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# Impact of meteorological factors on suicide risk: Insights from a generalized additive model analysis

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ABSTRACT

*Objective:* This study investigates the effects of two specific meteorological factors, Physiologically Equivalent Temperature (PET) and Diurnal Temperature Range (DTR), on suicide risk in Ilam City, Iran, using Generalized Additive Model (GAM) analysis to quantify their relationship with suicide risk.
*Methods:* Data on suicides from 2016 to 2022 were sourced from the Systematic Registration of Suicide Data (SRSD), alongside meteorological data (temperature, wind speed, humidity) obtained from the Ilam Meteorological Organization. PET was calculated utilizing Rayman Software, and DTR was defined as the difference between daily maximum and minimum temperatures. GAM was employed to model the relationships and assess lag effects.
*Results:* Over the six-year study period, 3112 suicides were recorded in Ilam City (mean: 1.42/day). Analysis revealed a linear exposure-response relationship for both PET and DTR on the same day (lag 0). The most notable finding was a consistent, cumulative increase in suicide risk associated with rising Diurnal Temperature Range (DTR). For each 1 °C increase in DTR, the risk escalated over successive lag periods, reaching a 3.24% increase (95% CI: 1.19, 5.33) over a 21-day period (lag 021).
*Conclusions:* This study demonstrates that temperature variability, measured by DTR, significantly associates with suicide risk in Ilam City, Iran. These results highlight the importance of incorporating meteorological data into suicide prevention strategies and early-warning systems. Future research should explore the underlying mechanisms of this relationship across different populations and climates.

## 1. Introduction

The context of this study is the persistent and pressing global public health challenge of suicide. Suicide remains a significant global public health issue, ranking as one of the leading causes of death, particularly among young adults. According to previuos study, approximately 703,000 individuals die by suicide each year, with a considerable proportion of these deaths occurring in low- and middle-income countries (Bertuccio et al., 2024). This context is particularly relevant in Iran, where rising suicide rates have prompted urgent calls for effective prevention strategies (Esmaeili et al., 2022). The multifaceted nature of suicide necessitates a comprehensive understanding of various risk factors, including psychological, social, and environmental elements (Favril et al., 2023).

Understanding environmental factors that influence suicide risk is critical for developing effective prevention strategies. While psychological and sociocultural factors have traditionally been the focus of suicide research, recent studies indicate that environmental conditions, particularly meteorological factors, can significantly impact mental health and suicidal behavior (Deisenhammer, 2003). Research has shown that fluctuations in weather conditions can affect mood, behavior, and overall well-being (Berk et al., 2014). For instance, extreme heat has been linked to increased aggression and irritability, while prolonged periods of cold can lead to feelings of isolation and depression (Chang et al., 2017). Consequently, exploring the relationship between meteorological factors and suicide risk can yield valuable insights for targeted interventions.

The purpose of this research is to advance this understanding by moving beyond simple temperature metrics and investigating more nuanced meteorological indices. Among the various meteorological

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factors, Physiologically Equivalent Temperature (PET) and Diurnal Temperature Range (DTR) are particularly relevant to understanding suicide risk. PET accounts for the combined effects of temperature, humidity, and wind speed, providing a more accurate representation of perceived thermal comfort than temperature alone (Höppe, 1999).

DTR, defined as the difference between the maximum and minimum temperatures within 24 h, reflects temperature variability and influences physiological and psychological responses. (Fischer et al., 2014). Both PET and DTR have been associated with mental health outcomes, suggesting that fluctuations in these meteorological factors may correlate with changes in suicide risk (Yu et al., 2023).

The primary aim of this study is to investigate the impact of PET and DTR on suicide risk in Ilam City, Iran. Our specific objectives are: first, to quantify the relationship between daily variations in PET and DTR and daily suicide counts. Second, to model these relationships using a Generalized Additive Model (GAM) to identify both immediate and lagged effects.

This analytical approach allows for the examination of non-linear relationships and the identification of potential lag effects, enhancing the understanding of how variations in temperature and humidity may influence suicidal behavior over time. By addressing these aspects, this study aims to provide localized, actionable evidence that can inform public health strategies and contribute to a more nuanced global understanding of the environment-mental health nexus.

## 2. Literature review

The association between ambient temperature and suicide is one of the most consistently reported findings. A multi-country multi-city study by (Kim et al., 2019) analyzing over 1.3 million suicides across 12 countries found a positive, often non-linear association, with the highest risk at approximately 27 °C. The relationship was more pronounced in Northeast Asia compared to Western countries, highlighting the role of regional and climatic context. Similarly, a systematic review and meta-analysis by (Frangione et al., 2022) concluded that short-term increases in temperature, particularly maximum daily temperature, were positively associated with suicide, with stronger effects observed among men and in the East Asia and Pacific region. These findings are supported by earlier studies; for example, (Lee et al., 2006) identified a spring peak and a positive association with ambient temperature in Taiwan, while (Deisenhammer, 2003) found that high-temperature days and days following thunderstorms were associated with a higher suicide risk in Austria.

However, the relationship is not uniform. Burkart et al. (2021) demonstrated that the effect of temperature on suicide in New Zealand depended on the type of variation: irregular (daily) temperature increases were positively related to suicide, whereas geographical variation (living in a warmer region) was negatively related. This crucial distinction underscores the complexity of predicting how long-term climate change might affect suicide rates. (Moore et al., 2018) further illustrated this ecological complexity, finding that seasonal and meteorological effects on suicide in Scotland were dependent upon local context and sex, with stronger effects apparent among men at a specific location (the Tay Road Bridge) but not across the country as a whole.

Beyond simple temperature metrics, researchers have begun to investigate more complex biometeorological indices. The PET, which integrates temperature, humidity, wind speed, and solar radiation, provides a more holistic measure of human thermal comfort. Its application in mental health research is growing, with studies suggesting it may be a more sensitive indicator of environmental stress than temperature alone (Yu et al., 2023). Similarly, the DTR represents a different dimension of thermal stress—variability rather than absolute level. Larger DTR values indicate greater intra-day temperature fluctuations, which have been linked to various physiological stresses (Qiu et al., 2013). The exploration of DTR in relation to suicide risk is a more recent and less common approach, offering a novel perspective on how temperature dynamics, not just levels, may influence mental well-being.

Other meteorological and environmental factors have also been implicated. (Aguglia et al., 2021) found a significant association between high-lethality suicide attempts and apparent temperature, solar radiation, and air pollution (PM ~ 2.5~). This aligns with other studies linking air pollution to increased suicide risk (Kim et al., 2019; Szyszkowicz et al., 2010), suggesting that multiple environmental stressors may act concurrently or synergistically.

Methodologically, the field has evolved from examining simple correlations to employing sophisticated time-series analyses. The GAM has been widely used in environmental epidemiology due to its flexibility in modeling non-linear exposure-response relationships and controlling for confounding factors like long-term trends and seasonality (Ma et al., 2020). This approach is crucial for accurately estimating the delayed and potentially non-linear effects of meteorological variables on health outcomes.

In summary, while a positive association between higher temperatures and increased suicide risk is well-established, significant gaps remain. These include a relative lack of studies in the Middle East, inconsistent findings regarding the effects of temperature variability (DTR), and the need for more research using comprehensive thermal indices like PET. The present study directly addresses these gaps by applying a robust GAM framework to investigate the impact of both PET and DTR on suicide risk in Ilam City, Iran, thereby contributing novel insights from a unique geographical and climatic setting.

## 3. Methods

### 3.1. Area

Ilam is a historical and cultural city located in Ilam Province, in southwest Iran, at 1200 m above sea level. The town's geographical coordinates are 33.6333° N latitude and 46.4167° E longitude. The mean annual rainfall in Ilam is approximately 600 mm. The absolute minimum and maximum temperatures recorded are −10 °C and 40 °C, respectively. The mean yearly air pressure is around 700 hPa, with an average temperature of 15 °C. The maximum and minimum temperatures are 30 °C and 0 °C, respectively, and the average humidity is about 60%. Fig. 1 illustrates the location of Ilam city.

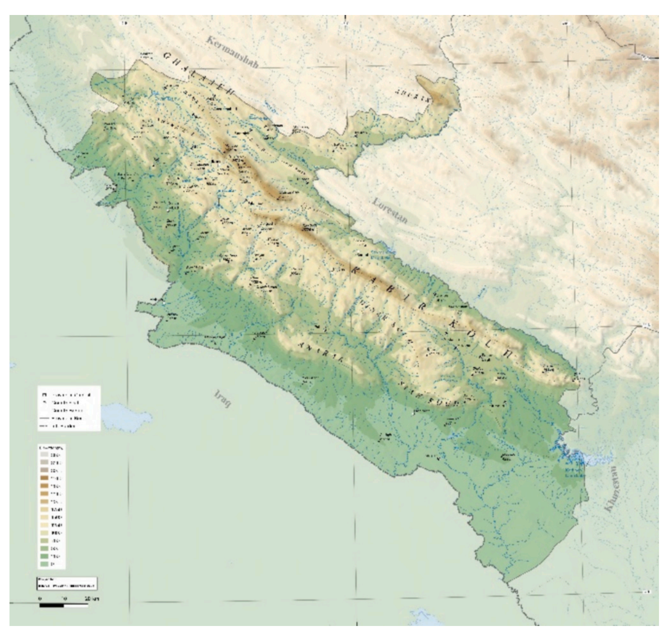


**Fig. 1.** Topographic map of Ilam Province.

### 3.2. Data collection

The data on suicides over six years (2016 to 2022) were obtained from the Systematic Registration of Suicide Data (SRSD). For the same period, data on daily maximum, minimum, and mean air temperatures (°C), wind speed (m/s), cloudiness, and relative humidity were also collected from the Ilam Meteorological Organization in Iran.

The study ensured data robustness through a rigorous process. Suicide records were cross-verified across multiple official sources (hospitals, forensic reports) to confirm accuracy. The final suicide dataset was complete, with no missing daily counts; days without events were recorded as zeros. For meteorological data, any day with a missing value for temperature, humidity, or wind speed was entirely removed from the analysis (listwise deletion). This process resulted in a complete, gapless daily dataset for both suicide and meteorological variables, forming a reliable foundation for the time-series analysis.

### 3.3. PET calculation

The PET index was calculated using Rayman Software, following similar methodologies in previous studies (Sharafkhani et al., 2018). DTR Calculation: The DTR is the difference between the maximum and minimum temperatures over one day. Medical and epidemiological studies have shown that sudden changes in daily temperature may cause physiological problems (Doganay et al., 2003; Garrett et al., 2011; Martinez-Nicolas et al., 2015; Qiu et al., 2013; Ryan, 2022).

### 3.4. Statistical analysis

The GAM was employed to assess the impact of meteorological factors, such as PET and DTR, on suicide risk. This approach has been used in previous research with a quasi-Poisson link function (Ma et al., 2020). To develop the foundational models for suicide outcomes, we adopted a parsimonious approach focused on our primary variables of interest. Specifically, other meteorological variables for which we had data—such as precipitation, wind speed, cloud cover, and absolute humidity—were excluded from the core model. This decision was made a priori to avoid multicollinearity, given that their effects are integrally captured by the composite PET index, and to maintain model clarity and interpretability for our key exposures (PET and DTR). The effects of the meteorological variables were subsequently analyzed using the model. We used smoothed spline functions to establish a flexible modeling instrument that accommodates the nonlinear and volatile relation between time and suicide. The model was subsequently employed to investigate the effect of meteorological variables. The Akaike information criteria was utilized to assess the model's fit. A penalized smoothing spline function was applied to control the influence of confounding factors, including time trends, holidays, and days of the week, in accordance with recent time series research.

Equation:

$$\log E(Yt) = \alpha + \beta Xt + s(\mathrm{time}, \mathrm{k} = 10 + 1) + \mathrm{holidays} + \mathrm{DOW}$$

where t is the day of the observation, E(Yt) refers to the expected number of suicide on day t, α indicates the intercept, β displays the regression coefficient, Xt illustrates the daily level of weather variables on day t, and s () denotes the smoother based on the penalized smoothing spline. Time trends are handled using the 10 degrees of free (df), which is based on the Akaike Information Criterion (AIC). The categorical variable DOW has a range from 0 to 6. The categorical variable holiday ranged 1for holidays and 0 for non-holidays.

The delayed impacts of meteorological factors on suicide were evaluated following the construction of the model. We investigated these potential lag effects through two methodologies, which included single-day lags (the influence of PET and DTR from lags 0 to 21) and multiple-day average lags (the influence of PET and DTR, lags 01 to 021). In addition, the spline function in the GAM was used to present exposure-response correlation curves between the meteorological variables and suicide. In addition, the percentage changes and their 95% confidence intervals (CIs) were used to express the effect of a one-unit increase in meteorological variables (PET and DTR) on daily suicide risk. All of the statistical analyses were two-sided at the 5% level of significance. R software (version 3.5.3) with the "mgcv" package (version 1.8–27) was employed for data analysis. To perform a sensitivity analysis, the df of the penalized smoothing spline function was adjusted from 2 to 15 for time.

### 3.5. Ethical approval

The present study was approved by the Ethics Committee of Ilam University of Medical Sciences (ethics code: IR.MEDILAM.REC.1401.088).

## 4. Results

During the study period, a total of 3112 suicides occurred in Ilam City, which averages approximately 1.42 cases per day. The mean (SD) values for PET and DTR were 17.91 °C (11.87) and 13.59 °C (3.91), respectively (refer to Table 1).

While the correlation between PET and daily suicide counts was statistically significant but weak ($r = 0.082$, $p < 0.01$), a more substantial correlation was observed between the two meteorological variables, PET and DTR ($r = 0.521$, $p < 0.01$). This indicates a moderate level of collinearity between PET and DTR, which was accounted for in our subsequent GAM analysis by modeling their effects separately (see Table 2).

Fig. 2 displays the exposure-response relationship curves illustrating PET and DTR in relation to suicide risk for the same day (lag 0). The curves for both PET and DTR revealed a clear and linear pattern (Fig. 2).

Table 3 provides the percentage changes in suicide risk associated with each unit increase in meteorological factors at various delays. A correlation was also observed between the risk of suicide and the meteorological variable DTR. Furthermore, during lags 2, 3, 4, 5, 6, 13, 14, 15, 20, and 21, the risk of suicide rose with each unit increase in DTR. Regarding the cumulative effect, the findings indicated that for each unit rise in DTR, the risk of suicide increased from 1.43 (95% CI: 0.11, 2.78) at lag 01 to 3.24 (95% CI: 1.19, 5.33) at lag 021 (see Table 3). These results suggest a consistent pattern, highlighting the potential impact of meteorological factors on suicide risk over time.

## 5. Discussion

This study provides critical insights into the relationship between meteorological factors and suicide risk in Ilam City, Iran. Our analysis revealed two key findings: a linear, same-day association between both PET/DTR and suicide risk, and a particularly strong, cumulative association between increasing DTR and elevated suicide risk over a 21-day period.

Over the study period, a total of 3112 suicides were reported, averaging approximately 1.42 cases per day. The mean values for PET and DTR were 17.91 °C (SD = 11.87) and 13.59 °C (SD = 3.91), respectively. The observed linear exposure-response relationships at lag 0 suggest an immediate association between daily thermal conditions and suicide risk. Increased DTR was associated with rising suicide risk across multiple lag intervals—specifically at lags 2, 3, 4, 5, 6, 13, 14, 15, 20, and 21. Notably, the cumulative effect indicated that for each unit rise in DTR, the risk of suicide increased from 1.43 (95% CI: 0.11, 2.78) at lag 01 to 3.24 (95% CI: 1.19, 5.33) at lag 021. These consistent patterns underscore the potential importance of monitoring temperature variability in public health assessments.

The mechanisms underlying these associations may involve a combination of physiological, psychological, and behavioral pathways.

**Table 1**
Summary of suicide counts and meteorological data.

| Variables | Daily measures | | | | | |
|---|---|---|---|---|---|---|
| | Mean ± S.D. | Min | P 25 | Median | P 75 | Max |
| Suicide counts | 1.42 (1.57) | 0 | 0 | 1 | 2 | 11 |
| Meteorological factors | | | | | | |
| PET (°C) | 17.91 (11.87) | −9.20 | 7.40 | 17.00 | 29.30 | 41.20 |
| DTR (°C) | 13.59 (3.91) | 1.60 | 11.40 | 14.60 | 16.40 | 22 |

SD, standard deviance; Min, Minimum; P25, 25th percentile; P75, 75th percentile; Max, Maximum; PET; physiological equivalent temperature, DTR, diurnal temperature range.

**Table 2**
Spearman's correlation between meteorological factors and suicide counts.

| | Suicide | Pet | DTR |
|---|---|---|---|
| Suicide | 1 | | |
| PET | 0.082** | 1 | |
| DTR | 0.029 | 0.521** | 1 |

PET; physiological equivalent temperature, DTR, diurnal temperature range.
** Correlation is significant at the 0.01 level (2-tailed).

From a physiological perspective, larger diurnal temperature swings can induce thermoregulatory stress and disrupt sleep patterns, which are known risk factors for mood disorders and impulsive behavior. The cumulative effect of DTR over several weeks suggests a potential build-up of allostatic load, where the body's stress response systems become dysregulated. Psychologically, unpredictable weather (high DTR) may exacerbate feelings of a lack of control or anxiety in vulnerable individuals. Furthermore, temperature variability can influence social behavior, potentially limiting outdoor social interactions during less comfortable periods, thereby increasing isolation—a key risk factor for suicide. Our finding of a stronger cumulative effect for DTR compared to the immediate effect of PET highlights the potential importance of prolonged exposure to environmental instability.

When contextualizing our results, we find both parallels and distinctions with the existing literature. Our core finding—that higher temperature metrics are associated with increased suicide risk—aligns with multi-country studies (Kim et al., 2019) and systematic reviews (Frangione et al., 2022). The stronger effect we observed for DTR adds a layer of nuance, suggesting that temperature variability itself is a significant factor, a finding that resonates with research highlighting the role of unstable weather patterns and ecological complexity in mental health (Moore et al., 2018). While other studies have focused on air pollution as an environmental stressor (Bakian et al., 2015; Szyszkowicz et al., 2010), our study did not measure this variable. However, it is plausible that meteorological factors like DTR and air pollution represent distinct, and potentially synergistic, environmental pathways influencing population mental health, a valuable area for future multi-exposure studies. Similarly, while seasonal peaks in spring (Bakian et al., 2015; Bando et al., 2017) are well-documented, our findings on DTR suggest that the *variability* of temperature within those seasons, rather than just the absolute rise, may be a contributing mechanism to this established seasonality.

In summary, this study contributes to a growing body of evidence demonstrating an association between meteorological factors and suicide risk. By moving beyond simple temperature measures to include PET and DTR, and by identifying a delayed, cumulative effect for DTR, our findings suggest that environmental instability may be as critical as absolute heat. Recognizing these intricate dynamics is imperative for developing effective, context-sensitive public health strategies focused on improving mental health outcomes in communities exposed to diverse environmental conditions.

## 6. Conclusion

This study concludes that daily temperature variability, measured by the DTR, has a significant and cumulative association with increased suicide risk in Ilam City, Iran. The research demonstrates that the risk escalates over a 21-day period following temperature fluctuations. These findings highlight the critical role of environmental factors in public health and suggest that meteorological data should be integrated into suicide prevention strategies. The authors recommend using forecasts of temperature instability to identify high-risk periods and launch targeted interventions. Future work should focus on validating these results in other regions and investigating the specific biological and social mechanisms that explain this relationship.

## CRediT authorship contribution statement

**Rahim Sharafkhani:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation. **Fathola Mohamadian:** Writing – review & editing, Writing – original draft, Investigation. **Yousef Veisani:** Writing – review &

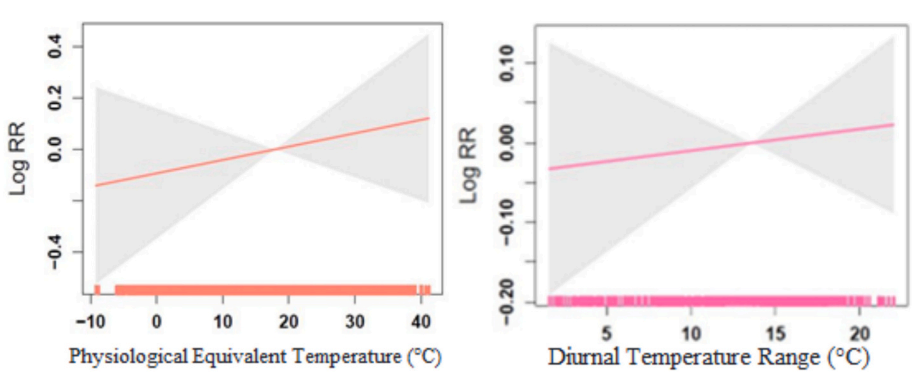


**Fig. 2.** The exposure-response curves of meteorological factors and suicide count in Ilam, Iran. The X-axis is the concurrent day meteorological data, the Y-axis is the predicted log relative risk (RR), is shown by the solid line, and the dotted lines represent the 95% confidence interval (CI). PET, physiological equivalent temperature. DTR, diurnal temperature range.

**Table 3**
Percentage change (%) in risk of suicide risk, according to meteorological variables.

| Lag structure | Lag | Variable | |
|---|---|---|---|
| | | PET (°C) 95% CIs | DTR (°C) 95% CIs |
| SDL | 0 | 1.04 (0.63, 1.43) | 0.83 (−0.37, 2.06) |
| | 1 | 1.12 (0.71, 1.52) | 0.81 (−0.36, 1.99) |
| | 2 | 0.98 (0.58, 1.39) | 1.31 (0.13, 2.52) |
| | 3 | 0.97 (0.58, 1.37) | 1.69 (0.49, 2.90) |
| | 4 | 0.94 (0.54, 1.34) | 1.21 (0.03, 2.41) |
| | 5 | 0.93 (0.53, 1.33) | 1.38 (0.19, 2.58) |
| | 6 | 0.87 (0.47, 1.27) | 1.62 (0.42, 2.83) |
| | 7 | 0.84 (0.44, 1.24) | 0.86 (−0.31, 2.04) |
| | 8 | 0.85 (0.45, 1.25) | 0.99 (−0.18, 2.18) |
| | 9 | 0.78 (0.38, 1.18) | 1.03 (−0.14, 2.22) |
| | 10 | 0.83 (0.43, 1.23) | 0.35 (−0.81, 1.52) |
| | 11 | 0.88 (0.48, 1.28) | 0.34 (−0.82, 1.51) |
| | 12 | 0.87 (0.47, 1.27) | 0.89 (−0.28, 2.09) |
| | 13 | 0.86 (0.46, 1.26) | 1.67 (0.47, 2.89) |
| | 14 | 0.84 (0.44, 1.24) | 1.35 (0.16, 2.56) |
| | 15 | 0.74 (0.34, 1.14) | 1.19 (0.005, 2.39) |
| | 16 | 0.70 (0.30, 1.10) | 0.98 (−0.22, 2.00) |
| | 17 | 0.71 (0.31, 1.11) | 0.83 (−0.34, 2.02) |
| | 18 | 0.66 (0.26, 1.06) | 0.67 (−0.49, 1.86) |
| | 19 | 0.69 (0.29, 1.09) | 0.50 (−0.66, 1.68) |
| | 20 | 0.68 (0.28, 1.08) | 1.62 (0.42, 2.84) |
| | 21 | 0.64 (0.24, 1.04) | 1.28 (0.09, 2.49) |
| MDAL | 01 | 1.08 (0.68, 1.49) | 1.43 (0.11, 2.78) |
| | 02 | 1.06 (0.66, 1.47) | 1.76 (0.33, 3.22) |
| | 03 | 1.05 (0.64, 1.46) | 2.18 (0.65, 3.74) |
| | 04 | 1.04 (0.63, 1.45) | 2.36 (0.75, 3.98) |
| | 05 | 1.03 (0.63, 1.44) | 2.57 (0.91, 4.26) |
| | 06 | 1.03 (0.62, 1.44) | 2.82 (1.11, 4.57) |
| | 07 | 1.01 (0.60, 1.42) | 2.83 (1.07, 4.61) |
| | 08 | 1.004 (0.59, 1.41) | 2.87 (1.08, 4.69) |
| | 09 | 0.98 (0.57, 1.39) | 2.92 (1.10, 4.78) |
| | 010 | 0.98 (0.57, 1.39) | 2.84 (0.98, 4.73) |
| | 011 | 0.98 (0.57, 1.40) | 2.76 (0.88, 4.68) |
| | 012 | 0.98 (0.57, 1.39) | 2.79 (0.89, 4.74) |
| | 013 | 0.98 (0.57, 1.39) | 2.97 (1.04, 4.94) |
| | 014 | 0.97 (0.56, 1.39) | 3.07 (1.12, 5.06) |
| | 015 | 0.96 (0.55, 1.37) | 3.11 (1.14, 5.12) |
| | 016 | 0.95 (0.53, 1.36) | 3.07 (1.09, 5.09) |
| | 017 | 0.94 (0.53, 1.35) | 3.08 (1.08, 5.12) |
| | 018 | 0.92 (0.51, 1.34) | 3.05 (1.04, 5.10) |
| | 019 | 0.92 (0.51, 1.34) | 3.03 (1.01, 5.10) |
| | 020 | 0.92 (0.50, 1.33) | 3.17 (1.14, 5.25) |
| | 021 | 0.92 (0.50, 1.33) | 3.24 (1.19, 5.33) |

PET; physiological equivalent temperature, DTR, diurnal temperature range (°C); SDL, single day lag; MDAL, multiple day average lag.

editing, Writing – original draft, Supervision, Software, Methodology, Formal analysis, Data curation.

## Declaration of Generative AI and AI-assisted technologies in the writing process

The author(s) declare that no artificial intelligence (AI) tools, including large language models (e.g., ChatGPT), were used for any part of the work related to the research, data analysis, or writing of this manuscript.

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## Declaration of competing interest

The authors declare no competing financial interests.

## Data availability

Data will be made available on request.

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