

The Heat is On – At Some Workplaces: Evidence from Incident-Level Hungarian Work Accident Register DO NOT DISTRIBUTE - PRELIMINARY

Szilard Erhart

szilard.erhart@gmail.com

Joint Research Centre

Balint Menyhert

Joint Research Centre

Caterina Rho

Joint Research Centre

Article

Keywords:

Posted Date: September 7th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10282055/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Scientific Reports

The Heat is On – At Some Workplaces: Evidence from Incident-Level Hungarian Work Accident Register

DO NOT DISTRIBUTE - PRELIMINARY

Szilárd Erhart^{1,*}, Bálint Menyhért², and Caterina Rho³

¹Joint Research Centre, European Commission, Ispra, <https://orcid.org/0000-0002-0550-895X>

²Joint Research Centre, European Commission, Ispra

³Joint Research Centre, European Commission, Ispra

*szilard.erhart@gmail.com

ABSTRACT

Rising temperatures pose an increasing threat to occupational safety, yet empirical evidence from Central and Eastern Europe remains limited. This study addresses this gap by providing a large-scale, incident-level assessment of heat-related accident risk in Hungary. Linking over 130,000 workplace accident records (2016–2021) with high-resolution hourly temperature data, we estimate Negative Binomial regression models to quantify the impact of thermal conditions on accident incidence. We find that deviations above 20 °C are associated with a significant increase in accident risk (IRR=1.037, $p<0.001$), while cold deviations show no significant effect. The analysis reveals substantial heterogeneity across sectors and worker groups. Contrary to the assumption that heat risks are confined to outdoor work, we find high heat sensitivity in Arts, Professional Services, and Administrative Services, alongside traditional high-risk sectors like Construction. Furthermore, the burden of heat stress is unevenly distributed: temporary (IRR1.12) and part-time (IRR1.25) workers face significantly higher risks than their permanent and full-time counterparts. Temporal analysis indicates that accident risk escalates linearly with the duration of the shift, peaking at the 10th hour (IRR1.20), suggesting a cumulative effect of heat fatigue. These findings demonstrate that heat is a significant and socially stratified occupational hazard in Hungary, underscoring the urgent need for adaptive labor policies that target vulnerable employment types and specific sectors beyond agriculture and construction.

Introduction

Research examining the impact of high temperatures on workplace safety has grown substantially, driven in part by rising global temperatures and the increasing frequency of extreme heat events^{1,2}. A consistent pattern has emerged across studies: as ambient temperatures increase, so does the likelihood of occupational accidents³. Elevated temperatures can affect both mental and physical functioning, thereby increasing the probability of errors by disrupting focus and motor coordination, particularly in physically intensive and/or outdoor occupations and leading to a growing number of accidents on the job⁴.

The risks of heat on worker safety is especially evident in agricultural and construction sectors⁵. The Copernicus satellite monitoring service found that global land areas experienced more days in 2025 than average with at least strong heat stress – defined as a ‘feels like’ temperature of 32°C or more – a level associated with a higher risk of illness and death⁶. The extreme temperatures not only compromised worker health but also resulted in substantial productivity and financial losses in Australia, representing an annual economic burden of around 6.2 billion US dollars or 0.33 to 0.47% of Australia’s GDP⁷. A recent literature review found that productivity losses at the global level are expected to increase up to 30–40% under the worst climate change scenario by the end of the century⁸. A systematic meta-analysis of epidemiological studies representing almost 22 million occupational injuries showed that the overall risk of occupational injuries increased by 1 per cent for every 1°C increase in temperature above reference values, and by 17.4 per cent during heatwaves⁹.

Indoor workspaces are not fully exempt from heat-related dangers. A study conducted in the United States observed that injuries also rise in indoor sectors such as manufacturing and logistics, particularly when ventilation is inadequate or machinery generates additional heat¹⁰.

Studies of shift work^{11,12,13} demonstrate that night shifts and extended working hours are strongly associated with elevated accident risks. The interaction between shift duration, circadian disruption, and recovery time between shifts creates cumulative risks, particularly in safety-sensitive sectors such as healthcare, transportation, and manufacturing.

Together, these studies provide strong empirical evidence that occupational heat stress should be treated as a serious safety concern. Although specific temperature thresholds and statistical estimates may vary, the consensus is clear: higher temperatures are linked to greater accident risk. As climate change continues to increase the prevalence of heat exposure, workplace policies and regulations must adapt to protect workers from the growing threat of heat-related injuries.

Despite rapidly growing international evidence on heat-related occupational risks, there is a notable absence of empirical studies from Central and Eastern Europe¹⁴, including Hungary. This gap is significant for several reasons. First, Hungary faces increasing frequency and intensity of heatwaves, making heat exposure an emerging workplace hazard across both outdoor and indoor sectors. Second, Hungary maintains exceptionally detailed, event-level accident registers that allow more precise analyses than the aggregated data available in many countries. Third, the structure of the Hungarian economy—with a sizable workforce in manufacturing, construction, transport, and agricultural activities—creates distinct exposure profiles that may differ substantially from those documented in Western Europe or North America. Finally, understanding heat-related accident patterns is increasingly important for national labour protection policies, as existing regulations do not yet explicitly consider climate-driven heat stress. By linking high-resolution accident records with hourly regional temperature data, this study provides the first systematic assessment of heat–accident relationships in Hungary, filling a key geographical and methodological gap in the literature.

The rest of the paper is structured as follows. Section 2 presents empirical results on to what extent heat risk affects workers safety in Hungary, at industrial, regional level. Section 3 discusses the methodological framework and data sources. Section 4 details the limitations of our empirical set-up. Section 5 concludes.

Results

We estimated the association between workplace accidents and temperature, workforce composition, and industry sector using a negative binomial regression model with an offset for workforce size as discussed in the Section on data and methods (Table 1). Heat deviations above the climatological norm were positively associated with accident incidence (IRR = 1.037; 95% CI: 1.029–1.045; $p < 0.001$), while cold deviations showed no significant effect (IRR = 0.999; 95% CI: 0.998–1.001; $p = 0.390$). These results based on Hungarian microdata confirm recent evidence of a positive association between high temperatures and occupational accident risk in Switzerland, Spain, and Korea^{15–17}. Among workforce characteristics, average employee age was marginally associated with increased risk (IRR = 1.004; 95% CI: 1.000–1.008; $p = 0.051$), and a higher proportion of male employees was linked to higher accident incidence (IRR = 1.427; 95% CI: 1.286–1.582; $p < 0.001$). Permanent contract status and full-time employment were protective (IRR = 0.687; 95% CI: 0.573–0.825; $p < 0.001$; and IRR = 0.470; 95% CI: 0.398–0.555; $p < 0.001$, respectively). Later accident hours were associated with lower accident incidence, while shift work was not significantly related to accident risk. Industry sector displayed substantial heterogeneity in accident rates. Mining and Quarrying (NACE B) exhibited the highest risk (IRR = 7.287; 95% CI: 5.306–10.004), followed by Construction (NACE F, IRR = 4.736; 95% CI: 4.203–5.334), Professional Services (NACE M, IRR = 2.735; 95% CI: 2.361–3.169), and Real Estate Activities (NACE L, IRR = 2.397; 95% CI: 2.081–2.761). Elevated risks were also observed in Information and Communication (NACE J, IRR = 1.517; 95% CI: 1.309–1.757), Human Health and Social Work (NACE R, IRR = 1.687; 95% CI: 1.464–1.944), and Arts, Entertainment, and Other Services (NACE STU, IRR = 1.792; 95% CI: 1.493–2.149). In contrast, Wholesale and Retail Trade (NACE G, IRR = 0.886; 95% CI: 0.801–0.980) and Transportation and Storage (NACE H, IRR = 0.687; 95% CI: 0.617–0.765) were associated with lower accident rates, while several other sectors did not differ significantly from the reference category (NACE O, Public Administration). Overall, these findings indicate that heat exposure, workforce composition, and particularly industry sector significantly influence workplace accident risk. High-risk sectors such as mining, construction, professional services, and real estate may benefit from targeted, sector-specific prevention and climate adaptation strategies.

The Heterogeneous Effect of Heat on Work Accident Risk

This subsection presents the Incident Rate Ratios (IRRs) derived from Negative Binomial models, quantifying the change in the work accident rate per 1 °C increase above a threshold of 20 °C (*temp_{hot}*), controlling for annual, sector, and shift-level covariates, as well as worker characteristics.

The effect of heat on accident risk varied significantly across NACE economic sectors (Figure 4b). Sectors exhibiting the highest heat sensitivity and elevated accident risk included Arts (IRR >1.20), Professional Services (IRR 1.15). Conversely, the lowest sensitivity was observed in Financial Activities and Real Estate (both IRR < 1.00), typical of indoor, climate-controlled environments. The heat-related accident risk was strongly modified by worker demographics and contract status (Figure 4a, 4d, 4c).

Temporary workers showed a notably higher heat sensitivity (IRR1.13) compared to permanent workers (IRR1.04). Similarly, part-time employees displayed substantially increased risk (IRR1.25) compared to full-time employees (IRR1.04).

Table 1. Negative Binomial Regression Results

Variable	Estimate	Std. Error	z value	Pr(> z)	IRR	95% CI (IRR)
Panel A: Temperature effects						
Cold temperature deviation	-0.001	0.001	-0.860	0.390	0.999	[0.998, 1.001]
Hot temperature deviation	0.037***	0.004	8.639	<2e-16	1.037	[1.029, 1.045]
Panel B: Worker and job characteristics						
Average age	0.004*	0.002	1.954	0.051	1.004	[1.000, 1.008]
Proportion male	0.356***	0.055	6.450	1.12e-10	1.427	[1.286, 1.582]
Proportion permanent	-0.376***	0.087	-4.301	1.70e-05	0.687	[0.573, 0.825]
Proportion full-time	-0.756***	0.094	-8.034	9.40e-16	0.470	[0.398, 0.555]
Average severity	-0.039	0.064	-0.606	0.544	0.962	[0.848, 1.090]
Proportion on the road	-0.204**	0.087	-2.339	0.019	0.816	[0.685, 0.972]
Average accident hour	-0.021***	0.005	-3.884	0.0001	0.979	[0.969, 0.989]
Proportion shift workers	-0.095	0.062	-1.541	0.123	0.909	[0.813, 1.016]
Panel C: Employment status proportions						
Panel D: NACE Industry Fixed Effects (reference = NACE O)						
Agriculture (A)	0.435***	0.045	9.753	<2e-16	1.545	[1.384, 1.724]
Mining (B)	1.986***	0.172	11.536	<2e-16	7.287	[5.306, 10.004]
Manufacturing (C)	0.078*	0.044	1.768	0.077	1.081	[0.992, 1.177]
Energy (D)	-0.084	0.066	-1.274	0.203	0.920	[0.829, 1.022]
Water (E)	-0.160***	0.056	-2.828	0.005	0.852	[0.754, 0.964]
Construction (F)	1.555***	0.055	28.444	<2e-16	4.736	[4.203, 5.334]
Trade (G)	-0.121**	0.047	-2.585	0.010	0.886	[0.801, 0.980]
Transport (H)	-0.376***	0.046	-8.236	<2e-16	0.687	[0.617, 0.765]
Hotels (I)	0.094*	0.051	1.861	0.063	1.099	[0.993, 1.217]
Info (J)	0.417***	0.063	6.677	2.44e-11	1.517	[1.309, 1.757]
Finance (K)	-0.064	0.062	-0.775	0.438	0.938	[0.843, 1.041]
RealEst (L)	0.874***	0.057	15.356	<2e-16	2.397	[2.081, 2.761]
ProfServ (M)	1.006***	0.059	17.150	<2e-16	2.735	[2.361, 3.169]
Admin (N)	0.254***	0.048	5.318	1.05e-07	1.289	[1.160, 1.432]
Public (P)	0.377***	0.045	8.344	<2e-16	1.458	[1.296, 1.640]
Edu (Q)	0.056	0.042	1.320	0.187	1.058	[0.975, 1.148]
Health (R)	0.523***	0.053	9.844	<2e-16	1.687	[1.464, 1.944]
Arts/Other (STU)	0.583***	0.059	9.814	<2e-16	1.792	[1.493, 2.149]

Notes: IRR = Incidence Rate Ratio. CI = Confidence Interval (95%). Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Cold and hot temperature deviations are measured in degrees Celsius from climatological norms. Average age: Mean age of employees (years). Proportion male: Share of male employees. Proportion permanent: Share of workers with permanent contracts. Proportion full-time: Share of full-time employees. Average severity: Mean severity score of accidents. Proportion on the road: Share of road accidents recorded as work accident. Proportion shift workers: Share of shift workers. Average accident hour: Mean hour of the accident.

Industry dummies (NACE): Fixed effects for NACE sectors; reference = NACE O. Year dummies (yearXXXX): Calendar year fixed effects were all insignificant and omitted from the table. The intercept represents the expected log count of accidents for the reference categories and mean covariate values.

Male workers exhibited a slightly elevated and statistically significant, risk increase (IRR1.06) compared to female workers (IRR1.04).

The IRR associated with heat exposure was not constant but increased linearly throughout the work shift (Figure 4f). The effect was lowest at the beginning of the shift (IRR0.95 at hour 0) and peaked at the end (IRR1.20 at hour 10), suggesting a role for accumulated heat stress or fatigue.

Heat exposure showed a relatively stronger association with accidents of lower severity (severity 2, IRR1.13) and a non-significant or potentially protective association with the most severe accidents (severity 4, IRR0.95) (Figure 4e).

Data and Methods

Data

Our primary dataset consists of official accident registers for the period 2016–2021, compiled by the Hungarian Ministry of Innovation and Technology (integrated after the data was provided for our research into the Ministry for the National Economy). In total, the database contains more than 130,000 event-level records.¹ Accidents are registered when they occur during, or in connection with, organized work and lead to incapacity exceeding three working days. In accordance with the European Statistics on Accidents at Work (ESAW) methodology, commuting and traffic accidents occurring between an individual's residence and workplace are excluded. In Hungary, commuting incidents involving an employer's own or rented vehicle are exceptionally classified as work-related accidents¹⁸. Employers are required to submit accident reports to the competent occupational safety authority on a monthly basis, within eight days of the reporting period. The descriptive statistics of the sample can be found in the Annex, (Table 3).

We combined the work accident dataset with heat observations (Figure 1). For the matching of accidents with weather conditions, we used the calendar days, hours and the regional codes.

For this study, we used the European Statistical Office (ESTAT) NUTS (*'Nomenclature des Unités Territoriales Statistiques'*, e.g. Nomenclature of Territorial Units for Statistics) regions and in particular NUTS3 statistics, covering county level observations for Hungary. We base our analysis on the dataset of temperature extremes in Europe NUTS regions (1980–2024)¹⁹. This dataset provides detailed measurements of extreme temperatures across Europe using different temperature-related metrics at multiple spatial and temporal scales. This dataset is a ERA5-Land reanalysis (0.1° daily temperature, 0.25° UTCI).

Methods

Temperature and Work Capacity

Rising global temperatures have intensified concerns about heat stress, with implications that go beyond productivity loss to include heightened risks of workplace accidents and injuries³. In the context of occupational safety, understanding how heat affects physical and cognitive performance is critical for both prevention strategies and risk assessment. The year 2030 is often cited as a benchmark for assessing future climate-related impacts, underscoring the need for quantifiable indicators and empirically grounded estimates.

Although health affects from heat stress cannot be directly measured in real-time, they can be inferred through physiological models, epidemiological data, and climate projections. Evidence suggests that temperatures above 24–26°C are already associated with reduced labour performance⁴, with risks accelerating sharply at higher thresholds (Table 2). At 33–34°C, a worker engaged in moderate-intensity activity may lose up to 50% of work capacity. Beyond 38°C (heat exhaustion), both physical endurance and cognitive functioning are compromised, elevating the probability of errors and accidents. Exposure above 39°C can be life-threatening, and at or above 40.6°C (heatstroke), the likelihood of severe organ damage, loss of consciousness, or death increases significantly. Weather and heat conditions during work can be exarabated by physical activity and other profession related characteristics (insulation form, protective work clothes, heat from energy intensive operations at the workplace, etc.)³

Notes: Adapted from ILO(2019)⁴.

Hourly temperature calculation

To estimate hourly temperatures from daily minimum and maximum observations, we applied a cosine-based diurnal model. This approach assumes that the daily minimum temperature typically occurs in the early morning (around 6:00) and the daily maximum in the mid-afternoon (around 17:00), with temperatures following a smooth sinusoidal pattern between these extremes²⁰. The model calculates the hourly temperature as a function of the mean daily temperature, the amplitude of the diurnal variation, and the hour of the day (Figure 2). This method has been widely used in environmental biophysics²¹ and agricultural meteorology²². Using this approach, we generated an 'hour_temp' variable for each observation in our accident dataset, providing a continuous estimate of air temperature at the hour of the reported incident.

¹These data are confidential and provide substantially more detail than publicly available statistics. For comparison, see establishment-level information from the U.S. Occupational Safety and Health Administration's [database](#), or aggregate EU [statistics](#) from Eurostat.

Figure 1. The framework of our research based on the Hungarian workplace accident register microdata matched with NUTS3 regional heat statistics

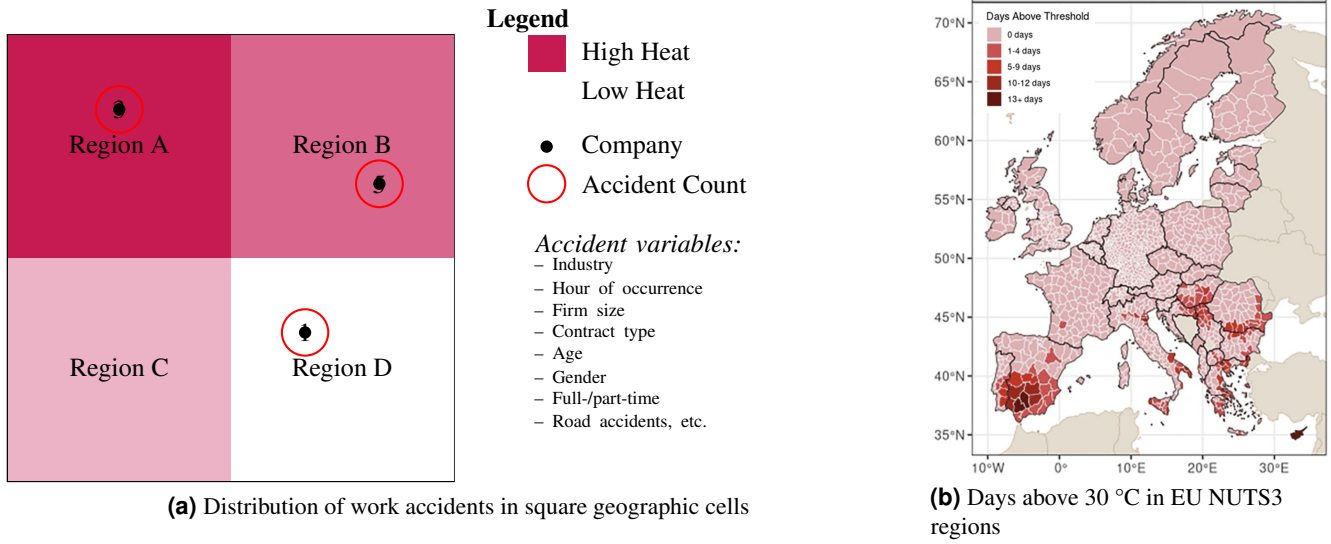
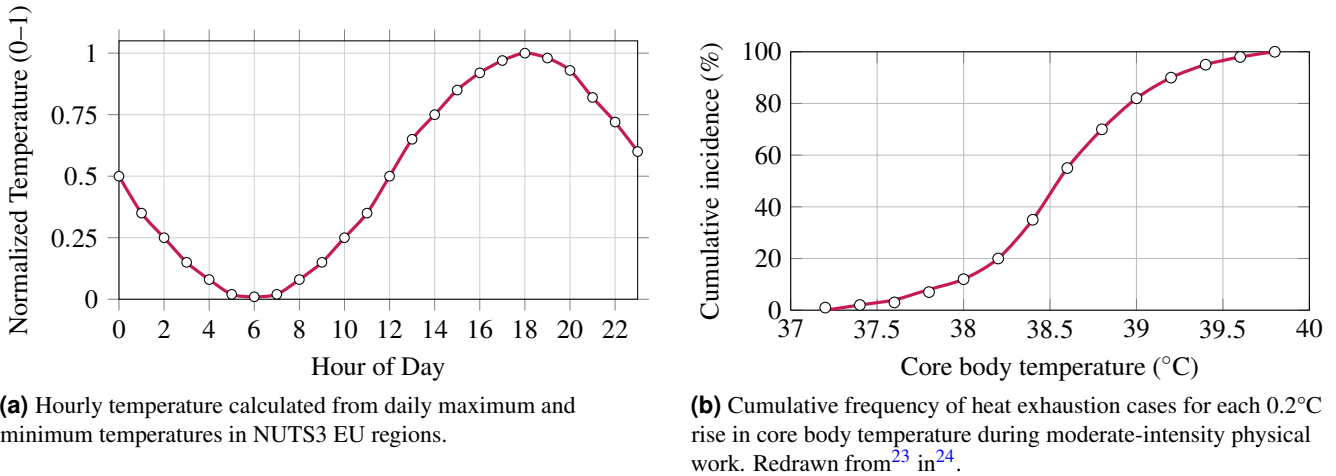


Figure 2. Functions of the hourly temperature calculations from minimum and maximum daily temperature and the impact of body temperature increase on labor productivity



Notes: (b) Hourly temperatures were normalised using $T_{\text{norm}} = \frac{T_{\text{hour}} - T_{\text{min}}}{T_{\text{max}} - T_{\text{min}}}$, where T_{hour} is the observed hourly temperature, T_{min} is the daily minimum temperature, and T_{max} is the daily maximum temperature. This rescaling allows comparisons across days with different absolute temperature ranges. Observations: 2010–2024. Source: *What's the TEE: Metrics of Temperature Extremes in Europe NUTS Regions (1980–2024)*¹⁹.

Table 2. Temperature and associated work capacity effects

Temperature (T, °C)	Effect on work capacity and safety
24–26°	Reduced labour productivity.
33–34°	Up to 50% loss of work capacity at moderate work intensity.
>38°	Heat exhaustion; impaired physical and cognitive functions, higher accident risk.
>39°	Potentially fatal without intervention.
>40.6°	Heatstroke; high risk of organ damage, unconsciousness, and death.

Econometric modelling

We used our panel dataset of reported workplace accidents by NACE sector and year, linked to hourly temperature observations. To capture exposure, we aggregated accidents and reported workforce counts within 5 °C temperature bins ranging from –15 °C to 35 °C. For each bin we calculated deviations below 15 °C (“cold” exposure) and above 20 °C (“hot” exposure). We then estimated negative binomial regression models with the count of accidents as the dependent variable, the log of workforce as an offset to account for exposure, and temperature deviations, sector (NACE) and year fixed effects as predictors. Additional workforce characteristics such as mean age and gender composition were included where available. Coefficients were exponentiated to obtain incidence rate ratios (IRRs), which express the multiplicative change in accident risk for a one-unit change in each predictor. This design allows comparison of temperature effects across sectors and years while controlling for workforce size and composition.

We model the number of workplace accidents using a negative binomial (NB) regression of the form:

$$Accidents_{itb} \sim \text{NB}(\mu_{itb}, \theta), \quad (1)$$

$$\log(\mu_{itb}) = \log(Exposure_{itb}) + X_{itb}\beta + \gamma_s + \delta_t + \phi_c, \quad (2)$$

where i indexes NACE sectors, t years, b temperature bins, and X_{itb} is a vector of temperature measures and workforce characteristics.

The parameter μ_{itb} denotes the expected number of accidents in industry i , year t , and temperature bin b , conditional on covariates. The parameter θ is the negative binomial dispersion parameter, with larger values indicating a distribution closer to Poisson and smaller values reflecting greater overdispersion. The log offset $\log(Exposure_{itb})$ corresponds to the workforce size, ensuring that coefficients are interpreted as incidence rate ratios.

The negative binomial model assumes that accident counts are conditionally independent given the covariates and that the variance exceeds the mean, consistent with overdispersed count data. The log-link function implies a multiplicative relationship between predictors and accident risk. Industry and year fixed effects are assumed to capture all time-invariant sector characteristics and common temporal shocks, respectively. No perfect multicollinearity among covariates is assumed, and exposure (workforce size) is treated as measured without error.

Discussion

These findings highlight that both environmental conditions and industry sector strongly influence occupational accident risk in Hungary. The pronounced effects of especially hot temperatures suggest that climate-related stressors are an important safety consideration. Industries with high accident IRRs (such as Mining, Construction) may benefit from targeted prevention measures during periods of extreme temperature. Employers and regulators could consider adapting work schedules, providing additional protective equipment, or enhancing training when adverse weather is forecast. Because year effects were small, the results imply that without proactive interventions, baseline risks remain relatively stable over time. Tailored prevention strategies that account for sector-specific hazards and temperature extremes could substantially reduce workplace accidents.

Assessing the relationship between heat exposure and occupational accidents presents several methodological and conceptual challenges. One of the primary difficulties lies in isolating the effect of heat from other contributing factors that influence workplace safety. Environmental heat often coincides with seasonal variables such as increased workloads, changes in shift patterns, or staffing fluctuations, all of which can independently affect accident rates. Disentangling these overlapping variables is essential but rarely straightforward.

Although our study is rich of incident level findings, increasing accuracy in quantifying individual heat exposure needs further efforts. To be as precise as possible, we investigated spatial correlation of ambient temperature (Figure 3). As Hungary

is a relatively small country with flat land, the mean, maximum and minimum temperature is highly correlated across NUTS3 regions. However, this may not accurately reflect the microclimate of specific work environments—particularly in indoor or semi-enclosed settings. See the animated temperature chart: [Click here to view animation](#).

In addition, reporting practices for workplace accidents can vary across sectors and jurisdictions, potentially introducing systematic biases. Some incidents may go unreported, particularly in informal or precarious employment contexts, skewing the data toward underestimation of the true burden. Construction, Agriculture and Tourism are sectors often considered as sectors with higher level of unregistered employment increasing the the probability of underestimating accident risks in these sectors.

Finally, temporal resolution is critical. The impact of heat on cognitive and physical performance may occur within short timeframes (minutes), while many accident reporting systems only log events daily or weekly. This mismatch can obscure short-term associations and limit the ability to detect causal relationships.

Overall, while there is growing evidence suggesting that heat stress contributes to increased occupational injury risk, more refined exposure metrics, improved and harmonized reporting systems, and integrative study designs are needed to clarify and quantify this relationship more accurately.

Policy recommendations

Policy recommendations based on this study must be comprehensive, addressing not only the obvious risks in outdoor work but also the societal and temporal factors that increase vulnerability.

The data supports moving away from simple "one-size-fits-all" regulations to a graded heat-response system. Since accident risk escalates above 20 C, policy should implement action tiers starting at moderate temperatures, not just extreme heatwave conditions, requiring passive cooling and mandatory hydration. These temperature-based protocols should be legally binding and apply universally across all economic sectors.

Furthermore, regulations must be updated to mandate equal safety protections for all employment types. The observed high susceptibility of temporary and part-time workers requires targeted legislative action to ensure these precarious employees receive the same thorough safety training, access to cooling measures, and autonomy to take necessary rest breaks as their permanent counterparts, with strict oversight and enforcement.

The findings on sectoral heterogeneity necessitate extending heat-stress protocols to the service economy. Awareness campaigns and new regulations are required for non-traditional high-risk sectors like Professional Services and Arts, where the risk is likely driven by cognitive fatigue and less robust climate control. Policy should also incentivize or mandate infrastructure retrofitting to provide adequate cooling in administrative and service buildings that may currently expose workers to unsafe thermal conditions.

Finally, to counteract the observed effect of cumulative heat fatigue, work safety policy must embrace dynamic shift management. This involves requiring employers to front-load high-intensity or mentally demanding work to the cooler hours of the day. Crucially, a system of progressive recovery periods should be mandated, increasing the frequency and duration of breaks as a shift advances toward the late afternoon and early evening, directly mitigating the risk associated with prolonged exposure and fatigue.

Conclusions

This study provides the first systematic empirical evidence of the relationship between ambient temperature and occupational accident risk in Hungary, filling a critical geographical gap in the European literature on work accidents. By utilizing granular, incident-level data linked to hourly temperature estimates, we demonstrate that heat exposure significantly elevates workplace accident rates, particularly when temperatures exceed 20 degrees Celsius.

Our findings highlight three critical dimensions of heat-related occupational risk. First, we observed substantial sectoral heterogeneity. While outdoor sectors like Construction and Mining show expected high risks, our results uncover substantial heat sensitivity in the service economy, specifically in Arts, Entertainment, and Professional Services. This challenges the traditional view that heat stress is solely an industrial or agricultural concern and suggests that cognitive fatigue in service sectors may be a significant, under-regulated hazard.

Second, the impact of heat is not uniform across the workforce but is socially stratified. Employees with precarious employment status—specifically those on temporary contracts and part-time schedules—exhibit a drastically higher susceptibility to heat-related accidents compared to permanent, full-time staff. This suggests that job insecurity may correlate with poorer working conditions or less autonomy to mitigate thermal stress.

Third, the analysis of shift timing reveals a pattern of cumulative fatigue. The linear increase in heat-related accident risk over the course of a work shift, peaking at the 10th hour, implies that current break schedules may be insufficient to prevent heat exhaustion as the workday progresses.

As climate change increases the frequency of high-heat days in Central Europe, existing occupational health and safety regulations must evolve. Our results suggest that "one-size-fits-all" temperature thresholds are likely insufficient. Effective mitigation requires sector-specific adaptation strategies for high-risk service sectors, enhanced protection for vulnerable workers on temporary contracts, and dynamic work scheduling to counteract cumulative fatigue during heatwaves. Without proactive adaptation strategies, the projected rise in temperatures threatens to exacerbate existing inequalities in occupational safety.

Data availability

The dataset of temperature extremes analysed during the current study are available in Ronnkvist, S. R. et al. What's the tee: Metrics of temperature extremes in Europe NUTS regions (1980–2024). *Sci. Data* 12, DOI: 10.1038/s41597-025-05352-7 (2025).¹⁹

The workplace accident dataset analysed during the current study is not publicly available due to the restriction of the data provider corresponding authority, e.g. the Hungarian Ministry for Innovation and Technology (integrated into the Ministry for the National Economy) and confidentiality and privacy regulations but is available from the corresponding authority on reasonable request.

The graphs and figures in the study will be publicly available in the Mendeley repository upon publication of the study: Erhart, Szilárd (2026), "XXXXXX", Mendeley Data, V1, doi: [XXXX](#)

References

1. Park, J., Kriebel, D. & Benmarhnia, T. Heat exposure and occupational injuries: A review of the literature and implications for workplace safety. *Environ. Res.* **194**, 110645, DOI: [10.1016/j.envres.2020.110645](#) (2021).
2. Mora, C. *et al.* Global risk of deadly heat. *Nat. Clim. Chang.* **7**, 501–506, DOI: [10.1038/nclimate3322](#) (2017).
3. Organization, I. L. Heat at work: Implications for safety and health — a global review of the science, policy and practice. Tech. Rep., International Labour Organization (2024). Accessed: YYYY-MM-DD.
4. ILO. Working on a warmer planet the impact of heat stress on labour productivity and decent work. (2019).
5. Zander, K. K., Botzen, W. J. W., Oppermann, E., Kjellstrom, T. & Garnett, S. T. Economic costs of heat-related illnesses: The case of agricultural workers in australia. *Environ. Res.* **137**, 235–245, DOI: [10.1016/j.envres.2014.11.002](#) (2015).
6. Copernicus Climate Change Service (C3S) / European Commission. Global climate highlights 2025. <https://climate.copernicus.eu/global-climate-highlights-2025> (2026). Accessed: 2026-01-19.
7. Zander, K. K., Botzen, W. J. W., Oppermann, E., Kjellström, T. & Garnett, S. T. Heat stress causes substantial labour productivity loss in australia. *Nat. Clim. Chang.* **5**, 647–651, DOI: [10.1038/nclimate2623](#) (2015).
8. De Sario, M. *et al.* Occupational heat stress, heat-related effects and the related social and economic loss: a scoping literature review. *Front. Public Heal.* **11**, 1173553, DOI: [10.3389/fpubh.2023.1173553](#) (2023).
9. Fatima, S. H., Rothmore, P., Giles, L. C., Varghese, B. M. & Bi, P. Extreme heat and occupational injuries in different climate zones: A systematic review and meta-analysis of epidemiological evidence. *Environ. Int.* **148**, 106384, DOI: [10.1016/j.envint.2021.106384](#) (2021). Accessed: YYYY-MM-DD.
10. Foster, J., Foster, J., Huang, G., Chuang, H.-Y. & Spengler, J. D. Climate and occupational injury in the usa: Is hot weather associated with increased workplace accidents? *Occup. Environ. Medicine* **76**, 592–599, DOI: [10.1136/oemed-2018-105517](#) (2019).
11. Fischer, D., Lombardi, D. A., Folkard, S., Willetts, J. & Christiani, D. C. Update of a meta-analysis of shift work and occupational accident risk. *Chronobiol. Int.* **34**, 1423–1426, DOI: [10.1080/07420528.2017.1367305](#) (2017).
12. Nielsen, H. B. *et al.* Shift work and risk of occupational, transport and leisure-time injury: a register-based case-crossover study of danish hospital workers. *Saf. Sci.* **120**, 728–734, DOI: [10.1016/j.ssci.2019.07.006](#) (2019).
13. Ropponen, A., van de Ven, P., Sallinen, M. & Harma, M. Working hour patterns and risk of occupational accidents: a data-driven study. *Saf. Sci.* **162**, 106050, DOI: [10.1016/j.ssci.2023.106050](#) (2023).
14. Binazzi, A. *et al.* Evaluation of the impact of heat stress on workers' health and productivity: A systematic review of the literature. *Ind. Heal.* **57**, 139–152, DOI: [10.2486/indhealth.2018-0121](#) (2019).
15. Martín, M. *et al.* The impact of extreme temperatures on occupational accidents: Evidence from switzerland. *Labour Econ.* **87**, 102567, DOI: [10.1016/j.labeco.2024.102567](#) (2024).
16. Orozco, A. *et al.* Temperature extremes and workplace accidents in spain: Evidence from 48 provinces, 1988–2019. *Environ. Res.* **231**, 116017, DOI: [10.1016/j.envres.2023.116017](#) (2023).

17. Lee, J., Lee, W. & Khang, Y.-H. Exposure to extreme temperatures and work-related injuries among Korean workers. *Saf. Heal. at Work*. **10**, 427–433, DOI: [10.1016/j.shaw.2019.10.002](https://doi.org/10.1016/j.shaw.2019.10.002) (2019).
18. ITM. Tájékoztató a munkabalesetek alakulásáról a feldolgozott munkabaleseti jegyzőkönyvek alapján 2021. (2022).
19. Ronkvist, S. R. *et al.* What's the tee: Metrics of temperature extremes in Europe's regions (1980–2024). *Sci. Data* **12**, DOI: [10.1038/s41597-025-05352-7](https://doi.org/10.1038/s41597-025-05352-7) (2025).
20. Parton, W. J. & Logan, J. A. A model for diurnal variation in soil and air temperature. *Agric. Meteorol.* **23**, 205–216, DOI: [10.1016/0002-1571\(81\)90105-9](https://doi.org/10.1016/0002-1571(81)90105-9) (1981).
21. Campbell, G. S. & Norman, J. M. *An Introduction to Environmental Biophysics* (Springer, New York, 2012), 2 edn.
22. Weiss, A. & Hays, C. J. Simulation of hourly air temperatures from daily min–max data. *Agric. For. Meteorol.* **132**, 181–193, DOI: [10.1016/j.agrformet.2005.07.002](https://doi.org/10.1016/j.agrformet.2005.07.002) (2005).
23. Sawka, M. N. & Pandolf, K. B. Physical exercise in hot climates: physiology, performance and biomedical issues. In Pandolf, K. B., Burr, R. E., Zajchuk, R. & Bellamy, R. F. (eds.) *Medical Aspects of Harsh Environments*, vol. 1 of *Textbook of Military Medicine*, 87–133 (Department of the Army, Office of The Surgeon General, and Borden Institute, Washington, DC, 2001). Available online via Semantic Scholar.
24. Organization, W. H. & Organization, W. M. *Climate Change and Workplace Heat Stress: Technical Report and Guidance* (World Health Organization and World Meteorological Organization, Geneva, 2025).

Funding Declaration

Szilard Erhart and Catherina Rho work in the Joint Research Centre of the European Commission.

Acknowledgments

The authors gratefully acknowledge the data and methodological support received by the Hungarian Ministry for Innovation and Technology (integrated into the Ministry for the National Economy) and Péter Nesztger in particular. Helpful comments and suggestions by **xxxxxx**, as well as participants at the **xxxxxx** seminar, are also greatly appreciated.

Author contributions statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, methodology, software, data curation, writing, original draft preparation, visualisation.

S.E. participated in the conceptualization and formulation of research, analyzed and visualized the results and wrote the main manuscript text.

B. M. worked on the cleaning and structuring of accident register.

C. R. participated in the conceptualisation of the research and in the finalisation of the research paper.

Additional information

The authors declare that they have no competing interests.

Table 3. Descriptive Statistics of Key Variables

Variable	Mean	SD	Min	Max
Age (years)	41.153	12.929	15	78
Male (yes = 1, no = 0)	0.636	0.481	0	1
Permanent (yes = 1, no = 0)	0.898	0.302	0	1
Fulltime (yes = 1, no = 0)	0.936	0.244	0	1
Severity (1 to 4)	1.023	0.241	1	4
Road (yes = 1, no = 0)	0.055	0.228	0	1
Hour (0 to 23)	11.564	4.286	0	23
Shift hour	4.260	2.672	0	40

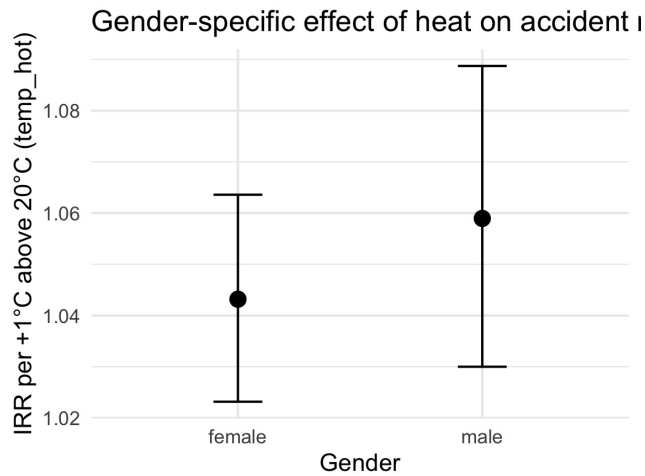
Heatmap showing the correlation matrix of the 15 Hungarian regions. The regions are listed on the diagonal: Budapest, Pest, Fejér, Komárom-Esztergom, Győr-Ménfőcsanak, Veszprém, Vas, Zala, Baranya, Somogy, Tolna, Borsod-Abaúj-Zemplén, Heves, Nógrád, Hajdú-Bihar, Jász-Nagykun-Szolnok, Szabolcs-Szatmár-Bereg, Bács-Kiskun, and Békés. The color scale ranges from -1 (dark red) to 1 (dark blue), with 0 being white. The diagonal elements are all 1.0, indicating perfect self-correlation. The off-diagonal elements show varying degrees of correlation between different regions, with some regions showing higher correlation than others.

Hungarian County	Average Number of Cases per Inhabitant
Budapest	1.001
Pest	1.001
Fejér	1.001
Komárom-Esztergom	1.000
Veszprém	1.000
Győr-Ménfőcsanak	1.000
Moson-Sopron	1.000
Zala	0.991
Baranya	1.001
Somogy	1.000
Tolna	0.980
Borsod-Abaúj-Zemplén	1.000
Hajdú-Bihar	1.001
Nógrád	0.999
Jász-Nagykun-Szolnok	0.990
Szabolcs-Szatmár-Bereg	0.980
Bács-Kiskun	0.991
Békés	-1.00

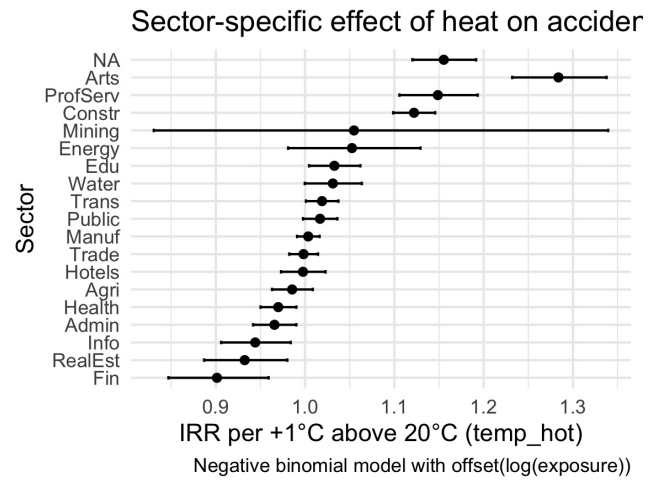
Heatmap showing the average number of COVID-19 cases per 100,000 inhabitants by county in Hungary, sorted by the number of cases. The color scale ranges from 0 (white) to 1.0 (dark red).

County	Average cases per 100,000 inhabitants
Budapest	1.00
Pest	1.00
Fejér	1.00
Komárom-Esztergom	1.00
Veszprém	1.00
Győr-Ménfőcsanak	1.00
Vas	1.00
Zala	0.91
Baranya	1.00
Somogy	1.00
Tolna	0.90
Borsod-Abaúj-Zemplén	1.00
Héves	1.00
Nógrád	0.90
Hajdú-Bihar	1.00
Jász-Nagykun-Szolnok	0.90
Szabolcs-Szatmár-Bereg	0.90
Bács-Kiskun	0.91
Békés	1.00

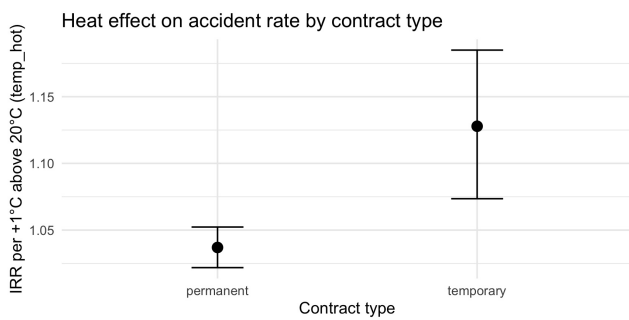
10/11



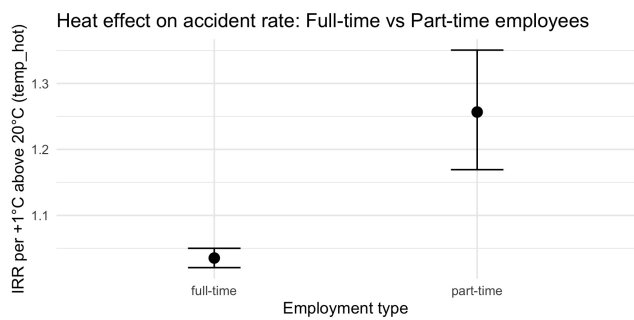
(a) by gender



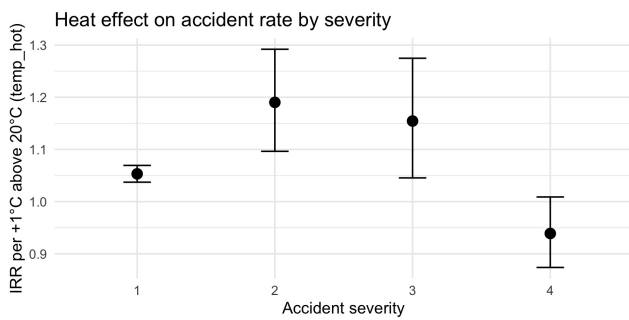
(b) by NACE sectors



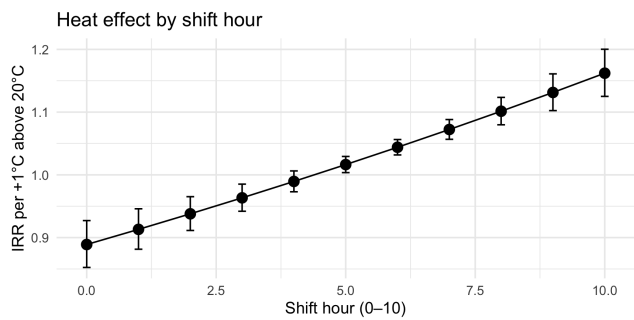
(c) by contract type



(d) by employment type



(e) by severity of the accident



(f) Accident shift hour

Figure 4. Estimated heat affect with detailed statistics.