# Bulletin n°23

# Veille thermique
# Période : octobre 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.*

## Sommaire :

# EPI, matériaux protecteurs/refroidissants

S. B. Alhadad, R. Ponampalam, L. S. X. Lim, I. C. C. Low, R. Kshitij, A. B. Karim, Z. Bin Salamoon, Y. Marimuthu and J. K. W. Lee.

**Effects of Heat Exposure and Ice Slurry Ingestion on Risk-Taking Behavior in Healthcare Workers.**

MEDICINE & SCIENCE IN SPORTS & EXERCISE. 2024;56(10):2016-25.

https://doi.org/10.1249/MSS.0000000000003486

*Purpose: Healthcare workers (HCWs) wearing personal protective equipment (PPE) experience physiological strain that can impair motor and psychological functions, potentially affecting patient care. We assessed the effects of heat exposure on maximal strength and risk-taking behavior among PPE-wearing HCWs and the efficacy of ice slurry to alleviate adverse effects. Methods: Seventeen HCWS completed two experimental trials in a crossover design, consuming 5 g<middle dot>kg(-1) of body mass of ambient drink (AMB) or ice slurry (ICE) before donning PPE and undergoing 2 h of simulated decontamination exercise (wet-bulb globe temperature (WBGT): 25.9 degrees C +/- 0.8 degrees C, PPE microenvironment WBGT: 29.1 degrees C +/- 2.1 degrees C). Body core temperature (T-c), heart rate (HR), chest skin temperature (T-sk), ratings of perceived exertion (RPE), thermal sensation (RTS), maximal voluntary contraction (MVC), risk-taking behavior (balloon analogue risk-taking task (BART)), and salivary cortisol were assessed. Results: Predrinking to postdrinking triangle T-c was greater in ICE (-0.2 degrees C +/- 0.1 degrees C) than AMB (-0.0 degrees C +/- 0.1 degrees C, P = 0.003). Post-drinking RTS was lower in ICE (2.7 +/- 1.2) than AMB (4.1 +/- 0.4, P < 0.001). ICE and AMB had similar T-c and HR (both P > 0.05), but T-sk was lower in ICE than AMB (P = 0.049). A lower MVC (30.3 +/- 6.7 vs 27.4 +/- 4.9 kg, P = 0.001) and higher BART-adjusted total pump count (472 +/- 170 vs 615 +/- 174 pumps, P = 0.017) was observed pretrial to posttrial in AMB but absent in ICE (both P > 0.05). Salivary cortisol was similar between trials (P = 0.42). Conclusions: Heat-exposed PPE-wearing HCWs had impaired maximal strength and elevated risk-taking behavior. This may increase the risk of avoidable workplace accidents that can jeopardize HCWs and patient care. Ice slurry ingestion alleviated these heat-related impairments, suggesting its potential as an ergogenic aid.*

C. Coehoorn, J. Teran, P. St. Martin, S. Newman and H. Cowart.

**Thermal Mapping Following Exercise In A Hyperthermic Environment While Wearing Firefighter Personal Protective Equipment: 2362.**

Medicine & Science in Sports & Exercise. 2024;56(10S).

https://doi.org/10.1249/01.mss.0001060148.12992.f6

*The present experiment sought to establish a thermal map of the body immediately following exercise in a hyperthermic environment (EHE) while wearing firefighter personal protective equipment (PPE). Our previous research has demonstrated that exercise in these hyperthermic conditions results in decreased neural function and non-optimal response inhibition. No studies have sought to determine the areas of the body and PPE that get the hottest during the EHE task. Here, we hypothesized that EHE would result in the head and helmet getting the hottest in comparison to other regions of the body. Sixteen participants (14 males, 2 females) performed a graded-exercise walking treadmill protocol in an environmental chamber (35 °C; 50% humidity) in PPE until completing the protocol or reaching a volitional maximum. Thermal images of the body and PPE were acquired using an infrared thermal camera before and immediately post-EHE. Infrared thermography revealed increased surface body and equipment temperature pre- versus post-EHE. The most significant temperature changes were*

*observed at the head (pre: 34.5 ± 0.5 °C; post: 37.2 ± 0.2 °C; $p < 0.001$) and within the helmet (pre: 28.3 ± 0.7 °C; post: 37.3 ± 0.4 °C; $p < 0.001$). This research demonstrated that the head and the inside of the helmet are the hottest areas post-EHE. Although speculative, these results could help to explain the cognitive issues discovered in our previous research. Further research is necessary to confirm the association between the heat in the head and the cognitive decline.*

# *Maladies liées à la chaleur*

M. J. Allen, D. J. Vecellio and J. S. Hoffman.

**Evaluating the relationship between heat-related illness and cooling center location in Virginia.**

NATURAL HAZARDS. 2024.

https://doi.org/10.1007/s11069-024-06946-x

*Extreme heat contributes to adverse health outcomes and public cooling centers are often used as both a heat-health mitigation and management strategy to protect public health during extreme heat events. While the presence of a cooling center should theoretically improve heat-health outcomes in the surrounding community, there are no quantitative studies evaluating this relationship. Using heat-related emergency department and urgent care center visits from the 2014-2020 summer seasons, this study evaluates the relationship between heat-related illness (HRI) and cooling centers in Virginia. In total, more than 10,000 incidences of HRI occurred over the period across 68% of Virginia ZIP codes as reported. Communities with a cooling center had higher rates of HRI than those without, and this difference was most significant in urban areas. This result was coincident with a significant increase in non-white residents in these ZCTA. Our results draw attention to the need for additional research on the topic of cooling center access, efficacy, and operations. Strategically locating cooling centers near or within vulnerable communities is one just consideration, and more work is needed to uncover if, when, who, and how communities are utilizing, or in many cases not utilizing or unable to utilize, cooling centers.*

# Outils et capteurs de mesure

X. Y. Chen, Z. Q. Li, L. K. Dai, W. M. Zeng, Z. L. Liu and M. Liu.

**Characteristics of intermittent heating by air source heat pump in rural areas of northern China based on indoor temperature effective guarantee rate.**

JOURNAL OF BUILDING ENGINEERING. 2024;95.

https://doi.org/10.1016/j.jobe.2024.110196

*Air Source Heat Pumps (ASHP) are widely used in rural areas of China due to their flexible control and comfort. However, the intermittent heating pattern commonly used by rural residents, with its multiple start-stops, leads to fluctuations in indoor temperatures and affects the comfort of the occupants. Existing studies typically employ Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) and Computational Fluid Dynamics (CFD) simulation methods to evaluate the indoor thermal environment under intermittent heating. However, these professional methods are complex and not readily accessible to rural residents, making it difficult for them to assess their indoor thermal environment. This study takes an approach by combining field surveys with building simulations to analyze the indoor thermal environment of ASHP intermittent heating. An indicator of the indoor temperature effective guarantee rate (R) was proposed (categorized into Rnight and Rdaytime metrics) and the threshold value for intermittent shutdowns was analyzed to quantify the characteristics of ASHP intermittent heating. Results showed that when compared to the Early (EH) and Late heating (LH) periods, the R is lowest in the Mid-heating (MH) period (reduced by about 3%-20 %), and the outdoor temperature was the main factor. Lengthening the heating duration and decreasing the frequency of operation can increase the R. In addition, the threshold value for ASHP intermittent heating shutdown is 30 min, and by incorporating the timevarying characteristics of temperature rise and fall of intermittent heating, the R can be predicted. This research offers valuable insights for creating a comfortable indoor thermal environment in rural residences.*

K. R. Wodzicki, K. E. Ennis, D. A. Knight, S. M. Milrad, K. D. Dello, C. Davis, S. Heuser, B. Thomas and L. Raye.

**Heat Stress Metrics, Trends, and Extremes in the Southeastern United States.**

JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY. 2024;63(10).

https://doi.org/10.1175/JAMC-D-24-0009.1

*Humid heat and associated heat stress have increased in frequency, intensity, and duration across the globe, particularly at lower latitudes. One of the more robust metrics for heat stress impacts on the human body is wet-bulb globe temperature (WBGT), because it incorporates temperature, humidity, wind speed, and solar radiation. WBGT can typically only be measured using nonstandard instrumentation (e.g., black globe thermometers). However, estimation formulas have been developed to calculate WBGT using standard surface meteorological variables. This study evaluates several WBGT estimation formulas for the southeastern United States using North Carolina Environment and Climate Observing Network (ECONet) and U.S. Military measurement campaign data as verification. The estimation algorithm with the smallest mean absolute error was subsequently chosen to evaluate summer WBGT trends and extremes at 39 ASOS stations with long continuous (1950-2023) data records. Trend results showed that summer WBGT has increased throughout much of the southeastern United States, with larger increases at night than during the day. Although there were some surprisingly large WBGT trends at higher elevation locations far from coastlines, the greatest increases were*

*predominantly located in the Florida Peninsula and Louisiana. Increases in the intensity and frequency of extreme (90th percentile) WBGTs were particularly stark in large coastal urban centers (e.g., New Orleans, Tampa, and Miami). Some locations like New Orleans and Tampa have experienced more than two additional extreme heat stress days and nights per decade since 1950, with an exponential escalation in the number of extreme summer nights during the most recent decade.*

Z. F. Zhu, Y. Su, J. Chen, J. Y. Zhang, L. X. Liang, Z. D. Nie, W. Tang, Y. S. Liang and H. Li.

**PEDOT:PSS-Based Wearable Flexible Temperature Sensor and Integrated Sensing Matrix for Human Body Monitoring.**

ACS APPLIED MATERIALS & INTERFACES. 2024;16(41):56082-94.

https://doi.org/10.1021/acsami.4c11251

*Flexible temperature sensors have been widely used in electronic skins and health monitoring. Body temperature as one of the key physiological signals is crucial for detecting human body's abnormalities, which necessitates high sensitivity, quick responsiveness, and stable monitoring. In this paper, we reported a resistive temperature sensor designed as an ultrathin laminated structure with a serpentine pattern and a bioinspired adhesive layer, which was fabricated with a composite of poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate)/single-wall carbon nanotubes/reduced graphene oxide (PEDOT:PSS/SWCNTs/rGO) and polydimethylsiloxane (PDMS). The temperature sensor exhibited a high temperature sensitivity of 0.63% degrees C-1, coupled with outstanding linearity of 0.98 within 25-45 degrees C. Furthermore, it showed fast response and recovery speeds of 4.8 and 5.8 s, respectively, between 25 and 36 degrees C. It also demonstrated exceptional stability when subjected to stress and bending disturbances with the maximum bending interference deviation of 0.03%. Additionally, it displayed good cyclic stability over a broad temperature range from 25 to 85 degrees C, and the standard deviation at 25 degrees C is 0.14%. A series of experiments including blowing detection, respiratory monitoring with or without a mask, and during rest or sleep were conducted to show the potential of the flexible temperature sensors in human body monitoring. Furthermore, a 4 x 4 flexible temperature sensor matrix was integrated to detect and map objects such as wrenches and blood vessels through human hand skin. The results were consistent with those of infrared measurements. The flexible temperature sensor is capable of real-time temperature monitoring and has the potential in tracking human respiration, assessing sleep quality, and mapping the temperature of various objects.*

C. B. Z. Ze, L. N. Nneme and L. Monkam.

**PMV/PPD model for predicting thermal comfort in air-conditioned buildings in hot and humid regions of Sub-Saharan Africa.**

INTERNATIONAL JOURNAL OF AIR-CONDITIONING AND REFRIGERATION. 2024;32(1).

https://doi.org/10.1007/s44189-024-00061-z

*The model for predicting thermal comfort conditions established by Fanger remains widely used in scientific work, as a default means of in situ measurements. However, the use of Fanger data leads to dissatisfaction among users of air-conditioned buildings in humid tropical areas. This conclusion emerges from the work of Kemajou and al. (Cameroon) and Olissan and al. (Benin) in 2012, after survey studies on the judgments of thermal sensations of people occupying various air-conditioned spaces. This article develops a correction model for the Fanger model, by coupling the latter to models for predicting skin temperature and heat loss by evaporation of sweat through the skin, as well as to the*

*skin thermal sensitivity of people active in a humid tropical climate. The model thus determined shows that the predicted optimal comfort temperatures are located in the range of 26.1 degrees C to 27.5 degrees C and better meets the expectations of the populations in this region. The respective differences with the investigations of Kemajou and al. and those of Olissan and al. are 0.40 degrees C and 0.55 degrees C. It also appears that the comfort humidity range is 30% to 80%, apart from any other safety measures.*

# *Travail dans une ambiance thermique extrême*

M. Sugiuchi, S. Arata, T. Ikaga, Y. Shiraishi, T. Hayashi, J. Nakano, S. Ando and S. Kawakubo.

**Analyzing multiple elements of physical office environment for maximizing perceived work efficiency: Insights from surveys of 58 offices during summer.**

BUILDING AND ENVIRONMENT. 2025;267.

https://doi.org/10.1016/j.buildenv.2024.112153

*Worker performance is affected by environmental stimuli in the office. Therefore, it is important to analyze the relationship between workers and multiple environment elements simultaneously in order to understand the relationship between the office environment and worker performance. In addition, surveying a large sample of offices simultaneously is desirable to obtain more practical insights. Therefore, this study surveyed multiple elements of the physical office environment related to worker performance in a large sample of offices. The elements of the physical office environment surveyed were air temperature, relative humidity, CO2 concentration, and sound pressure level during the summer. Along with measurements from 58 offices across 29 buildings in Tokyo, Japan, 947 responses to a questionnaire survey of workers conducted to evaluate work performance were analyzed to elucidate the relationship between these elements of the physical office environment and perceived work efficiency. The analysis showed that air temperature was more related to worker performance than to the other elements. In addition, 25 degrees C air temperature group was observed to be associated with high worker performance, with worker performance being lowest in the 27 degrees C group. This finding is expected to provide insight into indoor environments that can effectively enhance office worker performance.*

R. Kawakami, H. Hasebe, Y. Yamamoto, S. Yoda, G. Takeuchi, R. Abe, Y. Tosaka and Y. Nomura.

**Cooler break areas: Reducing heat stress among construction workers in Japan.**

BUILDING AND ENVIRONMENT. 2024;262.

https://doi.org/10.1016/j.buildenv.2024.111821

*This study explores the break environment conditions provided to construction workers in hot and humid climates and assesses the impact of the thermal conditions in rest areas on the physiological and psychological responses of the workers. It was conducted during summer in Japan with 26 male rebar workers across five construction sites by monitoring variables such as ambient temperature, humidity, step count, pulse rate, blood pressure, forehead skin temperature, and fatigue level. Workers worked for approximately 8-9 h per day, with scheduled 15-30-min short breaks at 10:00 and 15:00, in addition to a 1-h break at lunchtime. While the work sites exhibited temperatures ranging from 30.0 to 38.4 degrees C and relative humidity between 47.0 and 87.2 %, the thermal conditions in the rest areas varied, with temperatures from 26.9 to 35.8 degrees C and relative humidity from 45.4 to 83.4 %. We found that break periods in cooler areas led to lower pulse rates and prevented excessive pulse pressure decreases after exercise. Additionally, the combination of a cooler environment during breaks with a cooling jacket led to lower maximum forehead skin temperatures during the subsequent work periods. However, workers tended to report higher tiredness levels when break areas were cooler. Therefore, while providing cool rest areas is beneficial for worker recovery and preventing heat-related illnesses, the potential negative effects on workers' perception of tiredness should be considered.*

Z. Moradpour, M. J. Jafari, S. F. Dehghan, M. Jalali and G. Hesam.

**Heat stress, thermal comfort and control strategy in a warm-humid workplace.**

INTERNATIONAL JOURNAL OF BIOMETEOROLOGY. 2024.

https://doi.org/10.1007/s00484-024-02760-z

*The purpose of this study was to design a local ventilation system (LVS) to help reduce the moisture content of a Scalder hall, evaluate its comfort and thermal stress before and after implementation of LVS and introduce an appropriate index to evaluate warm and humid workplaces. The design of the LVS was performed according to the ACGIH standard (VS-30-01). Heat stress and thermal comfort assessment were performed before and after LVS using humidity index (Humidex), discomfort index (DI), heat index (HI), wet-bulb globe temperature (WBGT) and predicted mean vote index (PMV) indices and the results were compared with predicted mean vote index-predicted percentage of dissatisfied (PMV-PPD) subjective indices. The results of heat stress parameters showed that LVS was able to reduce relative humidity (RH) and wet temperature (tnw) by 47% and 7 degrees C, respectively. This has caused subjects to feel the heat from hot and very RH hot to warm and the hot and percentage of dissatisfaction has dropped by more than 70%. Design and implementation of a LVS reduced the ambient tnw by decreasing RH. Results also showed in warm and humid workplaces, DI index are highly correlated with subjective evaluation of thermal comfort and this index can be used to evaluate the thermal conditions of the workplaces.*

N. E. Bartman and D. Hostler.

**Physiological Strain During Work At Equivalent Wbgt In Wildland Firefighting Garments.**

MEDICINE & SCIENCE IN SPORTS & EXERCISE. 2024;56(10):852-.

https://doi.org/10.1249/01.mss.0001060100.74732.ea

*PURPOSE: Assess strain when walking on a treadmill wearing wildland firefighter garments in three environments with equivalent wet-bulb globe temperature (WBGT: ~28.5 °C). METHODS: Twelve subjects (age:24 ± 2 y) walked intermittently for 150 min in low-humidity (40 °C, 20% relative humidity (RH)), moderate-humidity (34 °C, 50% RH), and high-humidity conditions (29 °C, 90% RH) wearing fire resistant jacket, pants, gloves, and helmet with only the neck and face exposed. Heart (HR), respiratory (RR), and whole body sweat rates, core temperature (Tc), evaporative heat loss (EHL), and perceptual strain were assessed throughout. RESULTS: At 150 min, Tc (38.5 °C ± 0.3 °C) and HR (167 ± 19 bpm) were lower in low-humidity compared to high-humidity (38.8 °C ± 0.6 °C, p = 0.02; 174 ± 14 bpm, p = 0.004). RR was highest in high-humidity (30.6 ± 10.1 breaths/min, p = 0.002). Thirst, sweating sensation, fatigue, and perceived exertion were lower in low-humidity compared to moderate- and high-humidity (all p < 0.001). The EHL required for heat balance (Ereq) was lowest in high-humidity (p < 0.001) and the EHL deficit (Ereq – EHL) was lower in low-humidity (33 ± 22 W) compared to moderate-humidity (38 ± 23 W, p = 0.002) and high-humidity (39 ± 28 W, p = 0.002). There were no differences in whole body sweat rate (14.8 ± 5.8 g/min, p = 0.58) or thermal sensation (p = 0.40). CONCLUSION: Physiological strain while walking in the heat wearing wildland firefighter garments is higher in a humid environment after 2.5 hours. During shorter intervals, protective garments play a larger role in impaired thermoregulation compared to the environment*

R. A. I. Lucas, E. Hansson, B. D. Skinner, E. Arias-Monge, C. Wesseling, U. Ekström, I. Weiss, Z. E. Castellón, S. Poveda, F. I. Cerda-Granados, W. J. Martinez-Cuadra, J. Glaser, D. H. Wegman and K. Jakobsson.

**The work-recovery cycle of kidney strain and inflammation in sugarcane workers following repeat heat exposure at work and at home.**

EUROPEAN JOURNAL OF APPLIED PHYSIOLOGY. 2024.

https://doi.org/10.1007/s00421-024-05610-3

*Purpose To examine heat exposure at work and home and the work-recovery cycle and temporal variation of kidney strain, muscle injury and inflammation biomarkers in sugarcane workers. Methods 20 male sugarcane workers (age: 33 +/- 7 years) with a workplace Rest.Shade.Hydration (RSH) intervention were observed over 4 days, at the end (18 h post-shift recovery) and beginning of a work week (42 h post-shift recovery). Measures included work intensity (heart rate), gastro-intestinal temperature, estimated body core temperature (using heart rate), fluid consumption, pre- and post-work blood and urine samples, physical activity (accelerometery) away from work, plus ambient heat exposure at work and home. Results On workdays, workers awakened at approx. 02:40 after 5 h sleep in similar to 30 degrees C. Across work shifts, daily average WBGT ranged from 26 to 29 degrees C (cooler than normal) and average workload intensity ranged from 55 to 58%HRmax. Workers reported consuming similar to 8 L of water and similar to 4 x 300 mL bags of electrolyte fluid each day. Serum creatinine, cystatin C and creatine phosphokinase markedly increased post-work and decreased during recovery; serum potassium did the opposite (all $p < 0.01$). Biomarker concentration changes were similar between recovery periods (18 h vs. 42 h; all $p > 0.27$). C-reactive protein was the highest at the end of the work week ($p = 0.01$). Conclusion Despite RSH intervention, cross-shift kidney strain was marked (recovering overnight) and systemic inflammation increased over the work week. Thus, biomonitoring of kidney function in occupational populations should be performed before a work shift at any point in the work week. This is essential knowledge for field studies and surveillance.*

# *Travail par fortes chaleurs et périodes de canicule*

X. Guo, K. R. Weinberger, L. Tamburic, C. E. Peters and C. B. McLeod.

**Heat-related illness among workers in British Columbia, Canada: Extreme hot weather in 2021 compared to 2001–2020.**

Scandinavian Journal of Work, Environment & Health. 2024(7):545-54.

https://doi.org/10.5271/sjweh.4179

*British Columbia (BC), Canada, experienced an unprecedented summer with record-breaking high temperatures in 2021. Yet the health impact has not been examined in occupational settings. This study aimed to characterize occupational heat-related illness (HRI) among BC workers estimated by incidence rates and associations between heatwaves and HRI, compare risks from 2021 and prior summers of 2001–2020, and assess differential impacts on worker groups by demographics and occupations. We identified HRI from workers' compensation claims that occurred between June and August from 2001–2021 in BC. Incidence rates were calculated using working population estimates from Statistics Canada's Labour Force Survey. A time-stratified case-crossover design with conditional Poisson regression was used to examine the impact of heatwaves on occupational HRI. All analyses were stratified by year (2021 versus 2001–2020), age, sex, and occupation. Of the 521 claims identified, 107 (21%) occurred in 2021. Incidence rates for 2021 and prior summers were 3.97 [95% confidence interval (CI) 3.26–4.80] and 0.93 (95% CI 0.85–1.03) claims per 100 000 workers, respectively. This difference represents a 327% increase. Rates were higher in health occupations in 2021 versus 2001–2020. During 2001–2021, the risk of HRI during heatwave days was 4.33 (95% CI 2.98–6.27) times that during non-heatwave days, and the risk was higher among middle-aged workers and workers in trades, transport, and equipment operations. The 2021 heatwaves had greater impact on younger and female workers than those from prior summers. Conclusions : Heat is a crucial workplace hazard. Prevention strategies should prioritize at-risk workers and not be limited to heatwaves.*

# *Page(s) web*

**PAYS-BAS : l'engagement d'un couvreur en faveur de la protection contre les UV. Eurogip.fr, 1er août 2024.**

https://eurogip.fr/pays-bas-lengagement-dun-couvreur-en-faveur-de-la-protection-contre-les-uv/

*« Ed van der Want, couvreur depuis 38 ans, a contracté un cancer de la peau à cause d'une exposition prolongée aux rayons UV. Après plusieurs opérations, il est devenu un défenseur de la protection solaire sur les chantiers et a obtenu une modification de la convention collective de son secteur. »*