Vienna Yearbook of Population Research 2024 (Vol. 22), pp. 1–15
https://doi.org/10.1553/p-m53z-m2eh

RESEARCH ARTICLE

Impact of urban outdoor thermal conditions on selected hospital admissions in Novi Sad, Serbia

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ABSTRACT Climate change has been recognized as an important issue in public health, with particular concerns being raised about the effects of heat and cold extremes on health, and about seasonal changes over the year and their associations with increased mortality and hospitalizations. This paper explored the relationship between physiological equivalent temperature (PET) and cardiovascular and respiratory hospital admissions in Novi Sad (Serbia) with the aim of assessing the impact of urban outdoor thermal conditions on health. Analysis was performed using daily data on cardiovascular and respiratory hospital admissions by gender covering the period from January 1, 2016 to December 31, 2017. For the same period, PET was calculated using data from two urban meteorological network stations. The association between PET and hospital admissions was examined using a generalized additive model (GAM) combined with a distributed lag non-linear model (DLNM). The study found a non-linear relationship between PET and cardiovascular and respiratory hospital admissions, with a larger impact during the cold period of the year. The findings also indicated that under conditions of high PET, the cumulative RR increased for cardiovascular admissions (for males) and respiratory admissions (for females). People with pre-existing respiratory diseases were found to be more vulnerable under conditions of extremely low and moderately low PET, with a greater effect at lag 0–14 days. By contrast, for people with cardiovascular diseases, low PET was linked to a decrease in hospital admissions, with the risk being lowest at lag 0 and 0–3 days.

KEYWORDS Hospital admission • Physiological equivalent temperature • Cardiovascular diseases • Respiratory diseases • Serbia

Introduction

In response to global climate change, concerns have been raised about the impact of the climate on human health. The human body is exposed to different elements of the

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atmospheric environment that can influence an individual's level of thermal comfort, and that could affect the person's health (Romaszko-Wojtowitz et al., 2020). According to some authors, both heat and cold can place substantial physiological pressure on the human organism, which could have hazardous effects, including increased mortality, particularly among individuals with pre-existing cardiovascular and respiratory diseases (The Eurowinter Group, 1997; Analitis et al., 2008; Michelozzi et al., 2009; Guo et al., 2012; Gasparrini et al., 2015; Kouis et al., 2019; Borsi et al., 2021). The Eurowinter Group (1997) found that mortality rates in Europe were at or near their lowest levels when the mean daily temperature was 18 °C, and that mortality rates increased linearly as the temperature fell. Similar results were reported by Baccini et al. (2008), who detected a *V*- or a *J*-shaped curve in the association between the maximum apparent temperature and mortality rates. Some studies, such as a time-series analysis for 384 locations in 13 countries, observed that the mortality burden was more pronounced on colder days, and that most deaths were related to exposure to moderately hot and moderately cold temperatures (Gasparrini et al., 2015). Numerous studies have also reported an association between extreme temperatures and hospital admissions at different latitudes. A study conducted in Spain during the 1997–2013 period found that exposure to cold temperatures was linked to an increased risk of hospital admission for cardiovascular, cerebrovascular and respiratory diseases; whereas exposure to hot temperatures was associated with an increased risk of hospital admission for respiratory diseases only (Martinez-Solanas and Basanga, 2019). On the other hand, results for California showed that during the warm season (May–September), an increase in the mean apparent temperature was associated with an increase in hospital admissions related to certain cardiovascular diseases (Green et al., 2010). Generally, this association has been confirmed for exposure to both heat and cold, and has been shown to vary by latitude and cause of hospitalization (Schwartz et al., 2004; Phosri et al., 2020; Savić et al., 2023).

The different patterns reported for the mortality effects of hot and cold spells suggest that several different mechanisms are involved in the physiological processes leading to excess deaths. Prolonged exposure to heat stress can cause an increase in peripheral circulation, and may result in thermoregulatory failure. When the cardiac output cannot compensate for this effect, cardiovascular events, such as hyperthermia, dehydration, hypotension, heat exhaustion and renal failure, can occur, and may result in death, particularly among individuals with pre-existing cardiovascular diseases. By contrast, the mechanisms through which cold triggers cardiovascular responses are associated with acute cardiac events that can lead to cardiovascular dysregulation, primarily through vasoconstriction, which reduces blood flow and oxygen supply to the heart (Davidkovova et al., 2014; Liu et al., 2015; Shrikhande et al., 2023). Exposure to cold has also been linked to an increased risk of mortality from respiratory diseases, as cold weather may reduce the natural response mechanisms of the upper respiratory tract and shut down the immune response to infections (Jahan et al., 2022). Individuals with less adaptive capacity are more vulnerable to pulmonary issues due to broncho-constriction caused by breathing cold air (Conlon et al., 2011).

Consequently, in order to understand the association between climate and health, the concepts of human comfort and thermal stress must be considered. Various thermal indices have been developed that take these conditions into account (Frohlich et al., 2019; Borsi et al., 2021). Thermal indices based on the energy balance of the human body are often

https://doi.org/10.1553/p-m53z-m2eh

used to measure the effects of the thermal environment on humans (Matzarakis and Amelung, 2008). Because of their complexity, such indices are well-suited for assessing the impact of the thermal environment on human health. Thermal indices often include multiple climatological variables (e.g., air temperature, relative humidity, wind velocity, long and short wave radiation), as well as thermo-physiological variables related to human behavior (e.g., human activity and clothing), which greatly contribute to thermal sensation (Matzarakis and Amelung, 2008). This complexity is the main advantage of using thermal indices instead of just climatological variables (e.g., air temperature). One of the most commonly used thermal indices is physiological equivalent temperature (PET). Until now, only a few studies have used biometeorological indices, including physiological equivalent temperature (PET) and the universal thermal index (UTCI), to quantify the impact of climate on hospital admissions (Nastos and Matzarakis, 2006; Romaszko-Wojtowicz et al., 2020; Borsi et al., 2021; Arsenović et al., 2022).

The main objective of this paper is to assess the impact of urban outdoor thermal conditions on health by exploring the relationship between physiological equivalent temperature (PET) and hospital admissions due to cardiovascular and respiratory diseases in Novi Sad, Serbiato. Novi Sad is the second-largest city in Serbia, located in the north of the country. According to data from the population register, the city had about 300,000 inhabitants in 2016.

Data and methods

Hospital admission data

Hospital admission data for Novi Sad were obtained from the Institute for Public Health of the Vojvodina Province. Data were provided on a daily level, and the analysis was conducted by gender and causes of admission according to the International Classification of Diseases (ICD-10) for the period from January 1, 2016 to December 31, 2017. The analysis was performed for admissions due to cardiovascular diseases (I00-I99) and respiratory (J00-J99) diseases.

Physiologically equivalent temperature

Physiologically equivalent temperature (PET) is one of the most widely used biometeorological indices for the evaluation of the thermal comfort, thermal sensation and physiological stress levels of humans in the outdoor environment (Mayer and Höppe, 1987; Höppe, 1999; Matzarakis et al., 1999; Milošević et al., 2016; Chatterjee et al., 2019; Top et al., 2020). PET is "defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed" (Höppe, 1999). PET is based on the Munich Energy–balance Model for Individuals (MEMI), which models the thermal conditions of the human body in a physiologically relevant way (Höppe, 1999). Among the various thermal indices that are widely used for the assessment of human

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Table 1 Physiologically equivalent temperature (PET) for different grades of thermal sensation and physiological stress in Central Europe, modified by Dominik and Matzarakis (2020) after Matzarakis and Mayer (1996)

PET (°C)	Thermal perception	Physiological stress level
> 41	Very hot	Extreme heat stress
35–41	Hot	Strong heat stress
29–35	Warm	Moderate heat stress
23–29	Slightly warm	Slight heat stress
18–23	Comfortable	No thermal stress
13–18	Slightly cool	Slight cold stress
8–13	Cool	Moderate cold stress
4–8	Cold	Strong cold stress
≤ 4	Very cold	Extreme cold stress

thermal comfort, the PET index is the best fit for the climate region of Central Europe. Therefore, PET was selected for the analysis in this research. Additionally, compared to other thermal indices that are also based on the human energy balance, PET has the advantage of using a widely known unit (°C), which makes the results more comprehensible, particularly for readers who are less familiar with modern human-biometeorological terminology (Matzarakis et al., 1999; Dominik and Matzarakis, 2020).

PET considers the impact of air temperature, relative humidity, wind speed and global radiation fluxes on a standard human body. Furthermore, the PET calculation includes the latitude of the research area, as well as individual human characteristics such as height, weight, age, gender, the heat resistance of clothing and physical activity (W/m^2). In this research, standardized values that are the default in the Rayman model are used: gender – male; height - 175 cm; weight – 75 kg; age – 35 years; clothing – 0.9 (Clo); level of physical activity – 80 W/m^2 (Roshan et al., 2018). Table 1 shows how PET, a classification with nine classes of thermal perception, is applied in the context of Central Europe.

The meteorological data used for the PET calculation was provided from two fixed-site weather monitoring stations located in the urban area of Novi Sad. The calculation of PET was conducted in the RayMan microclimate model developed by Matzarakis et al. (2007, 2010).

Data analysis

The association between PET and hospital admissions due to cardiovascular and respiratory disease was examined using a generalized additive model (GAM) combined with a distributed lag non-linear model (DLNM) (Gasparrini et al., 2010). The DLNM was used to quantify the lagged and possible non-linear effects of PET on hospital admissions. The model used for the analysis was given as follows (previously applied by Arsenović et al., 2022):

$$\log(E(Y_t)) = \alpha + cb(\beta PET_{t,l}) + ns(humidity_t, 5) + \gamma \cdot wind_t + \lambda \cdot year_t + \nu \cdot month_t + \gamma \cdot DOW_t$$

https://doi.org/10.1553/p-m53z-m2eh

where t denotes the observation date, $E(Y_t)$ denotes the expected value of hospital admissions at day t and Y_t follows Quasi-Poisson distribution, cb denotes the "cross-basis" of daily mean PET, l is the maximum lag days and $ns(humidity, 5)$ is the natural cubic spline for relative humidity with five *dfs*. Wind was controlled for as a linear effect in the model. Possible confounders such as seasonality and the long-term trend were controlled for by including $year_t$ and $month_t$ as dummy variables in the model (Wei et al., 2020; Xu et al., 2019). DOW_t stands for day of the week on day t.

Since hospital admissions associated with exposure to temperature and PET could be extended for more than 10 days (Borsi et al., 2021; Wang et al., 2021), and to avoid underestimating cumulative effects, a natural cubic spline with 3 dfs for PET and the third degree polynomial were used for lags. To assess the risk related daily PET, we used the median of PET as the reference value (11.5 °C) for modeling respiratory hospital admissions. The minimum relative risk corresponded to a PET of 6 °C, which was the reference point for both the cardiovascular and the respiratory model (Arsenović et al., 2022).

Sensitivity analyses showed (Figure S2–4) that our estimates were robust to changing the maximum lag periods to 10, 14, 21 and 28 days, and to changing the degrees of freedom and the degrees of polynomial. The cumulative exposure-response relationship over a lag of 21 and 28 days almost coincided with the lag of 14 days. Since there were no substantial changes, the maximum lag for the cumulative effect of PET on hospital admissions was set to 14 days. In addition, to determine the impact of PET on hospital admissions due to cardiovascular and respiratory diseases, the cumulative effects were observed at the first, fifth, 95th and 99th percentiles of the PET – i.e., at, respectively, extremely low, moderately low, moderately high and extremely high PET. All analyses were performed in the R statistical environment (version 4.0.3) and "dlnm" (Gasparrini et at., 2010).

Results

The descriptive statistics of cardiovascular and respiratory hospital admissions are presented in Table 2. For the two-year study period, a total of 7,517 cardiovascular admissions and 5,551 respiratory admissions were registered, with a daily average of 10 cases of

Table 2 Daily number of hospital admissions for cardiovascular and respiratory diseases by gender in Novi Sad, Serbia (2016–2017)

Variables	Total admissions	Mean	SD	Min	Max
Cardiovascular diseases (I00-I99)	7517	10.28	4.90	1	30
Male	4439	6.07	3.34	0	20
Female	3078	4.21	2.46	0	13
Respiratory diseases (J00-J99)	5551	7.59	4.01	0	22
Male	3078	4.21	2.64	0	14
Female	2473	3.38	2.27	0	14

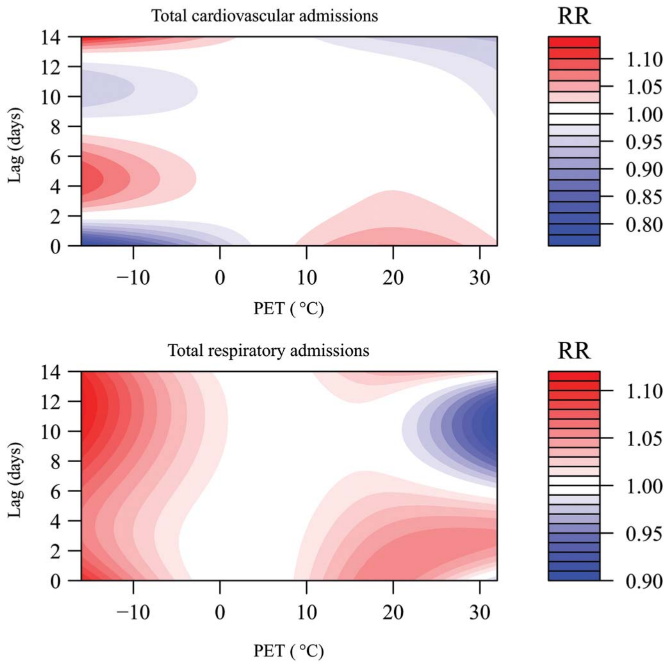
Note: SD = standard deviation; Min = minimum; Max = maximum.

cardiovascular diseases and about eight cases of respiratory diseases. Subgroup analysis showed a higher daily average number of admissions for males for both cardiovascular diseases and respiratory diseases.

During the study period, the daily average value for PET was 12.2 °C, the average humidity was 69.6% and the average wind speed was 0.71 km/h. The minimum value of PET was −16.5 °C, while the maximum value reached 33.5 °C (Table S1 and Figure S1, supplementary material available online at https://doi.org/10.1553/p-m53z-m2eh).

Figures 1 and 2 show the relative risk of hospital admission for cardiovascular and respiratory diseases at low and high PET values, using PET of 6 °C as the reference point. Results confirm that there was a non-linear relationship between cardiovascular and respiratory hospital admissions and PET. For cardiovascular disease admissions, the RR decreased under lower PET and at lag 0 and 0–3 days, with cumulative RR (95% CI) of 0.823 (0.713–0.950) and 0.786 (0.621–0.994) under conditions of extremely low PET, and of 0.890 (0.824–0.961) and 0.852 (0.751–0.966) under conditions of moderately low PET. For respiratory disease admissions the opposite effect was observed: i.e., low PET was associated with an increase in respiratory admissions and higher PET was associated with

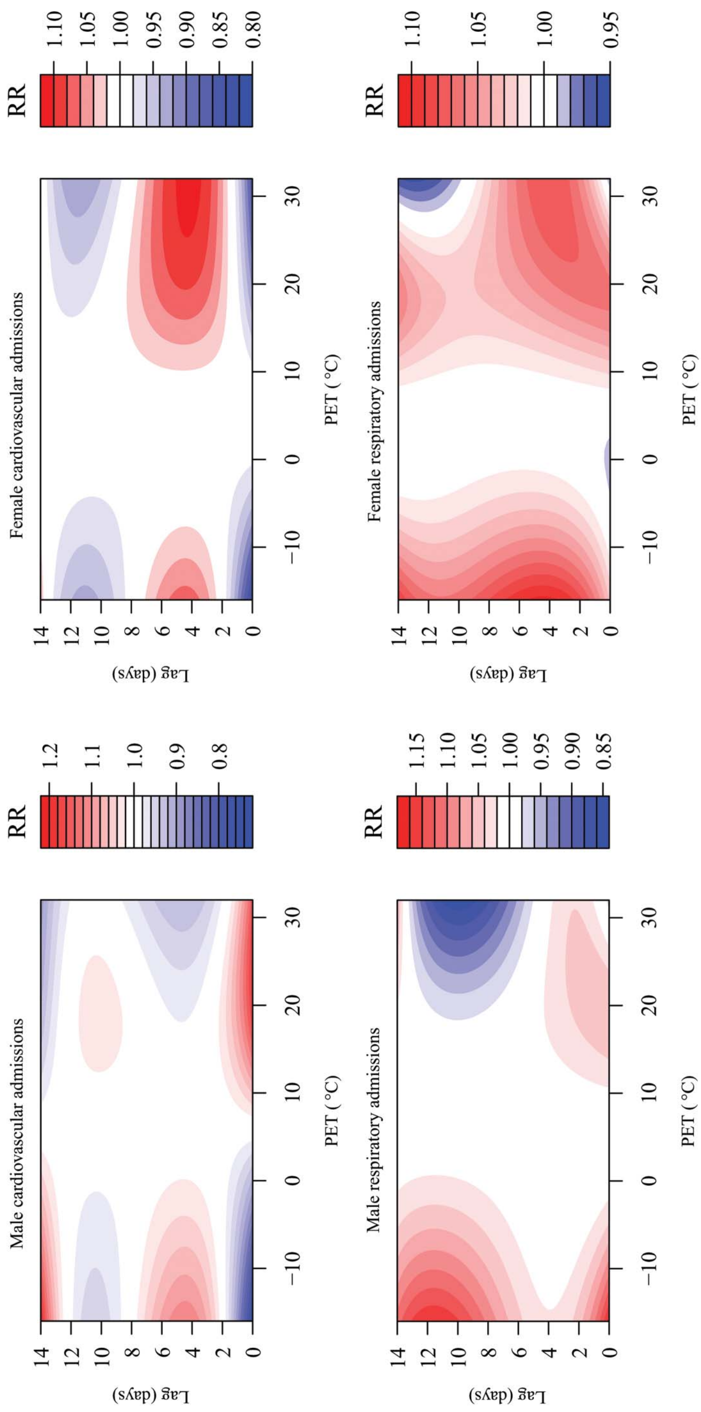
Figure 1 Relative risk of hospital admissions for cardiovascular and respiratory diseases with PET and lag (0–14 days), using PET of 6 °C as the reference point.



Source: Arsenović et al. (2022).

https://doi.org/10.1553/p-m53z-m2eh

Figure 2 Relative risk of hospital admissions for cardiovascular and respiratory diseases by gender with PET and lag (0–14 days) using PET of 6 °C as the reference point.



https://doi.org/10.1553/p-m53z-m2eh

a decrease in the risk of hospitalization, with the highest cumulative RR (95% CI) of 2.231 (1.539–3.232) and 1.414 (1.163–1.719) being observed under conditions of extremely low and moderately low PET and at lag 0–14 days (Arsenović et al. 2022).

The lagged effect of PET on daily cardiovascular and respiratory hospital admissions by gender is shown in Figure 1 and Table S2. When analyzed by gender, the cumulative RR of cardiovascular and respiratory admissions displayed a diverse pattern in terms of PET values and lag structure. For males, extremely low and moderately low PET at lag 0 and 0–3 days was associated with a decrease in cardiovascular admissions, while moderately high and extremely high PET had an adverse impact, with higher cumulative RR at lag 0 and 0–3 days. A statistically significant (95% CI) decrease in male cardiovascular admissions under conditions of extremely low PET and an increase in these admissions under conditions of moderately high PET were confirmed at lag 0 with cumulative RR of 0.789 (0.657–0.948) and 1.179 (1.028–1.354). For female cardiovascular admissions, a similar pattern was observed relative to lag days and low PET. Compared to male admissions, moderately high and extremely high PET at lag 0 was associated with a decrease in female cardiovascular admissions. Unlike for cardiovascular disease admissions, conditions of extremely low PET increased the risk of hospital admissions for respiratory diseases for both genders, with greater effects at lag 0–14 days and cumulative RR (95% CI) of 2.459 (1.496–4.043) for males and 1.980 (1.146–3.420) for females. For male respiratory admissions, a significant effect was also confirmed for moderately low PET at lag 0–14 days with cumulative RR of 1.540 (1.186–2.001). For female respiratory admissions due to moderately high PET, a significant increase at lag 0–7 days with cumulative RR of 1.547 (1.30–2.323) was found.

Discussion

This study found a non-linear association between PET and the risk of hospital admissions for cardiovascular and respiratory diseases, with the impact being greater during the colder period of the year. Under conditions of high PET, the cumulative risk of hospital admissions increased, but was not statistically significant at the 5% level. Cold thermal stress had extended lag effects (extremely low and moderately low PET) among individuals with preexisting respiratory diseases, who were more vulnerable, with greater effects at lag 0–14 days. Meanwhile, low PET was associated with a significantly reduced risk of cardiovascular hospital admissions, with the lowest risk at lag 0 and 0–3 days.

In previous research conducted by Arsenović et al. (2022), an analysis of the association between PET and cardiovascular and respiratory hospital admissions was conducted for two age groups: the population aged 65 and older and the population under age 65. The results of this study confirmed that both subgroups were vulnerable to respiratory diseases during the cold period of the year. Among the older population, extremely low and moderately low PET increased the risk of admission for respiratory diseases at all lag structures, while among the younger population, this risk was significant at lag 0–14 days. About 74% of all respiratory disease admissions were in the under 65 age group (Arsenović et al., 2022), which implies that this age group contributed significantly to the overall results

https://doi.org/10.1553/p-m53z-m2eh

for respiratory hospital admissions. However, the older population had an increased risk of respiratory hospital admissions at all lags, indicating that older people are particularly vulnerable under conditions of cold thermal stress.

A limited number of studies have examined the impact of PET on hospital admissions in Central European cities. The findings of this research are partially consistent with those of other studies that found a higher risk of cardiovascular admissions (Shiue et al., 2016a; Shiue et al., 2016b; Santurtun et al., 2020) and respiratory admissions (Nastos and Matzarakis, 2006) under conditions of lower PET. Our results regarding respiratory disease admissions differed from those of two other studies conducted by Borsi et al. (2021) for Ahvaz (Iran), which showed that low PET levels reduced the incidence of all respiratory diseases except asthma; and from those of a study for Olsztyn (Poland), which found that a decline in the UTCI led to a reduction in the number of asthma cases (Romaszko-Wojtowicz et al., 2020). Studies based on other meteorological indicators found, for example, that in Korea, the risk of hospital admission for cardiovascular or respiratory diseases increased at a higher diurnal temperature range (Lim et al., 2012). A study for Bangkok (Thailand) found that the diurnal temperature range effects for cardiovascular disease were higher during the winter, while the DTR effects did not change much throughout the year for respiratory disease (Poshri et al., 2020). A systematic review (64 studies were included) on the association between ambient temperatures and the risk of cardiovascular hospitalization found that temperature-related hospitalizations increased significantly with cold exposure and with low diurnal temperatures (Phung et al., 2016). In a recent study, Wang et al. (2021) confirmed that both low and high ambient temperatures increased the risk of hospital admissions for cardiovascular disease among farmers in China, with high temperatures having a greater impact.

The different results for the associations between meteorological indicators and cardiovascular and respiratory hospital admissions may be explained by differences in the methodological approaches these studies used. In general, fewer studies considered all respiratory diseases. These differences can also be explained by whether latitude (Michelozzi et al., 2009; Gasparrini et al., 2015) or certain socio-demographic factors (Ellena et al., 2020) were taken into account. Additionally, Michelozzi et al. (2009) pointed out that the delivery of health care (e.g., admission policies, availability of hospital beds and classification of diagnoses) varies across European countries, and that for specific diseases, the probability of hospitalization may differ depending on the availability of primary care and outpatient services, social care arrangements and clinical management practices.

In a subgroup analysis by gender, we found that for both males and females, low PET decreased the risk of admission for cardiovascular diseases and increased the risk of admission for respiratory diseases. Under conditions of high PET, males appear to be more vulnerable, as the results showed an increased risk of cardiovascular admissions for males at lag 0. Thus, our findings for gender were inconsistent with those of the abovementioned study (Borsi et al., 2021), which reported that for both females and males, low PET decreased the risk of admission for all respiratory diseases except asthma.

Our study of temperature-related mortality in Novi Sad confirmed that during the colder period, lower temperatures were associated with increased mortality. Furthermore, the results showed that cardiovascular and respiratory disease mortality were higher during

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the colder period of the year (Arsenović 2019), but also that hospital admissions due to cardiovascular diseases were lower under conditions of low PET. Since this study reported results based on data from one city only, it is not possible to generalize the results to other cities. Nonetheless, these findings provide important insights into the association between mortality and climate conditions, which is a public health concern, not only for urban populations in Serbia, but also for populations in other countries for whom higher overall and cardiovascular mortality during cold periods has been reported. However, the reasons why the cardiovascular mortality and hospitalization patterns diverged, and through what mechanisms conditions of low PET decreased the risk of cardiovascular admissions, remain unclear. Thus, further investigations are needed to clarify these differences.

This study is the first to examine the relationship between outdoor thermal conditions (using PET) and hospital admissions not only in Serbia, but anywhere in Central Europe. Worldwide, only a few previous studies have used PET in investigations of thermal indices and hospitalization. Thus, the results presented in this paper can contribute to future research on other cities, particularly those with temperate climates. Numerous studies have focused on the association between ambient temperatures or extreme temperature events and health, with most relying on cross-sectional observations of the effects of heatwaves or cold spells on health. There are also many studies on the relationship between ambient temperatures and mortality or hospital admissions. By contrast, there is considerably less evidence based on thermal indices regarding the effects of temperature on mortality, and particularly on morbidity and hospital admissions. Using PET as one of the thermal indices, the results of this study provide new and additional information on this topic, as the PET calculation included four different parameters (i.e., air temperature, relative humidity, wind speed and global radiation), and took exposure to extreme (low and high) PET into account. Finally, to our knowledge, this is the first study of the effects of PET on hospital admissions that has addressed the effects of PET on both cardiovascular and respiratory diseases.

Some limitations of this study should be mentioned. Socio-demographic indicators (i.e., education, marital status, occupation and income) that could lead to bias in the observed associations between PET and hospitalizations were not included in the analysis. Research conducted by Xu et al. (2020) found that in Brazil, the risk of hospitalization associated with temperature variability was higher for the populations of lower-middle-income and upper-middle-income cities. The adverse health effects of climate on the human body are also related to education (Borell et al., 2006; Michelozi et al., 2005), living arrangements (Fouillet et al., 2006) and marital status (Wan et al., 2022). Nevertheless, in other studies, limited evidence has been found that the effects of temperature exposure can be modified by different socio-demographic characteristics (Son et al., 2019). Since the analysis in this study was limited to gender, the possible implications of this approach should be mentioned. The reported decrease in cardiovascular admissions under conditions of low PET might be less pronounced or reversed in a population with lower socioeconomic status and with lower education. Education could be a strong indicator of socioeconomic status, as it is often used to estimate people's income levels, living conditions and occupations (Brunner, 2001; O'Neill et al., 2003), and people with higher education generally have higher well-being and a better quality of life (Liberatos et al., 1988; Hummer and Hernandez, 2013). In addition, education could play an important role in reducing the

https://doi.org/10.1553/p-m53z-m2eh

negative impact of extreme climate events, given that individuals may gain knowledge, skills and competencies through formal education that can influence their adaptive capacity (Muttarak and Lutz, 2014). However, the role of education in the vulnerability of populations could vary by gender, and the findings on these effects have not been consistent across studies. In Barcelona, Borell et al. (2006) studied excess mortality during the summer of 2003, including how it differed by age, gender and educational level. The authors found that excess mortality was more pronounced among women, particularly those with low education or less than primary education. A study on social inequalities in heat-related mortality among the population of the city of Turin showed that the risk was higher for men with a higher educational level and for women with a lower educational level (Ellena et al., 2020).

Moreover, the results by gender could be further differentiated by marital status, considering that recent findings indicate that unmarried individuals are more vulnerable than their married counterparts under conditions of extreme heat (Wan et al., 2022). The results of studies conducted in Italy reported that vulnerability to heat-related mortality was higher among widows and widowers (Stafoggia et al., 2006), and among separated and divorced women (Ellena et al., 2020). A recent study for the Czech Republic also showed that mortality risk due to heat was particularly high among single, divorced and widowed individuals. The findings further indicated that the risk was higher in divorced women than in divorced men, and that men faced the highest risk when they were widowed (Vesier and Urban, 2023). However, while there is a large body of literature on the role of gender and marital status in heat-related mortality, the results are not uniform. Thus, future research should seek to clarify these discrepancies.

Finally, this study did not include some other confounding factors, such as the quality of health care and behavioral risk factors, which are associated with hospital admission risk.

Conclusion

The results of this study strengthen the evidence on the impact of climate conditions on human health. We found that extremely low and moderately low PET were more strongly associated with hospital admissions than moderately high and extremely high PET. Analysis by gender also showed that under conditions of moderately high PET, the risk of hospital admission due to cardiovascular diseases was higher for males, while the risk of hospital admission due to respiratory diseases was higher for females. These results provide some important insights for designing preventive measures to reduce population exposures to non-optimal and extreme urban outdoor thermal conditions.

Additionally, the findings of this study could help to reduce public health expenditures, as significant numbers of hospital admissions could be avoided with appropriate preventive actions and policies.

Supplementary material

Available online at https://doi.org/10.1553/p-m53z-m2eh

Supplementary file 1. Tables S1–S2, Figures S1–S4.

Acknowledgements

This research has been supported in part by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through the Grant No. 451-03-47/2023-01/200125.

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