Bulletin n°34

Veille thermique
Période : février 2026

Objectifs :

L'INRS est de plus en plus sollicité sur des questions concernant les activités en entreprise par forte chaleur : les activités en extérieur, l'été en période de canicule, mais aussi les activités en intérieur, dans des lieux aux conditions thermiques extrêmes. L'objectif de cette veille est de se tenir informé sur ces thématiques, dans une période où la problématique thermique croît avec les changements climatiques.

La bibliographie extraite de la base de données INRS-Biblio, permet la consultation des ressources en version PDF.

Les liens mentionnés dans le bulletin donnent accès aux documents sous réserve d'un abonnement à la ressource.

La validation des informations fournies (exactitude, fiabilité, pertinence par rapport aux principes de prévention, etc.) est du ressort des auteurs des articles signalés dans la veille. Les informations ne sont pas le reflet de la position de l'INRS.

Sommaire :

EPI, matériaux protecteurs/réchauffants

S. M. Mortazavinejad, L. Vinches and S. Hallé.

Thermal resistance analysis of cold-protective clothing using numerical modeling: Influence of natural-based nonwoven fabric structure and wind flow conditions.

INTERNATIONAL COMMUNICATIONS IN HEAT AND MASS TRANSFER. 2026;173.

https://doi.org/10.1016/j.icheatmasstransfer.2026.110802

Natural-based nonwovens featuring hollow fibers are promising for cold-protective clothing due to biodegradability and low thermal conductivity. However, their thermal behavior under varying wind intensities and orientations remains insufficiently understood. This study investigates heat-transfer mechanisms using a twodimensional numerical model based on the porous media approach under local thermal equilibrium. To account for radiation, a radiative thermal conductivity term was integrated into the energy equation. The methodology employs a novel isolation technique: by simulating an impermeable textile zone while maintaining other transport properties, the coupled effects of conduction and radiation were separated from total heat transfer to quantify the convective contribution. The model was validated against experimental data; results show that increasing thickness is inefficient; a 2.18-fold thickness increase improved thermal resistance by only 9.9%. In contrast, reducing air permeability to levels mimicking a thin film yielded a 2.83-fold improvement by suppressing the convection that initially account for 86.2% of total heat transfer at 4 m/s. These findings indicate that controlling permeability is significantly more critical than increasing bulk for enhancing insulation. This work provides a rigorous framework for designing lightweight, high-performance thermal barriers where a balance between thermal protection and water vapor transmission is essential for cold-protective clothing.

EPI, matériaux protecteurs/refroidissants

N. Soleimani, A. Dehghan and H. Dehghan.

Effect of vest structure, airflow velocity, and humidity on evaporative cooling capacity using a thermal manikin.

SCIENTIFIC REPORTS. 2026;16(1).

https://doi.org/10.1038/s41598-026-41309-5

Climate change has exacerbated heat stress, particularly for outdoor workers. Evaporative cooling vests (ECVs) mitigate occupational heat stress. Their cooling capacity depends on the structural design, air temperature, air velocity, and humidity. This study investigated the cooling capacity and efficiency of four ECV designs under various environmental conditions. Four ECVs-polymer-based punched (ECVPP), polymer-based (ECVPB), cellulose-based (ECVCB), and TECHNICHE (ECVTECH)-were evaluated via a thermal manikin under controlled conditions (ambient temperatures: 35 degrees C and 40 degrees C; relative humidity: 20% and 40%; air velocities: 0.1, 0.4, and 1.0 m/s, respectively). The cooling capacity was measured by monitoring the energy consumption of the manikin over two-hour periods. The efficiency was calculated as the cooling capacity relative to the latent heat of water evaporation. Thermal imaging captured the surface temperature distribution. At 40 degrees C, ECVCB and 30 degrees C, the ECVPP consistently outperformed the other vests, achieving cooling capacities of 81.7 W and 78.5 W, respectively. These peak values were observed under higher air velocity conditions (1 m/s). Correlations ($R = 0.9$, $p < 0.001$) between the amount of evaporated water and the cooling capacity were observed. Thermal imaging confirmed that the progressive cooling capacity decreased due to evaporation-efficiency varied by vest design, highlighting the superiority of ECV_CB. This study highlights the performance of cellulose-based ECVs in hot, dry conditions, driven by enhanced evaporation rates. Higher air velocities improved the cooling capacity but reduced the efficiency, underscoring the need to balance airflow, humidity, and vest design for optimal performance. These findings provide insights for improving ECV functionality in occupational heat stress scenarios.

M. J. Ibn Amin, R. Rathour, S. Rana and A. Das.

Optimization of Material Content on the Protective Performance of Fire Fighter's Clothing Using Box-Behnken Design.

FIRE AND MATERIALS. 2026.

https://doi.org/10.1002/fam.70049

Extreme fire-protective clothing (FPC) designed for firefighters must simultaneously fulfil both comfort and fire protection requirements. The outermost layer of turnout suits plays a vital role in determining the protective performance of fire-resistant fabrics. This study investigates the thermal protective performance of woven fabrics by varying radiative thermal intensity (20-40 kW/m2), the air gap between the heating source and the fabric (0-12.5 mm), and para-aramid content (0%-100%). A systematic analysis was conducted to examine the influence of para-aramid content, air gap, and heat intensity on the protection time using the Box-Behnken experimental design. A quadratic model was developed and validated, demonstrating high accuracy, with an average relative error of 5.38% between the predicted and experimental values. ANOVA confirmed the model's significance, showing that all factors, their interactions, and the square of heat intensity significantly affected the protection time. Experimental results showed that protection time positively correlates with para-aramid content and air gap but decreases with increasing heat intensity. Maximum protection exceeding 30 s was *achieved using 100% para-aramid composition, a 12.5 mm air gap, and a heat flux of 20 kW/m2. These findings offer a comprehensive framework for designing high-performance thermal protective fabrics for extreme conditions.*

Maladies liées à la chaleur

S. M. Mousavi, H. Dehghan and S. Yazdanirad.

A critical systematic narrative review of the WBGT index for heat stress assessment in diverse climatic regions: insights from Iran.

INTERNATIONAL JOURNAL OF BIOMETEOROLOGY. 2026;70(3).

https://doi.org/10.1007/s00484-025-03093-1

Heat stress is a major occupational hazard in hot environments. This narrative review evaluated the limitations of the Wet Bulb Globe Temperature (WBGT) index across different climatic zones and explored alternative or complementary indices. We searched PubMed, Scopus, Web of Science, and SID for articles published between January 2013 and December 2024 with English and Persian language. Keywords used in the search included "WBGT", "Wet Bulb Globe Temperature", "heat stress index", "occupational exposure", and "Iran climate" (Boolean combinations). After removing duplicated papers and screening the remained articles by two independent reviewers, 42 papers were included for qualitative synthesis. In arid/dry regions, WBGT tended to underestimate physiological strain (low wet-bulb temperature despite high radiant heat), while in humid coastal areas, it sometimes overestimated the heat strain risk (high wet-bulb temperature but complex interactions with airflow and clothing). Comparative analyses showed UTCI and PHS can improve physiological prediction in specific contexts, but it requires more data and equipment. WBGT remains practical for many workplaces, but country- or climate-specific calibration, integration with physiological monitoring (e.g., heart rate), and hybrid approaches are recommended to improve worker protection.

G. Comp, C. Finch, K. Kupanoff, M. Sandoval, M. Lloyd, N. Aldaco, D. Kirk, P. Pugsley, L. Nordstrom, B. W. Koenig, A. Narang, J. Snow, M. Kamer, A. Foster, G. Patel and J. R. Stowell.

Fighting Fire with Ice: A Multisite Collaboration to Evaluate the Impact of Prehospital Cold Water Immersion on Heat Stroke Patients.

PREHOSPITAL EMERGENCY CARE. 2026.

https://doi.org/10.1080/10903127.2026.2636148

ObjectivesHeat stroke is a life-threatening condition requiring rapid recognition and immediate cooling. Cold water immersion (CWI) is the most effective cooling modality; however, its adoption and use by emergency medical services (EMS) agencies has been limited and described primarily in case reports. In 2024, the Phoenix Fire Department (PFD) implemented a novel rapid-cooling bag and protocol for prehospital CWI across a large urban area. This study describes the implementation, patient characteristics, cooling effectiveness, and clinical outcomes of the program.MethodsThis retrospective observational study included adults with heat stroke who were treated with the PFD prehospital CWI protocol between May 1 and September 30, 2024. Prehospital, emergency department (ED), and inpatient data were evaluated from EMS charts and electronic medical records across four hospital systems. Descriptive statistics summarized demographics, treatment characteristics, cooling duration, temperature change, neurologic trajectory, and outcomes.ResultsOne hundred and eighty-three patients met study criteria as having a tympanic temperature of at least 40 degrees C with central nervous system dysfunction, attributable to or associated with environmental heat exposure. The median prehospital tympanic temperature was 41.4 degrees +/- 0.9 degrees C, and nearly one-third presented with temperatures above 42.2 degrees C. Median prehospital immersion time was 13.5 min (9-17.8, range 5-66). Prehospital time was defined as care provided outside the hospital prior to ED

arrival and transfer of care. Temperature decreased from prehospital to emergency department arrival in 72.1% of patients with an average decrease of 2.0 +/- 1.5 degrees C. The median GCS increased from prehospital, 8 (4-10), to hospital arrival, 9 (3-14), and hospital discharge, 15 (14-15). Survival decreased with increasing prehospital temperature and was lowest among those presenting at or above 42.2 degrees C. One hundred and twenty-seven (69.4%) patients were discharged neurologically intact (GCS = 15).ConclusionsA prehospital CWI protocol is feasible in a large urban EMS system and provides rapid temperature reduction and improved neurologic status in patients with heat stroke. The findings suggest a meaningful clinical benefit and broad operational feasibility. Further prospective, multicenter studies are needed to define the resulting impact, optimize workflows, and guide wider adoption of prehospital immersion cooling.

U. Reischl.

Wildland Firefighter Heat Stress Management.

FIRE-SWITZERLAND. 2026;9(2).

https://doi.org/10.3390/fire9020068

Wildland firefighting involves prolonged, high-intensity physical work performed under hot, variable, and operationally demanding conditions, placing firefighters at substantial risk of heat-related illness. This paper synthesizes current evidence on the mechanisms, contributing factors, and management of heat stress in wildland firefighting, with a specific focus on physiologically and operationally relevant considerations aligned with NIOSH, NFPA, and USFS guidelines. Heat stress is conceptualized as a cumulative process resulting from the interaction of metabolic heat production, environmental heat load, protective clothing, and individual susceptibility. Key environmental contributors include high ambient temperatures, humidity, and solar and fire-related radiant heat, while occupational demands such as sustained heavy work, extended shift durations, limited recovery, and the thermal burden of personal protective equipment further exacerbate risk. Individual factors-including fitness, hydration status, acclimatization, fatigue, and underlying health conditions-modify heat tolerance and vulnerability. This review highlights evidence-based exposure management strategies tailored to wildland fire operations, including work-rest cycles, heat acclimatization protocols, and practical cooling interventions, and addresses the operational constraints that shape their implementation. This paper further emphasizes the role of standardized training programs in prevention, early symptom recognition, and rapid response. Together, these integrated approaches provide a focused framework for reducing heat-related morbidity and enhancing wildland firefighter safety.

Outils et capteurs de mesure

Y. Hashimoto.

A Comprehensive Review of Non-Invasive Core Body Temperature Measurement Techniques.

SENSORS. 2026;26(3).

https://doi.org/10.3390/s26030972

Core body temperature (CBT) is a fundamental physiological parameter tightly regulated by thermoregulatory mechanisms and is critically important for heat stress assessment, clinical management, and circadian rhythm research. Although invasive measurements such as pulmonary artery, esophageal, and rectal temperatures provide high accuracy, their practical use is limited by invasiveness, discomfort, and restricted feasibility for continuous monitoring in daily-life or field environments. Consequently, extensive efforts have been devoted to developing non-invasive CBT measurement and estimation techniques. This review provides an application-oriented synthesis of invasive reference methods and representative non-invasive approaches, including in-ear sensors, infrared thermography, ingestible telemetric sensors, heat-flux-based techniques, and model-based estimation using wearable physiological signals. For each approach, measurement principles, accuracy, invasiveness, usability, and application domains are comparatively examined, with particular emphasis on trade-offs between measurement fidelity and real-world implementability. Rather than ranking methods by absolute performance, this review highlights their relative positioning across clinical, occupational, and daily-life contexts. While no single non-invasive technique can universally replace invasive gold standards, recent advances in wearable sensing, heat-flux modeling, and multimodal estimation demonstrate growing potential for practical CBT monitoring. Overall, the findings suggest that future CBT assessment will increasingly rely on hybrid and context-aware systems that integrate complementary methods to enable reliable monitoring under real-world conditions. This review is intended for researchers and practitioners who need to select or design CBT monitoring systems.

T. O. de Crom, B. Scholten, E. Traini, K. van der Sanden, B. Kingma, F. Pekel, M. Ghosh, H. Notø, M. C. Turner, M. A. Alba Hidalgo, L. Klous, M. Albin, H. A. Kolstad, J. Selander, C. Ge and A. Pronk.

Exposure to heat at work: development of a quantitative European job exposure matrix (heat JEM).

Scandinavian Journal of Work, Environment & Health. 2026;52(1):7-18.

https://doi.org/10.5271/sjweh.4243

OBJECTIVE: With climate change exacerbating occupational heat stress, objective and systematic exposure assessment is essential for epidemiological studies. We developed a job exposure matrix (JEM) to assign occupational heat stress exposure across Europe. METHODS: Aligned with the International Organization for Standardization (ISO: 7243, 8996 and 9920), the heat JEM provides region- and year-specific estimates of annual heat stress hours by job title, using the International Standard Classification of Occupations 1988 for Europe [ISCO-88(COM)]. Heat stress was defined as wet bulb globe temperature effective (WBGTeff) exceeding WBGT reference (WBGTref). Outdoor and indoor WBGT were determined using historical, region-specific hourly meteorological data (temperature, radiation, humidity, wind speed) across Europe, between 1970 and 2024. WBGT values were adjusted for job-specific clothing to obtain WBGTeff. WBGTref was based on metabolic rate, calculated using body surface area and job-specific physical activity, and adjusted for acclimatization status. Further adjustments were made for the job title-specific presence of local heat and cooling

sources, time spent indoors versus outdoors, and working schedules. RESULTS: The number of annual hours workers experience heat stress is highest among jobs involving local heat sources and physical demanding tasks, especially when work clothing is mandatory. Southern Europe has a higher annual heat stress burden compared to other regions. Exposure varies across calendar years and is substantially higher among unacclimatized versus acclimatized workers. CONCLUSIONS: Incorporating job-, region-, and year-specific factors, the heat JEM provides a harmonized tool for studying occupational heat stress. Its transparent framework allows for updates with new data and extensions to other years and regions.

Y. Z. Zhao and J. H. M. Bergmann.

Real-time estimation of core body temperature for heat stress monitoring in hot environments using wearable heart rate sensors.

BUILDING AND ENVIRONMENT. 2026;293.

https://doi.org/10.1016/j.buildenv.2026.114368

Accurate and continuous assessment of physiological heat strain is increasingly important as global temperatures rise and heat-exposure scenarios become more common across occupational, athletic, and built environments. This study proposes a novel framework that enables a standard wearable heart-rate (HR) sensor to function as a real-time CBT estimation system. The method integrates a probabilistic Hidden Markov Model that captures the shifting physiological states of exercise and recovery with a non-parametric Particle Filter that models nonlin ear thermophysiological dynamics. A bidirectional coupling between these components allows state-conditioned likelihoods from the filter to refine the HMM belief, while the updated state probabilities guide subsequent filter updates through soft switching. An improved genetic algorithm further enhances robustness during resampling. Across two independently collected exercise-heat-stress datasets, the proposed model achieved the best ac curacy (RMSE = 0.359 degrees C and 0.371 degrees C), outperforming established EKF-based approaches. These findings demonstrate that physiologically informed, probabilistic modeling can transform ubiquitous wearable devices into practical tools for real-time heat-strain monitoring in hot environments.

S. He, L. C. Shen, S. Chen, F. F. He, J. Yang, M. Fu, J. L. Wu, X. Zheng, Y. Y. Li and W. G. Weng.

Study on thermophysiological responses for heavy-load activity in hot environment: factors interaction experiments.

ENERGY AND BUILDINGS. 2026;358.

https://doi.org/10.1016/j.enbuild.2026.117182

Operations carrying heavy-load while wearing personal protective equipment (PPE) in hot environment can exacerbate heat strain. This study aimed to investigate the multi factors interact to modulate human physiological responses. Human trials were performed in climate chambers wherein the ambient temperatures at 25 degrees C and 40 degrees C. Participants walked at activity intensity of 2 km/h and 5 km/h while carrying the total extra weight of 0.45 kg and 15 kg. Clothing ensembles included normal clothing and chemical protective clothing (CPC) and CPC served as boundary data for comparative assessments. Core temperature (Tc), heart rate (HR), skin temperature (Tsk) and respiratory frequency (RF), as well as perceptual responses were measured. A two-way repeatedmeasures analysis of variance was employed to assess factor interactions effects, meanwhile the ratio of WBGTeff/ WBGTmax (RWW) was adopted to comprehensively evaluate the effects of all *experimental variables on physiological responses. Results demonstrated that activity intensity and total extra weight were the primary drivers of HR, RF and Tc at 40 degrees C with 15 kg load. High ambient temperature directly drove an upward trend in Tsk (36.6-38.0 degrees C). Additionally, CPC usage increases the Tsk and delayed Tc recovery post-trial. Critically, interactive effects among the tested factors further compromised physiological homeostasis. This study establishes a composite framework for quantifying combined environmental and occupational stressors on physiological responses. Human trials under extreme high temperature environment (40 degrees C) help database expansion and suggestion for the short-term occupational health of heat-exposed workers.*

Travail par fortes chaleurs et périodes de canicule

N. Q. L. Tran, C. R. Chu, H. Phung, S. Nghiem, H. Le, T. H. Tran and D. Phung.

Heat exposure and agricultural workers' health: A global systematic review with implications for Peri-urban and semi-urban Southeast Asia.

URBAN CLIMATE. 2026;65.

https://doi.org/10.1016/j.uclim.2026.102811

Agricultural workers are among the most climate-vulnerable populations, particularly in tropical and low-to middle-income regions. Using the PRISMA framework, this systematic review analysed 97 studies from 27 countries on the health impacts of high temperatures in agricultural settings. The review also further discusses on Southeast Asia, where rapid urbanisation is increasingly shifting agricultural labour into semi-urban and peri-urban zones. The majority of reviewed studies were conducted in North America (54.6%), with the United States alone contributing 38.1%. Despite the high vulnerability of agricultural populations in regions like Africa, South America, and Asia, these areas remain significantly underrepresented in the literature on heat exposure and agricultural worker health. Common health outcomes included self-reported Heat-related illnesses (27.8%) and kidney issues (20.6%), followed by physiological strain (14.4%), occupational injuries (10.3%). However, critical health domains such as cardiovascular health (7.2%), mortality (3.1%), mental well-being and other symptoms (less than 2%) remain significantly understudied. Over one-third of studies relied on recalled exposure without direct heat measurement, while others used ambient temperature, WBGT, or composite thermal indices to quantify heat stress. In Southeast Asia, nine studies reported consistent risks of HRI, kidney strain, and physiological stress, but none focused specifically on peri-urban agricultural workers. Rapid urbanisation has created transitional peri-urban zones where agricultural workers increasingly reside. These areas often lack formal infrastructure, healthcare access, and regulatory protections, exacerbating exposure to extreme heat, particularly through the urban heat island effect. Addressing these gaps requires integrating labour protections into urban climate strategies and developing context-specific interventions for vulnerable agricultural communities.

Actualités février 2026

- ## Travail par fortes chaleurs et périodes de canicule

Canicule : des horaires adaptés pour les agents des déchèteries. Ouest-France (presse p.16), 03 février 2026

La Banque de France lance l'Outil de Diagnostic pour l'Adaptation au Changement Climatique (ODACC), un service gratuit en ligne pour accompagner toutes les entreprises face aux risques climatiques. Banque-france.fr, 12 février 2026

Changement climatique : ces entreprises azuréennes qui commencent à s'adapter aux risques. Lejournaldesentreprises.fr, 19 février 2026

Le changement climatique, nouveau risque majeur au travail en agriculture. Lefigaro.fr, 26 février 2026

Climate, heat and work: what Canada's new thermal stress rules mean for HR. Hrreporter.com, 17 février 2026

- ## EPI, matériaux protecteurs/refroidissants

Protecting those who protect us: App State studies the cooling limits of new firefighter gear. Today.appstate.edu, 24 février 2026