fuel consumption of their vehicles.
- Inform vehicle buyers about the importance of vehicles optical properties on their cooling needs, fuel consumption and tailpipe emissions. Raise awareness on the importance of preferring wind-shields and windows with low-transmissivity / high-reflectivity and external paints with high reflectivity.

Employers (managers of transportation companies) should consider the following:

Keep your drivers cool

- When planning to update/renew your transportation fleet, ask information on the optical properties of the vehicles materials (i.e. external paint and glazing), and prefer those with low-transmissivity / high-reflectivity windshields and windows, as well as those with high-reflectivity external paints. This will contribute to minimize the fleet AC cooling needs.

Help your drivers to stay hydrated

- Enable short work breaks to promote cooling and re-hydration
- Promote regular drinking (i.e. provide cold water or other cooled, unsweetened drinks)
- Offer easy access to toilets (to prevent “voluntary” but detrimental insufficient hydration)

Work planning and recovery

- Consider re-scheduling of certain work tasks or change timing to perform most demanding manual tasks during cooler times of the day that may reduce heat-load for the driver
- Plan activities and breaks
- Allow for recovery phases in cool environments, protected from light and noise

Additional mitigation measures

- Provide appropriate garments with good evaporative cooling performance (e.g. made out of synthetics fibres or linen).
- As the seat restricts heat dissipation in the back, buttock and thigh region, integrated ventilation or cooling systems in the driver seat would contribute to heat dissipation.
- Promote fitness of your collaborators as it will improve their overall health and, specifically, their heat tolerance.

4 Conclusions – take home messages

Improved resilience towards current and future environmental heat stress, call for actions: at the *continental level* (cross-country agreements to minimize emissions and prevent further rise in temperature, frequency and severity of heat waves), at the *regional level* (in particular in the vulnerable regions) and at the *local work places*. The present report both provide policy-relevant evidence for decision makers and concrete solutions for workers in specific industries. The Heat-Shield guidance from "general" Heat Action Plans to specific solutions – i.e. information for employers and employees have been tested and verified (either demonstrating improved productivity or reduced health risk for workers) or adjusted to optimize effectiveness and improved implementation potential (including feasibility and sustainability aspects).

5 References

Alahmad, B., Shakarchi, A. F., Khraishah, H., Alseaidan, M., Gasana, J., Al-Hemoud, A., Koutrakis, P., & Fox, M. A. (2020). Extreme temperatures and mortality in Kuwait: Who is vulnerable? *Sci Total Environ*, *732*, 139289. https://doi.org/10.1016/j.scitotenv.2020.139289

Antecol, H., & Bedard, K. (2006). Unhealthy assimilation: why do immigrants converge to American health status levels? *Demography*, *43*(2), 337-360. https://doi.org/10.1353/dem.2006.0011

Bonauto, D., Anderson, R., Rauser, E., & Burke, B. (2007). Occupational heat illness in Washington State, 1995–2005. *American Journal of Industrial Medicine*, *50*(12), 940-950. https://doi.org/doi:10.1002/ajim.20517

Boschetto, B., De Rosa, E., Marini, C., & Salvatore, M. A. (2016). Safety at work in Italy: A comparison of Italians and foreigners. *Espace Popul Soc*, *3*, https://doi.org/10.4000/eps.6610.

Binazzi, A., Messeri, A., Levi, M., Bonafede, M., Bugani, M., Morabito, M., Baldasseroni, A. (2019). Evaluation of the impact of heat stress on the occurrence of occupational injuries: Meta-analysis of observational studies. *American Journal of Industrial Medicine* 1-11. https://doi.org/10.1002/ajim.22946

Carter, R., 3rd, Cheuvront, S. N., & Sawka, M. N. (2007). A case report of idiosyncratic hyperthermia and review of U.S. Army heat stroke hospitalizations. *J Sport Rehabil*, *16*(3), 238-243. https://doi.org/10.1123/jsr.16.3.238

Ciuha, U., Pogačar, T., Kajfež Bogataj, L., Gliha, M., Nybo, L., Flouris, A.D., Mekjavic, I.B. (2019). Interaction between Indoor Occupational Heat Stress and Environmental Temperature Elevations during Heat Waves. Weather, Climate, and Society 11(4), 755-762. https://doi.org/10.1175/WCAS-D-19-0024.1

Ciuha, U., Valenčič, T., Mekjavic, I.B. (2020). Cooling efficiency of vests with different cooling concepts over 8-hour trials. Ergonomics. https://doi.org/10.1080/00140139.2020.1853820

Dineen, S. M., Ward, J. A., & Leon, L. R. (2020). Prior viral illness increases heat stroke severity in mice. *Exp Physiol*. https://doi.org/10.1113/EP088480

Flouris, A. D., Babar, Z., Ioannou, L. G., Onarheim, K. H., Phua, K. H., & Hargreaves, S. (2021). Improving the evidence on health inequities in migrant construction workers preparing for big sporting events. *BMJ*, *374*, n1615. https://doi.org/10.1136/bmj.n1615

Flouris, A. D., Ioannou, L. G., Dinas, C. D., Mantzios, K., Gkiata, P., Gkikas, G., Vliora, M., Amorim, T., Tsoutsoubi, L., Kapnia, A., Dallas, K., Nintou, E., Testa, D. J., Sfakianakis, K., & Agaliotis, G. (2019). *Assessment of occupational heat strain and mitigation strategies in Qatar – Key Findings*.

Flouris, A. D., McGinn, R., Poirier, M. P., Louie, J. C., Ioannou, L. G., Tsoutsoubi, L., Sigal, R. J., Boulay, P., Hardcastle, S. G., & Kenny, G. P. (2018). Screening criteria for increased susceptibility to heat stress during work or leisure in hot environments in healthy individuals aged 31-70 years. *Temperature (Austin)*, *5*(1), 86-99. https://doi.org/10.1080/23328940.2017.1381800

Foster, J., Hodder, S.G., Goodwin, J., Havenith, G. (2020). Occupational Heat Stress and Practical Cooling Solutions for Healthcare and Industry Workers During the COVID-19 Pandemic. Annals of Work Exposures and Health 64, 9, 915-922. https://doi.org/10.1093/annweh/wxaa082

Garcia-Leon, D., Casanueva, A., Standardi, G., Burgstall, A., Flouris, A.D., Nybo, L. (2021). Current and projected regional economic impacts of heatwaves in Europe. Nat Commun 12, 5807. https://doi.org/10.1038/s41467-021-26050-zet

Gubernot, D. M., Anderson, G. B., & Hunting, K. L. (2015). Characterizing occupational heat-related mortality in the United States, 2000–2010: An analysis using the census of fatal occupational injuries database. *American Journal of Industrial Medicine*, *58*(2), 203-211. https://doi.org/doi:10.1002/ajim.22381

International Standard. (2004). ISO 8996: Ergonomics of the thermal environment — Determination of metabolic rate. In. LND, UK.

Ioannou, L.G., Mantzios, K., Tsoutsoubi, L., Panagiotaki, Z., Kapnia, A.K., Ciuha, U., Nybo, L., Flouris, A.D., Mekjavic, I.B. (2021). Effect of a simulated heat wave on physiological strain and labour productivity. Int. J. Environ. Res. Public Health 18, 3011. https://doi.org/10.3390/ijerph18063011

Ioannou, L. G., Tsoutsoubi, L., Samoutis, G., Bogataj, L. K., Kenny, G. P., Nybo, L., Kjellstrom, T., & Flouris, A. D. (2017). Time-motion analysis as a novel approach for evaluating the impact of environmental heat exposure on labor loss in agriculture workers. *Temperature (Austin)*, *4*(3), 330-340. https://doi.org/10.1080/23328940.2017.1338210

Kenny, G. P., Groeller, H., McGinn, R., & Flouris, A. D. (2016). Age, human performance, and physical employment standards. *Appl Physiol Nutr Metab*, *41*(6 Suppl 2), S92-S107. https://doi.org/10.1139/apnm-2015-0483

Kjellstrom, T., Freyberg, C., Lemke, B., Otto, M., Briggs, D. (2018). Estimating population heat exposure and impacts on working people in conjunction with climate change. *Int J Biometeorol,* 62(3), 291-306. https://doi.org/10.1007/s00484-017-1407-0

Laitano, O., Leon, L. R., Roberts, W. O., & Sawka, M. N. (2019). Controversies in exertional heat stroke diagnosis, prevention, and treatment. *J Appl Physiol (1985)*, *127*(5), 1338-1348. https://doi.org/10.1152/japplphysiol.00452.2019

Leon, L. R., & Bouchama, A. (2015). Heat stroke. *Compr Physiol*, *5*(2), 611-647. https://doi.org/10.1002/cphy.c140017

Leon, L. R., & Kenefick, R. W. (2017). Pathophysiology of heat-related illnesses. In *Auerbach's Wilderness Medicine* (pp. 249-267). Elsevier Health Sciences.

Masanotti, G., Bartalini, M., Fattorini, A., Cerrano, A., Messeri, A., Morabito, M., Iacopini, S. (2019). Work in Harsh Hot Environment: Risk Evaluation on Thermal Stress in a Farm during Green Pruning Activity. *Biomedical Journal of Scientific & Technical Research* 16. https://doi.org/10.26717/BJSTR.2019.16.002865

Messeri, A., Morabito, M., Bonafede, M., Bugani, M., Levi, M., Baldasseroni, A., Binazzi, A., Gozzini, B., Orlandini, S., Nybo, L., & Marinaccio, A. (2019). Heat stress perception among native and migrant workers in Italian industries-case studies from the construction and agricultural sectors. *Int J Environ Res Public Health*, *16*(7). https://doi.org/10.3390/ijerph16071090

Morabito, M., Messeri, A., Crisci, A., Bao, J., Ma, R., Orlandini, S., Huang, C., Kjellstrom, T. (2021). Heat-related productivity loss: benefits derived by working in the shade or work-time shifting. *International Journal of Productivity and Performance Management* 70, 3, 507-525. https://doi.org/10.1108/IJPPM-10-2019-0500

Mora, C., Dousset, B., Caldwell, I. R., Powell, F. E., Geronimo, R. C., Bielecki, C. R., Counsell, C. W., Dietrich, B. S., Johnston, E. T., & Louis, L. V. (2017). Global risk of deadly heat. *Nature Climate Change*, *7*(7), 501.

Notley, S. R., Meade, R. D., D'Souza, A. W., Friesen, B. J., & Kenny, G. P. (2018a). Heat loss is impaired in older men on the day after prolonged work in the heat. *Med Sci Sports Exerc*, *50*(9), 1859-1867. https://doi.org/10.1249/MSS.0000000000001643

Notley, S. R., Meade, R. D., D'Souza, A. W., McGarr, G. W., & Kenny, G. P. (2018b). Cumulative effects of successive workdays in the heat on thermoregulatory function in the aging worker. *Temperature (Austin)*, *5*(4), 293-295. https://doi.org/10.1080/23328940.2018.1512830

Notley, S. R., Poirier, M. P., Sigal, R. J., D'Souza, A., Flouris, A. D., Fujii, N., & Kenny, G. P. (2019). Exercise heat stress in patients with and without type 2 diabetes. *JAMA*, *322*(14), 1409-1411. https://doi.org/10.1001/jama.2019.10943

Nybo, L., Kjellstrom, T., Bogataj, L. K., & Flouris, A. D. (2017). Global heating: Attention is not enough; we need acute and appropriate actions. *Temperature*, *4*(3), 199-201. https://doi.org/10.1080/23328940.2017.1338930

Onarheim, K. H., Phua, K. H., Babar, Z. R., Flouris, A. D., & Hargreaves, S. (2021). Health and social needs of migrant construction workers for big sporting events. *BMJ*, *374*, n1591. https://doi.org/10.1136/bmj.n1591

Orrenius, P. M., & Zavodny, M. (2009). Do immigrants work in riskier jobs? *Demography*, *46*(3), 535-551. https://doi.org/10.1353/dem.0.0064

Piil, J.F., Lundbye-Jensen, J., Christiansen, L., Ioannou, L., Tsoutsoubi, L., Dallas, C.N., Mantzios, K., Flouris, A.D., Nybo, L. (2018). High prevalence of hypohydration in occupations with heat stress—Perspectives for performance in combined cognitive and motor tasks. PLoS ONE 13(10), e0205321. https://doi.org/10.1371/journal.pone.0205321

Pogačar, T., Casanueva, A., Kozjek, K., Ciuha, U., Mekjavić, I.B., Kajfež Bogataj, L., Črepinšek, Z. (2018). The effect of hot days on occupational heat stress in the manufacturing industry: implications for workers' well-being and productivity. Int J Biometeorol 62, 1251–1264. https://doi.org/10.1007/s00484-018-1530-6

Pogačar, T., Kajfež Bogataj, L., Črepinšek, Z., Nybo, L. (2017). Comprehension of climatic and occupational heat stress amongst agricultural advisers and workers in Slovenia. Acta Agriculturae Slovenica 109, 3. https://doi.org/10.14720/aas.2017.109.3.06

Sawka, M., & O'Connor, F. (2020). Disorders due to heat and cold. In L. Goldman & A. I. Schaffer (Eds.), *Goldman - Cecil Medicine* (pp. 659-693). Elsevier/Saunders.

Sawka, M. N., Leon, L. R., Montain, S. J., & Sonna, L. A. (2011). Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Compr Physiol*, *1*(4), 1883-1928. https://doi.org/10.1002/cphy.c100082

Sterud, T., Tynes, T., Mehlum, I. S., Veiersted, K. B., Bergbom, B., Airila, A., Johansson, B., Brendler-Lindqvist, M., Hviid, K., & Flyvholm, M. A. (2018). A systematic review of working conditions and occupational health among immigrants in Europe and Canada. *BMC Public Health*, *18*(1), 770. https://doi.org/10.1186/s12889-018-5703-3

Tudor-Locke, C., Ainsworth, B. E., Washington, T. L., & Troiano, R. (2011). Assigning metabolic equivalent values to the 2002 census occupational classification system. *Journal of Physical Activity and Health*, *8*(4), 581-586.

USDAAF. (2003). *Heat stress control and heat casualty management* (Technical Bulletin, Medical 507 / AFPAM 48-152 (I), Issue.

Zander, K. K., Botzen, W. J., Oppermann, E., Kjellstrom, T., & Garnett, S. T. (2015). Heat stress causes substantial labour productivity loss in Australia. *Nature Climate Change*, *5*(7), 647.

Appendix 1

Work Heat Action Plan
WHAP

A HEAT-DEFENSE PLAN FOR KEEPING WORKERS SAFE AND PRODUCTIVE IN THE HEAT

A guide for employers, enterprises, trade unions and occupational health professionals

Prepared by the European Commission supported

HEAT-SHIELD PROJECT team

(Lead institution: University of Copenhagen, Prof. Lars Nybo)

www.HEAT-SHIELD.eu

August 2021

Overview

This document presents issues to consider in preparing protection for people who need to work in hot conditions. Heat waves are becoming more common and more intense in most of Europe. Working people working outdoors are at particular risk, but many workers in workshops, factories and warehouses can also be affected if an effective cooling system is not available. Ongoing climate change will increase the risks.
Additional information and infographics suitable for display inside workplaces, available in several languages; see list at end) can be found on the website: **www.HEAT-SHIELD.eu**

Have a plan

Don't be caught off guard! You need to plan for preventive actions during periods of high heat stress in your workplace ***before*** hot weather occurs. Such an advance plan should include everything you will need in terms of materials, for example refillable 1coolers or water containers that can provide workers with additional hydration, or provision of ice to provide additional cooling. It is essential to ensure that all employees are familiar with the heat defence plan and know what they should do to take care of themselves and their colleagues during periods of hot weather.

Pay attention to the weather and the local climate

Again, don't be caught off guard! Sign up to a weather notification service that will alert you to an approaching period of hot weather that could affect both your workers' health and productivity. We recommend the HEAT-SHIELD weather notification system (https://heatshield.zonalab.it/). In addition to weather notifications, you will also receive recommendations on what defence actions you should take in high heat conditions. Such actions will vary according to the weather, the type of work being undertaken and the clothing workers wear to work. Some protective clothing increases heat risks.

The hazards of excessive heat in workplaces are not only associated with heat waves. In large parts of the world the typical seasonal variations in climate create heat conditions that threaten the health and productivity of working people. You can find user-friendly information about the current and likely future climate in your location in the Heatshield supported website www.ClimateCHIP.org. The changing climate will increase heat problems in most parts of the world. The website pops up if you put the word "climatechip" into Google. You can then go to "Your Area" to see the ongoing maximum daily temperature trend in the location of the computer. You can use the search function to find information about a different location. The website has information about different heat variables for each month including the occupational heat stress index WBGT. You can also find trends for future increases in heat based on different climate change models.

Assess the risk

It is important to note that ***everyone*** is susceptible to heat stress and the related health risks. While older people are at particular risk during heat waves, studies have shown that young healthy men performing physically intense jobs actually suffer the most heat related health problems. It is useful to make a list of all those who might be at extra risk for heat related injuries. Such a list should include older workers, workers with physically demanding jobs, workers who operate in particularly hot areas (e.g. exposed to the sun, works close to hot machinery), new workers who have not experienced occupational heat stress before and workers who have had issues with heat in previous hot periods. During hot weather consideration should be given to assigning these workers to lighter tasks, giving them extra breaks, and checking with them every now and then to make sure they are feeling alright. It is also a good idea to establish a buddy system where workers check in with each other every half hour about how they are feeling.

Give extra breaks

Working in excessive heat slows many types of work activities and reduces hourly productivity. While it may seem counterintuitive, giving workers extra breaks throughout the day may reduce the negative impact of heat on net productivity. Hotter weather means that workers naturally take more unplanned breaks and slow down their work intensity. We recommend that you plan for 2-5 minutes break every 30 minutes, which reduces the number of unplanned breaks and gives workers time to cool down through the use fans, cool water, or other methods (see below). There is an international standard for work/rest time distribution in relation to heat levels (ISO standard 7243, 2017) and certain countries have similar guidance (e.g. NIOSH in the USA, 2016).

Reorganize the work day

An effective way to maintain workers' health and performance in hot periods is to reschedule the workday. This can be done by starting the work day 1 to 2 hours earlier so that the workers are most active during the cooler hours of the day. Work can be rescheduled so that the most physically demanding tasks, (when workers produce the most internal body heat) are carried out during the coolest hours of the day. Lighter tasks can be conducted during the hottest hours of the day. The same approach can be used for both indoor and outdoor work.

Provide hydration

This is probably the most important point of the entire plan. As dehydration intensifies the negative effects of heat on the body and decreases cognitive performance, which can lead to increased mistakes, accidents and injuries. Chronic dehydration will increase the likelihood of workers developing kidney disorders after long-term daily heat exposure. In particularly hot and sweaty conditions, a worker may sweat as much as 10 litres per work shift of 8-10 hours. It is particularly concerning that many workers arrive at their workplace in a dehydrated state. In hot situations workers should drink additional water before work starts.

During work workers need to be encouraged to drink regularly. This can be helped by reminder posters in common areas, and the provision of multiple water stations at job sites. Outdoor workers can be encouraged to carry hydration backpacks or belts with water bottles so they have constant access to water. In outdoor work sites easily accessible drinking water fill-up stations should be established.

Additionally, in "heavy sweating" situations, simply drinking water may not be sufficient to remain hydrated and protected. It may be necessary to add electrolyte solutions to the drinking water to replace salts lost from the body via the sweat. Affected individuals may also add extra salt to their diet, unless they have heart and blood pressure issues. Extreme heat exposure and work situations of this type will need expertise analysis.

Create "cooling oases"

As stated above, planned rest breaks are essential to maintain worker productivity. The benefits from rest breaks can be optimized by providing cooling oases for workers. Examples include dedicated rooms with air conditioning and cool water, or special areas, distant from hot machinery, can be equipped with electric fans and drinking water. Outdoors, the ideal rest area will have natural air flow and shade. If shade is not available, portable sun canopies and water should be supplied.

Cooling options during breaks

For extra cooling during breaks, several options exist:

Ice slurry ingestion: this can be done by adding shaved ice to drinks. An ice slushy/slurry machine is a good option for making ice readily available. While ice is the most desirable option, simply cooling water has a beneficial effect.
Arm immersion: immersion of the arms into water and ice for 5 minutes has been shown to be a very effective and simple way to effectively and quickly cool a person.

Cooling vests: Cooling vests come in two different forms, either using "phase change" materials or evaporative cooling. Phase change vests contain ice or cooling gel that gradually cools the wearer as they work. These vests are highly effective, however, effective cooling ceases when the ice or cooling gel melts. The vest needs to be changed and freezers need to be close by to re-cool the vests. Evaporative cooling vests need to be wet and cool the wearer as the water evaporates. However, while these vests are less of a logistical challenge, they are not effective in high humidity environments. There are new types of clothing coming onto the market that have personal fan units incorporated into them.

Ice towels: This method is a cheaper alternative to cooling vests. Towels are wetted and filled with ice. This can be a good solution during short periods with very high heat stress for cooling workers down during rest breaks. They can also be used in emergency situations when there is an acute need to lower skin temperature. If used over a prolonged period, they can lower deep core temperature as well.

Stationary Ventilation with fans: Increasing air flow across the skin enhances the body's natural heat loss processes, namely sweating. If the skin is wettened with a spray, cloth, or sponge, extra evaporative cooling occurs in addition to sweating.

Optimize clothing

A very effective way to improve worker comfort, health and performance in the heat is to ensure they are wearing appropriate clothing for the conditions. Clothing worn in hot conditions should be light, loose, and made of breathable fibres and textures to maximise the passage of air across the skin surface. Outdoors workers should wear long pants, long-sleeved shirts and hats to protect their skin against solar radiation. Lighter coloured clothing also helps to reflect solar radiation. Indoors workers are advised to wear light, loose clothing that exposes as much skin as possible to facilitate heat loss. For those working in industries requiring the use of heavier protective clothing, it is advisable to wear garments with mesh incorporated over areas such as the armpits, groin, elbows and back of the knees.

Signs and symptoms of heat illness

It is important for management and workers to be aware of the signs and symptoms of heat illness. These include:

Early symptoms

- Tiredness
- Weakness
- Dizziness
- Headache
- Muscle Cramps

More severe symptoms

- Cessation of sweating
- Breathing: fast and shallow
- Confusion
- Nausea or vomiting
- Fainting
- Skin: may be cool and moist
- Paleness
- Pulse rate: fast and weak

Treating heat illness

In the event of workers experiencing symptoms of heat illness, you should:

1. Move them to a cool area out of the sun
2. Loosen their clothing and sit them down to rest
3. Give them cool water to drink
4. Apply cool water to their skin

If a worker loses consciousness, call emergency medical services immediately. In the interim, apply whatever cooling is available, e.g. wetting the skin, applying ice to the body, particularly around the head and neck, and immersing the person in a tub of cool water if one is available.

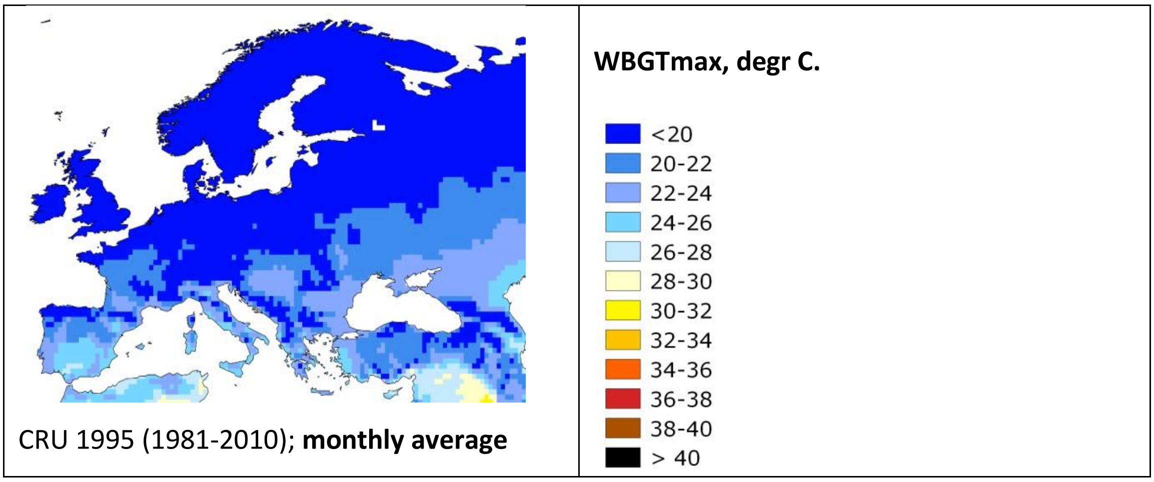
It is important also to keep records of any occurrence of symptoms like these or heat impacts on worker discomfort or productivity loss to enable detailed analysis of improved prevention methods. Reports of this kind will also improve projections of future heat impacts as climate change progresses.

Climate change consequences

An important current concern is the ongoing and future climate change and the consequences for a variety of workplaces as heat conditions worsen. The environmental heat levels will certainly increase and the likely developments in Europe are shown in the Figure below. WBGT (Wet Bulb Globe Temperature) is a commonly used occupational heat stress index. When the hourly levels exceed 26°C, physically intense work, such as in construction and agriculture, health and productivity is adversely affected. The figure shows monthly averages of daily maximum WBGT levels in the shade. Working in the sun during the middle of the day would add 2-3°C to these levels. The hottest days in a typical hot month would have levels 2-3°C higher, but serious heat waves can bring much higher levels.

Protection of working people from excessive heat with plans as outlined above will become more and more important in large parts of Europe. In addition, enterprises and communities need to take actions to reduce the actual climate change. This means reducing the emissions of greenhouse gases and local actions include the following:

- production and use of electricity from renewable sources (e.g. solar panels on factory roofs; solar driven air conditioning systems on roofs);
- reduction of energy waste in production processes and in heating or cooling systems in workplace buildings;
- limiting travel needs for staff: work from home; hold on-line virtual staff meetings; encourage the use of public or active transport (bicycling or walking) for essential work travel or commuting;
- implementation of operational changes that limit production of greenhouse gases in the workplace processes.



CRU 1995 (1981-2010); **monthly average**

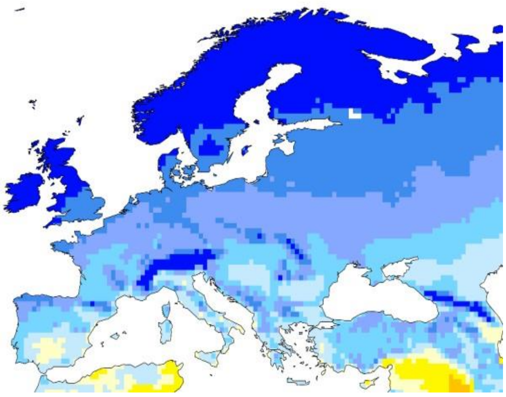
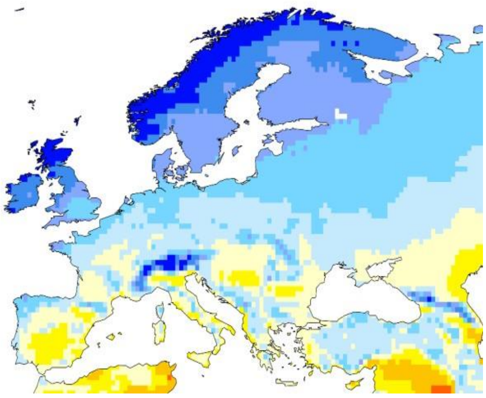
	
HadGem - GFDL mid-point, RCP6.0, 2085 (2071- 2099); **monthly average**	HadGem - GFDL mid-point, RCP6.0, 2085 (2071- 2099); **hottest 3 days**

Figure A1: Regional distribution of afternoon heat levels (hourly) in Europe during the hottest month; recent years and end of century values; WBGT heat index levels in the shade (Kjellstrom et al., 2018)

Further questions?

For more information on these and other ways to heat-proof your workplace, visit www.heat-shield.eu or contact consult@heat-shield.eu for free guidance on heat-health actions for your workplace. The website has copies of the infographics and can be printed for local use (in “Public Guidance” section. Languages available: English, French, German, Greek, Italian, Dutch, Portuguese, Slovenian, Spanish, Swedish). Country specific information and heat protection standards and recommendations, in local language, can also be sought on the internet.

Appendix 2

<u>A READY-MADE HEAT-DEFENSE PLAN FOR KEEPING WORKERS SAFE AND PRODUCTIVE IN THE HEAT</u>

<u>Please see accompanying document for detailed explanation of each category</u>

Be ready before the hot weather season	✓
Have a plan in place before the hot weather season	
Make sure all workers know the plan	
Organize a buddy system	
Have all needed equipment in place before the hot weather season	
Assess the risk	✓
Know that everyone can be at risk, but in particular	
Older workers	
Workers with physically demanding jobs	
Workers exposed to especially hot conditions	
New workers	
Know where the heat is coming from:	
Temperature	
Humidity	
Radiative heat	
Lack of air movement	
Pay attention to the weather	✓
Personalized weather platforms	
Local weather	
Give extra breaks	✓
If no breaks are given, workers will stop and slow down on their own. Counteract these affects by giving:	
2 min water breaks every 30 min	
5 min breaks every hour	
Longer breaks for more intense environments	
Reorganize the work day	✓
Start the work day 1-2 hours early	
Reschedule daily so the most physically demanding tasks are performed in the mornings	
Stay hydrated	✓
Dehydration hurts workers' productivity as well as their short and long term health. Strategies include:	

Make sure water is always nearby	
Workers should be drinking until their urine is light yellow or clear	
Ensure sufficient and clean lavatories are present so workers do not voluntarily dehydrate to avoid using facilities	
Special consideration for field workers:	
Provide workers with water carrying devices (e.g. belts and backpacks)	
Create water caches where workers can go to hydrate (e.g. fresh water jugs in shaded areas) and provide time to use lavatories	
Create cooling stations	✓
To improve the effectiveness of taking breaks, provide designated cooling stations which are:	
Equipped with fresh cool drinking water	
Stationary ventilators if AC not possible	
Small air-conditioned rooms indoors	
Shaded tents/parasols	
Cooling options	✓
Ice slushies	
Arm immersion	
Cooling vests	
Ice towels	
Stationary ventilation	
Optimize clothing	✓
Indoor:	
Incorporate ventilation patched into protective clothing	
Outdoor:	
Wear long loose-fitting, light-coloured, light-weight breathable garments and a hat	
Signs and symptoms of heat illness	✓
These include:	
cessation of sweating, paleness, muscle cramps, tiredness, weakness, dizziness, headache , confusion, nausea or vomiting, fainting, cool and moist skin, fast and weak pulse rate, fast and shallow breathing	
Treating heat illness	✓
In the event of a worker experiencing the symptoms of heat illness, you should:	

1. Move them to a cool area and out of the sun **2. Sit down and take a quick rest** **3. Drink plenty of cool water** **4. Apply a cool water on skin**	

Appendix 3: non sector-specific infographics

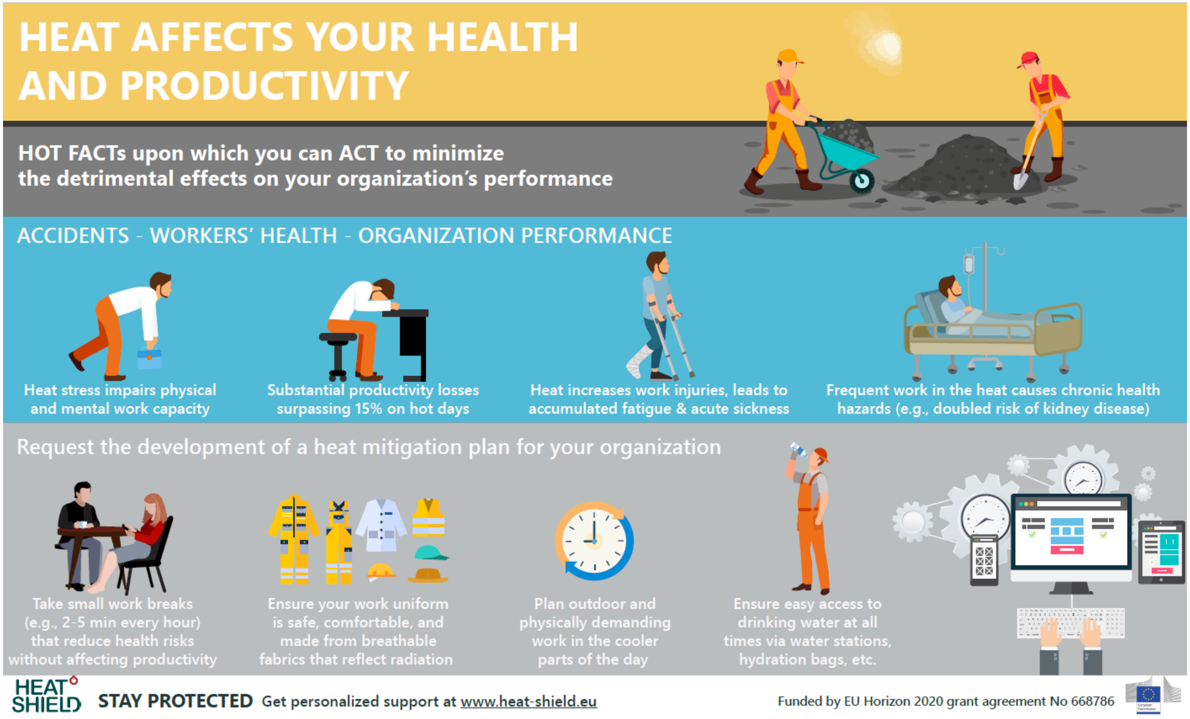


Figure A3.1: The HEAT-SHIELD infographic on heat stress effects on health and productivity

Figure A3.2: The HEAT-SHIELD infographic on preserving productivity in hot environments

Figure A3.3: The HEAT-SHIELD infographic on heat injuries

Figure A3.3: The HEAT-SHIELD infographic on hydration

Appendix 4 – The assessment of the HEAT-SHIELD platform

Report on activities performed within WP6 in the year 2020. A cross-sectional survey on the implementation of actions in the workplace to mitigate the effects of heat stress during summer 2020 in Italy.
(prepared by Emanuele Crocetti, Gianpaolo Romeo, Miriam Levi)

Introduction

The Horizon 2020 HEAT-SHIELD (Integrated intersectoral framework to increase the thermal resilience of European workers in the context of global warming) project aims to identify innovative technological solutions, preventive measures and specific behavioural guidelines for workers. Ultimately, it is intended to protect workers' health from the risks associated with high temperatures. Heat stress is the result of the sum of the ambient temperature with the production of intra-body heat due to physical activity. In addition, many other factors related to both the environment (humidity, natural ventilation, natural shading, etc.) and the organization of work (the type of clothing, frequency of breaks, availability of cold water and shade, air conditioning, etc.) can increase or mitigate heat stress.

One activity performed to achieve the HEAT-SHIELD's objectives has been the development of Occupational Heat-Health Warning System capable of providing customized heatwave forecasts and recommendations for the prevention of the negative health effects of heat stress for workers employed in several occupational sectors (agriculture, construction, transport, tourism and manufacturing). This tool provides each user with a personalized thermal risk forecast with specific recommendations for the next 5 days (and, with less reliability, up to 45 days). Personalization is achieved by using personal anthropometric characteristics, information on clothing, the level of intensity in the work, acclimatization and the characteristics of the environment in which the work takes place. Furthermore, the forecast is accompanied by specific guidelines to mitigate the effects of heat.

The aim of the present survey was to evaluate the use of the HEAT-SHIELD web-based platform and above all the implementation of measures aimed at mitigating the effects of heat during the summer season 2020 among Italian users.

Materials and methods

As part of the WP-6 of the HEAT-SHIELD project, different types of questionnaires have been developed: "before" questionnaires (before the company starts to apply mitigation measures) and "after" questionnaires (after companies applied measurements). Furthermore, as regards the "after" typology, specific questionnaires were addressed to workers and employers. This survey used an adapted version of the original "after for workers" questionnaire developed by Tjasa Pogačar. The survey was advertised in the HEAT-SHIELD platform webpage by adding a specific area "Take part in a survey on the mitigation of thermal stress in workers". In addition, an e-mail about the survey was sent to all platform users.

By clicking on the 'survey button', users were given access to the following introduction to the survey (in Italian), which summarizes the objectives: "As part of the European project HEAT-SHIELD (Integrated intersectoral framework to increase the thermal resilience of European workers in the context of global warming), we are conducting a research study on the heat stress perceived by workers in the hottest months of the year. We would like to hear from you on the effectiveness of the thermal stress mitigation measures that have been applied in your company. Your answers will help us develop guidelines to minimize the negative effects of heat and the resulting reduction in productivity. The survey takes no more than 10 minutes and the responses will be completely anonymous.

If you have any questions about this questionnaire, you can send an email to project.heathshield@google.com. We greatly appreciate your contribution". Before responders began to fill the questionnaire, there was a specific request for consent to the processing of personal information. The questionnaire was in Italian and had 18 questions. The questions addressed the following five topics:

- Personal data: age, gender and occupation.
- Activity: occupational sector, geographical location [classified as North (including Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piemonte, Trentino-Alto Adige, Valle d'Aosta, Veneto) Centre (Lazio, Marche, Toscana, Umbria) and South Italy (Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia, Sardinia, Sicilia)], and the altitude of the working environment (plain, hill, mountain).
- Portal: used for weather forecasts.
- Heat risks and prevention: awareness, who had informed her/him, how he/she was informed.
- Measures to mitigate the heat effect: whether any measures were implemented, type of measures, the satisfaction of measures concerning personnel aspect, productivity, social aspects, inequalities and general satisfaction.

There were three types of possible answers: open, drop-down menu (with also the open option), and Likert-type. The latter ones were related to the effects of the measures on specific dimensions (personal, productivity, social, inequalities, and overall) and could vary on a five-point scale from “not at all satisfied” (score 1) to “extremely satisfied” (score 5). The questionnaire was self-administered during the summer months of 2020. A first invitation to participate was sent during the last week of July and three reminders were sent in the first, the second and last week of September 2020. The collected data were analysed using descriptive statistics (frequency, mean, standard deviation) and analytical tests. Chi-squared test and Fisher's exact test were used for categorical variables, Student's t test for continuous ones. The five answers based on a score (from 1 to 5) were analysed with the Spearman's rank correlation coefficient for pairs of questions to check whether two (or more) scores' distributions were independent and with the Kolmogorov-Smirnov test to compare the equality of a distribution in two different populations. In particular, we compared men vs women, and managers vs. labourers. All analyses were performed by using Stata version 12.1

Results

From July 24th to September 22nd 2020, 36 participated in the questionnaire. Responders represented the 14.8% (36/244) of all those invited, i.e., those who had used the web-based platform at least once. They were 30 men (83.3%) and 6 women (16.7%), their age varied from 29 to 65 years with a mean of 53.2 years (SD 9.09). Age did not differ (t-test p=0.85) between men (mean 53.3 years, SD = 1.69) and women (52.5, SD = 3.68).

The responders covered a wide range of sectors. The majority of them (14, 38.9%), were employed in manufacturing activities (e.g. food industries, tobacco industry , textile / tanning industries, wood industry, paper, product manufacturing; overall 12 men and 2 women), five (13.9%; 4 men and 1 woman) worked for the public administration and defence, four (11.1%, all men) in scientific and technical activities, three (8.3%, all men) in the supply of electricity, gas, steam and air conditioning, two (5.6%, one man and one woman) in agriculture, forestry and fishing, two (5.6%) in the supply of electricity, gas, steam and air conditioning (both men). The last six people belonged to six different sectors (2.8% each): Financial and insurance activities (man), Construction (man), Extraction of minerals from quarries and mines (man), Instructions (man), Healthcare and social assistance (woman), and Information and communication services (woman).

Almost half of the responders (47.2%) worked in central Italy, 38.9% in the north and (13.9%) in the south. With regard to the altitude of the working environment, 23/30 worked in the plain (76.7%), 5 (16.7%) in the hills, and 2 (6.7%) in the mountains. The altitude did not differ across the three geographic area (Fisher's exact test, p = 0.215). Also, according to the duties the majority of the responders, 10/32 (27.8%) were involved in the protection and prevention service (8 Responsible for the protection and prevention service, Representative for quality certification and in charge for prevention service, and 1 Prevention technician) and 4 (11.1%) worked as directors. Overall, 8 responders (22.2%) were considered in the managerial group and 28 (77.8%) among labourers.

Regarding the question of whether they had been advised on how to act during hot days to mitigate the heat-related risks, 23 (63.9%) replied that they had been informed, whereas 13 (36.1%) had not. Most of the respondents replied that they had been informed by a (unspecified) reference figure (18/35, 58.1%). This was the response of all 8/13 who said they were not informed and 10/23 (43.5%) who did. The most frequently used single mean of information was orally (18/33, 54.5%), the Internet (6, 18.2%) and a training course carried out in the workplace and orally (5/33, 15.2% each), 16 answers mentioned two or more combined ways (those mentioned, and also flyers, WhatsApp, Twitter, newspapers, friends and family, TV and radio and workplace alerts, etc.). Oddly, 3/13 of those who declared not to have been informed mentioned a specific training course in the workplace.

Regarding the use of the HEAT-SHIELD web-based platform, 22 (61.1%) stated they were and 14 were not (38.9%) users. Thirty-four people replied to the question “Which measures to reduce negative heat impact did company use this/last year?” The most frequent answers (multiple choice possible) were ‘Making myself more aware about the risks of heat” chosen by 28/34 people, “Availability of water” 17/34, “Planning short breaks” 10/34, “Setting up shade/cooled areas” 5/34. Out of the measures one person replied “Nothing has been done”.

The question of whether the use of HEAT-SHIELD's suggested thermal mitigation measures applied by the company has helped to improve personal thermal well-being by reducing heat-related problems, received 9 (25.0%) scores 1 (worst score), two score 2 (5.6%), 11 score 3 (30.6%), 9 score 4 (25.0%) and 5 (13.9%) score 1 (best score) (Figure A4.1).

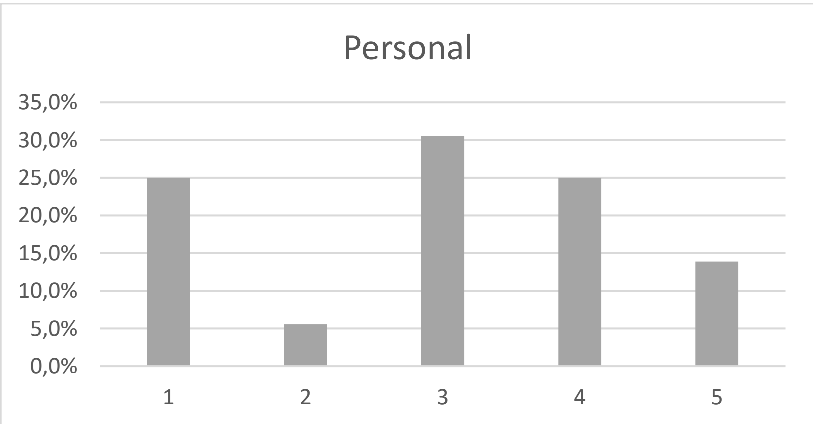


Figure A4.1: Answers to the question “Did the implementation of the measures to mitigate the effects of heat, recommended by HEAT-SHIELD, by your company improved your thermal well-being reducing heat-related problems (exhaustion, tiredness, headache, etc.)? From 1 (no) to 5 (very much).

The most appreciated (most frequently cited) measures mentioned together were “Making myself more aware of the risks arising from heat”, “Through training on the risks arising from heat", "Making me feel part of a common project', "Improving the protection of my health"," Offer all workers some of the measures (availability of water, breaks during the shift, etc.) "," Planning of short but frequent breaks during the work shift "," Exemption of the most vulnerable workers such as neighbouring ones to retirement, new hires or workers with chronic pathologists with more strenuous activities". They were all mentioned by 9/34 respondents (26.7%). Two answers stated: "I collected information on my own", and "I collected information in discussions with colleagues", respectively.

The question "whether the use of the measures improve your productivity as far as you can assess in loss of working hours?" (from 1 the worst to 5 the best score) got the following answers: number 1 five answers (13.09%), 2 six (16.7%), 3 fourteen (38.9%), 4 seven (19.4%), and 5 four (11.1%). In Figure A4.2 the scores' distribution is shown.

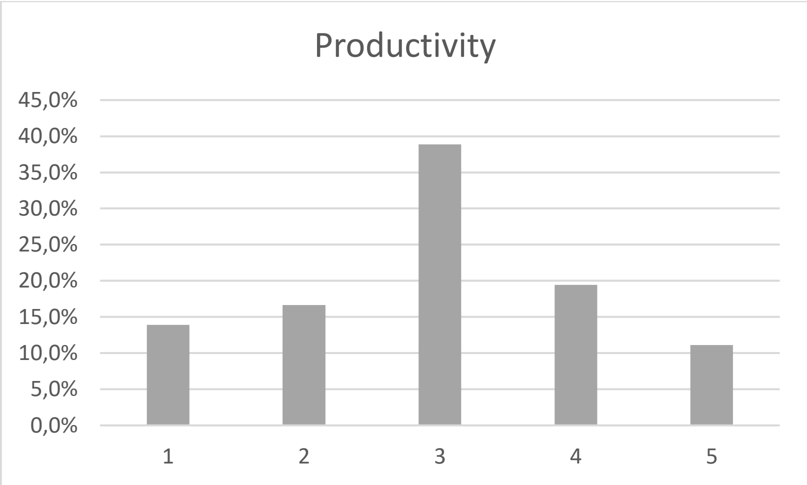


Figure A4.2: Answers to the question "Did the implementation of the measures to mitigate the effects of heat, recommended by HEAT-SHIELD, by your company improved your productivity as far as you can assess in loss of working hours? From 1 (no) to 5 (very much).

The Spearman's rho was 0.632, showing a certain amount of correlation between the two set of scores for "personal" and "productivity" questions, the value of the corresponding p, <0.001, is against the independence of the two set of answers.

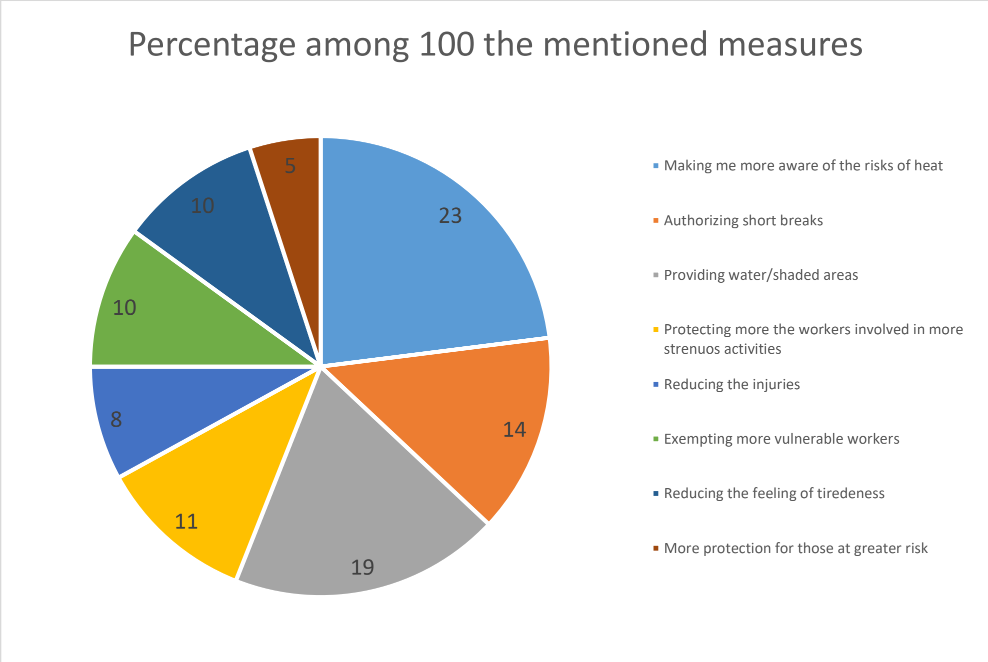


Figure A4.3: Most effective measures with regards to productivity.

Several answers mentioned more measures, the most frequently cited were “Making myself more aware of the risks deriving from heat” 23/100, “With the availability of water and of shaded/cooled areas”, 19/100, and “Planning of short but frequent breaks during the work shift”, 14/100. All the measures, and their relative frequency, are shown in Figure A4.3.

Two negative open answers stated that “The problem was not handled” and “common sense was applied. Moreover, no recommendations were found in the portal related to office work”. Another question addressed the perceived effect of the use of applied mitigating measures on the cooperation among co-workers and with employer (social aspect). The answers (from 1 the worst to 5 the best score) got the following scores: number 1 was chosen for five answers (13.9%), 2 for eight (22.2%), 3 for ten (27.8%), 4 ten (27.8%), and 5 for three answers (8.3%). Figure A4.4 shows the distribution of scores.

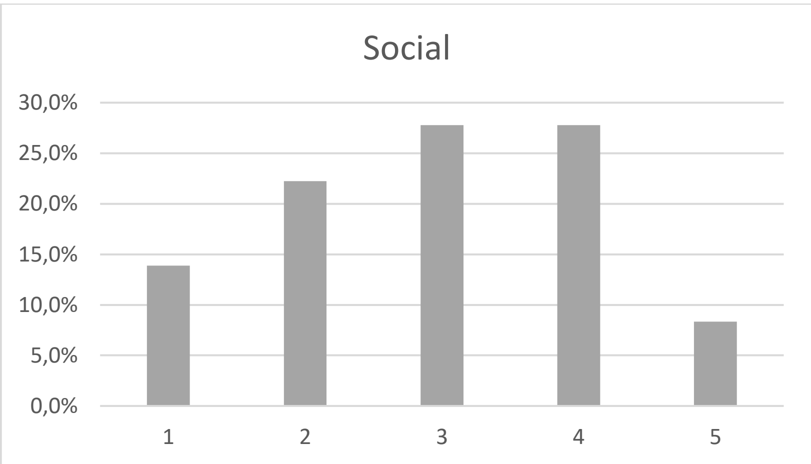


Figure A4.4: Answers to the question “Did the implementation of the measures to mitigate the effects of heat, recommended by HEAT-SHIELD, by your company was effective in coping with problems and cooperating among co-workers and with employer? From 1 (no) to 5 (very much).

The Spearman's rho between the scores to the 'social' and those to the 'personal' effects was 0.693 and that with 'productivity' of 0.879, both the sets of answers did not were independent ($p<0.001$). As regards the most mentioned measures (generally chosen together with others) for their 'social' effectiveness they were: "The training on the risks deriving from heat" relevant for 20/32 responders, followed by "Training on the risks deriving from heat", 19/32, "Enhancing the protection of my health", 14/7 and "Offering all workers some of the measures (availability of water, breaks during the shift, etc.)" 7/32. One open question stated that "The problem was not handled" and another "My colleagues and I acted according to common sense". One of the questions investigated the perceived effect of the use of mitigating measures in reducing inequalities. The score 1 was chosen by fourteen participants (38.9%), score 2 five (13.9%), score 3 eleven (30.6%), score 4 and 5 three each (8.3% each), Figure A4.5.

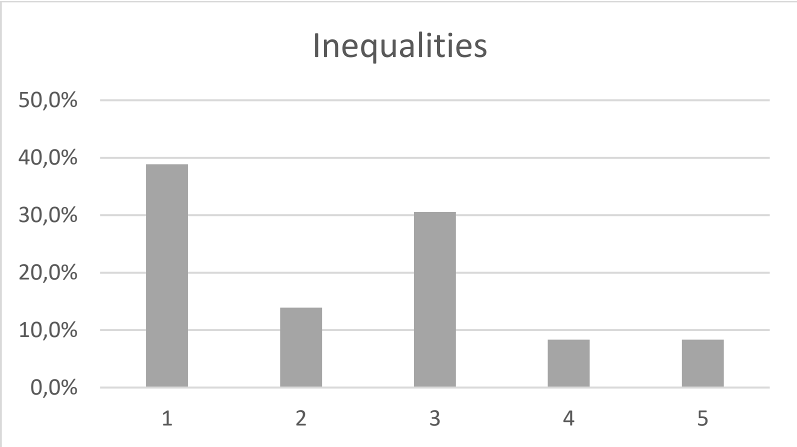


Figure A4.5: Answers to the question "Did the use of the measures reduce inequalities among workers (male-female, ethnic/religious background, young-old, etc.)? From 1 (no) to 5 (very much)

The Spearman rho coefficients was rather poor between inequalities and personal (0.4621, although was $p < 0.001$), and it was slightly better for the 'social' (0.697, $p < 0.001$) and productivity question (0.727, $p < 0.001$).

In Figure A4.6 the measures most frequently mentioned as effective in reducing 'inequalities' are shown among the 28 participants in the survey who answered this specific question. Multiple answers were possible.

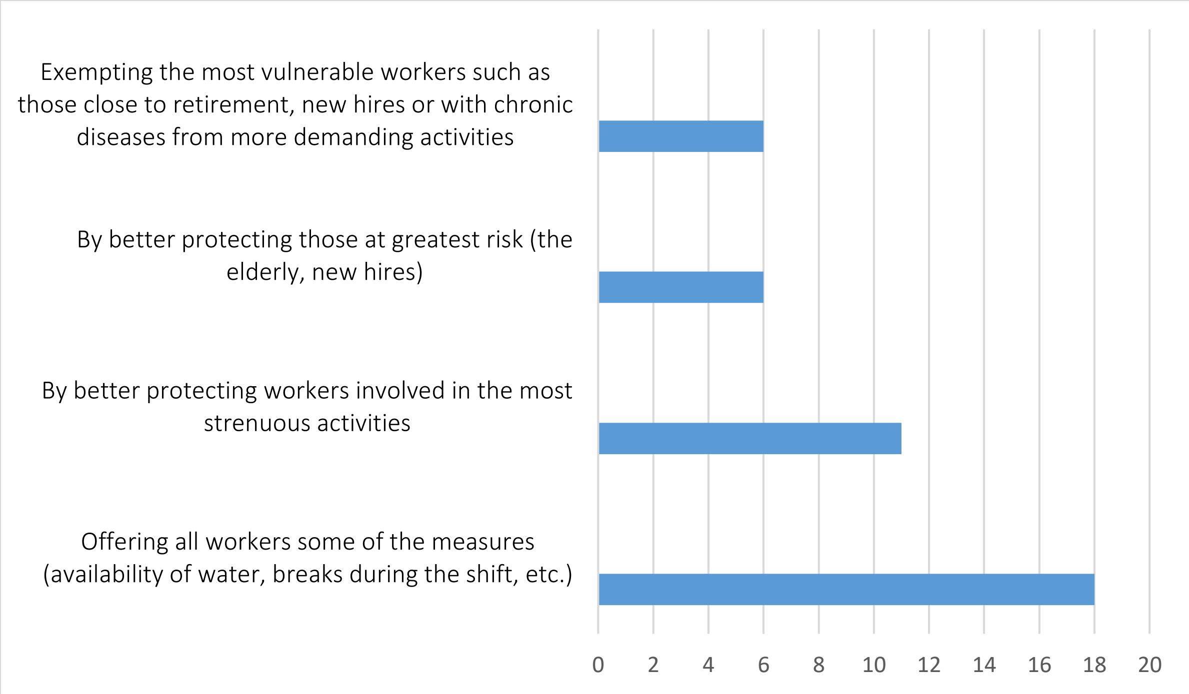


Figure A4.6: The measures most frequently cited as effective in reducing inequalities.

One open question stated that "The problem was not handled" and another "My colleagues and I acted according to common sense". The last question addressed the overall satisfaction with the measures currently adopted in your workplaces for reducing the effects of heat. Five responders (13.9%) very fully unsatisfied (score 1), four chose score 2 (11.1%), thirteen score 3 (36.1%), four score 4 (22.2%) and sic score 5 (full satisfaction) (16.7%), Figure A4.7.

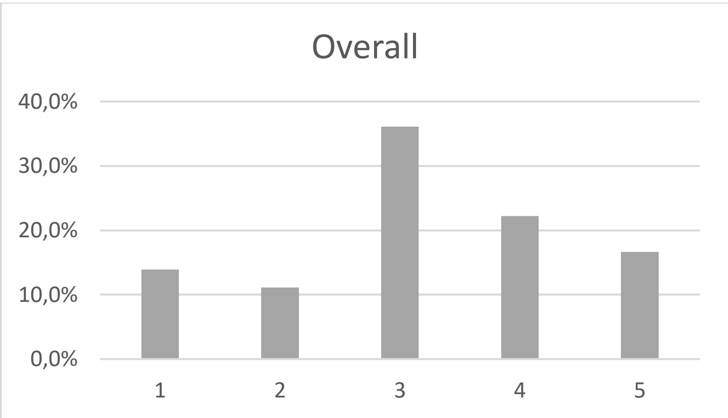


Figure A4.7: Are you satisfied with the measures currently adopted in your workplaces for reducing the effects of heat? Assess from 1 (no) to (very much).

The Spearman's rho with the previous four answers were: with personal (0.7058), with productivity (0.7816), with social (0.7963), and with inequalities (0.6393). In Table A4.1 the scores are presented for each responder and each question. To be noticed that some participant used the same score for all the questions. This pattern was particularly frequent for the score 1 ("not at all satisfied"), 4 people, and for score 3 (the average) and 5 ("completely satisfied"), 3 people each. All the people who used the same score to reply to all the five questions were labourers.

Table A4.1. Scores for each Likert question, ordered by answers to "personal" question.

Personal	Productivity	Social	Inequalities	Overall
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	2	2	1	2
1	3	3	1	3
1	3	3	3	3
1	3	3	3	3
1	4	2	3	3
2	2	2	2	3
3	1	2	1	3
3	2	2	2	1
3	2	2	2	2
3	3	2	1	4
3	3	3	1	3
3	3	3	3	3
3	3	3	3	3
3	3	3	3	3
3	3	4	3	3
3	3	4	3	4
3	5	4	3	4
4	2	1	1	3
4	3	3	3	5
4	3	3	4	4
4	3	4	1	5
4	4	4	2	4
4	4	4	2	4
4	4	4	2	4
4	4	4	3	3
4	4	4	4	4
5	3	3	1	2
5	4	4	4	5
5	5	5	5	5
5	5	5	5	5
5	5	5	5	5

For each one of the five Likert score questions we compared the sets of answers among men and women. The two groups did not differ for age (52.5 women and 53.3 years men, t-test p = 0.8473). Moreover, the use of the HEAT-SHIELD platform was practically the same (women 50.0% men 63.3%, Fisher's exact p=0.658). The two-sample Kolmogorov-Smirnov tests for equality of distribution functions did not detect any significant differences between sexes, for any of the five answers, although p was quite close to the significant level for the 'personal' one for which the median of the scores was 2.2 for women and 3.1 for men.

As regards duties, the two groups – managers and labourers - did not differ neither for age ('labourers' 51.9 'managers' 57.6 years, t-test p = 0.12) nor for gender (women 17.9% and 12.5 % respectively, Fisher's exact test p = 1.00). In addition, they use of the HEAT-SHIELD web-based platform was similar (57.1% vs. 75.0% users, Fisher's exact P = 0.44). Also, the geographical location (Fisher's exact p = 0.345), as well as the working altitude (Fisher's exact p = 0.286) did not differ between the two groups.

The Kolmogorov-Smirnov test showed that the answers to the question 'social' were not equally distribute between labourers and managers (p = 0.046), the median of the scores was 2.79 for the former and 3.5 for the latter. Moreover, for the question ‘overall’ the probability was close to the level of significance (p = 0.076), median of the scores 2.96 for labourers and 3.875 for managers. For the other three questions, although not statistically significantly different the median of the scores was slightly lower for labourers for ‘personal’ and ‘productivity’ and for managers for ‘inequalities’.

Discussion and conclusions

Thirty-six portal’s users answered the questionnaire aimed at evaluating both the use of the HEAT-SHIELD platform and the implementation of heat mitigating measures in the workplace during the 2020 summer season. The overall-invited people were the 244 corresponding to all those who had visited the website at least once. Considering this denominator, the participation rate was only 14.8%. Less than two thirds (61.1%) of the responders declared to use the HEAT-SHIELD platform to get personalized heat risk, with alarms and guidance on actions to mitigate heat effects. Personalised heat forecasts and recommendations are the main goals of the platform and the previous two answers show that some extra work needs to be done to promote the platform and to improve its capability of reaching the users for whom it was developed.

In 2020, the HEAT-SHIELD site statistics showed a daily average of 33.7 visitors (57.3 visits), with a huge fluctuation from month to month (from 5.2 in December to 76.9 in February). The number of visitors was quite high in the first three months (as in the last months of 2019), and then decreased significantly in the second quarter. In July, the number of visitors returned to be similar to that of the beginning of the year and the number of visits was the highest of the year (41,569 with 8,084 total pages visited). In the second half of the year, visitors steadily declined to a few hundred or even tens. We have not highlighted any specific changes in numbers following the sending of the invitation and reminder. In the period July-September the visits were 6,123, 17.8% of which lasted more than 30 seconds (up to more than one hour) to be considered the most significant contacts. However, the interpretation of these results is not straightforward considering that frequent visitors need just a few seconds to regularly check weather forecast (as recommended). At least some of these findings could be due to the Covid-19 pandemic that has dramatically affected the personal and professional lives of the entire population, including a total lockdown that lasted from March 9 to May 19 and selected lockdowns during the fall and winter. Participants belonged to a wide range of occupational sectors, not only the main five for which specific recommendations are provided (agriculture, construction, transport, tourism and manufacturing). Moreover, the declared duties show a wide range of jobs including also some rather far from the target (e.g., teacher) clue for the interest in the general population, but also the need to reach more and more effectively the activities at higher risk. A relevant proportion of participants were involved in prevention’s services. Therefore, presumably they may also share the specific information among their colleagues in the workplace. Thirty-eight-point nine percent of the responders considered the measures implemented positive (score 4 and 5) for the personal effect, 38.8% overall, 36.1% socially, and 30.6% for productivity. The smallest proportion of positive scores was for the questions about inequalities (16.7%, score 4-5). Almost two companies out of three (63.9%) had informed their employees about the risks connected with heat. More actions have to be undergone to reach also the remaining ones.

All the implemented measures corresponded to the HEAT-SHIELD recommendations: availability of water, short and frequent breaks, awareness about the heat risk, specific schedules of the work involving less the hottest hours, exemption of more fragile workers, Provision of shaded/cooled areas, etc. These answers are quite reassuring showing that the general message about the heat risk and how to prevent it is well known, at least, by some of the companies that applied them. The answers on the perceived effects of the implemented measures on different dimensions (personal, productivity, social, inequalities, overall) had a certain amount of correlation and the Spearman's rho ranged from 0.46 (between personal and inequalities) to 0.88 (between productivity and social). Therefore, it seems that responders perceived heat stress as related to different aspects but all belonging to a unique problem. Some responders used the same score throughout all the five questions, this was the case of 5 people who answered always with score 1, 3 with scores 3 and 5, and 1 with score 4. Fully satisfied and unsatisfied all belong to the labourer category. Trying to identify predictors for the score we analysed separately women and men. The question about inequalities got lower scores among women than men, although the difference did not reach the statistical significance level. Moreover, according to the declared duties we split the responders into labourers and managers to check if they had answered the Likert questions in different or similar ways. The two groups did not differ as regards age, gender, and proportion of users of the HEAT-SHIELD website. Moreover, they were similarly informed on heat's risks. As regards the questions on the effect of implemented measure on social aspects of work, the two distributions of score were significantly different and those related to overall effect were almost significant. Therefore, at least for these questions the duty may predict different scores to the same topic.

In conclusion, the general impression is that the website is a valid resource for the majority of the participants. In the companies that have implemented measures to mitigate heat stress, usually more than one measure has been mentioned, all belonging to those recommended. However, although the topic is relevant and rose the interest of many different types of workers, some of those at greater risk of heat stress may not have been reached. Therefore, more efforts are needed to increase the diffusion of the web-based platform, especially among workers who are the most at risk, and act for loyalty-building of users in order to make their visits to the platform regular to at best benefit from the personal weather forecast. Unfortunately, the concomitant Covid-19 pandemic may have had an effect also on the use of the website; a more reliable evaluation of the website activity would need usual and steady personal and professional conditions.

Appendix 5 – STRATEGIES FOR THE MANUFACTURING SECTOR

A5.1. Assessment of the heat-wave related productivity loss (field study)

(Prepared by Urša Ciuha and Igor B. Mekjavić)

Background

The study (Ciuha et al., 2019) evaluated the effect of heat waves on overall equipment efficiency (OEE) in the ''odelo d.o.o.'' company (Prebold, Slovenia), manufacturing automobile rear lights. The company employs over 1500 people, the majority of which are involved in the production process. The production area encompasses 40000 m^2, with five main interconnected halls. The halls have ventilation systems that exchange the air between the indoors and outdoors and regulate humidity, which needs to be maintained within a curtain range to ensure the quality of the product. Exchange between the indoor and outdoor air is especially effective at greater temperature gradients, meaning that during the cooler seasons the indoor air can affectively be cooled by supplying outdoor cool air to warm indoor environment. To increase ventilation, vents are also used. Since the company operates 24 hours per day for 7 days per week (''24/7'') with similar steady production process throughout the day, the heat from the machinery is constantly generated and can only be partly removed by the existing ventilation systems. This becomes an issue during summer and especially during heat waves, when heat accumulation becomes too severe (~30–32°C at the injection molding stations throughout the day) to be handled by existing ventilation systems, with temperature gradients between the indoor and outdoor conditions too low to notably affect the temperature within the factory. Work in the manufacturing process comprises plastic injection molding, metallization of components, and packaging/storage. The present analysis focused on the manufacturing hall devoted to injection molding, as it has the greatest source of thermal energy and thus the highest measured temperatures during normal weather conditions. Workers involved in the injection molding process are required to perform moderate intensity work, wearing normal clothing (T-shirt and trousers) (Figure A5.1.1).

Figure A5.1.1: Worker station at the odelo company

The workforce is predominantly female. The analysis of OEE was conducted during the summer months (June, July, and August) in 2017. Measurements were also performed during a control period in May of the same year. To collect information regarding indoor and outdoor absolute air temperatures of the company, the manufacturing halls were instrumented with 33 data loggers (MSR Electronics GmbH), measuring air temperature and humidity. Apart from the data loggers, a weather station (Davis Instruments Corp.) was installed on the factory grounds. The OEE score was used as an objective measurement of work efficiency, continuously calculated and monitored throughout the day for each of the working shifts. This method was considered as the least invasive and most acceptable by the companies' management and the workers, as it did not require extra effort and considered group performance, respectively.

Results

Outdoor air temperature was lower during the control period in spring (14.3 ± 2.8°C) than during the summer months (22.8 ± 4.9°C; $p < 0.001$). It did not significantly differ among the four heat waves.

Throughout the spring and summer months, the *indoor air temperature* was continuously higher (31.3 ± 1.9°C), whereas the relative humidity (RH) was continuously lower (35% ± 6%; $p < 0.001$) relative to the outdoor conditions, respectively (22.3 ± 5.2°C, and 68 ± 19%). The indoor air temperature was lower during the spring (29.0 ± 0.8°C; $p < 0.001$) relative to summer months (31.5 ± 1.9°C). It was higher during all heat waves ($p < 0.001$) relative to the air temperature measured before and after the heat waves. Indoor pre-heat-wave air temperature was similar to the temperature measured after the heat wave. During all heat waves, similar indoor air temperature was measured. Indoor air temperature was lower during the night shift (29.9 ± 1.5°C; $p < 0.001$) relative to temperatures measured in the morning (31.8 ± 1.6°C) and afternoon (32.2 ± 1.9°C) shifts.

Irrespective of the outdoor and indoor air temperature differences between the spring and summer months, the *OEE* was not affected by seasons, with similar OEE measured during spring and summer. The only exception was the OEE measured after the fourth heat wave (69 ± 9%), which was significantly lower than the one measured in spring (82 ± 6%; $p = 0.009$). A drop in OEE was observed after the second heat wave was already completed, namely in the post-heat-wave period. This drop was from 84 ± 7%, measured during the heat wave, to 78 ± 4% ($p = 0.014$) in the period after the heat wave. A substantial drop in OEE was also observed after the fourth heat wave, decreasing from 79 ± 8% to 69 ± 9% ($p = 0.021$), which, however, did not reach our Bonferroni-adjusted statistical significance level of 0.017.

Conclusions

The main finding of this study is that industrial productivity was affected in periods following heat waves rather than being directly affected during the four heatwave periods. In the periods following two of the four documented heat waves there was a significant drop in OEE, suggesting that insufficient recovery and interaction between occupational exposure and overall daily heat strain (outside working hours) are of importance for the integrated impact on indoor workers. Namely, during normal weather conditions, the outdoor air temperatures are significantly lower than those at the work stations. As a result, the workers can recover from any level of heat strain developed during the 8-h shift, due to the 16-h exposure to normal ambient conditions at home and at activities outside of work. This is reflected in an unchanged OEE score during normal weather conditions. During periods of heat waves, the workers may not be able to recover completely from the heat strain, experienced at work as well as home. As a consequence, a longer period of heat exposure may affect OEE because of a cumulative effect that results from an inability of the workers to recover properly after leaving work. This cumulative effect of heat waves may result in fatigue and thus a drop of OEE after a certain period.

A5.2. Assessment of the physiological strain to a simulated heat wave (laboratory study)

(Prepared by Urša Ciuha and Igor B. Mekjavić)

Background

Following the results from a field study (Ciuha et al., 2019), this next – laboratory study (Ioannou et al., 2021) focused on the evaluation of physiological responses during exposure to a heat wave and investigated the potential cumulative effects on labour productivity. Namely, despite this plethora of studies confirming the impact of short-term heat stress on workers' health and productivity, no controlled studies have been performed to investigate the cumulative effect of a prolonged heat wave on the labour productivity and physiological strain experienced by workers. The likely reason for this is the complexity of such study, which requires participants` confinement to temperature-controlled conditions 24/7, simulating the conditions to which the workers would be exposed during a heat wave. Furthermore, the industrial environment is not conducive to complex physiological measurements, which can be conducted in laboratory simulations. Measurements, such as skin and core temperatures, that are essential for determining the thermal status of workers, are considered too invasive in the working process. Therefore, the aim of this study was to transfer the working conditions within the odelo factory to a more controlled environment, where also other measurements could be obtained (i.e. skin and core temperature measurements, subjective interpretation of the environment, work performance etc.).

The study was conducted at the Olympic Sport Centre Planica (Rateče, Slovenia). Seven male participants were confined for ten days to designated areas of the centre in which the ambient temperature and relative humidity were monitored and regulated to simulate the conditions pre, during, and post-heat-wave. Specifically, every day they conducted a simulated work-shift in the laboratory and lived on one floor of the facility for the remainder of the time. Meals were taken in the cafeteria, which was the only area in which the ambient conditions were not controlled and hence always neutral (~23°C). A total of two hours per day was spent in the cafeteria (breakfast: 40 min, lunch: 40 min, dinner: 40 min). All participants arrived at the Olympic Sport Centre Planica on the same day. The first day (day 0) was dedicated to familiarisation with the experimental protocol. During this day we also obtained baseline measurements of body mass, body stature, and body composition using dual energy X-ray absorption (DXA, Hologic, Discovery W, QDR series; Hologic, Bedford, MA, USA). The participants were also familiarised with the simulated labour duties (i.e. computer tasks and physical activity) they would be conducting during their work-shift in the experimental days of the study. The following nine days were the experimental days, where the participants were exposed to temperate day-time/night-time temperatures on days 1 to 3 (pre-heat-wave) and on days 7 to 9 (post-heat-wave). While, on days 4 to 6 the ambient day-time/night-time temperatures were elevated to simulate the conditions of a heat wave. Specifically, air temperature was neutral (work = ~25.4°C and rest = ~22.3°C) pre/post-heat-wave and hot (work = ~35.4°C and rest = ~26.3°C) during the heat wave. Relative humidity was set to ~45% throughout the experiment. Solar radiation and air velocity were minor since our experiments took place in a shaded indoor environment, simulating an indoor manufacturing process. Wet-Bulb globe temperature was neutral (work = ~20.3°C and rest = ~17.6°C) pre-/postheat-wave and hot (work = ~29.0°C and rest = ~21.1°C) during the heat wave. During the experimental days, all participants underwent a simulated work-shift (duration = 08:40) on a daily basis followed by rest (duration = 07:20) and sleep (duration = 08:00) periods in a controlled environment. A strict time-framed (wake up: 07:00, breakfast: 08:00, work: 08:40–12:00, lunch: 12:00, work: 12:40–18:00, dinner: 18:20, free time: 19:00–23:00, shower time: 21:40–22:20, and sleep: 23:00) protocol of different psychophysical tasks was followed. To assure that the thermal and physiological strain experienced by our participants was not a product of endogenous factors, we instructed them to restrict physical activity during their free time to essential daily activities. No restrictions were placed on food/water (tap water) consumption, shower temperature, sleeping attire, or any other kind of work or non-work-related behaviour. During all the work-shifts, participants were provided with coveralls.

The level of physiological strain experienced by our participants throughout the study was assessed from measurements of body temperature [core temperature and mean skin temperature], heart rate, subjective ratings (thermal comfort and thermal sensation), and hydration status (urine specific gravity). The participants underwent two 40-min stepping sessions (STEP) on a daily basis at a rate of 12 steps per minute on a 20 cm-stepper (2.8 METs) to simulate the physiological strain experienced by workers during “manual or unskilled labour, light effort”. Each STEP session was followed by a 1-h simulated assembly line task (SALT), requiring the participants to perform quality control inspections of these electronic circuit boards in order to identify and discard faulty products and repair certain types of defective products (Figure A5.2.1).

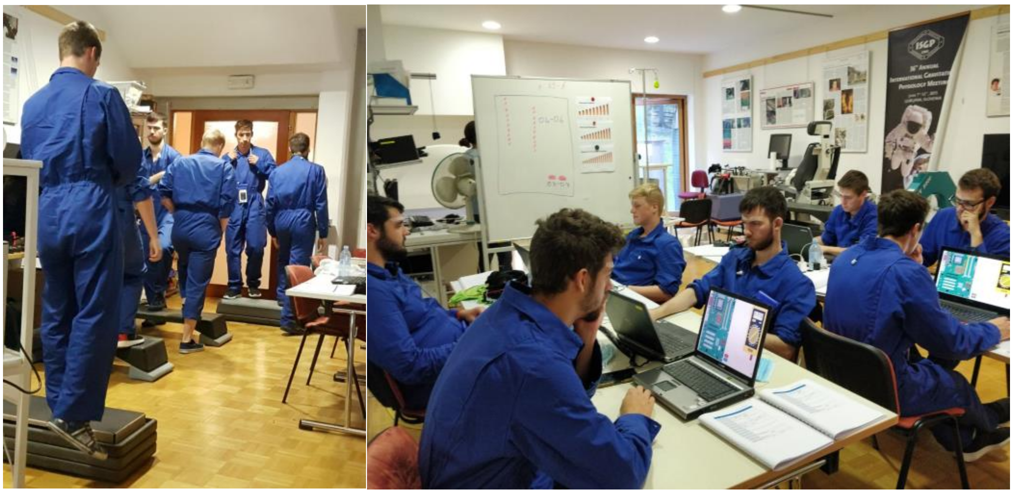


Figure A5.2.1: Participants during the simulated heat-wave study, doing the stepping (left figure) and simulated assembly line task (right figure).

Results

The simulated heat wave had unfavourable impacts on the physiological strain experienced by the participants. Specifically, skin temperature of the participants was approximately 1.2°C higher before the start of the work-shifts during the hot days (days 4–6) compared to the neutral ones (days 1–3 and 7–9) ($p < 0.05$). On the other hand, no such significant differences in the core temperature and heart rate were found before the start of the work-shifts. Moreover, heat wave impaired considerably the efficiency and physiological strain during SALT and STEP sessions. Interestingly, we found that during the simulated heat wave, visits to the toilet (neutral ambient temperature) increased by ~19.0% and were 1 min longer in duration (neutral days 3.2 min vs. hot days 4.2 min) ($p < 0.05$)—a finding possibly reflecting behavioural thermoregulation. No significant differences were found in urine specific gravity (i.e. at the end of work day) of our participants between the period prior to the heat wave and all the experimental days. We found significant moderate relationships during SALT sessions between efficiency and the variables of physiological strain index ($r = 0.344$, $p = 0.001$), thermal comfort ($r = 0.296$, $p = 0.003$), and thermal sensation ($r = 0.331$, $p = 0.001$). Moderate relationships during STEP sessions were identified between core temperature and the variables of skin temperature ($r = 0.373$, $p < 0.001$), heart rate ($r = 0.582$, $p < 0.001$), thermal comfort ($r = 0.301$, $p = 0.003$), and thermal sensation ($r = 0.281$, $p = 0.005$). Skin temperature was moderately related with heart rate ($r = 0.468$, $p < 0.001$) and strongly related to the subjective scales of thermal comfort ($r = 0.762$, $p < 0.001$) and thermal sensation ($r = 0.750$, $p < 0.001$). Heart rate was related with thermal comfort ($r = 0.502$, $p < 0.001$) and thermal sensation ($r = 0.444$, $p < 0.001$).

Conclusions

Despite following the current guidelines which seem to have a protective role in the physiological strain experienced by workers who work in such conditions, we found that the simulated heat wave increased the number of mistakes committed, the time spent on unplanned breaks, and the physiological strain experienced by workers. Our findings are in line with previous studies showing that occupational heat stress affects the capacity of workers to meet the cognitive and physical demands of their work. Although the identified increase in the number of mistakes made by our participants during the SALT task was just one percentage point higher during the first day (+1.0%p) and even lower during the second and third days of the heat wave (+0.5%p); this translates to a 35% increase in the overall number of mistakes committed during the onset of the heat wave or to a 17% increase throughout the heat wave compared to the neutral conditions. The economic fallout of this phenomenon might be devastating for small enterprises, with possible spill over effects and irreparable damage to the reputation of the company. The identified heat-induced labour loss involves several physiological mechanisms. Firstly, a heat-induced increase in the deep body temperature is an important contributing factor able to impair human cognitive performance and decision-making. Furthermore, hydration state is undoubtedly one of the most important pillars for healthy and productive work. This becomes even more apparent during work under heat stress, where water loss in the form of sweat often exceeds water consumption. Another key component of the identified heat-induced increase in the number of mistakes committed by our participants was their thermal comfort/sensation during SALT sessions, supporting previous findings which state that workers report higher labour productivity when their individual thermal satisfaction is greater.

A5.3 Assessment of different personal cooling systems/vests as a mitigation strategy (laboratory manikin and human study)

(Prepared by Urša Ciuha and Igor B. Mekjavić)

Background

Based on the results of the field (Ciuha et al., 2019) and laboratory (Ioannou et al., 2021) study, clearly demonstrating the effect of heat waves on work performance, the management of the odelo manufacturing company (Prebold, Slovenia) expressed an interest to explore the option of implementing personal cooling strategies in their production halls. It is well known that such strategies, including cooling vests, can provide an efficient and economically viable solution, especially since in many working scenarios air-conditioning might not be feasible, as it either provides insufficient cooling or presents a substantial financial burden (such as in the case of manufacturing industry with large industrial halls). However, choosing an appropriate vest for a specific condition can be challenging, as there is a wide variety of cooling vest types available and the choice relies mainly on manufacturers' descriptions of the products. Managers responsible for the safety and wellbeing of workers have no methods available with which to objectively compare cooling vests and thus be able to decide which would be the optimal solution for a specific type of work and working environment. Void of their cooling capacity, the material and design of a vest has an inherent resistance to the transfer of heat from the skin to the environment (thermal resistance), and represents a barrier for evaporation of sweat from the skin surface (evaporative resistance). Thus, an inefficient cooling vest can become a burden by adding an additional layer of insulation and a barrier for evaporation of sweat from the body. All vests will contribute such a burden once their cooling capacity is exhausted or impaired.

Therefore, the aim of this study (Ciuha et al., 2020) was to evaluate the cooling capacity of various commercially available vests of different cooling concepts. The measurements were conducted in controlled ambient conditions inside a climatic chamber using a whole-body thermal manikin. Based on an extensive market analysis more than 80 different cooling vests were identified, reviewed, and classified according to the cooling concept used. From each category, including *air-cooling vests, water cooling vests, evaporative vests, vests using phase-change materials and hybrid vests*, a few representatives were purchased, with a final number of 23 different variations of the vests. Their cooling capacity, thermal and evaporative resistance were determined on a thermal manikin. For the purpose of the study, a new measuring protocol was developed to determine a cooling capacity of each vest based on the average as well as maximal cooling power (P_{avg}/P_{max}; $W{\cdot}m^{-2}$) and cooling duration (min) – over 8-hour trials. Furthermore, five vests of different cooling concepts which provided the best combination of cooling power and duration on a thermal manikin, were evaluated on 10 male participants, while measuring and collecting their physiological responses (skin temperature, core temperature, microclimate temperature and relative humidity, heart rate) subjective reports (thermal comfort, sensation, moisture perception and perceived exertion), and cognitive performance (various tests). The trials were conducted in climatic chamber, starting with 30 minutes of sitting, after which the participants donned a cooling vest and started their 2.5 hr of walking on a treadmill with a speed of 4.5 $km.hr^{-1}$ and 1 % grade (Figure A5.3.1).

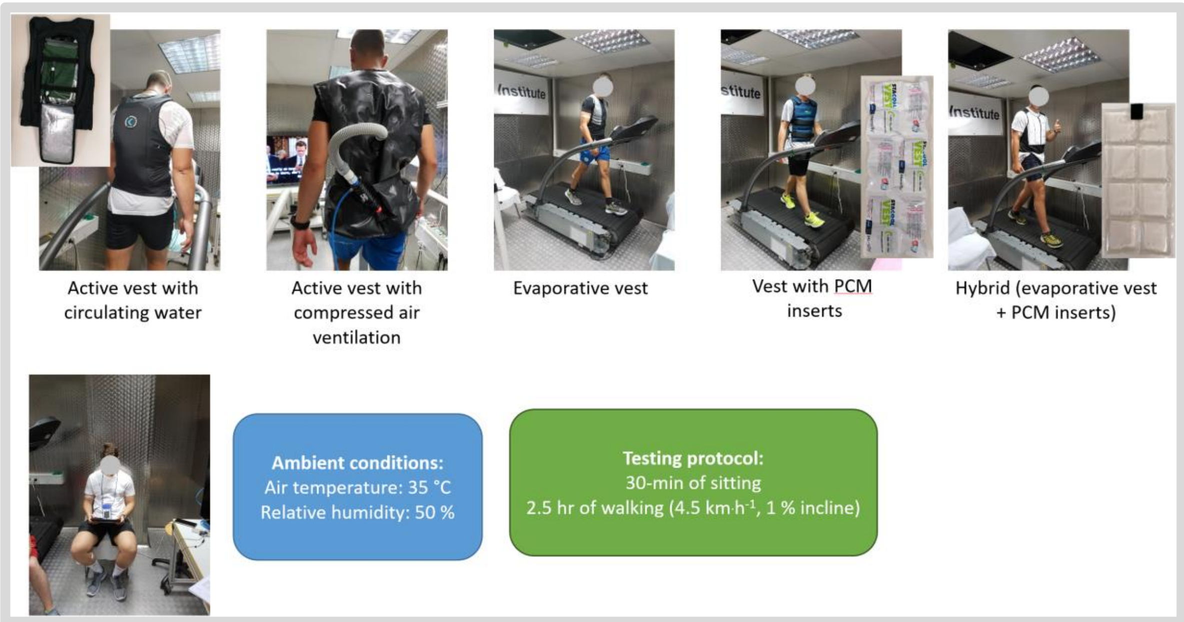


Figure A5.3.1: Experimental trials with five different tested cooling vests during walk (above) and rest with no vest with participant completing the cognitive performance tests before and after the walk (below)

Results

Based on the power and cooling duration of each vest, the area under the curve (AUC) was calculated. This value therefore presents the vest's cooling capacity. When comparing the vests with the largest AUC from each category according to the cooling concept, the *active-air-cooled vest* had the greatest cooling capacity (331 W.h.m^{-2}), followed by *vest with phase-change material inserts* (164 W.h.m^{-2}), the *hybrid vest* (146 W.h.m^{-2}), *active-water-cooled vest* (118 W.h.m^{-2}) and lastly by the *evaporative vest* (113 W.h.m^{-2}). These were also the vests that were further evaluated on participants.

The study on participants showed that all the vests reduced rectal temperature, with majority of them, except the evaporative vest, also reducing the torso skin temperature when compared to control condition with no cooling vest. Physiological responses, including core and skin, and microclimate temperature and relative humidity, were also reflected in subjective reports, with participants clearly identifying differences in perceptions during different trials. As expected, the active-air-cooled vest connected to unlimited source of compressed air cooled by a vortex system provided constant and stable cooling throughout the trial (torso skin temperature: ∼33.0°C). The strongest cooling was provided by the vest using PCM inserts, which reduced the torso skin temperature down to ∼27°C, reaching the same temperature as the active-air-cooled vest towards the end of the walk. Also active-water-cooled vest and hybrid vest were able to reduce the torso skin temperature substantially (the lowest measured torso skin temperature between 29 and 30°C, respectively), but their cooling power started to decrease after the first half of the 2.5 hr walk, reaching similar levels as in control trial by the end of the walk. Evaporative vest reduced the torso skin temperature only by ∼1°C when compared to control trial.

Conclusions

Under the given ambient conditions (temperature: 35°C, relative humidity: 35%) with a thermal manikin, the cooling capacities differed significantly among different vests and cooling concepts. For instance, some vests with frozen phase-change material inserts provided more aggressive cooling for a shorter period of time whereas evaporative vests provided milder cooling, but for longer periods. Thus, the former might not be suitable for industry workers during an 8-h shift.

When tested on participants, the vests in general provided shorter cooling duration than specified by manufacturer. If used in the working settings, this would mean that the majority of the vests (excluding the active-air-cooled vest, connected to unlimited source of power) would need to be reactivated. For some of the vests, this would require pre-planning, such as freezing of the inserts or preparing of the ice, whereas others, specifically evaporative vests, could be reactivated easily by saturating them with water. Therefore, the decision on the type of the cooling vest should be based on practicality, efficiency, comfort and affordability for a specific working scenario.

Appendix 6 – AGRICULTURE

A6.1 The report on project activities in Italy

(Prepared by Miriam Levi, Alessandro Messeri, Marco Morabito)

Background

Workers involved in moderate or high-intensity agriculture outdoor activities during the warm season are especially prone to heat-related health problems. Physical work activities create endogenous heat production, which adds to the environmental heat stress, and the workplace accident risk is also affected. Temperature extremes may lead to diminished occupational performance capacity and general performance degradation with a consequent increase of accidents and occupational injuries. UNIFI and CNR-IBE were involved in a recent meta-analysis (Binazzi et al., 2019), conducted to retrieve studies on the effects of climate change on occupational injury risk during the warming season. Pooled risk estimates for time-series and case-crossover studies combined, and then separated for sub-groups found increased risks for male gender, age <25 years and agriculture. In addition, in order to assess the efficiency of different strategies, UNIFI and CNR-IBE selected three different farms (FA) in the agricultural sector located in Tuscany region.

FA1 (Figure A6.1.1) is a flower-nursery farm engaged in the production of citrus fruits in greenhouses and is located in the province of Pistoia (Tuscany). The province of Pistoia is one of the Italian areas with the highest concentration of flower-nursery companies and the plants produced by these companies are exported throughout Europe. The production of citrus fruits, due to the winter cold, is carried out exclusively in the greenhouse where, during the summer period, the thermal conditions in which the workers are engaged, are characterized by intense heat (high temperature and very high humidity inside the greenhouses). More than 10 workers of this farm participated in the case studies foreseen in WP3 for two summer seasons (2017 and 2018).

Figure A6.1.1: FA1 (Source: UNIFI-IBE-CNR)

FA2 (Figure A6.1.2) is a winery farm engaged in the production of Vernaccia wine in in the province of Siena (Tuscany). The province of Siena, as well as that of Florence, is known all over the world for the production of high-quality wines which are exported all over the world. The wine sector in Tuscany represents one of the most important economic sectors, certainly the most important as regards the agricultural sector. During the summer, workers are engaged in outdoor activities and in particular in the green pruning and in the tying of the shoots, fundamental operations to guarantee a good production and ripening of the grapes. Such workers can therefore be exposed to extremely hot conditions in June, July and August. About 10 workers of this farm participated in the case studies foreseen in WP3 for two summer seasons (2018 and 2019).

Figure A6.1.2: FA2 (Source: UNIFI-IBE-CNR)

FA3 (Figure A6.1.3) is another winery farm engaged in the production of Chianti wine in the province of Florence (Tuscany). Over 10 workers were also monitored in this farm for three summer seasons (2017, 2018 and 2019)

Figure A6.1.3: FA3 (Source: UNIFI-IBE-CNR)

For evaluating, the effectiveness of HEAT-SHIELD strategies the following methodology was adopted:

Step 1: Identify potential work-sites (2016 and 2017)

Step 2: Select work-sites where HEAT-SHIELD strategies could be implemented and evaluated

Step 3: Contact work-site in-charge and tell them about the project

Step 4: Weather stations have been installed at the selected farms in order to continuously monitor the main meteorological parameters during the summer period.

Step 5: Days at risk of heat were identified, also exploiting the first version of the prototype of the hot warning system created as part of WP5 and, during these days, tests were realized in selected farms (2017 and 2018). In particular, a hot risk assessment questionnaire, a thermal sensation assessment questionnaire was administered at three moments of the working day. In addition, physiological measures on workers were taken (heart rate, oxygen saturation, urine sampling, and body weight). During the observation an analysis of the activity was carried out with particular attention to the description of the activities, the average and maximum duration, the period affected by the work situation, the number of workers exposed and the factors to be accurately quantified (air temperature, humidity, radiation, air movements, workload, clothing characteristics).

Results

From the data collected in the case study performed at FA3 (Teruzzi and Puthod farm), a scientific work was published (see Masanotti et al., 2019). During the study have been collected useful information to train and inform employers and workers, gives correct example on how this kind of risk should be assessed. Showing that already today it is appropriate to consider it with particular attention, in order to be able to adequately prevent it.

Another scientific paper (see Messeri et al., 2019) was carried out using the data and questionnaires collected from all farms (FA1, FA2, FA3) and this paper too can be a very important tool in raising awareness of the importance of hot risk assessment in the occupational field and in particular in the agricultural sector. In fact, the agricultural sector represents a strategic occupational field that in relatively recent years involve an increasing number of migrant workers, and therefore require a better management of cultural aspects, that may interact with and impact on heat-related health risk. For this reason, the study evaluated heat-stress perception and management among native and immigrant workers. The data collected (104 case studies), showed migrant workers declared that work required greater effort than do native Italian workers but reported less impact from heat on productivity and thermal discomfort. In addition, migrant workers were mainly informed through written or oral communications, while native workers received information on heat-health issues through training courses. These findings are of importance for future information and mitigation actions to address socio-cultural gaps and reduce heat-stress vulnerability.

The microclimatic data collected by the instrumentation installed at the farms were used to calculate the wet-bulb globe temperature and to estimate the hourly productivity loss and the economic cost during the typical working time (from 8 a.m. to 5 p.m.) and by advancing of 1 h and 2 h working time. The hourly productivity loss and the related economic cost significantly decreased by working in the shade and by work-time shifting (for more details see Morabito et al., 2021). Useful information to plan suitable heat-related prevention strategies to counteract the effects of heat in the workplace are provided. These findings are essential to quantify the beneficial effects due to the implementation of specific heat-related adaptation measures to counter the impending effects of climate change.

Current (previous) heat defence practices

Heat stress is a problem as confirmed by all the FA managers. It could affect worker's productivity and heat related illness. The selected farms are already using measures to counter the effects of heat on workers' health and productivity, such as a change in working hours during the summer season. The personnel manager of the FA1, for example, anticipated the entry to work at 5: 30/6: 00 from the beginning of June to the end of August while the exit is set at 12 noon. FA2 also provides for a shift in working hours during the hottest period of the year with entry to work which is anticipated by 1 hour (from 7 to 6:00) in the summer hottest periods. All the farms also organized specific training days to inform workers about the risks associated with heat exposure.

Appendix 7 – CONSTRUCTION

A7.1 The report on project activities in Spain - Acciona

(Prepared by Anurag Bansal)

Background

In order to assess the efficiency of different strategies, ACCIONA Construction (ACC) selected four different work-sites, so as to cover as many as possible different types of activities performed in a typical construction industry. Of these four sites, a total of 31 members participated, 4 were managers and 27 were workers.

WS-1 is a work-site located in Madrid (Spain) where the main task was assembly of a Tunnel Boring Machine (TBM). In this task on average 70% of the work is performed outdoor in an uncovered area, while 30% of the task is performed indoor (under a covered area). WS-2 is a work-site located in Madrid (Spain) where the main tasks are maintenance of the different machines used in construction for example Asphalt extenders, Dumpers, TBM, Compacters, etc. In this task on average 50% of the work is performed outdoors in an uncovered area and, the remaining 50% is performed indoors.

Fig. A7.1.1: WS-1 (source: ACCIONA)

Fig. A7.1.2: WS-2 (source: ACCIONA)

WS-3 is a work-site located in Toledo (Spain) where the main task was construction of a road. In this task, all the work is performed outdoor in an uncovered area. WS-4 is a work-site located in Madrid (Spain) where the main tasks was construction of a residential building. Here, 40% of the activities are performed outdoor in an uncovered area (before the construction of walls and slabs) and 60% indoor (under covered area).

Fig. A7.1.3: WS-3. (source: ACCIONA)

Fig. A7.1.4: WS-4 (source: ACCIONA)

For evaluating, the effectiveness of HEAT-SHIELD strategies the following methodology was adopted

Step 1: Identify potential work-sites (2019)

Step 2: Select work-sites where HEAT-SHIELD strategies could be implemented and evaluated

Step 3: Contact work-site in-charge and tell them about the project without giving them information on how to cope with heat

Step 4: During spring 2020 circulate the “before” questionnaire that are developed and translated in local language within the project

Step 5: Before summer 2020, circulate all the respective information (platform, infographics, instructions, etc.)

Step 6: During the summer, keep regular communication with them and collect relevant data

Step 7: During autumn 2020, circulate the “after” questionnaire to the same WG so as to evaluate the effectiveness of the HEAT-SHIELD strategies based on data collected during summer 2020.

All participants were male, age of 31 to 60 years.

Results

All workers who participated considered heat stress as a problem. Construction activities requires lot of time (up to 100%) that is spent in heat and hence they are exposed to heat stress conditions, as replied 85% participants. However, 89% of them have not taken days off due to heat stress in last 10 years. 55% of the participants categorized the temperature on their work-site as “very warm”. They sweat a lot - 70% of the respondents chose the option “clothes sticking to the skin surface” while 11% chose the option “fully wet”. For 63% the surrounding temperature was “hot”, for 15% it was “warm”, for 11% it was “extremely hot” and for 11% it was “neither hot nor cold”. However, only 11% of the participant felt “exhausted” while 89% felt “tired”. 4% of the workers consider the working space as “limited”, 33% as typical” and 63% as “spacious”. When asked about where they do most of their work, the reply was, 70% do it “outdoor”, 11% performs it “indoor”, and 19% replied “both outdoor and indoor”. 82% of the workers wear “cotton and synthetic” cloths (light-reflecting jackets are mostly made up pf synthetic material). 48% of the workers perform their activities “walking” as opposed to 11% who perform their activities ”usually sitting”.

As confirmed by the managers, the most significant negative impact of heat is productivity decrease due to “worker absenteeism”. When asked which measures did they used to reduce negative impact of heat, two WS managers told that used “reduced-work hour, i.e. from 8am till 2pm” strategy apart from having fresh-water drinking facility at different locations in their work-sites, giving short-breaks and providing PPEs to the workers. The other two WS managers that they provided solar cream, PPE to all their workers and, also re-schedule the activities by changing shifts so that the same worker is not exposed to the same work environment.

Current (previous) heat defence practices

Heat stress is a problem as confirmed by all the WS managers. It could affect WS productivity and heat related illness (50% have recorded restricted duty in the past). They perform real-time monitoring of heat-stress, based on air temperature and worker inputs. At one WS they use Dry bulb temperature and wet bulb globe temperature. All the WS have Heat action plans that are managed by H&S and company's medical staff. Front-line supervisors are the ones who are conducting pre-job evaluation to assess the level of heat-stress, and based on written guidance they implement necessary precautions. However, there is no training program for managing heat-stress or heat-related illness. All the WS uses PPEs, hydration regimes and work-rest ratios as preventive action, however, one WS in addition also uses central or local air-conditioning. In order to overcome negative impacts of heat they inform workers periodically— through face-to-face workshops and open-discussions.

Feedback on the HEAT-SHIELD heat defence plan (and other materials)

HEAT-SHIELD strategies have resulted in improving one-way or other the workers' well-being, relation with co-workers and therefore resulted in increasing productivity (as measured through for example absenteeism of workers from work). The HEAT-SHIELD platform and materials have also given a good impression on the users as they provided a useful source of information in mitigating heat-stress. Unfortunately, due to the unprecedented situation created by Covid-19 pandemic, strategies were not able to be exploited to the fullest. At two WS's managers were not able to use the HEAT-SHIELD platform because of other urgent and un-avoidable need to implement workers' safety and health strategies to combat covid-19 pandemic.

Overall, WS managers found HEAT-SHIELD strategies handy and effective (rating of 3 or above on a 0-5 scale, where 0-means no improvement, and 5-means maximum improvement), as they helped reduce the worker absenteeism through personalized weather prediction and detailed infographics.

However, activities for various sectors should be more specific. Mobile application should have the option of synchronization of location of WS team (including their physical conditions), this could help to provide immediate first-aid to the worker (if required).

BARIERS for adopting measures

70% of the workers did not use HEAT-SHIELD platform due to the fact that they did not have access to desk-top in work-sites (possibility to use the platform as an app or even with smart watch).

A7.2 The report on project activities in UK

(prepared by Josh Foster, James Goodwin and George Havenith)

UK Met office. FitzRoy Road, Exeter, Devon, EX1 3PB

A series of meetings was held with the MET office with the aim to develop a joint approach/action. Members from Loughborough University pitched the HEATSHIELD project to the UK Met-Office. The aim of the pitch was to form a collaboration (HEATSHIELD/Met-Office); where the MET office would benefit from the latest and most up-to-date science on how to maintain health and productivity in the heat; where Lboro would benefit from acquiring met office industrial links and exposure on the MET-OFFICE web page. The industrial links were to allow access to industry which would help Lboro fulfil the requirements for WP6. A partnership was however not achieved despite genuine interest and enthusiasm for the project. Funding issues for the MET office side were a dealbreaker.

Conversations with Loughborough University's Health and Safety Office (Neil Budworth (Lboro Health and Safety Director))

Writing new Loughborough University health and safety policy for workers during heat wave events in the UK, collaborating with Prof Neil Budworth (Health, Safety, and Risk Manager, Loughborough University). The new policy advises on how to classify a heat event, and mitigation measures for indoor and outdoor workers, based mostly from HEAT-SHIELD research. Loughborough University is a large institution which employs 3,800 staff and has 18,000 students.

From these contacts, connections were made to be able to present the heat shield work at the UK occupational health conference, 2020.

Developing partnership with British Occupational Hygiene Society (BOHS) for developing access to industry

First contact 4/12/2018. This was followed by a series of meetings and presentations of the heatshield work to BOHS.

First meeting (BOHS visit EERC 4/3/2019) - Josh prepared presentation. In attendance: Simon Festing, John Dobbie, HEATSHIELD.

EERC meeting 21/05/2019 (JF, JG, JS)

Teleconference meeting Simon Festing 28/06/2019

Derby meeting BOHS 17/07/2019

Produce legal agreement between Loughborough University and BOHS 12/08/2019

Meet legal team Loughborough Uni 17/09/2019

Amend legal agreement to non-binding MoU, ready for singing. The agreement includes 30/01/2020: BOHS promote new findings from HEATSHIELD research

Joint working by means of pilot exercises for specific purposes of evaluating evidence related to advice for different industrial sectors (satisfying WP6), e.g. on infographics (receiving feedback)

Based on the interests and needs of BOHS, and the developing COVID crisis, with expanding heat stress especially in clinical work settings, Foster agreed to a request from BOHS to prepare a scientific paper for the BOHS Journal *Annals of Work Exposure and Health.*

In 2020, a new CEO for BOHS was appointed (Kevin Bampton). New update meeting 06/04/2020

To keep things moving forward, EERC asked by BOHS to produce some documents for construction and agriculture to attract them to need for HEATSHIELD heat stress intervention – 07/04/2020

First draft documents produced for construction and agricultural industries (See Annex A and B). Document provide details of why heat stress is a problem. Includes predictive modelling of extra labour requirements with increasing heat, and projected economic cost with and without cooling solutions validated by HEATSHIELD 19/04/2020

Above documents amended and ready to be distributed by BOHS to relevant project managers. 23/04/2020

Meeting to discuss BOHS next steps (HEATSHIELD members only). Agree to focus majorly on construction, and less so on agriculture based on BOHS feedback. 23/04/2020

As part of agreement with BOHS (MoU, see above), produced a commentary paper which was originally intended to promote the general impact of heat stress on industry workers' health and productivity. In light of the COVID pandemic, we produced a commentary paper (see Foster et al., 2020). 30/04/2020

Meeting to discuss BOHS progress regarding links to Agriculture and Construction for the purpose of Loughborough fulfilling field work related to WP6. 21/05/2020

Ongoing collaboration is BOHS to prepare documents for dissemination. Produced 600 word article for BOHS to disseminate to those involved in highway construction in the UK (See Annex C). 28/05/2020

Central HEATSHIELD meeting with all partners to discuss WP6 and refine heat action plan and decision trees produced by Nathan Morris.

BOHS/Loughborough work to form partnership with EDF Energy, a major energy supplier in Europe. An agreement was put in place for Loughborough to visit the site of a new power plant (Hinkley Point C). The aim of the field visit was to assess the heat strain levels in workers and identify avenues for implementation of HEATSHIELD cooling strategies. – 02/07/2020

Hinkley Point C agree for Loughborough to make first visit to assess heat stress severity. Visit set for 13/08/2020 – 21/07/2021

Plan produced for HPC visit by JF to maximize output for WP6 deliverable – 05/08/2020

Questionnaire to field workers produced to satisfy requirements for WP6. Aim to assess impact of heat on workers.

Visited HPC construction site of two nuclear reactors. Identified areas for potential heat stress issues and ways in which this can be negated in the future. Full details sent to BOHS and EDF energy. EDF do not follow up for future correspondence. During the visit, EDF not convinced of a requirement for adoption of HEATSHIELD guidelines. Major hurdle being the need to employ somebody to implement cooling solutions despite hot weather in the UK being sporadic and inconsistent. Despite that, there is a clear risk of heat stress in workers at HPC.

Therefore we recommended the adoption of a heat action plan and implementation being triggered according to the HEATSHIELD web platform. 14/08/2020

Loughborough participant in and present at the BOHS annual conference (online) to promote HEATSHIELD and further opportunities for WP6 delivery. Required production of a 20 minute prerecorded powerpoint presentation - 01/10/2020

Produce report on findings from HPC visit (see Annex D) 20/09/2020

Summary

While substantial time was committed to developing the various contacts and generate materials for BOHS, unfortunately the COVID circumstances made it difficult to actually interact with industrial partners directly. Hence, most work was done at a higher level via BOHS through which valuable feedback on heat shield and its ‘products’ was obtained.

Annex A1

Occupational heat stress in the agricultural sector: Implications for labour capacity.

- The UK will experience more frequent, prolonged, and intense periods of hot weather as a result of climate change. The summer season of 2019 was “much warmer than average” and is projected to get hotter for the next 50 years. Increased climatic heat is an occupational hazard. Occupational heat stress can negatively affect workers’ health and their performance capacity, which subsequently may **lower productivity and income** for the individual and/or company. **Increased project costs** with heat are directly related to lost working efficiency or indirectly via illness/sickness of individual workers. Heat already contributes heavily to global labour loss and is expected to rise until at least the year 2050 regardless of the CO_2 emission scenario (Figure A1.1).

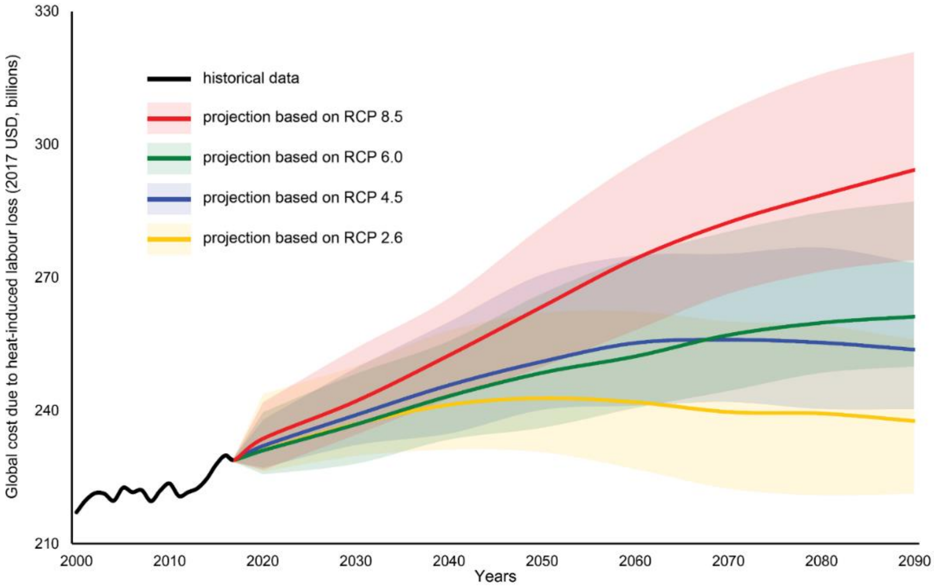


Figure A1.1: Projections of global cost due to heat-induced labour loss.

- Occupational heat stress is an important parameter in the agricultural sector, which contributes 1% of UK GDP. It is particularly relevant here because many tasks rely on manual work as the prevailing and, sometimes, only feasible method for performing tasks. Harvesting makes up a large proportion of the work shift and has been shown to be susceptible to heat induced productivity loss in several studies. The different tasks relevant to agriculture and the order of physical work intensity is shown below in Figure A1.2.

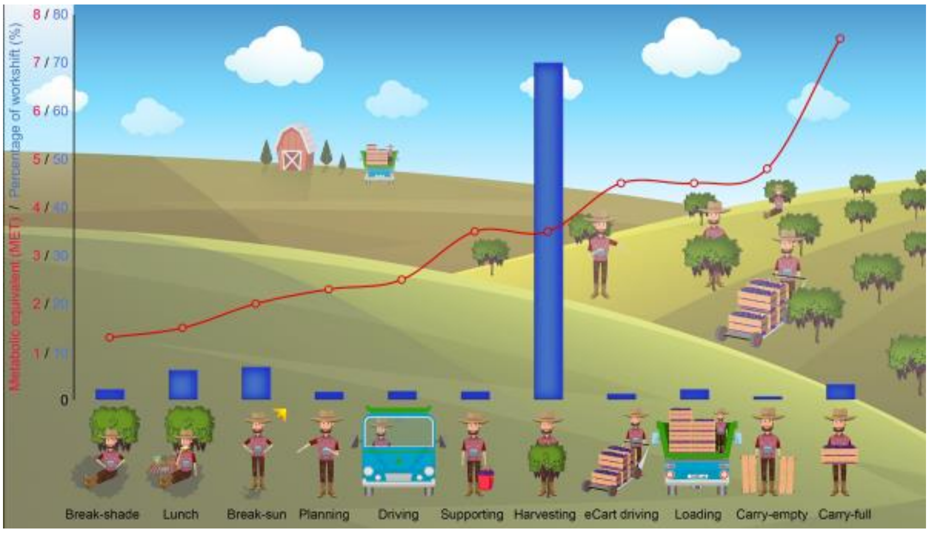


Figure A1.2: Tasks relevant to agriculture and the order of physical work intensity

- HEATSHIELD have conducted field studies in the agricultural industry to determine the extent of lost productivity. Using video analysis (time-motion analysis), we determined productivity in hot and cool working conditions, and found a clear relationship between air temperature and labour loss (Figure A1.3). Specifically, 16% of the work shift was lost on irregular breaks when air temperature exceeds 29°C*. Unplanned breaks are commonly used by workers to find repose from the heat and help lower their heat strain, but at the cost of reduced productivity.

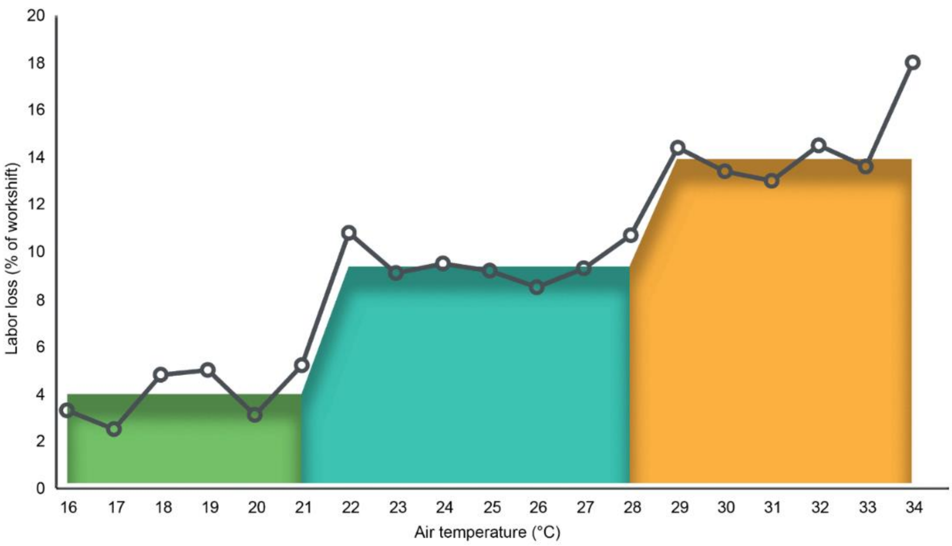


Figure A1.3: Relationship between air temperature and labour loss in % of workers

- The graph shows the consequences of heat stress on agriculture. We show that labour capacity decreases with rising temperature. As reference, the summer of 2019 saw temperatures reach near record highs of 38°C. In conditions seen during the 2003 European heat wave, labour loss due to heat reached would have reached nearly 30%. The data above shows that an entire work shift is lost per 10 shifts once air temperature reaches 22°C*.

- Productivity loss is only one facet to consider. With prolonged heat, workers are more likely to take sick leave due to i) heat causing issues associated with sustained dehydration, and ii) heat increasing likelihood of workplace accidents. HEATSHIELD partners find that 50% of workers in agriculture start the shift already dehydrated. The combination of dehydration and environmental heat can aggravate heat stress symptoms in agricultural workers, and cause health issues.

- Overall, occupational heat stress compounds productivity loss in the agricultural industry. The United Kingdom is likely to experience the worst impacts during heat waves, but negative health and economic effects are seen in a typical British summer.

Occupational heat stress in the agricultural sector: Effective solutions

- It is advisable that agricultural firms, from large industrial operations to small family farms, consider/develop an appropriate heat response plan as it will benefit both employer and employee perspectives. Single or combined heat resilience methods appropriate/applicable for the specific work setting should be identified and translated into feasible actions and habits that workers can adopt during hot periods – with timely information at the beginning of the summer and regular follow-up reminders.

- This plan may be qualified by a designated person and benefit from consulting advanced warning weather systems to warn in advance when a period of hot weather is expected. An advanced weather warning system with personalised recommendations is available http://heatshield.zonalab.it/

- Below are the effects of some tested interventions on labour loss (Figure A1.4).

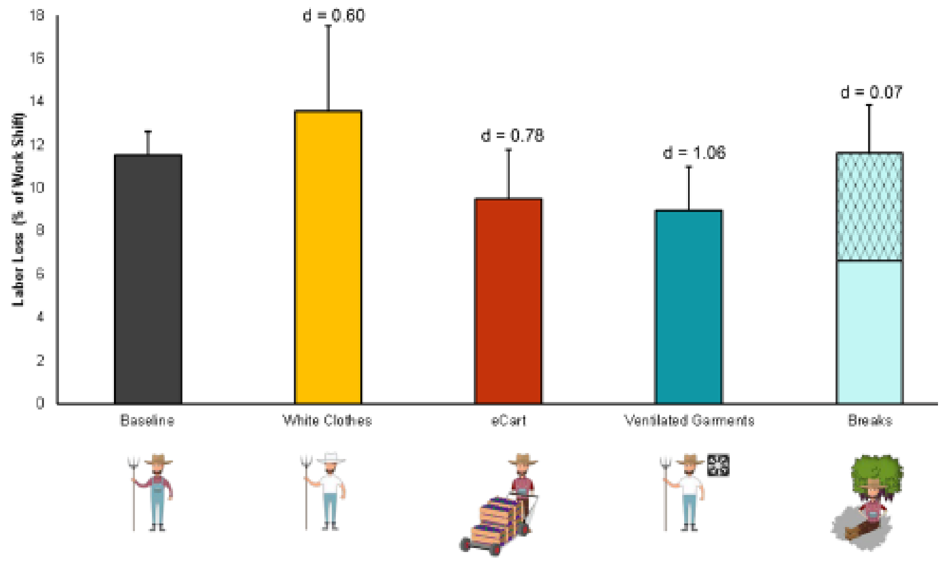


Figure A1.4: Effects of tested interventions on labour loss in % of workers

- Adding ventilation into garments offered the most effective biophysical solution to mitigate climate induce heat stress. Figure A1.5 below shows some specialised garments with ventilation added to the side panel.

Figure A1.5: Specialized garments with ventilation

- In general, the same effect can be achieved by reducing the total amount of skin covered by clothing by wearing a t-shirt vs long sleeve (if indoors), wearing looser fitting clothing which allows for greater air flow underneath the clothing, and wearing clothing with a wider knitting pattern which allows for more air flow to pass through the clothing. Additionally, lighter colours should be selected on sunny days in outdoor environments to increase the reflection of solar radiation.
- Adequate hydration solutions have an enormous positive impact on reducing time spent on irregular breaks, improving productivity. Staying hydrated is critical for maintained productivity and health in the agricultural industry. Unfortunately, most workers forget or fail to rehydrate from day-to-day. Thus, 50% of agricultural workers arrive at work in a dehydrated state. This means they start the day at an elevated risk for hyperthermia and acute kidney injury, as well as low probability for performing at their best during their work shift. For this reason, it is important that strategies are put in place for workers to have access to cold/cool water throughout the day.
- Reschedule the most physically demanding work tasks to the coolest time of day

Annex B1

Occupational heat stress in the construction sector: Implications for labour capacity and build delays.

- The UK will experience more frequent, prolonged, and intense periods of hot weather as a result of climate change. The summer season of 2019 was “much warmer than average” and is projected to get hotter for the next 50 years. Increased climatic heat is an occupational hazard. Occupational heat stress can negatively affect workers’ health and their performance capacity, which subsequently may lower productivity and income for the individual and/or company. Increased project costs with heat are directly related to lost working efficiency or indirectly via illness/sickness of individual workers. Human function depends on a balance between internal (metabolic) heat production and heat-exchange with the environment. If metabolic heat is not released to the environment, this heat will warm up the worker, increase heat strain, impair both physical and cognitive function and potentially provoke fatal overheating.

- Occupational heat stress is an important parameter in the construction sector, which contributes 8% of UK GDP. Last summer, the UK reached 37°C, and had one of its warmest summers on record. It is particularly relevant to construction because many tasks rely on manual work as the prevailing and, sometimes, only feasible method for performing complex tasks. Job types shown to be vulnerable to heat in the scientific literature are rebar work, bricklaying, masonry work, labouring, frame workers, and steel erection. However, almost all construction tasks where workers are exposed to heat will suffer negative productivity consequences.
- HEATSHIELD have conducted field studies in the construction industry to determine the extent of lost productivity. Using video analysis (time-motion analysis), we determined productivity in hot and cool working conditions, and found 10.1% of the working day was spent on unplanned, irregular breaks in the heat, but this decreased to 2.7% on a cooler day. Unplanned breaks are commonly used by workers to find repose from the heat and help lower their heat strain, but at the cost of reduced productivity.
- Environmental heat stress is best measured by the Wet-Bulb Glove Temperature (WBGT). It provides a temperature based on air temperature, thermal radiation from sunlight or heat generating equipment, humidity, and wind speed. HEATSHIELD have generated a productivity loss model based on WBGT, which can be used to calculate other economic metrics. The relation of these metrics to WBGT is shown below (Figure B1.1), assuming no mitigation efforts to curtail the effect of heat on workers.

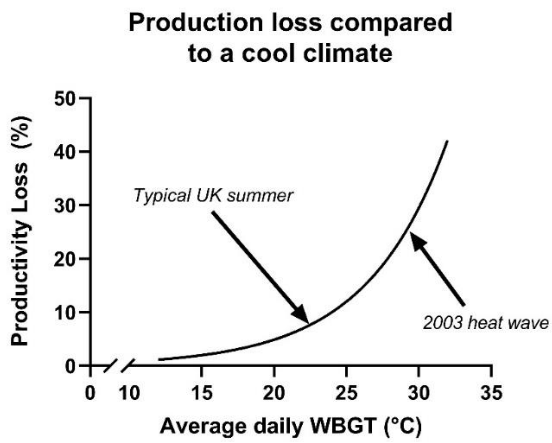


Figure B1.1: Relationship between average daily WBGT and productivity loss in %

- The graph shows the consequences of heat stress on construction. We show that labour capacity decreases exponentially with rising WBGT, even for an unremarkable British summer. In conditions seen during the 2003 European heat wave, labour loss due to heat reached nearly 30%. For a summer build lasting 3 months, such conditions would delay total build time by about 40 days, and the extra labour required to mitigate these delays (~3 extra shifts per 10 shifts) would cost ~ £3,000.00.
- Productivity loss is only one facet to consider. With prolonged heat, workers are more likely to take sick leave due to i) heat causing issues associated with sustained dehydration, and ii) heat increasing likelihood of workplace accidents. HEATSHIELD

partners find that 90% of workers in construction start the shift already dehydrated, and 80% remain dehydrated after the shift. The combination of dehydration and environmental heat can lead to the following symptoms in construction workers, shown in Figure B1.2.

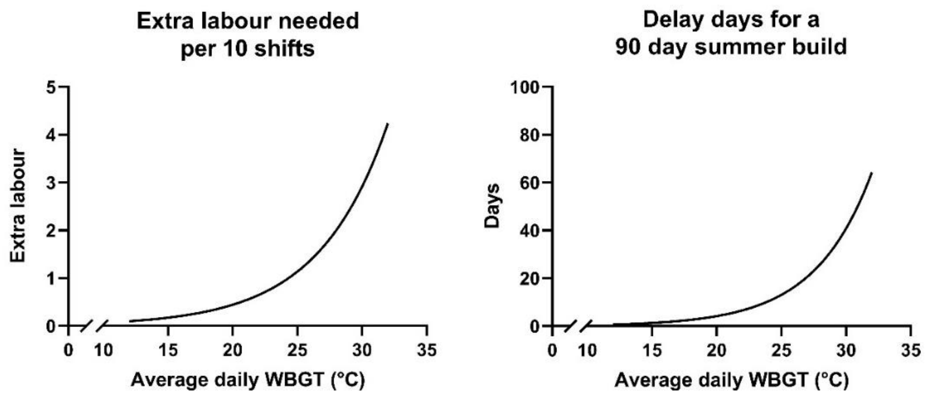


Figure B1.2: Relationship between extra labour needed per 10 shifts and average daily WGBT (left), delay days for a 90-day summer build and average daily WGBT (right)

- Overall, occupational heat stress compounds productivity loss in the construction industry. The United Kingdom is likely to experience the worst impacts during heat waves, but negative health and economic effects are seen in a typical British summer. The HEATSHIELD project has developed countermeasures to alleviate the effect of heat on workers, reducing the need to reinforce labour supplies which incurs an economic burden.

Occupational heat stress in the construction sector: Effective solutions

- HEATSHIELD partners have developed and screened different methods which can mitigate the negative economic impacts of heat in construction.
- It is advisable that construction firms, from large multinational corporations to small local contractors, consider/develop an appropriate heat adaptation plan to protect both employer (by maintaining productivity) and employee (by minimizing health risks) benefits. This plan may be qualified by a designated person and benefit from consulting advanced warning weather systems to warn in advance when a period of hot weather is expected. An advanced weather warning system with personalised recommendations is available http://heatshield.zonalab.it/
- The figure B1.3 below demonstrates the impact of some other interventions screened on a construction site in Zaragoza, Spain, for their effect on reducing labour loss.

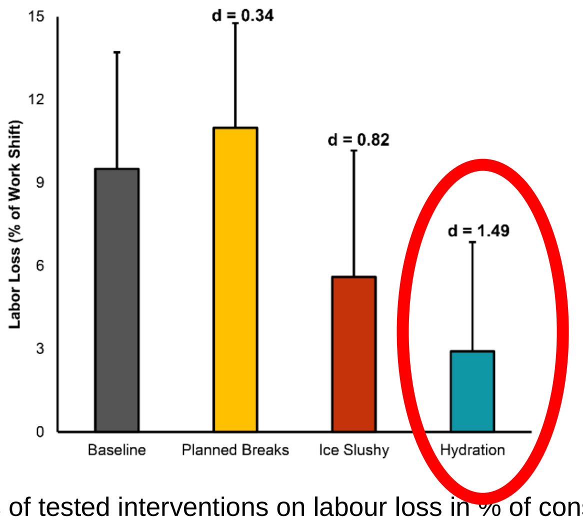


Figure B1.3: Effects of tested interventions on labour loss in % of construction workers

- Adequate hydration solutions have an enormous positive impact on reducing time spent on irregular breaks, improving productivity. Staying hydrated is critical for maintained productivity and health in the construction industry. Unfortunately, most workers forget or fail to rehydrate from day-to-day. Thus, 90% of construction workers arrive at work in a dehydrated state. This means they start the day at an elevated risk for hyperthermia and acute kidney injury, as well as low probability for performing at their best during their work shift. For this reason, it is important that strategies are put in place for workers to have access to cold/cool water throughout the day, even when working on different floors or remote areas of a construction site.

- Clothing is important for construction workers because it can lower the worker's thermal stress. Construction workers require special protective clothing (gloves, helmet, boots, etc.). To facilitate heat loss, clothing worn during the work shift should be selected based upon promoting air flow across the skin and improving sweat evaporation (reducing clothing evaporative resistance). This can be accomplished by reducing the total amount of skin covered by clothing by wearing a t-shirt vs long sleeve (if indoors), wearing looser fitting clothing which allows for greater air flow underneath the clothing, and wearing clothing with a wider knitting pattern which allows for more air flow to pass through the clothing. Additionally, lighter colours should be selected on sunny days in outdoor environments to increase the reflection of solar radiation. In situations where long, rigid clothing must be worn (e.g. coveralls), ventilation patches can be incorporated into more protected areas such as under the arms and between the legs to help promote air flow through the garment (Figure B1.4).

Figure B1.4: Specialized work clothes with ventilation patches under the arms and knees

Annex C

<u>Article to Safer Highways</u>

Environmental heating is a growing challenge for our community and problems are already experienced by millions of people during the summertime and aggravated further during heat waves. The United Kingdom (UK) will be and has already been directly affected by global warming. We will experience more frequent, prolonged, and intense periods of hot weather, evident by the fact that last summer was much warmer than average and is projected to get hotter for the next 50 years, even with aggressive mitigation of greenhouse gases. Increased climatic heat exposure is a significant occupational hazard. Working in hot conditions can result in poor judgment and risk-taking behaviours, increase the risk of kidney disease through dehydration, and reduce the physical productivity of workers. The health, safety, and productivity consequences of heat should not be taken lightly even with accompanying technological development.

The construction sector makes up about 8% of UK GDP, but its workers are especially vulnerable to the effect of heat. The industry has already suffered a 25% output loss due to the COVID-19 pandemic and cannot afford further losses due to heat. Moreover, increased adoption of face masks and PPE due to COVID-19 aggravates symptoms of occupational heat strain. Taken together, exposing employees to hot workplace conditions (either caused by weather and/or protective clothing) is likely to jeopardize the health and safety of the worker, incur build delays, and increase project costs. It is particularly relevant to construction because many tasks rely on manual work as the prevailing and, sometimes, only feasible method for performing complex tasks. Job types shown to be vulnerable to heat in the scientific literature are rebar work, bricklaying, masonry work, labouring, frame workers, and steel erection. However, almost all construction tasks where workers are exposed to heat will suffer negative health productivity consequences.

HEATSHIELD is a European Union funded project which aims to combat the negative impact of heat on European workers. The project began in 2016 and involves a collaboration of Europe's leading experts in human physiology and climatology. First, researchers identified the extent of the problem using field observations and laboratory simulations, finding that heat *already* has a significant effect on health and work efficiency, but there exists a lack of up-to-date measures in place for employers to alleviate the impact. The graphics below (Figure C.1) demonstrate the impact of environmental heat on the production loss, based only on how much physical labour can be performed by an employee with increasing heat.

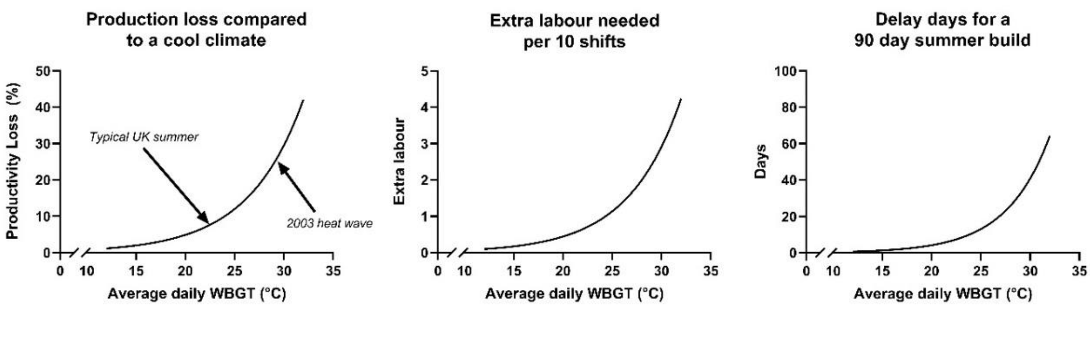


Figure C.1: Relationship between production loss compared to a cool climate and average daily WGBT (left), extra labour needed per 10 shifts and average daily WGBT (centre), delay days for a 90-day summer build and average daily WGBT (right)

The models presented are based on work simulations conducted in state-of-the-art climatic chambers at the Environmental Ergonomics Research Centre, Loughborough University. The economic implications of heat are clearly relevant to the UK. Our typical summer results in nearly 10% lost productivity, which can be counteracted with expensive additional labour, or not counteracted at all, at the cost of significant build delays. Importantly, as a result of climate change, our "typical" summer temperature is undoubtedly going to increase for at least another 50 years regardless of climate policy. Last summer, the UK reached 37°C, and had one of its warmest summers on record. Such a climate results in a WBGT close to 30°C, a significant hazard to construction productivity and worker health and safety.

Physical productivity loss is only one factor to consider. With prolonged heat, workers are more likely to take sick leave due to i) heat causing issues associated with sustained dehydration, and ii) heat increasing likelihood of workplace accidents. HEATSHIELD partners find that 90% of workers in construction start the shift already dehydrated, and 80% remain dehydrated after the shift. The combination of dehydration and environmental heat can lead to symptoms in construction workers shown in the below graphic (Figure C.2).

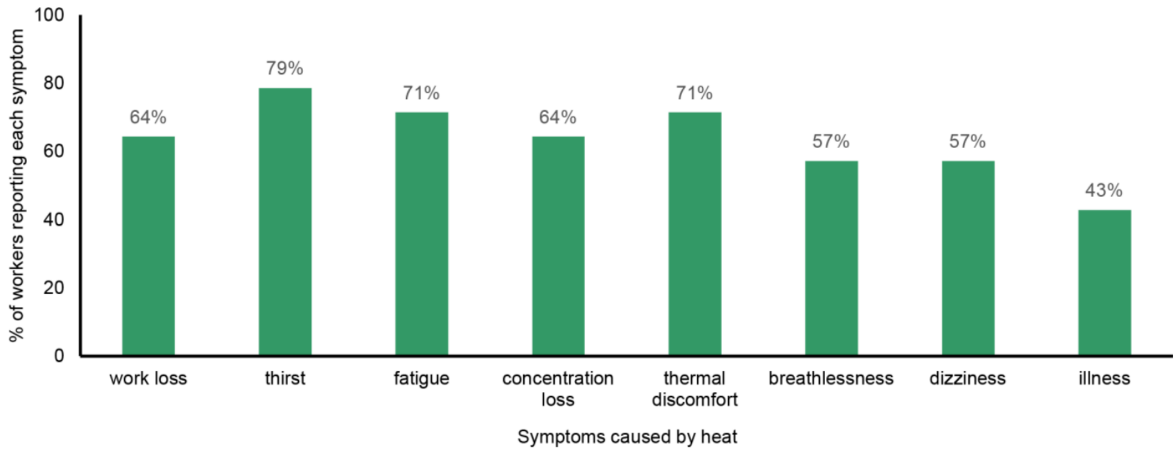


Figure C.2: Percentage of construction workers reporting different symptoms caused by heat at work.

Site managers, policy makers, and health and safety professionals can help to reduce the impact of environmental heat and PPE on construction workers. Key outputs from the HEATSHIELD project have identified and screened cost effective and practical solutions to reduce the impact of heat on workers in this sector. This not only benefits the health and wellbeing of the worker but can negate the requirement to hire extra labour in order to meet tight project deadlines. Simple solutions such as maintaining hydration are most effective and most practical for industry but are often overlooked. Alarmingly, HEATSHIELD members document that up to 70% of workers *arrive* to work already dehydrated, a condition which is well known to aggravate occupational heat stress. Additional solutions such as crushed ice ingestion, clothing adaptation, and the use of a specialised '*cooling oasis*' during work breaks all help to alleviate occupational heat stress.

Scientists from HEATSHIELD identified early in the project that correct implementation of these strategies requires partnership with experts in occupational hygiene. Working together with members of the British Occupational Hygiene Society (BOHS) ensures that the most up to date science can be disseminated and used widely in industry. This can be achieved with specialist on-site evaluations and with an accessible training platform.

Annex D

Report on implementation of HEATSHIELD guidelines at the Hinkley Point C nuclear power plant construction site

(Prepared by Josh Foster, Simon Hodder, James Goodwin, and George Havenith; Environmental Ergonomics Research Centre, Loughborough University, United Kingdom)

Introduction

While the United Kingdom (UK) is not considered a hot climate in general, it can experience transient, unpredictable periods of hot weather in the summer months. For example, the UK experienced a significant heatwave in August 2020, where temperatures exceeded 34°C in the South (see link for details). Such temperatures are likely to negate workers' health and productivity without mitigation strategies. Through a partnership with the British Occupational Hygiene Society (BOHS), Loughborough University assessed the feasibility for implementation of HEATSHIELD strategies within a major construction site during this heatwave. The construction site (Hinkley Point C, HPC) employs over 5,000 people and its purpose is the development of a nuclear power station in Somerset, UK. The power station will hold two nuclear reactors. Loughborough conducted an onsite assessment Friday 7th August 2020. The aims of the visit were 1) to document current risk of occupational heat stress in HPC's workforce, 2) document current strategies used to alleviate heat strain, and 3) document challenges and opportunities in implementation of HEATSHIELD guideline.

Methodology

An on-site visit to HPC construction site (Somerset, UK) was conducted on 07/08/2020. On this day, the peak temperature in Somerset was ~30°C which coincided with the August heatwave noted in the introduction. HPC is a project to construct a 3,200 MWe nuclear power station with two reactors in Somerset, England. The site is approximately 400 acres in size, equivalent to over 1.5 million square metres. The site is managed by 6 major subcontractors but the health and safety is managed by EDF energy, the main contractor.

Loughborough researchers were escorted around the site by the site safety advisor for EDF energy. The tour lasted approximately 2 hours and during which time we took an audit of the current working practices, areas where risk of heat strain is high, current methods used to alleviate the risk, and areas which heat safety can be improved. Following the tour, we interviewed the site safety advisor to document his (point-by-point where applicable) feedback on the checklist developed by HEAT-SHIELD (see Appendix 2).

Findings

There were several factors rendering workers at risk of heat strain at HPC. The issues are related to:

- Heavy personal protective equipment/clothing which limits dry and evaporative heat losses. Shown in Figure D.1.

- Topological factors which limit natural air movement and increase reflective solar influx to the worker. Shown in Figures D.2 and D.3.
- Logistical difficulties in providing water to workers. Particularly those engaged in work within the nuclear reactors. Shown in Figures D.3 and D.4.
- The site is large (400 acres) and distinctly three-dimensional i.e., workers often have to climb up and down to access work areas, as well as walk relatively large distances.
- No heat defence plan based on weather alerts.
- Primarily older work force (age > 50 years typical). Physiologically, this population is considered more at risk compared with younger workers. But more work experience in the older workforce may contribute to improved self-regulation/pacing, which is protective against heat stress.

Figure D.1: PPE requires two layered upper (high visibility t-shirt and jacket), high visibility trousers, gloves, goggles, hard hat, and safety boots.

Figure D.2: Heat sink.

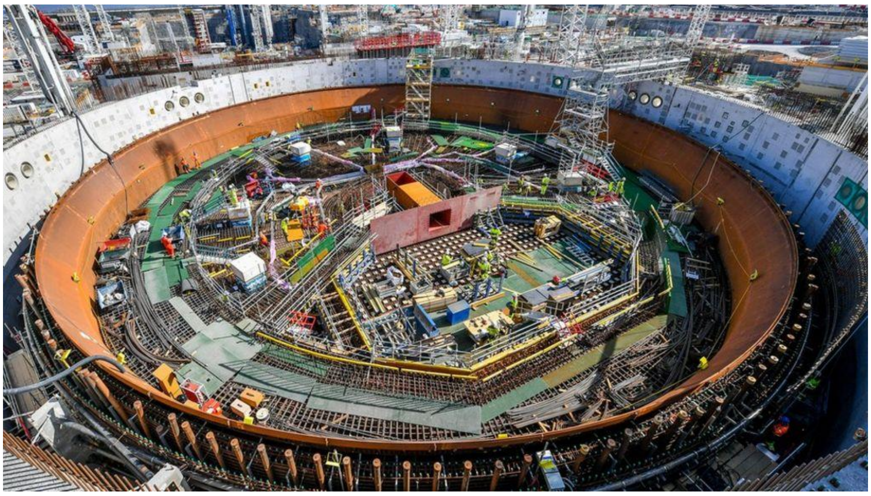


Figure D.3: Reactor 1.

Current heat defence practices

The current methods employed to avoid occupational heat stress issues are:

- A strong encouragement for workers to self-pace. Work productivity loss due to such pacing is recognised but is considered acceptable from a health and safety perspective. Hinkley Point C has not had a serious health and safety incident due to workplace heat. The perspectives of the workers are unknown.
- Water stations are positioned throughout the site. In some areas these are not easily accessible i.e., working in the reactors or in heat sinks, where heat stress severity is likely to be the greatest.
- An informal buddy system is utilised with regards to monitoring fellow workers in hot conditions.
- ‘Toolbox talks’ are daily, regular guidance given to small groups regarding hydration advice, urine colour etc. Notices on site, regularly changed. Guidance on hydration pre- and post-work is unclear.
- Workers have a health check every 6 months to assess blood pressure, lung function, and hearing. If test results are returned as problematic, workers are advised to visit their Doctor.

Feedback on the HEATSHIELD heat defence plan

The United Kingdom only experiences transient heat episodes which typically last 1 – 2 weeks. That heat is not a daily consideration for the workers at HPC renders it less likely that time and finances will be invested in heat avoidance strategies. Despite areas where heat stress is significant, coupled with limited water availability, heat stress is not considered a problem because of the lack of individuals who present with signs of heat exhaustion. For health and safety operatives, more of their time is required for managing more common hazards such as trips and falls, manual handling issues, and working at height.

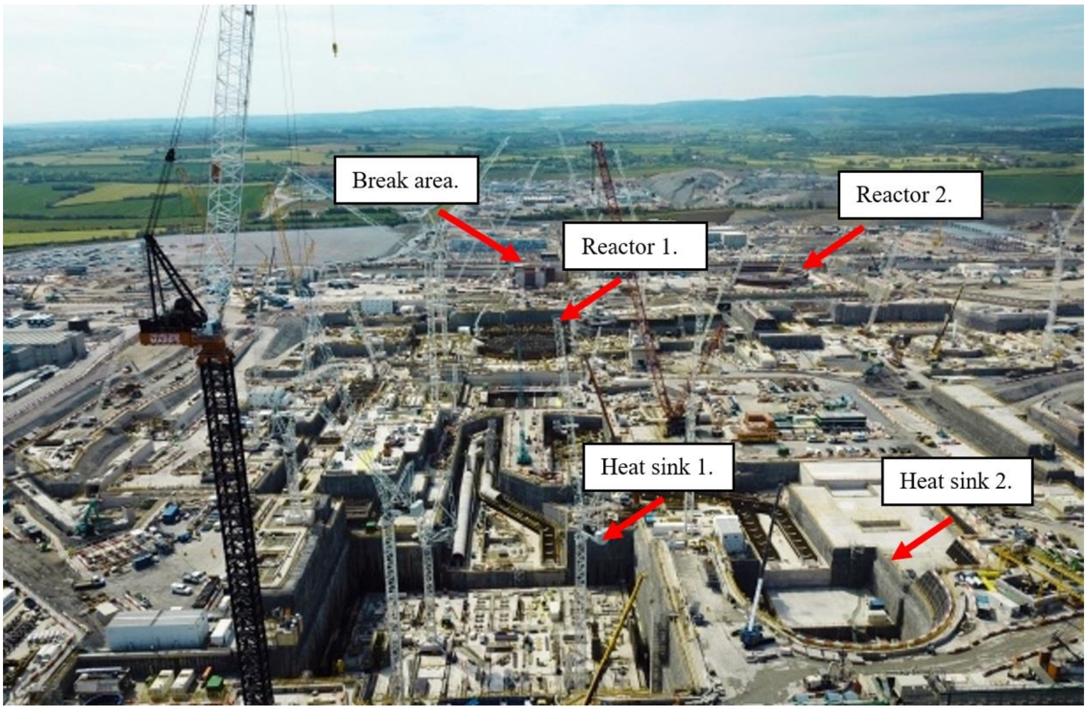


Figure D.4: Overview of Hinkley Point C construction site.