Bulletin n°19

Veille thermique
Période : juin 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

Z. J. Liu, R. Wang, Z. X. Liu, Z. H. Wang and X. Meng.

Employing PCM vests to improve the thermal comfort for staff wearing mascot costumes in summer.

JOURNAL OF ENERGY STORAGE. 2024;89.

https://doi.org/10.1016/j.est.2024.111732

Due to the high thermal resistance, limited ventilation efficiency, and substantial weight of mascot costumes, staffs wearing mascot costumes in summer are subjected to significant thermal stress, resulting in physiological strain and posing a grave threat to their health. To improve the thermal comfort of staff wearing mascot costumes, this study employed a phase change material (PCM) vest with a phase -change temperature of 26 degrees C as a cooling measure. The 32 participants were recruited and randomly divided into two groups to analyze the effect of the PCM vest. The results showed that, participants wearing mascot costumes along with an additional PCM vest underneath (MC-PCM) experienced a decrease in oral temperature by 0.06 degrees C and mean skin temperature by 0.63 degrees C, compared to those wearing common mascot costumes (CMC). However, there was an increase in bodymass loss relative to initial weight by 0.045 % and heart rate by 5.08 bpm. Wearing the additional PCM vest can improve humidity sensation and thermal sensation, In addition, the average thermal comfort voting score of participants wearing MC-PCM was 0.24 lower than that of participants wearing CMC. It was showed that employing a PCM vest reduced heat stress evidently in staff wearing mascot costumes in high -temperature environments and improved their thermal comfort.

W. F. Song, X. Z. Xie, Y. Q. Liang, X. Y. Lu, Y. Ye and Y. J. Tong.

Investigation on a new semiconductor cooling garment for reducing heat stress of outdoor workers performing moderate activities in a hot and humid environment.

ENERGY AND BUILDINGS. 2024;312.

https://doi.org/10.1016/j.enbuild.2024.114174

The incidence of heat waves increases frequently over the last decades in China and the worldwide, which will be more frequent, persistent, and intense with global warming and rapid urbanization. Outdoor workers, as the most influenced groups, die every year due to the severe heat illnesses associated with the thermal environments. Though various personal cooling garments (PCGs) have been developed to reduce the heat stress of human body working in extremely thermal environments or in indoors, less research studies were performed for developing PCGs for outdoor workers. Besides, there still lacks study for developing PCGs with good portability, large, prolonged and steady cooling effect. Therefore, in this study, a newly developed semiconductor cooling clothing was developed based on semiconductor units (SCG), and its actual cooling performance was evaluated by having ten males performing a moderate activity in a hot and humid condition (i.e., 30 +/- 0.5 degree celsius, RH = 80 +/- 5 %, partial water vapor pressure = 3.5 kPa). The total experimental duration was 60 min, consisting of 60-min walking at 5.0 km/h. The key findings showed that the SCG could significantly reduce the mean skin temperature, torso skin temperature as well as local skin temperatures of human body under moderate exercise intensities ($p < 0.05$). Perceptual sensations in the whole-, upper-, and lower- body were remarkably improved during exercise ($p < 0.05$). In addition, the cooling performance of SCG was still significant approaching the end of the trials. Besides, no body movement restriction was discovered

for subjects in SCG while performing typical postures. It was thus concluded that the SCG is effective in alleviating body heat strain while exercising in a hot and humid environment. The findings contribute to the body of knowledge in improving the health and well-being of outdoor workers while working in hot and humid environments.

G. Xia, X. Y. Bian, Y. F. Wang, Y. Lam, Y. Y. Zhao, S. J. Fan, P. Qi, Z. Qu and J. H. Xin.

Janus outdoor protective clothing with unidirectional moisture transfer, antibacterial, and mosquito repellent properties.

CHEMICAL ENGINEERING JOURNAL. 2024;490.

https://doi.org/10.1016/j.cej.2024.151826

Personal protective clothing with versatile and durable features is highly desirable for daily and specific environmental scenarios. Especially for outdoor workers or sports enthusiasts, prolonged outdoor exposure requires their clothing to be more functional to cope with a wide range of situations, such as heat stress in summer, odor generation after sweating, and mosquito bites. These not only reduce the wearing comfort of clothing, but also bring potential heat stroke, skin infections and diseases brought by mosquitoes. Currently, most outdoor protective clothes focus on a single function, such as waterproofing and UV protection and are not able to cope with the demand of multiple protections. In this paper, we developed permethrin-containing triblock cationic polymers (PTCPs) that can multi-functionalize outdoor clothing. Benefiting from their high affinity to polyester fibers, PTCP modified polyester yarns were obtained by an aqueous based finishing process. After that, a scalable machine-knitting fabrication technique is employed to fabricate Janus outdoor protective clothes (Janus-OPC). The as-prepared Janus-OPC exhibited excellent one-way moisture transfer properties (forward cumulative oneway transfer index (OWTI) of 924.23%, and backward OWTI of -690.52%), antimicrobial properties (97.73% and 99.72% against E. coli and S. aureus, respectively), and mosquito repellent properties (repelling rate of 76.19%). Moreover, the protective performance of the Janus-OPC was maintained after 50 times of equivalent home laundering cycles. This multifunctional protective clothing opens up a new direction for the nextgeneration outdoor wear.

R. Boisvert, M. McQuerry and S. Schofield.

Relationship between firefighter protective clothing design ease and heat stress.

INTERNATIONAL JOURNAL OF CLOTHING SCIENCE AND TECHNOLOGY. 2024.

https://doi.org/10.1108/IJCST-11-2023-0160

Clothing fit, including garment ease and drape, impacts the volume of air between clothing layers and the body, directly affecting the amount of heat that can be transferred through a multi-layer clothing system. As most acute firefighting fatalities are caused by overexertion and heat strain, the purpose of this research was to determine the impact of ease allowances on air gaps in structural firefighting turnout suits and their subsequent effect on total heat loss (THL) when worn on a three-dimensional form.Design/methodology/approachFour turnout suits with chest ease allowances of 6 '', 8 '', 10 '' and 12 '' were evaluated using an ANDI dynamic sweating thermal manikin. The average predicted manikin THL of each ensemble was calculated from the thermal and evaporative resistance measurements. A three-dimensional (3D) body scanner was utilized to calculate the distance and volume of clothing air gaps between the base layer and each turnout suit.FindingsResults demonstrate that reductions in upper body ease measurements trend towards statistically significant increases in THL, to a point, with fit limitations being reached before benefits can be significantly realized. An increase in standard chest

ease measurements significantly decreased heat loss, even when forced convection from movement was considered.Originality/valueThis is the first article of its kind to explore the relationship between garment ease and predicted manikin THL, especially for fire service protective clothing. Findings indicate a valid recommendation for turnout gear designers and manufacturers to optimize clothing fit to improve breathability and potentially reduce incidents of heat strain in the fire service.

Maladies liées à la chaleur

L. Y. Qiu, Z. W. Zhu, Z. X. Zhou, E. S. Im, S. K. Min, Y. H. Kim, Y. Kim, D. H. Cha, J. B. Ahn and Y. H. Byun.

Amplification of the discrepancy between simplified and physics-based wet-bulb globe temperatures in a warmer climate.

WEATHER AND CLIMATE EXTREMES. 2024;44.

https://doi.org/10.1016/j.wace.2024.100677

The Simplified Wet Bulb Globe Temperature (sWBGT) is widely used in heat stress assessments for climatechange studies, but its limitations have not been thoroughly explored. Building on recent critiques of sWBGT ' s use for current climate on global scale, this study examines sWBGT ' s biases using dynamicallydownscaled sub -daily climate projections under multiple future emission scenarios. The analysis is aimed at understanding caveats in the application of sWBGT and the uncertainties in existing climate change analysis dependent on sWBGT. Results indicate sWBGT ' s biases are heavily influenced by local near -surface air temperature, with overestimation of heat stress in East Asia regions, particularly hot and humid areas, due to static assumptions of radiation and wind speed. This overestimation is amplified in warmer climates, leading to exaggerated projected heat stress increases in future. In contrast, underestimations are found for heat stress levels attributed to low wind speeds and strong radiations, such as over the Tibetan Plateau and certain extreme events. Additionally, sWBGT underestimates variability in extreme heatwave events compared to WBGT in both current and future climates, irrespective of overestimation in absolute heatwave intensities. This study emphasizes the limitations of sWBGT, especially in future warmer climates. Importance of sub -daily data for capturing daily maximum heat stress level and reflecting diurnal variations in different components is also discussed. In conclusion, we recommend using Liljegren ' s model (i.e., physics -based calculation) with high -resolution subdaily climate data for more accurate outdoor heat stress assessments in climate change studies.

D. Filingeri, A. Valenza, S. Ficarra, V. Filingeri, P. R. Worsley and A. Bianco.

A case report on the physiological responses to extreme heat during Sicily's July 2023 heatwave.

PHYSIOLOGICAL REPORTS. 2024;12(11).

https://doi.org/10.14814/phy2.16107

July 2023 has been confirmed as Earth's hottest month on record, and it was characterized by extraordinary heatwaves across southern Europe. Field data collected under real heatwave periods could add important evidence to understand human adaptability to extreme heat. However, field studies on human physiological responses to heatwave periods remain limited. We performed field thermo-physiological measurements in a healthy 37-years male undergoing resting and physical activity in an outdoor environment in the capital of Sicily, Palermo, during (July 21; highest level of local heat-health alert) and following (August 10; lowest level of local heat-health alert) the peak of Sicily's July 2023 heatwave. Results indicated that similar to 40 min of outdoor walking and light running in 33.8 degrees C Wet Bulb Globe Temperature (WBGT) conditions (July 21) resulted in significant physiological stress (i.e., peak heart rate: 209 bpm; core temperature: 39.13 degrees C; mean skin temperature: 37.2 degrees C; whole-body sweat losses: 1.7 kg). Importantly, significant physiological stress was also observed during less severe heat conditions (August 10; WBGT: 29.1 degrees C; peak heart rate: 190 bpm; core temperature: 38.48 degrees C; whole-body sweat losses: 2 kg). These

observations highlight the physiological strain that current heatwave conditions pose on healthy young individuals. This ecologically-valid empirical evidence could inform more accurate heat-health planning.

Z. X. Zhou, T. Nguyen-Xuan, H. Liao, L. Y. Qiu and E. S. Im.

Characterization of temperature and humidity effects on extreme heat stress under global warming and urban growth in the Pearl and Yangtze River Deltas of China.

WEATHER AND CLIMATE EXTREMES. 2024;44.

https://doi.org/10.1016/j.wace.2024.100659

With global warming accelerating, the heavily populated and rapidly urbanized coastal regions of the Pearl River Delta (PRD) and the Yangtze River Delta (YRD) stand as representative areas with mounting concerns about extreme heat stress. This study analyzes differentiated effects of temperature (TAS) and relative humidity (RH) on human heat stress measured by wet -bulb globe temperature (WBGT) in those urban regions based on machine learning and mathematical derivation, while also examining the impacts of global warming and urbanization on prospective heat risks. To generate fine -scale climate projections targeted at the PRD and YRD, two global projections forced by Representative Concentration Pathway (RCP) 8.5 scenario are dynamically downscaled using non -hydrostatic Regional Climate Model version 4.7 (RegCM4), with the urban density and extent updated every year based on Shared Socioeconomic Pathways 5-8.5 (SSP5) scenario, thereby incorporating the transient urban growth into future projections. The bias -corrected downscaled simulations effectively capture the distinct interdependencies between TAS and RH on WBGT across different regions, similar to the observed patterns during the historical period. While the absolute contribution of TAS to WBGT is larger than RH regardless of warming levels and regions, the relative increase in RH becomes more pronounced with warming. Under RCP8.5 scenario, unprecedentedly extreme WBGT is projected to emerge in the far future (2080 - 2099). In contrast, the effect of urbanization appears to be more dominant in the near future (2030 - 2049) as urban density under SSP5 scenario is projected to peak around the 2040s and gradually decrease afterwards. The reduction of RH is found in the intensely urbanized areas locally, but it does not significantly lower WBGT because the positive contribution of increased TAS is more dominant. As a result, highly urbanized regions still exhibit higher WBGT compared to other areas. In addition, urban heat island effect is more pronounced for compact areas with high urban density (i.e., PRD) and at night. Despite the smaller temperature increase from urban heat island effect compared to global warming, it can play a critical role in exacerbating heat stress, adding to the already dangerous humid and hot conditions.

M. Ntoumani, H. Soultanakis, E. Rivas, B. Dugué, A. W. Potter, I. Yermakova, A. Douka and K. Gongaki.

An integrated thermal sensation scale for estimating thermal strain in water.

MEDICAL HYPOTHESES. 2024;187.

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Acceptable definitions of thermal sensation for cold and hot water immersion do not exist. The use of subjective thermal sensation scales remains unsolved with broad psycho-physiological, and semantic implications. We hypothesize that perception of thermal sensation could be a valid and reliable indicator for thermal strain during exposure in water. We aimed to provide a theoretical background for behavioral thermoregulation and neurocognition to support an integrated thermal sensation scale for estimation of thermal load during head-out water immersion. This research used a mixed methods approach. Domains were identified and items were measured for thermal load to examine the content

validity. Thereafter, we formed an integrated scale based on standard 10,551 of International Organization for Standardization (ISO). Finally, we conducted a pilot study for the face validation of the scale based on a 30 min head-out water immersion at 26 degree celsius in healthy adults (females, n = 4; males, n = 4; age: 22.6 +/- 8.0 years; body mass, 67.7 +/- 9.5 kg; height, 169.0 +/- 5.6 cm). We identified three aspects (environment, physiological and behavioral thermoregulation) and a total of 18 items, of whom eight items (water temperature, immersion duration, core temperature, skin temperature, body heat storage, shivering, thermal sensation, and thermal comfort) were acceptable based on terms of scale-level content validity index (SCVI = 92 %). Conditions incorporated into our scale included: icy < 12 degrees C, cold 12-24 degree celsius, cool 24-29 degree celsius, neutral 29-38 degree celsius, warm 38-43 degree celsius, and hot > 43 degree celsius. We found excellent face validity based on a reported homogenous cool feeling and physiological thermoregulatory responses. Our study revealed our model could reasonably characterize body thermal load though whole-body thermal sensation based on well-established thermoregulatory mechanisms during water immersion. Further research is needed to validate the accuracy of our behavioral model in a variety of water temperatures and in a larger sample size.

M. K. Chithramol, S. G. Ahmed and S. R. Shine.

Modeling of thermoregulatory mechanisms of typical Indian male and female subjects under hot and cold stress.

INTERNATIONAL JOURNAL OF ADVANCES IN ENGINEERING SCIENCES AND APPLIED MATHEMATICS. 2024.

https://doi.org/10.1007/s12572-024-00375-6

Human thermoregulation models are valuable for predicting the thermoregulatory response of the human body under diverse environmental conditions, especially in situations where conducting experiments would be dangerous. In the current study, variation in thermoregulatory response between men and women is investigated using a 2-D, gender-specific thermoregulation model. The model's passive system consists of 12 segments and is developed using the Pennes bioheat equation and finite difference method. The active system accounts for all regulatory responses, including counter-current heat exchange, respiratory heat loss, and the threshold. The model is validated using available experimental results in literature. The developed code analyzes the effectiveness of different thermoregulatory defense mechanisms in both males and females under hot and cold environments. Results suggest that shivering and sweating are the most effective defense mechanisms under cold and hot conditions, respectively, for both genders. Gender-based disparities in mean skin temperature during sudden cold exposure, revealing that men consistently display higher temperatures due to their greater capacity for active shivering resulting from higher muscle mass. Extended exposure of people with spinal cord injury to high temperatures may pose a risk to their lives as the core temperature can rise uncontrollably. During therapeutic hypothermia, skin temperatures are notably more affected than core temperatures, with this effect being particularly pronounced in hot ambient conditions for both males and females. However, females display elevated temperatures for the head and feet during hot exposures, whereas males exhibit higher temperatures for the chest during cold exposures.

Travail par fortes chaleurs et périodes de canicule

R. A. Elshamy, A. M. Eladl and M. F. Zaitoun.

Climatic changes: knowledge and adaptation behavior to heat-related illness among solid waste disposal workers.

JOURNAL OF THE EGYPTIAN PUBLIC HEALTH ASSOCIATION. 2024;99(1).

https://doi.org/10.1186/s42506-024-00155-x

Earth's climate changes are progressing at an alarming rate. One of the most severe effects of climate change is extreme heat. This study aimed to assess knowledge and adaptation behavior to heat-related illness (HRI) among solid waste disposal workers in the 10th of Ramadan City, Egypt, and to study the predictors for their knowledge and adaptation behavior.Methods An exploratory cross-sectional study was conducted on 220 solid waste disposal workers. A structured interview questionnaire was used to assess the studied workers' sociodemographic and occupational characteristics, heat exposure risk, and their knowledge, and adaptation behavior.Results The results showed that 40% and 30% of participants had adequate levels of total knowledge and adaptation behavior, respectively. There was a statistically significant relationship between workers' knowledge and both age and education. There was a statistically significant relationship between workers' adaptation behavior and age, duration of employment, working hours, and education. A binary logistic regression for significant predictors of knowledge and adaptation behavior showed that age and education were the most significant predictors.Conclusion Solid waste disposal workers were at high risk of HRI due to their low levels of knowledge and adaptation behavior regarding HRI. Educational health programs that guide workers to follow healthy behaviors and prevent HRI are recommended.

Y. W. Tang and Z. Y. He.

Extreme heat and firms' robot adoption: Evidence from China.

CHINA ECONOMIC REVIEW. 2024;85.

https://doi.org/10.1016/j.chieco.2024.102161

This is the first study to explore the relationship between extreme heat and firms' robot adoption. The findings demonstrate that, relative to a day in the reference temperature bin, an extra day with an average temperature above 30 degrees C reduces the probability of a firm adopting robots and the cumulative number of robots a firm has adopted. The channels of tightened financial constraints and the increased comparative advantages of industrial robots over labor are important in explaining the documented impacts. The negative effects of extreme heat are only pronounced for non-state-owned enterprises, firms with negative working capital, and firms in industries with fewer automation opportunities. Moreover, local adaptation in high-temperature regions mitigates the negative impacts of extreme heat on robot adoption. This study focuses on firms' adaptive behavior under extreme heat, which previous studies have largely overlooked, with implications for policymakers concerned with climate change adaptation and industrial automation.

J. C. Flunker, J. T. Spector, M. Blancas, N. L. Briggs, M. Flores, C. R. Whitaker, T. Schoonover and T. Cardoso.

Farmworker-Relevant Heat Exposure in Different Crop and Shade Conditions.

JOURNAL OF AGROMEDICINE. 2024.

https://doi.org/10.1080/1059924X.2024.2365647

Agricultural workers are at risk of heat-related illness, which is preventable. Few field studies have compared farmworker-relevant heat exposure in different conditions. We examined heat exposure over time in different potential shade and work locations to inform future occupational heat prevention approaches.MethodsWe assessed heat exposure in Eastern Washington State (WA) cherry and grape fields in August 2022. QUESTemp degrees monitors recorded Wet Bulb Globe Temperature (WBGT) and Black Globe Temperature (BGT) every 10 min from approximately 07:00-14:00 for three days in the center of crop rows (mid-row), under portable shade structures (shade), and in open field (open) locations. Linear mixed effects regression (LMER) models compared WBGT and BGT among field locations. Hourly time-weighted average WBGT and comparisons with occupational exposure limits (OELs) were computed for different hypothetical work-rest cycles during the hottest sampling hours, assuming different worker effort levels, rest locations (mid-row versus shade), and acclimatization statuses.ResultsAcross all crops and locations during the study period, the mean/SD air temperature was 31 degrees C (88 degrees F)/3.9 degrees C (6.9 degrees F), with a maximum temperature of 39 degrees C (102 degrees F) and a mean/SD relative humidity of 30%/9.6%. LMER models suggested no significant difference in mid-row versus open WBGT but significantly lower WBGT in shade versus open locations for both cherries (main effect -5.14: 95% confidence interval [CI] -6.97,-3.32) and grapes (-6.20: 95%CI -7.73,-4.67), though this difference diminished over the course of the day. BGT was significantly higher in the mid-row than the shade (cherries main effect 14.33: 95%CI 9.52,19.13 and grapes 17.10: 95%CI 13.44,20.75). During the hottest sampling hour, the exceedances of OELs were reduced with assumptions of increased shaded break lengths, reduced effort level, and acclimatization.ConclusionsShade canopies, but not the crops studied, provided significant reductions in heat exposure. We observed increased protection from heat assuming longer shaded breaks and reduced effort levels. Results highlight the need for additional field research on the effectiveness, feasibility, and acceptability of different shade types and work-rest cycles to guide employer optimization of best practices for worker protections, including acclimatization before high heat, sufficient shaded rest time, reduced effort levels as the day warms, and avoiding work in peak heart.

Actualités juin 2024

- ## Travail par fortes chaleurs et périodes de canicule

Canicule: une protection efficace des travailleurs à l'extérieur est essentielle. Lenouvelliste.ch, 5 juin 2024

Travailler dehors, passer des examens, le quotidien difficile des Grecs assommés par la canicule. Lexpress.fr, 12 juin 2024

Une chaleur lourde au travail ne se prend pas à la légère. Infodimanche.com, 18 juin 2024

Le travail des paramédics pendant les journées de chaleur extrême. Noovo.info, 19 juin 2024

Des travailleurs estriens doivent s'adapter à la chaleur accablante. Ici.radio-canada.ca, 20 juin 2024

Chômage-intempéries dans le BTP : la canicule intégrera bientôt la liste des risques éligibles. Liaisons sociales Quotidien (Presse, p. 4-5), 24 juin 2024

Enjeux environnementaux : quels outils pour préserver la santé des travailleurs ? Protection sociale Informations (Presse, p. 13-14), 25 juin 2024

If you can't stay indoors during this U.S. heat wave, here are a few ideas. Msn.com, 17 juin 2024

For India's garbage pickers, a miserable and dangerous job made worse by extreme heat. Msn.com, 30 juin 2024

- ## Outils et capteurs de mesure

Intelligence artificielle et vidéo dans la capsule santé. Ouest-france.com, 24 juin 2024

- ## Maladies liées à la chaleur

How long does heat exhaustion last? What to know about the heat-related illness. Eu.freep.com, 17 juin 2024

Deadly heat sets alarm bells ringing over Paris Olympics. Independent.co.uk, 18 juin 2024

Heatstroke Versus Heat Exhaustion: What's the Difference? Everydayhealth.com, 18 juin 2024

LDH launches expanded heat-related illness dashboard, issues new guidance documents. Ldh.la.gov, 24 juin 2024

- ## EPI, matériaux protecteurs/refroidissants

Fanning the Flames of Textile Science. News.ncsu.edu, 13 juin 2024

Arc Flash Gear: A Comprehensive Guide. Electricityforum.com, 18 juin 2024

Keep workers safe during hazardous heat. Safetyandhealthmagazine.com, 20 juin 2024

WEARABLE SWEAT MONITOR USES MACHINE LEARNING TO PROTECT WORKERS FROM DEHYDRATION. Umass.edu, 24 juin 2024

Vêtements professionnels d'été légers et thermorégulants. Négoce (Presse, p.51), 28 juin 2024