

# Bulletin n°18

## Veille thermique

### Période : mai 2024

#### 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.*

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## EPI, matériaux protecteurs/refroidissants

Q. R. Zhang, H. R. Cheng, S. J. Zhang, Y. L. Li, Z. W. Li, J. Ma and X. H. Liu.

**Advancements and challenges in thermoregulating textiles: Smart clothing for enhanced personal thermal management.**

CHEMICAL ENGINEERING JOURNAL. 2024;488.

<https://doi.org/10.1016/j.cej.2024.151040>

*This review addresses the burgeoning field of thermoregulating textiles, highlighting their role in enhancing human thermal comfort and reducing building energy consumption. It delves into the development and application of smart textiles, leveraging novel materials and methods to regulate heat transfer between human skin and the environment. The review systematically explores various thermoregulating strategies, including radiative, conductive and responsive mechanisms in both active/passive and bidirectional textile systems. It provides a critical analysis of the strengths and limitations of these smart textiles and identifies crucial challenges in the field. Furthermore, it offers forward-looking insights into future research trajectories in the rapidly evolving domain of advanced thermoregulating clothing. The roadmap for future development in thermoregulating textiles includes enhancing current materials, innovating new solutions and ultimately establishing global standards for widespread, versatile applications across various industries.*

C. Quartucci, R. Wibowo, V. Do, S. Bose-O' Reilly, D. Nowak, V. Weinhhammer, T. Weinmann and S. Rakete.

**Assessment of subjective well-being of healthcare workers in response to heat and personal protective equipment under controlled conditions using a standardized protocol.**

JOURNAL OF OCCUPATIONAL MEDICINE AND TOXICOLOGY. 2024;19(1).

<https://doi.org/10.1186/s12995-024-00418-5>

*Due to climate change, the increasing frequency of hot summer days and heat waves can result in occupational heat strain, especially in non-air-conditioned workplaces. Healthcare workers (HCW) engaged in patient care are particularly affected, as they are additionally exposed to physical stress. The use of personal protective equipment (PPE) can aggravate heat strain in HCW. This study aimed to examine the subjective well-being of HCW when exposed to heat and PPE under controlled conditions. Methods This study was designed as a randomized crossover trial. Participants performed standardized healthcare tasks in a climatic chamber for approximately 3.5 h at different indoor temperatures (22 degrees C and 27 degrees C) and varied working conditions (with or without PPE). The effects on participants' subjective well-being, encompassing thermal, physiological and psychological stress were assessed using a customized questionnaire. Results Heat had a greater effect than PPE on thermal, physical and psychological stress. Conversely, PPE had a greater effect on physical demand and effort. For the majority of outcomes, combined exposure to heat and PPE resulted in the highest perceived discomfort. Furthermore, the participants reported increased sweating and other discomforts when working at elevated temperatures or with PPE. Conclusions In this study, heat and PPE, but particularly the combination of both factors, were identified as unfavorable working environments. Although the trials were conducted in a controlled environment, the outcomes provide valuable information about the effect of heat and PPE on HCW in a real-life setting. Furthermore, the design used in this study can be beneficial in evaluating the effect of mitigation strategies.*

R. J. Zhang, J. Y. Zhang and J. Z. Zhang.

**Dynamic Response of Phase Change Heat Exchange Unit with Layered Porous Media for Pulsed Electronic Equipment.**

AEROSPACE. 2024;11(5).

<https://doi.org/10.3390/aerospace11050331>

*Effective heat dissipation challenges transient high-power electronic devices in hypersonic vehicle cabins. This study introduces a Phase Change Heat Exchange Unit with Layered Porous Media (PCHEU-LPM) employing pulsed heat flow at the top and forced convection at the bottom. The primary aim was a comparative parametric study analyzing the thermal response of the heating surface under pulsed heat flow conditions. The geometric model was generated using electron microscopy images of manufactured objects and the numerical model was established based on the enthalpy-porosity method. Numerical simulations explored amplitude and frequency effects on pulsed thermal excitation, evaluating temperature and phase fields. A comprehensive time-frequency transformation assessed the temperature response. The results indicated an initial decrease and subsequent increase in interface temperature fluctuation with pulse heat flux amplitude growth. Temperature field uniformity correlated with natural convection strength in two-phase and liquid-phase regions. At mid and low frequencies, the phase change process increasingly suppressed interface temperature fluctuations. Optimal pulse thermal excitation selection was crucial for minimizing temperature fluctuations while maintaining the interface temperature within the expected phase transition range. In conclusion, a novel design concept is posited herein, aiming to enhance surface temperature uniformity and broaden the applicability of electronic devices through the manipulation of porosity rates.*

H. Otani, T. Goto, Y. Kobayashi, H. Goto, Y. Hosokawa, K. Tokizawa and M. Shirato.

**The fan cooling vest use reduces thermal and perceptual strain during outdoor exercise in the heat on a sunny summer day.**

INTERNATIONAL JOURNAL OF BIOMETEOROLOGY. 2024.

<https://doi.org/10.1007/s00484-024-02690-w>

*The fan cooling vest is coming into very common use by Japanese outdoor manual workers. We examined that to what extent using this vest reduces thermal strain and perception during outdoor exercise in the heat on a sunny summer day. Ten male baseball players in high school conducted two baseball training sessions for 2-h with (VEST) or without (CON) a commercially available fan cooling vest on a baseball uniform. These sessions commenced at 10 a.m. on separate days in early August. The fan airflow rate attached the vest was 62 L·m<sup>-2</sup>·s<sup>-1</sup>. Neither ambient temperature (Mean +/- SD: VEST 31.9 +/- 0.2 degrees C; CON 31.8 +/- 0.7 degrees C), wet-bulb globe temperature (VEST 31.2 +/- 0.4 degrees C; CON 31.4 +/- 0.5 degrees C) nor solar radiation (VEST 1008 +/- 136 W·m<sup>-2</sup>; CON 1042 +/- 66 W·m<sup>-2</sup>) was different between trials. Mean skin temperature (VEST 34.5 +/- 1.1 degrees C; CON 35.1 +/- 1.4 degrees C), infrared tympanic temperature (VEST 38.9 +/- 0.9 degrees C; CON 39.2 +/- 1.2 degrees C), heart rate (VEST 127 +/- 31 bpm; CON 139 +/- 33 bpm), body heat storage (VEST 140 +/- 34 W·m<sup>-2</sup>; CON 160 +/- 22 W·m<sup>-2</sup>), thermal sensation (-4-4: VEST 0 +/- 2; CON 3 +/- 1) and rating of perceived exertion (6-20: VEST 11 +/- 2; CON 14 +/- 2) were lower in VEST than CON (all P < 0.05). Total distance measured with a global positioning system (VEST 3704 +/- 293 m; CON 3936 +/- 501 m) and body fluid variables were not different between trials. This study indicates that the fan cooling vest use can reduce thermal strain and perception during outdoor exercise in the heat on a sunny summer day. Cooling with this vest would*

*be effective to mitigate thermal risks and perceptual stress in athletes and sports participants under such settings.*

N. N. Liu, L. J. Huang, J. Sun, R. F. Dou, Z. Wen, M. Q. Yu and X. L. Liu.

**Influence of crack and pore structure characteristics on the thermal protective performance of thermal barrier coatings based on LBM.**

NUMERICAL HEAT TRANSFER PART A-APPLICATIONS. 2024.

<https://doi.org/10.1080/10407782.2024.2355629>

*The architecture of porous skeletons and large crack defects in thermal barrier coatings significantly influence the thermal protective performance of the coatings. In this study, the quartet structure generation set method was applied to fabricate coatings with wedge-shaped pore structures. A temperature field prediction model was developed through the lattice Boltzmann method. The results indicate that lengthening crack length and reducing the crack inclination angle or depth elevate the peak temperature gradient and surface temperature. Specifically, the temperature gradient near a 933- $\mu$ m-long crack was 1.3 times greater than that near a 248- $\mu$ m-long crack, with the surface temperature reaching 1221 degrees C. Similarly, the temperature gradient near a 50- $\mu$ m-deep crack was twice that near a 200- $\mu$ m-deep crack, and the surface temperature reached 1191 degrees C. Conversely, the temperature gradient near a crack with a 30 degrees inclination angle was 0.6 times that of a 10 degrees crack, accompanied by a decrease in the coating surface temperature.*

X. H. Liu, M. Tian and Y. Y. Wang.

**Mechanical strength recognition and classification of thermal protective fabric images after thermal aging based on deep learning.**

INTERNATIONAL JOURNAL OF OCCUPATIONAL SAFETY AND ERGONOMICS. 2024.

<https://doi.org/10.1080/10803548.2024.2345511>

*Currently, numerous studies have focused on testing or modeling to evaluate the safe service life of thermal protective clothing after thermal aging, reducing the risk to occupational personnel. However, testing will render the garment unsuitable for subsequent use and a series of input parameters for modeling are not readily available. In this study, a novel image recognition strategy was proposed to discriminate the mechanical strength of thermal protective fabric after thermal aging based on transfer learning. Methods. Data augmentation was used to overcome the shortcoming of insufficient training samples. Four pre-trained models were used to explore their performance in three sample classification modes. Results. The experimental results show that the VGG-19 model achieves the best performance in the three-classification mode (accuracy = 91%). The model was more accurate in identifying fabric samples in the early and late stages of strength decline. For fabric samples in the middle stage of strength decline, the three-classification mode was better than the four-classification and six-classification modes. Conclusions. The findings provide novel insights into the image-based mechanical strength evaluation of thermal protective fabrics after aging.*

B. Liu, R. Y. Zhang, Y. J. Wu, Y. E. Wang, T. Yu, X. Li, M. B. Pu, X. L. Ma and X. A. Luo.

**Radiative Cooling and Protective Clothing Through Lamination of Hierarchically Porous Membrane.**

ADVANCED MATERIALS TECHNOLOGIES. 2024;9(10).

<https://doi.org/10.1002/admt.202301808>

*Personal protective clothing is designed to safeguard medical personnel from highly infectious diseases. However, it often compromises comfort, especially when worn outdoors during epidemics like the global COVID-19 outbreak. This can lead to discomfort and even heatstroke. To tackle this issue, radiative cooling is incorporated into personal protective clothing by integrating hierarchically porous poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) membranes into the fabric. These membranes possess a remarkable solar reflection rate of 96.9% and a strong mid-infrared emittance of 95.2%. In practical scenarios, when exposed to clear sunny weather at midday, wearing radiative cooling personal protective clothing has the potential to reduce the temperature by 4.7 degrees C compared to commercially available personal protective clothing. Moreover, the lamination of porous PVDF-HFP membranes enhances the protective capacity by increasing the synthetic blood penetration pressure from 7 to 20 kPa. The manufacturing process is straightforward, cost-effective, and aligns with industry standards, making it suitable for large-scale implementation in epidemic prevention and control. This technology offers comfortable protection while minimizing the risk of heatstroke. Personal protective clothing is designed to shield healthcare workers from the threat of highly contagious diseases. However, its use in hot seasons may induce discomfort and even heatstroke in users. By synergistic optimization of the passive radiative cooling performance and protective capability, users' thermal comfort can be enhanced through radiative cooling, all while maintaining protection performance.*

## Outils et capteurs de mesure

S. C. C. Tan, T. C. K. Tran, C. Y. N. Chiang, J. M. Pan and I. C. C. Low.

### External auricle temperature enhances ear-based wearable accuracy during physiological strain monitoring in the heat.

SCIENTIFIC REPORTS. 2024;14(1).

<https://doi.org/10.1038/s41598-024-63241-2>

*Body core temperature ( $T_c$ ) monitoring is crucial for minimizing heat injury risk. However, validated strategies are invasive and expensive. Although promising, aural canal temperature ( $T_{ac}$ ) is susceptible to environmental influences. This study investigated whether incorporation of external auricle temperature ( $T_{ea}$ ) into an ear-based  $T_c$  algorithm enhances its accuracy during multiple heat stress conditions. Twenty males (mean  $\pm$  SD; age = 25  $\pm$  3 years, BMI = 21.7  $\pm$  1.8, body fat = 12  $\pm$  3%, maximal aerobic capacity ( $VO_{2max}$ ) = 64  $\pm$  7 ml/kg/min) donned an ear-based wearable and performed a passive heating (PAH), running (RUN) and brisk walking trial (WALK). PAH comprised of immersion in hot water (42.0  $\pm$  0.3 degrees C). RUN (70  $\pm$  3% $VO_{2max}$ ) and WALK (50  $\pm$  10% $VO_{2max}$ ) were conducted in an environmental chamber ( $T_{db}$  = 30.0  $\pm$  0.2 degrees C, RH = 71  $\pm$  2%). Several  $T_c$  models, developed using  $T_{ac}$ ,  $T_{ea}$  and heart rate, were validated against gastrointestinal temperature. Inclusion of  $T_{ea}$  as a model input improved the accuracy of the ear-based  $T_c$  algorithm. Our best performing model (Trf3) displayed good group prediction errors (mean bias error = -0.02  $\pm$  0.26 degrees C) but exhibited individual prediction errors (percentage target attainment  $\pm$  0.40 degrees C = 88%) that marginally exceeded our validity criterion. Therefore, Trf3 demonstrates potential utility for group-based  $T_c$  monitoring, with additional refinement needed to extend its applicability to personalized heat strain monitoring.*

## Travail dans une ambiance thermique extrême

J. O. Ogundiran, J. Nyembwe, A. S. N. Ribeiro and M. G. da Silva.

### **A Field Survey on Indoor Climate in Land Transport Cabins of Buses and Trains.**

ATMOSPHERE. 2024;15(5).

<https://doi.org/10.3390/atmos15050589>

*Assessing indoor environmental quality (IEQ) is fundamental to ensuring health, well-being, and safety. A particular type of indoor compartment, land transport cabins (LTCs), specifically those of trains and buses, was surveyed. The global rise in commute and in-cabin exposure time gives relevance to the current study. This study discusses indoor climate (IC) in LTCs to emphasize the risk to the well-being and comfort of exposed occupants linked to poor IEQ, using objective assessment and a communication method following recommendations of the CEN-EN16798-1 standard. The measurement campaign was carried out on 36 trips of real-time travel on 15 buses and 21 trains, mainly in the EU region. Although the measured operative temperature, relative humidity, CO<sub>2</sub>, and VOC levels followed EN16798-1 requirements in most cabins, compliance gaps were found in the indoor climate of these LTCs as per ventilation requirements. Also, the PMV-PPD index evaluated in two indoor velocity ranges of 0.1 and 0.3 m/s showed that 39% and 56% of the cabins, respectively, were thermally inadequate. Also, ventilation parameters showed that indoor air quality (IAQ) was defective in 83% of the studied LTCs. Therefore, gaps exist concerning the IC of the studied LTCs, suggesting potential risks to well-being and comfort and the need for improved compliance with the IEQ and ventilation criteria of EN16798-1.*

Z. Mirsanei, Y. Asemani, M. Derakhshanjazari, V. Gharibi, P. Norouzi, S. Mahdavi and R. Cousins.

### **The influence of occupational heat stress on serum inflammatory cytokines among traditional bakery workers in Iran.**

PLOS ONE. 2024;19(5).

<https://doi.org/10.1371/journal.pone.0302847>

*Heat exposure exceeding the ISO7243:1989 standard limit can contribute to health problems among employees in a variety of workplaces. Ignoring heat standard requirements in hot working conditions such as bakeries results in physiologic and health problems, as well as an elevated risk of later illnesses. In this analytical case-control study, the serum levels of four inflammatory factors (interleukin-1 beta, interleukin-6, tumor necrosis factor-alpha, and C-reactive protein) were assessed using an enzyme-linked immunosorbent assay. 105 male artisan bakers (in four job classifications in bakeries and staff) were compared based on demographic characteristics and inflammatory factors. The findings of the study showed correlations between serum interleukin-1 beta, interleukin-6, and C-reactive protein levels and thermal exposure in the occupational environment and employment type. Moreover, some differences in serum level of interleukin-1 beta and job type were observed. Heat overexposure affected the increase of interleukin-1 beta and C-reactive protein secretion. As a result of years of working in high-temperature conditions, inflammation can lead to subsequent diseases in workers. To protect their health from this occupational hazard, additional safeguards are needed. Our recommendations could also be applied to overly hot work environments that may cause heat stress in workers.*

## Travail par fortes chaleurs et périodes de canicule

E. J. Tetzlaff, C. Cassan, N. Goulet, M. Gorman, B. Hogg and G. P. Kenny.

**"Breaking down in tears, soaked in sweat, and sick from the heat": Media-based composite narratives of first responders working during the 2021 Heat Dome.**

AMERICAN JOURNAL OF INDUSTRIAL MEDICINE. 2024;67(5):442-52.

<https://doi.org/10.1002/ajim.23576>

*During the summer of 2021, a deadly, unprecedented multiday Heat Dome engulfed western Canada. As a result of this extreme heat event (EHE), emergency dispatchers received an unparalleled increase in incoming 911 calls for ambulance, police, and fire (as first responders) services to attend to hundreds of heat-vulnerable community members succumbing to the heat. With 103 all-time heat records broken during this EHE and indoor temperatures of nearly 40 degrees C, the first responders attending these calls faced extensive job demands and highly challenging operating conditions. Initial investigations have explored the health system-level impacts; however, little has been done to explore the impact on the first responders themselves. Therefore, this study aimed to improve our understanding of EHEs' impacts on the operational capabilities and health of first responders, specifically police, fire, ambulance, and dispatch services. A systematized review and content analysis of media articles published on the 2021 Heat Dome in Canada was conducted (n = 2909), and four media-based composite narratives were developed highlighting police, fire, ambulance, and dispatch services. The Job Demands-Resources (JD-R) model was applied as a theoretical framework for occupational burnout. ResultsThe media-based composite narratives highlighted that first responders faced record-breaking call volumes, increased mental-health-related claims, and exhaustive heat-related physiological stress. Using the JD-R model as a theoretical framework for occupational burnout, we identified three measures of stressful job demand: work overload (e.g., the surge in call volume, firefighters responding to medical emergencies), emotional demands (e.g., severe medical emergencies, sudden deaths, unresponsive patients, distraught family members), and physical demands (e.g., resuscitation in personal protective equipment, heat-related illness). The experiences described underscore the importance of supporting first responders during work in extreme heat conditions. These findings have important implications for addressing rising rates of burnout during and following public health crises, such as EHEs, a problem that is increasingly being recognized as a threat to the Canadian public healthcare system.*



## Page(s) web

**Quand le soleil menace tout le monde... même les travailleurs. Karolane Landry, Preventionautravail.com, 5 mars 2024.**

<https://www.preventionautravail.com/soleil-menace-tout-le-monde/>

*L'article, sous forme d'interview, aborde la prévention du cancer de la peau en soulignant l'importance de la protection solaire. Il met en avant la nécessité de réduire l'exposition aux rayons UV, surtout pour les personnes à la peau claire et les travailleurs exposés au soleil. Les recommandations incluent le port de vêtements avec protection UV, l'utilisation régulière de crème solaire, le port de chapeaux et de lunettes de soleil, et l'éducation sur les risques des coups de soleil et des cabines de bronzage. L'article souligne également l'importance de sensibiliser les gens à ces pratiques de prévention à travers des initiatives et des conférences.*

**Extreme temps not the only factor in construction worker heat illness: study. Safetyandhealthmagazine.com, 20 mars 2024.**

<https://www.safetyandhealthmagazine.com/articles/25190-extreme-temps-not-the-only-factor-in-construction-worker-heat-illness-study>

*L'article traite de la prévention des maladies liées à la chaleur chez les travailleurs de la construction. Une étude révèle que même des températures extérieures modérées peuvent augmenter le risque de maladies liées à la chaleur. L'étude souligne l'importance de la surveillance de la température corporelle, de la déshydratation, de la gestion de l'intensité du travail, et de l'équipement adéquat pour prévenir les maladies liées à la chaleur.*

## Actualités mai 2024

- Travail par fortes chaleurs et périodes de canicule

[Les pistes du gouvernement pour prévenir les accidents du travail.](#) Lopinion.fr, 02 mai 2024

[Les femmes, premières victimes du réchauffement.](#) Le Monde (Presse, p. 34), 09 mai 2024

[Un risque pour la santé du travailleur au-delà de 28°C.](#) L'Union (Presse, p. ARD2), 10 mai 2024

[Le Code du travail ne prévoit rien concernant la chaleur.](#) L'Union (Presse, p. LAO3), 10 mai 2024

[Un vendangeur serait bien décédé de la chaleur.](#) L'Est éclair (Presse, p. EST5), 11 mai 2024

[Un nouvel outil pour prévenir le risque « canicule » dans les travaux publics.](#) Le Moniteur.fr, 21 mai 2024

[Avis aux médias : La FTO et le NPD de l'Ontario lanceront une campagne pour la réglementation du stress thermique dans les lieux de travail de l'Ontario.](#) globenewswire.com, 21 mai 2024

[Le BTP dans le viseur des services de la DEETS.](#) Zinfos974.fr, 31 mai 2024

[Au-delà de 28 °C, effectuer un travail physique, comme le travail dans les vignes, génère des risques.](#) Vitisphere.fr, 31 mai 2024

[Navigating legislative deadlocks in platform workers rights: What can we imbibe from EU's platform directive?](#) Timesofindia.com, 01 mai 2024

[NIHHIS Heat Safety Awareness Week: Protecting Workers And Businesses As Summer Heats Up.](#) Environmental-expert.com, 02 mai 2024

[Outdoor workers at risk amid scorching heat - Society.](#) Thejakartapost.com, 04 mai 2024

[Cruel Summer: Rethinking how to live, work in a world that is getting warmer.](#) Economicstimes.indiatimes.com, 18 mai 2024

[Dans la chaleur de l'Inde, les ouvriers de Delhi travaillent dans des conditions "brûlantes".](#) Zonebourse.com, 23 mai 2024

[Labour Deptt awares workers about Do's, Don'ts on current heat wave.](#) Earlytimes.com, 25 mai 2024

[Gardeners, Landscapers: Watch Out for These High Heat Danger Signs.](#) Healthday.com, 25 mai 2024

[Heatwave and the death of a worker: What heat action plan must focus on.](#) Indianexpress.com, 31 mai 2024

[Admin: Set up water coolers, shaded areas for workers.](#) Timesofindia.com, 31 mai 2024

- **Travail dans une ambiance thermique extrême**

*May Day 2024: Workers on a warming planet deserve stronger labour protections.* Yukon News (Presse, p. 6), 03 mai 2024

- **Outils et capteurs de mesure**

*Capteur de température.* Mesures (Presse, p. 64), 29 mai 2024

[External auricle temperature enhances ear-based wearable accuracy during physiological strain monitoring in the heat.](#) Nature.com, 30 mai 2024

- **Maladies liés à la chaleur**

[Heatwave hits many in Tamil Nadu, none reported.](#) Newindianexpress.com, 6 mai 2024

Revoke the heat stroke. Pakistan Observer (Presse), 22 mai 2024

[New Zealand blackcurrant extract modulates the heat shock response in men during exercise in hot ambient conditions.](#) Greenmedinfo.com, 29 mai 2024

[Vitamin D deficiency, high blood pressure, and other health conditions that can increase the risk of heatstroke.](#) Timesofindia.com, 29 mai 2024

[Climate Change And Mental Health: How Extreme Heat Can Affect Mental Illnesses.](#) Menafn.com, 29 mai 2024