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Mask wearing behavior in hot urban spaces of Novi Sad during the COVID-19 pandemic

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HIGHLIGHTS
• Heat and masks influence human thermal sensation, comfort, and behavior.
• An urban park is most comfortable during the day, a river quay in the evening.
• A sun-exposed urban square is the most uncomfortable area.
• 97% of residents feel uncomfortable while wearing a mask outdoors in hot weather.
• The urban park is perceived as the safest outdoor space for not contracting COVID-19.

GRAPhICAL ABSTRACT

ABSTRACT

Urban overheating (due to climate change and urbanization) and COVID-19 are two converging crises that must be addressed in tandem. Fine-scale, place-based, people-centric biometeorological and behavioral data are needed to implement context-specific preventative measures such as mask-wearing. This study collected local biometeorological measurements in diverse urban spaces (square, urban park, river quay) in Novi Sad, Serbia on hot sunny summer days (27–30 August 2020) during the COVID-19 pandemic. Observations were supplemented by an online survey asking questions about thermal sensation, comfort, and concurrent protective behavior of the local population. Biometeorological measurements show that the main square in the city center was the most thermally uncomfortable area. According to the survey, it was also perceived as the least safe space to not contract the virus. The urban park was perceived as the most thermally comfortable area in the morning and during midday. It was also considered the safest urban space for outdoor activities. In the evening, the river quay was the most thermally comfortable area in the city. Intra-urban differences in Physiologically Equivalent Temperatures were highest during midday, while differences in air temperatures were highest in the evening. More than 70% of the respondents did not wear face masks when it was hot because of breathing issues and feeling warmer than without mask. Most people wearing a mask felt “slightly warm” in the morning and evening, while the majority of respondents felt “hot” during midday. Only 3% of the respondents felt comfortable while wearing a mask, while 97% experienced some degree of discomfort (from slight discomfort to very uncomfortable). Our study shows that fine scale temporal and spatial urban biometeorological data and population surveys should be included in decision-making processes during the pandemic to develop climate-sensitive health services that are place-based, people-centric, and facilitate planning towards green, resilient, and inclusive cities.

Keywords:
Urban climate
Mask wearing behavior
COVID-19
Outdoor thermal comfort
Heat stress

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1. Introduction

In 2020, the outbreak of a novel corona virus (COVID-19) impacted public health worldwide (Watts et al., 2020) with more than 90% of all reported COVID-19 cases registered in cities (Acuto et al., 2020; UN-Habitat, 2020). Urban areas are often COVID-19 hotspots due to high population density and increased economic activity (Sharifi and Khavarian-Garmir, 2020). At the same time, urban areas experience warmer temperatures in the summer months than their rural counterparts due to the urban heat island, posing additional health risks for urban populations.

Recent studies have investigated the relationship between meteorological parameters and COVID-19 transmission and/or mortality rates at a global, regional, and city scale. Weather-virus interactions have been studied worldwide, e.g., in China (Ran et al., 2020), India (Gupta et al., 2020), USA (Bashir et al., 2020), Italy (Saffliee Haghsenas et al., 2020), Brazil (Auler et al., 2020), Norway (Menebo, 2020), and the UK (Ghost et al., 2020). The impact of air temperature (T_a) and humidity on COVID-19 has been studied most frequently, e.g., Awasthi et al., 2021; Guo et al., 2020; Pramanik et al., 2020; Yao et al., 2020. Less attention has been paid to influences of wind speed (Pani et al., 2020), solar radiation (Runkle et al., 2020), precipitation (Huang et al., 2020), evaporation (Singh et al., 2021), and cloud cover (Gurhte et al., 2020). Thermal comfort interactions with COVID-19 are still rarely studied (Jamshidi et al., 2020; Rubin et al., 2020) as they require detailed biometeorological data (e.g., temperature, humidity, wind speed, global radiation) that are difficult to obtain. Furthermore, disease etiology and hospitalizations can occur independent of outdoor biometeorological conditions, such as temperature changes, given the role of vaccinations and other protective measures (mask wearing behavior and physical distancing). Accordingly, previous studies produced mixed results on the meteorological sensitivity of the virus and disease. The varying temporal and spatial resolution of input data, different types of statistical analyses, and the omission of confounding factors influenced the quality of the obtained results (World Meteorological Organization (WMO), 2021), as the ability to understand emergent diseases requires a robust understanding, which was lacking at first. Results might be inconclusive due to the omission of non-meteorological factors, which can play an important role in the combined analysis of weather and COVID-19. Non-meteorological factors influencing COVID-19 transmission include preventative measures (e.g., wearing masks, physical distancing, lockdowns, regular handwashing) and urban parameters (e.g., population density, infrastructure, accessibility to urban areas, demographics, economy, transport, health conditions, etc.). To date, only a few studies assessed the influence of weather, urban parameters, and/or preventative measures on COVID-19 holistically at global (e.g., Wu et al., 2020), national (e.g., Rubin et al., 2020; You and Pan, 2020), or city scales (e.g., Nakada and Urban, 2020; Pequeno et al., 2020; Pirouz et al., 2020a, 2020b).

As countries and cities introduced stringent measures to contain the virus and minimize the pressure on hospitals to save lives (OECD, 2020), it is paramount to obtain local information at fine spatial and temporal scales about the weather/demographics/protective measures to stipulate appropriate mitigation and adaptation strategies. The World Health Organization (WHO) recommended to respond to the COVID-19 outbreak by monitoring and analyzing public perceptions, knowledge, and attitudes about the pandemic through rapid surveys, which can help identify gaps and misinformation (WHO, 2020a). Surveys should investigate public perceptions of masks and their usage, as masks are part of the prevention and control measures to limit the spread of the virus. Combined with other self-protecting measures (e.g., social distancing, more frequent hand washing, limited large gatherings) face masks are proven to significantly reduce the spread of the virus (Gallaway et al., 2020; Li et al., 2020). However, despite mask mandates during the pandemic, some people preferred to not wear masks or wore them improperly due to reduced comfort. Further potential impacts of mask use include headache and/or breathing difficulties, development of facial skin lesions, irritant dermatitis, worsening acne (Al Badri, 2017; Scheid et al., 2020), increased facial temperatures (Scarano et al., 2020), and discomfort (Jefferson et al., 2020; Matusiak et al., 2020). When recommending mask usage, it is necessary to evaluate impacts on the population and to assess mask effectiveness to prevent and control transmission (WHO, 2020b).

Extreme heat can hamper the implementation of COVID-19 protective measures such as mask-wearing. Interventions to address both health risks (extreme heat and COVID-19) must be carefully planned based on the best available science and accurate data. Unfortunately, the availability of regional, city, and neighborhood scale data remains limited compared to the national level. Highly localized data and statistics are essential to monitor progress, design effective, targeted policies, and use response resources efficiently to identify hotspots. Improving such data collection and analysis becomes critical in an era where most of the world’s population resides in cities (United Nations, 2020). The COVID-19 pandemic had asymmetrical impacts across territories and cities, but many policy responses were uniform, highlighting the need for place-based and people-centered approaches (OECD, 2020). Unfortunately, a large volume of swiftly published research on COVID-19 (a median time from receipt to acceptance of 6 days for journal articles) has raised concerns about the quality of the evidence and the risk of misinformation being spread with harmful consequences (Ioannidis, 2020) that can lead to confusion, poor policy decisions, and public mistrust in science (Palayew et al., 2020).

The present study provides localized, place-based data and insights into the human-biometeorological conditions and mask wearing behavior of city dwellers in public outdoor spaces in the city of Novi Sad, Serbia. The study has three objectives: 1) Measurement of human-biometeorological conditions in contrasting urban environments (urban square, urban park, river quay) during hot summer days in 2020 during the COVID-19 pandemic; 2) Concurrent visual inspection of mask wearing behavior of the local population; and 3) Development, implementation, and analysis of an online survey on how hot weather and mask wearing behavior influenced the thermal sensation and overall outdoor thermal comfort (OTC) of the local population. This study provides novel insights into how mask wearing behavior changes with outdoor temperature. It reveals the local variability of human-biometeorological conditions and mask-wearing behavior in diverse urban settings to facilitate the development of policy measures targeting COVID-19 transmission and heat mitigation in a Central European city.

2. Study area, data, and methods

2.1. Study area

Novi Sad is the second largest city in the Republic of Serbia, with 102 km² of built-up and urban green/blue areas and a population of 330,000 people (data from 2017). The city is located on the Pannonian Plain in Central Europe (45°16’N, 19°50’E) (Fig. 1), thus most of the urban area is flat with an absolute elevation between 72 m and 80 m (Geletić et al., 2019). Novi Sad has complex urban forms with seven built-up ‘local climate zones’ (LCZs) based on Stewart and Oke’s (2012) classification (Šecero et al., 2015). The central urban area (including downtown) is characterized as a densely built-up zone consisting of mid-rise buildings (16-to-18 stories) and low-rise houses and buildings (one-to-three stories) with little green space. Residential (mid-rise and low-rise buildings) and industrial areas, on the outlying parts of the city, are connected to the central urban area by avenues and boulevards. Leal Filho et al. (2021) showed that the total percent of green areas in Novi Sad is about 7.6%; it ranges from 5% to 15% (in 15% to 33% of the most urbanized areas to 15% in the outskirts). A prominent “green avenue” is the quay of the Danube River where the Danube width is 260 m to 680 m. Unfortunately, over the last 40 years, no additional urban parks and green spaces have been created within city boundaries. Despite urban planning recommendations, local authorities have not focused on the implementation of vertical/horizontal greenery on buildings (green walls and roofs) or added vegetation in inter-block buildings. To the south of the city is the low-lying Fruška Gora Mountain, which peaks at 539 m and is covered by a dense deciduous forest (Savić et al., 2018; Geletić et al., 2019). Hinterland consists of arable land (Fricke et al., 2020) with small patches of dense or scattered deciduous forests.
Novi Sad has a Cfb climate (temperate climate, fully humid, warm summers, with at least four months of average $T_a$ above 10 °C) according to the Köppen-Geiger climate classification system (Kottek et al., 2006). The mean monthly $T_a$ ranges from −0.3 °C in January to 21.8 °C in July, and the mean annual precipitation is 623 mm (based on data between 1949 and 2015). Since 2003, heat waves have occurred more frequently in Serbia and Europe as a whole, mostly during the summer. One of the most intensive heat waves in Novi Sad occurred in July 2007, with an absolute maximum $T_a$ of 41.6 °C. Since then, particularly in 2012, 2015, 2017 and 2019, multiple intensive heat waves have occurred in Novi Sad (Arsenović et al., 2019).

2.2. Methods

The methods used in this study are illustrated in a flowchart that outlines the three data collection approaches, locations, times of day, and data analysis (Fig. 2).

2.3. Human-biometeorological measurements

We performed human-biometeorological measurements at three locations in Novi Sad on four hot summer days (from 27th to 30th August 2020). Three locations in the city (Figs. 1 and 3) were selected based on two main principles: 1. Selection of urban areas with different urban designs that influence micro-meteorological conditions in: a) a built-up area (the main square), b) a green urban area (park), and c) a blue and green urban area (river quay); and 2. Selection of the main pedestrian zones in the city to analyze pedestrian mask-wearing behavior. Based on these principles, we selected urban areas that have different built-up, vegetation, and water fractions, surface types, shading, impervious and pervious fractions, and sky view factors. For example, the built-up percentage in a 500 × 500 m grid cell area can vary 5–15% for the river quay, 30–45% for the urban park, and 90–100% for the main square (Unger et al., 2011). This influences the micro-meteorological conditions in urban areas and can lead to substantial differences in temperature, humidity, wind speed, and radiation that influence the OTC conditions of urban residents at the micro- and local scale in urban areas (Stewart and Oke, 2012; Oke et al., 2017; Milošević et al., 2021). Accordingly, this was hypothesized to impact the mask-wearing behavior of residents. All selected locations were in proximity; the main square is 500 m away from the urban park, which is 900 m away from the river quay. The conditions during the field measurements were hot with maximum daily $T_a$ of 36 °C, no precipitation, no cloud cover, low wind speed, and intense solar radiation (Republic Hydrometeorological Service of Serbia, 2020).

One-minute measurements of air temperature ($T_a$, in °C), relative humidity ($R H$, in %), wind speed ($v$, in m s$^{-1}$), and globe temperature ($T_g$, in °C) were collected during three periods of the day: i) morning (06:00 h – 09:00 h Central European Summer Time - CEST), ii) midday (12:00 h – 15:00 h CEST), and iii) evening (18:00 h – 21:00 h CEST). 1-min measurements were averaged over 15-min for further analysis. The 15-min averages were used to minimize the impact of the Kestrel 5400 Heat Stress trackers sensor lag on mean radiant temperature results. The globe thermometer (Fig. 3, right) requires 7–10 min to adjust to a new situation (from shaded/cloudy to sun-exposed or back). An average of 15 min assures that the Kestrel meter has enough time to adjust to exposure changes. Using 10- or 15-minute averages of 1-minute measurements is common in human-biometeorological studies (e.g., Skarbit et al., 2017; Unger et al., 2018; Milošević et al., 2021). The Kestrel meter was deployed at least 15 min prior to the measurement to allow the sensors to equilibrate to the atmospheric conditions. It was also ensured that the wind vane is oriented according to the predominant wind direction. The Kestrel meters were calibrated in compliance with the published specifications for the specific measurements. Accuracy and range of the sensors are provided in Appendix 1.
2.4. Estimation of human-biometeorological indices

Mean radiant temperature ($T_{mrt}$) and Physiologically Equivalent Temperature (PET) were selected as human-biometeorological indices in this study, as both can be calculated from the measured values of $T_g$, $T_a$ and $v$ as follows (Thorsson et al., 2007):

$$T_{mrt} = T_g + \frac{273.15}{C_0/C_1} \left[ 1 + \frac{1.1 \cdot 10^5 \cdot v^{0.6} \cdot T_g - T_a}{\varepsilon \cdot D^{0.4}} \right]^{-1} - 273.15$$

where $D$ is globe diameter (mm), and $\varepsilon$ is globe emissivity. Based on the calculated values of $T_{mrt}$, measured $T_a$, RH, $v$, and default values for personal characteristics, we calculated 15-minute average PET values for all observation periods and sites using the RayMan model (Matzarakis et al., 2007; Matzarakis et al., 2010). PET estimates and $T_{mrt}$ values were used to analyze thermal sensation based on the classes of physiological stress for humans developed for Europe (Appendix 2) by Matzarakis and Mayer (1996).

2.5. Visual inspection of mask wearing behavior during the COVID-19 pandemic

During the field work (August 2020), mask-wearing was mandatory indoors and highly recommended outdoors. Additional measures involved limiting the number of people allowed in one space with physical distance of at least 1.5 m, enhanced sanitation, etc. (Appendix 3). These measures imposed several limitations on our research approach. As personal contact was limited and people generally avoided interactions with strangers, we performed a non-intrusive, distant visual inspection of people’s mask-wearing behavior during the human-biometeorological measurements. We counted the number of people: i) wearing a mask, ii) not wearing a mask, and iii) not wearing a mask properly. Proper mask wearing is defined according to WHO guidelines, i.e., the mask must cover nose, mouth and

Fig. 2. Overview of methods used in this study.
chin, and the straps must be behind the head or ears. This provided a general picture about mask-wearing practices at different urban locations (square, park, quay) during particular time periods (morning, midday, and evening).

2.6. Online survey

In parallel to the human-biometeorological measurements, a questionnaire survey about people’s thermal sensation and comfort while wearing a face mask was administered online using Google Forms. Considering the epidemiological situation during the research period, a face-to-face survey was not feasible. Instead, the survey was implemented via Google Forms and distributed online via social media platforms (Facebook, Twitter, LinkedIn) during and after the field work period (August 27 to 30, 2020). The survey contained 19 questions divided into five sections: i) demographics (e.g., sex, age, place of living, health status); ii-iv) mask-wearing behavior and thermal sensation vote (TSV) while wearing a face mask at various times of day; and v) problems associated with wearing/not wearing a face mask. A questionnaire survey was based on outdoor thermal comfort studies and standards (ASHRAE, 2010; Johansson et al., 2014; Lau et al., 2019) and was distributed online since the first day of the field measurements. The thermal sensation vote (TSV) while wearing a face mask was assessed based on the seven-point ASHRAE scale (ASHRAE, 2010): thermal sensation was reported from cold (−3) to hot (+3), with a neutral sensation of 0. The overall comfort was rated using a four-point scale (from comfortable to very uncomfortable) (Middel et al., 2016). The survey questions are provided in Appendix 4.

3. Results

3.1. Human-biometeorological conditions

The maximum morning \( T_a \) (30.2 °C) was recorded at the main square, which was 3.0 °C higher compared to \( T_a \) in the urban park (Fig. 4). \( T_a \) was, on average, up to 4.8 °C higher at the main square than in the park, while similar mean \( T_a \) values were measured at the square and the quay (Appendix 5 and 6a). The river quay and park had similar mean RH, which was about 9 to 10% higher than at the main square, while low wind speeds (<1.7 m s\(^{-1}\)) were registered at all locations (Appendix 5 and 6a). Conditions at the urban park were “comfortable” in the morning...

![Fig. 3. Measurement sites in Novi Sad. Center of yellow circle (left) shows locations of deployed Kestrel 5400 Heat Stress Trackers (right) at: Location 1 - Main square; Location 2 - Urban park; and Location 3 - River quay. NOTE: Yellow circle (diameter of 80 m) indicates the approximate area in which the visual inspection of mask wearing behavior of citizens was performed.](image)
with an average PET of 22.9 °C (no thermal stress, see Appendix 2). In contrast, the downtown square and quay areas were “slightly warm” with “slight heat stress”, exhibiting an average PET of 25.3 °C and 25.6 °C, respectively. PET values peaked in the “hot” (“strong heat stress”) and “very hot” (“extreme heat stress”) category at the quay and the square, respectively, while the park was “warm” with moderate heat stress (Appendix 6a).

Ta differences between locations were smallest during midday (Fig. 4, Appendix 6b). The sun-exposed square had the highest mean Tg with 46.6 °C, while the lowest mean Tg of 35.8 °C was measured in the park (Appendix 5 and Appendix 6b), illustrating the heat mitigation potential of tree shade for human thermal exposure (Middel et al., 2021). The river quay exhibited slightly higher RH compared to the square and park due to the proximity to the river (5 to 6%), while v was low at all locations (Appendix 5 and Appendix 6b). The highest intra-location differences in OTC were observed at midday. The urban park exhibited the lowest mean PET (32.6 °C), while substantially higher mean PET values were recorded at the river quay and the main square (48.7 °C and 52.7 °C, respectively) (Fig. 4, Appendix 6b). OTC conditions in the park were in the category of moderate heat stress, while extreme heat stress was noticed at the other locations.

The largest intra-urban Ta differences were observed in the evening with the main square having up to 2.9 °C higher Tg than in the park and 4.1 °C higher than at the river quay (Fig. 4, Appendix 6c). Mean Tg values suggest that the river quay is the most comfortable urban area in the evening with 2 °C lower mean Tg compared to the urban park and up to 5.3 °C lower mean Tg than the urban square (Appendix 5 and Appendix 6c). The river quay also showed the highest mean RH with about 14% difference when compared to the main square, while low mean v values were registered at all locations (< 1.0 m s⁻¹) (Appendix 5 and Appendix 6c). The main square exhibited the highest average Tmrt and PET values. However, the lowest average Tmrt and PET were recorded at the river quay and not in the urban park (Appendix 6c). Both the river quay and the urban park registered slight heat stress, while the main square imposed moderate heat stress on pedestrians.

3.2. Mask wearing behavior and online survey

At all study locations and times of day, most observed pedestrians (>70%) did not wear face coverings (Fig. 5), although mask-wearing was highly recommended outdoors by the local and national government. As the day progressed, the number of people wearing a mask decreased. Improper mask-wearing behavior across sites varied the most during the warmest hours of the day. Improper mask-wearing was more common than correct mask-wearing, especially at the main square during the morning and midday hours (19–20%). People usually carried a mask in their hand, on an
elbow, or under the chin, and it seemed that they carried a mask out of habit or because they were leaving or heading towards an indoor space. The maximum percentage of people wearing mask properly during the observation periods was 10% in urban park during the morning hours, while sometimes that percentage was as low as 1% (Fig. 5). The difference in percentage of people wearing mask properly seems to depend more on the time of day and to a lesser degree on the location. This is a direct consequence of temperature increase from morning to midday into the evening hours, as well as due to changes in people's activities. E.g., in the morning and at midday, people wore masks for business or shopping activities, while in the evening, people were outdoors on a relaxed walk, so they did not wear masks.

The online survey was completed by 294 respondents (Appendix 7). More females (65.3%) than males (34.7%) participated in the survey, and respondents aged 25 to 34 had the largest share in the survey (34.7%). Almost 25% of respondents suffer from a chronic disease, and 43.2% of them declare that they have cardiovascular issues (Appendix 7).

Fig. 6 shows the distribution of TSV obtained from the online survey. Most people wearing a facial mask felt “slightly warm” in the morning (40%) and evening (39%). During midday, most respondents felt “hot” (57%) wearing a facial mask (Fig. 6). Some TSVs are in the “neutral” category in the morning (29%) and evening (17%), but only few sensations are neutral during midday (4%). No mask-wearing respondents reported cool / cold TSVs during the field work campaign. This agrees well with the field measurements and calculated OTC suggesting that the combined effect of increased $T_a$, $T_{wet}$, and PET with mask-wearing decreases people's comfort and makes them feel warm or hot depending on the time of day.

Respondents were also asked to rank their overall comfort while wearing a mask. Only 3% felt comfortable wearing a mask, while 97% experienced some degree of discomfort (from slightly to very uncomfortable) (Fig. 7a). Almost 66% reported that their skin was wet or sweaty while wearing a mask, and about 75% reported having problems breathing normally. These are recognized as two important reasons behind their uncomfortable feeling while wearing a mask. Various reasons and explanations were provided by respondents for not wearing a mask (Fig. 7b). The most dominant are related to problems with breathing heavily (24%) and feeling warmer than usual while wearing a mask (18%). Other reasons are related to masks not mandated outdoors, increased sweating, foggy glasses, or skin irritation.

Survey participants were asked to describe where they feel safe or unsafe getting infected with the virus (Fig. 8a). 71% of survey respondents feel safest staying at home. Of the three study sites, people feel safest of not getting infected in urban parks (17%) and near the river (about 5%). They feel least safe in the city center (main square) (about 2%).
Furthermore, about 5% reported that they feel safe in nature outside the city (e.g., Fruška Gora Mountain, forests, at the weekend house outside Novi Sad, etc.). With respect to safety, the survey also tested for a change in habits during the COVID-19 pandemic to stay safe and healthy. 43% of the survey participants responded that they were avoiding direct contact with other people by practicing physical distancing and by avoiding going to public places such as cafes/restaurants due to COVID-19 (32%). Still, 14% of the respondents said they did not change their habits (Fig. 8b).

4. Discussion

We concurrently studied human-biometeorological conditions and mask-wearing behavior during the COVID-19 pandemic on four hot summer days in diverse urban environments of the city of Novi Sad (Serbia). The study was motivated by the call of the WMO and WHO to try to obtain meteorological and COVID-19 related data and public perceptions and attitudes at the finest spatial and temporal scales to support public health policy and the COVID-19 response in cities (WMO, 2021; WHO, 2020a).

Human-biometeorological measurements show that the urban square is the hottest and most uncomfortable area of the city at all times of day. Differences in OTC are highest during midday, while differences in $T_a$ are highest in the evening, confirming the negative impact of the urban heat island on the local population. The urban park is the most comfortable outdoor location during morning and midday hours, while the river quay is the most comfortable urban area in the evening. This suggests that local authorities should promote the usage of parks during morning and midday, and the river quay during the evening period as previous studies have shown that high temperatures (e.g., during hot weather and heatwaves) may increase the risk of respiratory and cardiovascular diseases, especially for elderly, children, and individuals with pre-existing conditions (Xu et al., 2016; Song et al., 2017; Savić et al., 2018; Arsenović et al., 2019). This is especially true for the European and Eastern Mediterranean regions that have been the most vulnerable to the extremes of heat of all the WHO regions (Watts et al., 2020). Unfortunately, these risks are further augmented due to COVID-19, as these heat-vulnerable groups could experience an even higher risk of virus infection compared to the general population (WMO, 2021).

Wearing a facial mask helps protect from COVID-19 infection, and its universal public acceptance is an important policy to reduce the transmission of COVID-19 (Liu et al., 2020). However, wearing a mask is not convenient during hot weather as evidenced by this study. During midday and in the early evening, only 1 to 5% of observed pedestrians wore a facial mask properly, which could negatively affect the efforts to reduce transmission rates (WMO, 2021). Unfortunately, most studies on the correlations of meteorological factors and COVID-19 parameters did not include the effect of mask-wearing behavior, which could lead to misleading conclusions about the protective influence of higher temperatures (WMO, 2021). Understanding the impacts of non-meteorological factors can be critical for the development and optimization of COVID-19 control measures (Rubin et al., 2020) and development of climate-sensitive health services and interventions (WHO/WMO, 2016).

Results from our survey show that most people feel "slightly warm" (morning, evening) or "hot" (midday) while wearing a face mask outdoors in hot summer weather. 97% of survey participants responded they feel uncomfortable while wearing a face mask outdoors on hot days. Similar mask-wearing behavior was found by Cherrie et al. (2019), while Betsch et al. (2020) implied that mandatory policy regarding mask-wearing appears to be a more effective and socially responsible measure to prevent COVID-19. Survey participants in Novi Sad feel the safest in the comfort of their home to not get infected. This is not surprising as the risk of spreading
Infectious diseases are often elevated in crowded urban areas such as main squares and streets. Therefore, when outdoors, the residents of Novi Sad felt safest in urban parks and near rivers but not in the city center. This highlights the importance of green and blue infrastructure as nature-based solutions (Bauduceau et al., 2015; Langergraber et al., 2021) that provide a "safe haven" for the local population during the pandemic. These areas are also the most comfortable parts of the city. The WHO also recommends that urban authorities should keep outdoor spaces such as urban parks and river quays open for relaxation and exercise with social distancing to maintain good health and mental wellbeing (WHO, 2020a). The results from our survey are in accordance with Xie et al.’s (2020) study of Chengdu city, China, in which residents acknowledged urban parks as safe places for outdoor activities and social interaction during the pandemic. Venter et al. (2020) pointed out that urban parks of Oslo (Norway) were more frequently used for recreation and pedestrian activity during the COVID-19 outbreak. Similar results were found for parks in the US and in Paris, France (OECD, 2020). However, some countries and cities restricted free access to outdoor public spaces during the pandemic, such as Turkey (Ahsan, 2020) and Serbia due to curfews. Our study points out that public spaces such as urban parks and river quays should remain open for local population in Serbia (based on the Novi Sad example), as these areas are perceived as the safest and the most thermally comfortable during hot summer weather.

This study has several limitations. First, the human-biometeorological survey was performed online due to COVID-19 physical distancing restrictions. Survey participants were randomly recruited online using social media platforms (e.g., Facebook, Twitter, LinkedIn), and accordingly, the survey is biased towards individuals with social media accounts (most respondents are up to 44 years of age) (see Appendix 7). Second, we observed the mask-wearing behavior of people who were standing or sitting at/crossing (bisecting) the main square/urban park/river quay near the location of the instrument (in a circle with a circumference of about 150–250 m and a diameter of about 80 m, see Fig. 3). Accordingly, some pedestrians who walked behind us could not be considered, even though we tried to occasionally look and observe behind us. Thirdly, we did not perform statistical tests to investigate the relationship between human-biometeorological conditions, COVID-19 transmission, infection rates, and mask wearing behavior due to the short measurement period and the absence of reliable data on COVID-19 related health indicators and non-meteorological factors (e.g., demographic data, transportation, health-care system capacity, mobility, metrics on economic development). Forth, we framed the COVID-19 issue in the context of heat, mask wearing behavior, urban design, and policy, leading to a single comprehensive study, although these issues are worth exploring separately in more detail.

The aim of the study was to showcase the diversity of the local human-biometeorological conditions during hot summer days and the subsequent diversity of perceptions and opinions of the local population regarding mask-wearing and thermal comfort, which should be considered while developing strategies and policies of adaptation to and mitigation of the pandemic in urban areas. A study of Acuto et al. (2020) pointed out that COVID-19 interventions must be general in nature but specific in application to attend to the diversity of billions of urban dwellers affected by the crisis to rebuild cities more sustainably after the pandemic “by attending to urban inequalities that underpin the crisis, and by … allowing urban expertise, and cities, closer to the heart of the global response”.

Aligning urban planning with human health is essential, and it should be achieved by expanding investments in an equitable green transformation that will create lasting solutions and reduce the risks of future crises and adequately mitigate the impacts of climate change in cities (United Nations, 2020).

5. Conclusions

Urban environments exhibit diverse human-biometeorological conditions at the micro- and local scale that influence the outdoor thermal comfort and mask-wearing behavior of local population. Urban parks are recognized as the safest places for outdoor activities, which implies that local governments should keep them accessible during pandemics. They are also the most comfortable areas in terms of thermal sensation for the local population during daytime hours on hot summer days. The biggest differences between the locations in OTC were noticed at midday, when the city park was the most comfortable urban area. During the evening, the most comfortable urban area is the river quay near the Danube River. The biggest intra-urban differences were noticed in the evening when the main square had the highest air temperature, and the river quay had the lowest air temperature. Accordingly, local governments should promote urban park and river quay usage during pandemics with major focus on protective measures such as physical distancing and/or limiting of the number of visitors, if necessary, rather than mask mandates that cause discomfort to the population. This is shown in Novi Sad, where most people wearing a face mask felt “slightly warm” in the morning and evening and “hot” during the midday, which influenced that 97% of respondents felt some degree of discomfort (from slight to very uncomfortable) while wearing a face mask during hot summer weather in a Central European city.

Past pandemics influenced the design and planning of contemporary cities. Contemporary and future urban planning need to consider the development and supply of open public green and blue spaces for the local population, especially in dense, vulnerable, climate-sensitive neighborhoods (i.e., urban hot spots) during the pandemic. This requires the collection of knowledge and insights on the human-biometeorological conditions and individual mask-wearing behavior during the peak of the COVID-19 crisis that can be essential for future planning of healthy, comfortable, inclusive, and equitable cities. To achieve this goal, local, regional, and national governments need accurate local data to develop more precise local plans (e.g., investment in green and blue infrastructure, nature-based solutions, essential public services, health inequalities) and long-term policy choices (e.g., development of health services, housing, and transport policies) to increase resilience to future pandemics in urban areas.

CRediT authorship contribution statement

Dragan Milošević: Conceptualization, Writing – original draft, Methodology, Investigation. Ariane Middel: Software, Writing – review & editing. Stevan Savić: Conceptualization, Writing – review & editing, Investigation, Visualization. Jelena Dunjić: Visualization, Writing – review & editing, Investigation. Kevin Lau: Writing – review & editing. Rastislav Stojsavljević: Writing – review & editing, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.152782.

References

Acuto, M., Larcom, S., Keil, R., Ghojeh, M., Lindsay, T., Camponeschi, C., Parnell, S., 2020. Seeing COVID-19 through an urban lens. Nat. Sustain. 1–2. https://doi.org/10.1038/s41893-020-00620-3.
the mask. Int. J. Environ. Res. Public Health 17 (13), 1–9. https://doi.org/10.3390/ijerph17134624.

Scheid, J.L., Lupien, S.P., Ford, G.S., West, S.L., 2020. Commentary: physiological and psychological impact of face mask usage during the covid-19 pandemic. Int. J. Environ. Res. Public Health 17 (18), 6655. https://doi.org/10.3390/ijerph17186655.

Ščeron, I., Savić, M., Milošević, D., Marković, V., Bajanski, I., 2015. Development of an automated urban climate monitoring system in Novi Sad (Serbia). Geogr. Pannonica. 19 (4), 174–183. https://doi.org/10.5937/GeoPan1504174S.

Shaffier Hagihoezas, S., Pirouz, B., Shaffier Hagihoezas, S., Pirouz, B., Piro, P., Na, K.S., Cho, S.E., Geem, Z.W., 2020. Prioritizing and analyzing the role of climate and urban parameters in the confirmed cases of COVID-19 based on artificial intelligence applications. Int. J. Environ. Res. Public Health 17 (10), 3730. https://doi.org/10.3390/ijerph17103730.

Sharift, A., Khavarian-Garmir, A.R., 2020. The COVID-19 pandemic: impacts on cities and major lessons for urban planning, design, and management. Sci. Total Environ. 142391. https://doi.org/10.1016/j.scitotenv.2020.142391.

Singh, O., Bhardwaj, P., Kumar, D., 2021. Association between climatic variables and COVID-19 pandemic in National Capital Territory of Delhi, India. Environ. Dev. Sustain. 23 (6), 9514–9528. https://doi.org/10.1007/s10668-020-01003-6.

Skarbit, N., Stewart, I.D., Unger, J., Gál, T., 2017. Employing an urban meteorological network to monitor air temperature conditions in the ‘local climate zones’ of Szeged, Hungary. Int. J. Climatol. 37, 582–596. https://doi.org/10.1002/joc.5623.

Song, X., Wang, S., Hu, Y., Yue, M., Zhang, T., Liu, Y., Tian, J., Shang, K., 2017. Impact of ambient temperature on morbidity and mortality: an overview of reviews. Sci. Total Environ. 586, 241–254. https://doi.org/10.1016/j.scitotenv.2017.01.212.

Stewart, I.D., Oke, T.R., 2012. Local climate zones for urban temperature studies. Bull. Am. Meteorol. Soc. 93 (12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1.

Thorson, S., Lindberg, F., Ellisson, I., Holmer, B., 2007. Different methods for estimating the mean radiant temperature in an outdoor urban setting. Int. J. Climatol. 27 (14), 1983–1993. https://doi.org/10.1002/joc.1537.

Unger, J., Savić, M., Gál, T., 2011. Modelling of the annual mean urban Heat Island pattern for planning of representative urban climate station network. Adv. Meteorol. 398613. https://doi.org/10.1155/2011/398613.

Unger, J., Skarbit, N., Gál, T., 2018. Evaluation of outdoor human thermal sensation of local climate zones based on long-term database. Int. J. Biometeorol. 62 (2), 183–193. https://doi.org/10.1007/s00484-017-1440-z.

United Nations (UN), 2020. Policy brief: COVID-19 in an urban world. Available at: https://www.un.org/sites/un2.un.org/files/ag_policy_brief_covid_urban_world_july_2020.pdf. Accessed on December 21, 2020.

United Nations Human Settlements Programme (UN-Habitat), 2020. Opinion: COVID-19 demonstrates urgent need for cities to prepare for pandemics. Available at: https://unhabitat.org/opinion-covid-19-demonstrates-urgent-need-for-cities-to-prepare-for-pandemics. (Accessed 20 June 2021).

Venter, Z.S., Barton, D.N., Gundersen, V., Figari, H., Nowell, M., 2020. Urban nature in a time of enigmatic recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. Environ. Res. Lett. 15 (10), 104075. https://doi.org/10.1088/1748-9526/abbb396.

Watts, N., Amann, M., Arnell, N., Ayebe-Karlsson, S., Beagley, J., Belesova, K., Boyko, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Coleman, S., Dalin, C., Daly, M., Dassadi, N., Dasgupta, S., Davies, M., Contello, A., 2020. The 2020 report of the Lancet countdown on health and climate change: responding to converging crises. Lancet https://doi.org/10.1016/S0140-6736(20)32290-X.

World Health Organization (WHO), 2020. Strengthening preparedness for COVID-19 in cities and urban settings: interim guidance for local authorities (No. WHO/2019-nCoV/Urban-preparedness/2020.1).

World Health Organization (WHO), 2020. Advice on the use of masks in the context of COVID-19: interim guidance, 5 June 2020 (No. WHO/2019-nCoV/IPC/Masks/2020.4).

World Health Organization (WHO)/World Meteorological Organization (WMO), 2016. Climate Services for Health: Improving Public Health Decision-making in a New Climate. Geneva. https://public.wmo.int/en/resources/library/climate-services-health-care-studies.

World Meteorological Organization (WMO), 2021. First report of the WMO COVID-19 task team review on meteorological and air quality factors affecting the COVID-19 pandemic. Available at: https://library.wmo.int/doc_num.php?explnum_id=10555 Accessed on June 20, 2021.

Wu, Y., Jing, W., Liu, J., Ma, Q., Yuan, J., Wang, Y., Du, M., Liu, M., 2020. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci. Total Environ. 729, 139051. https://doi.org/10.1016/j.scitotenv.2020.139051.

Xu, J., Loo, S., Faruqy, K., Sun, D., 2020. Urban parks as green buffers during the COVID-19 pandemic. Sustainability. 12 (17), 6751. https://doi.org/10.3390/su12176751.

Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., Tong, S., 2016. Impact of heatwave on mortality under different heatwave definitions: a systematic review and meta-analysis. Environ. Int. 89, 193–203. https://doi.org/10.1016/j.envint.2016.02.007.

Yao, M., Zhang, L., Ma, J., Yuan, J., Wang, Y., Du, M., Liu, M., 2020. An effect of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci. Total Environ. 729, 139051. https://doi.org/10.1016/j.scitotenv.2020.139051.

Zhu, X., Liu, S., Zhu, Y., Zhou, J., Liu, S., Wang, Z., Zhang, H., Gao, H., Du, J., Li, X., Zou, Q., Wang, J., Liu, L., 2020. Association between COVID-19 morbidity and meteorology in Wuhan, China. J. Biometeorol. 73 (1), 139178. https://doi.org/10.1029/2020GL089286.