An overview of the impact of the COVID-19 pandemic on urban heat challenges

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Abstract. This study aims to present an overview of the impact of COVID-19 on urban heat challenges. First, this study developed a framework for understanding the linkages between COVID-19 and urban heat challenges. In particular, the framework considered COVID-19 pandemic in aspects of anti-pandemic measures (restriction, protection, individual consciousness) and anti-pandemic periods (lockdown and normalization), and analyzed urban heat challenges in aspects hazards, mitigation, and adaptation and hazards. Built upon this, this study collected the evidence of the impact of the COVID-19 on urban heat challenges in air quality, energy, economy, heat illnesses, and adaptation and mitigation strategies. This study will allow government authorities and experts in various fields to recognize the increasing vulnerability of entire cities to high temperatures as a result of current anti-epidemic strategies. Meanwhile, it provides a reference to the development of a robust, effective, and stable system for addressing urban heat challenges during public health events.

Keywords. Urban heat challenges, COVID-19, mitigation and adaptation

1. Introduction

The outbreak of the COVID-19 has changed people's activities and lifestyle. In particular, the lockdown of cities and nations has been an effective approach to cutting the virus transmission so that people have to at least follow the self-quarantine and social distances. As such, the COVID-19 pandemic has brought new challenges to urban heat mitigation and adaptation. For instance, the nocturnal land surface temperature (LST) reduced by 0.11~0.26°C in Europe, ~0.7°C in the US and 0.27 °C in Canada (Parida et al., 2021). The daytime and nighttime UHI intensity (UHII) of several Chinese megacities reduced by 0.25 °C and 0.23 °C, respectively (Liu et al., 2022). Although UHII generally decreased during the epidemic's major blockade, in this context of frequent global extreme heat events, the slight reduction in UHII during COVID-19 does not allow cities to fall into a cooler temperature range, and there is still an extreme heat risk. For example, the epidemic lockdown period in North America (2020.3 to 5) had...
the lowest spring temperature in North America since 2014, but temperatures from March to May were still above average (NOAA, 2020). Furthermore, in the context of prioritizing anti-epidemic measures, on the one hand, many cooling public venues were fully closed or had a limited number of venue personnel during the major outbreak lockdown, resulting in fewer public cooled places available and accessible, as well as a narrower range of people served by the places. On the other hand, virus's quick spread led people to adjust their normal habits of avoiding heat, preferring to stay at home rather than go out. Moreover, people who stay at home for an extended duration were not immediately threatened by external sun radiation. As a result, air conditioning (AC) became the only way to provide continuous cooling, but the ability to use AC declined due to the economic and energy burdens that people suffered during the epidemic. This is prominent for people living in informal settlements during hot summers (GHHIN, 2020). Overall, the COVID-19 pandemic can aggravate urban heat impacts. A clear understanding of this can generate implications on urban heat mitigation and adaptation.

However, the linkage between COVID-19 pandemic and urban heat challenges has not been well clarified, because: (i) Most studies focus on COVID-19’s impact on environment, economy, and energy, and few load the pandemic into urban heat context and consider their coupling effects. (ii) Few studies address COVID-19’s impact on heat mitigation and adaptation measures, and (iii) Most studies focus on urban heat challenges during the Great Lockdown, but limited studies have regarded extreme heat during the pandemic. To address such gaps, this study aims to reveal the challenges of COVID-19 to urban heat challenges and solutions. The study was conducted with the consideration of three anti-pandemic measures including restrictive measures, protective measures and individual consciousness, and two periods including the lockdown and the new normal to explore the pandemic impact on urban heat hazards, adaptation measures, and mitigation strategies. This study can provide a reference to the coordination of anti-pandemic measures and heat action plans, and support the formulation of policies and guidelines for dealing with urban heat and COVID-19 simultaneously.

2. **Urban heat challenges and mitigation and adaptation solutions**

2.1. **Urban heat hazard**

Temperature increase in cities is a driver to ozone concentration increase because of photochemical phenomenon. NOx concentration can potentially increase in hot days, which might be because extreme hot weather is generally accompanied by calm winds (Lai, 2009). Second, AC are the most effective adaptation strategies and the main choice for cooling so that extreme hot weathers strengthen people’s reliance on AC facilities, resulting in the increase in electricity use. Moreover, extreme heat leads to peak electricity load increase upon the high temperature around noon. Furthermore, electricity use increase is associated with office work patterns, shifting office electricity use increase to residential during weekends and nights (Santamouris et al., 2015). Third, urban heat leads to economic losses, primarily due to the reduction of work productivity and labor absenteeism. There could be labor migration towards comfortable and livable cities and countries, leading to employment reduction. Beyond this, extreme heat leads to economic losses by increasing healthcare expenditure, energy and water bills, food spoilage and food production reduction. Fourth, health risks and threats are an important aspect. During extreme heat, morbidity and mortality can rise. Heat-related illnesses include respiratory, digestive, skin heat damage, and cardiovascular illnesses. Heat can also lead to mental and psychological illnesses such as persistent mental disorders, anxiety, dissociative and somatoform disorders, and depressive disorders.

2.2. **A framework for addressing urban heat challenges**

To address urban heat challenges, governments, experts and scholars have suggested prevention, mitigation and adaptation strategies (Figure 1). The mitigation strategies are long-term urban planning and design measures for the reduction of average temperature. There are four dimensions of strategies including water bodies, urban greening, innovative materials and urban form. The implementation of
these strategies requires long-term practices and trails across investigation, planning, simulation, calculation, optimization, operation, and maintenance to achieve expected cooling effects.

In comparison, adaptation measures are considered in community and individual dimensions. At the community level, adaptation measures are expected to be implemented in three phases, including the preparation phase before an extreme heat event, the direct responses to heat during the event, and the provision of medical services for people with heat-related illnesses. At the individual level, before and during an extreme heat event, people can pay attention to the heat level, identify nearby cooling centers, check the electricity and cooling equipment in houses, thereby reducing the probability of illnesses.

Figure 1. The framework of adaptation and mitigation strategies

2.3. Concept of COVID-19 on urban heat
The coronavirus has super transmissibility and lethality. In addition to the harm caused by the virus to people's physical functions, there are many negative effects associated with some measures taken to control the virus transmission. According to the World Health Organization WHO (2021), the anti-pandemic measures include three aspects, such as restrictive measures (some government measures to restrict travel and gatherings, such as quarantine), protective measures (government and individual protective measures to avoid virus spread, such as wearing masks, disinfection, checking health codes), and individual consciousness (behavioral changes due to concerns about the virus, such as changes in travel patterns and ways to escape the heat) (See Figure 2).

Moreover, most countries have transitioned from an initial lockdown to a pandemic normalization period, and people's production and lifestyle are gradually back onto right track. However, the pandemic normalization is not a return to the pre-pandemic era. Many aspects are still affected, and various industries are constantly looking for new solutions under the new normal. Accordingly, this paper aims
to analyze the possible impacts of the pandemic on heat mitigation and adaptation. This paper is expected to reveal the relationship between the pandemic and high temperature. Following Figure 2, the linkage of three anti-pandemic measures (restriction, protection, individual consciousness) and two anti-pandemic periods (lockdown and normalization) with urban heat challenges (e.g. mitigation, adaptation and hazards) will be analyzed.

Figure 2. The interrelationships between the COVID-19 and urban heat.

3. New challenges of urban heat during the pandemic

3.1. Changes of urban heat hazards

3.1.1. Environment (UHII). UHI weakened during the pandemic. In Pakistan's megacities, for example, surface UHII dropped by an average of 20% (Ali et al., 2021) (Table 1). Most researchers relate this to lower human heat emissions since anthropogenic heat causes a 2-3°C increase in near-surface air temperature (Singh et al., 2022). This was highly supported by the case of Osaka, Japan that, when heat emissions from AC in business sectors decreased by 90.2 % during the city closure, the surface temperature dropped by 0.13°C (Nakajima et al., 2021). The pandemic lockdown has also reduced major human activities and air pollution, reducing the temperature gap between cities and surrounding rural/suburban areas. Although this reduction is temporary and moderate, and there is an upward trend as the restrictions are gradually eased. Nonetheless, it still provides a valuable opportunity to study the role of human factors in urban climate, and also provides strong evidence for governments in making environmental protection decisions.

Table 1. The air pollutants and UHII variations in early 2020 compared to 2019.

| City     | Melbourne | Tokyo     | New York | Multan | Peshawar | Faisalabad | Karachi |
|----------|-----------|-----------|----------|--------|----------|------------|---------|
| Variations | -0.14°C   | -0.05°C   | -0.11°C  | -0.7°C | -0.2°C   | -1.1°C     | -0.3°C  |
3.1.2. *Energy*. The shutdown of production and transportation during the pandemic lockdown has reduced the total energy demand. After climate adjustment, China's electricity demand during the coronavirus lockdown in February 2020 fell by 11% compared to February 2019 (IEA, 2021). However, during the pandemic, there were great differences in electricity consumption by different building types (Kang, 2021). The energy use of residential buildings increased during the pandemic, while the energy use of other building types decreased, especially office and education.

If there is a heatwave during the COVID-19, it will increase energy consumption and further cause energy insecurity. Energy insecurity is related to household economics, housing and appliances, household electricity demand, and related policies (Drehobl et al., 2020). On the one hand, the impact brought by the combination of the pandemic and high temperature makes people stay at home longer. Due to work, study, lighting and cooling, family's electricity demand increased, and the time of peak electricity consumption changed. The unbalanced changes in energy consumption had a certain impact on the original national power distribution system and even led to paralysis. On the other hand, due to compounding effects of heat and COVID-19 on the economy, people's income decreased and unemployment rose, which led to a heavier energy burden on vulnerable groups. In Illinois, the energy burden for low-income consumers increased from 2.31% to 2.44% (Lou et al., 2021). These factors increased energy inequality and further increased the public's risk of heat exposure. Therefore, it is necessary to rethink the issue of energy quotas for different building types in the post-pandemic era, to more effectively manage buildings' energy consumption in unpredictable disaster situations.

3.1.3. *Economy*. The combination of the pandemic and high temperature has threatened the workforce, work efficiency, working hours, and worker health and safety. For example, under the outdoor high temperature environment, the medical personal protective equipment which is required to be worn during the pandemic, hindering the heat exchange between the human body and the environment, and increased the core temperature and local temperature of the human body (Morabito et al., 2020). ISO7933 (2004) proposes that if the core temperature of a person exceeds 38°C, most people will have excessive and disturbing physiological changes (Broede et al., 2018).

However, due to the use of PPE, the time for the human body to reach thermal disorder is shortened, which in turn shortens people's working hours and reduces work efficiency. During the pandemic period of high temperature in summer, the implementation of work from home (WFH) measures also reduced people's work efficiency. A study in Japan showed (Morikawa, 2021) that the productivity of WFH was only 60% to 70% of that in a normal workplace. The combined effect of these factors can also lead to a decline in the economy.

3.1.4. *Heat-related illness*. The compound risk of high temperature and pandemic affects the public in two aspects (Wilhelmi et al., 2021), including socio-geographic factors (region, age, gender, income) and pandemic factors (restriction measures, protective measures, self-protection awareness, and concerns of the COVID-19). These factors impaired people’s ability to address heat and exacerbated people's heat-related symptoms. Strategies such as closed management, traffic control, and stay-at-home orders brought about by anti-pandemic restrictions increased people's heat risk in hot and unusual summers. Due to long-term social isolation, lack of support from social communication, cooling, medical resources, and inner anxiety and loneliness brought about by high isolation, people could be more sensitive to heat perception (Wilhelmi et al., 2021). Measures such as COVID-19 screening, health code inspection, and body temperature monitoring increased the thermal burden of medical staff wearing protective clothing in hot days, and also increased heat exposure time of public queuing up.

Due to the self-protection behaviors, such as wearing disposable masks, gloves, and protective clothing, local and global temperature of human bodies could increase. Liu et al. (2020) showed that wearing a face mask increased the average surface temperature of bodies and increased heart rates, which ultimately led to lower fitness and comfort levels. People's travel preferences were also changed. People were reluctant to choose public transportation and carpooling services. During the pandemic, public transport usage dropped by 80% (Wai et al., 2022). In the absence of adequate road shade,
walking or cycling increased public risk of heat exposure. Self-isolation and worries about the virus caused psychological diseases, such as depression, anxiety, sleep disorders, domestic violence and so on (Fuse-Nagase, 2022). Meanwhile, AC reduction due to concerns about the spread of viruses or improper use increased people's thermal discomfort. The symptoms of heat-related diseases such as heat stroke are similar to the initial symptoms of the Novel Coronavirus (GHHIN, 2020), which also caused psychological burden and increased health risks.

These above-mentioned pandemic factors further exacerbated the original imbalance of socio-geographic factors, such as income in social factors. During the pandemic, most people faced the unemployment. For instance, the U.S. unemployment rate was at its lowest since records began in 1948 (BLS, 2022). Under the dual effects of the pandemic and high temperature, whether during the lockdown or the normalization period, the scope of vulnerable groups was expanded, including but not limited to elder people (>65years and especially >85years), pregnant women, people with underlying diseases, people who work outdoors, staff in hospitals, people who are marginalized and isolated, and people who are overly worried about the outbreak or have COVID-19 (Shumake-Guillemot, 2020).

3.2. Adaptation measures changes

The pandemic affects adaptation measures in three aspects. In the preparation stage: Before an extreme heat event, in the context of anti-epidemic priority, from the national to community and then individual level, attention to high temperature can be diverted. For example, governments promote numerous pandemic prevention measures, to enable the public to understand the virus transmission route and the latest pandemic information. As a result, governments’ attention to issue heat warnings and heat reduction knowledge reduced. The access to social information about high temperatures reduced, and the public could not effectively make adequate preparations for the coming extreme heat. There are also many difficulties in activating emergency systems to deal with extreme heat, such as regular visits to vulnerable groups with high temperatures, and timely transportation of high-risk groups to AC centers.

During heat periods, anti-pandemic measures (e.g. restriction, protection, individual consciousness) led to the increasing time spent at home. In general, people have spent around 10% to 40% more time at home since the outbreak (Data, 2020). Extremely hot weather can induce a rise in indoor temperatures, potentially causing heat discomfort. AC that swiftly reduce indoor temperatures are employed frequently for cooling. Moreover, when people are unable to walk outside to escape the heat, AC becomes the only effective and long-lasting way for homebound people to acclimatize to the heat. However, people's ability to use AC at home could reduce during the COVID-19 period (Wilhelmi et al., 2021). Lower-income and even unemployment or concerns about the spread of the virus could lead to AC usage reduction. Even though with the ability to use AC, it is an unsustainable adaptation measure. There is a conflict between original government's electricity quota for residential buildings and the increase in residential demand for AC electricity during the pandemic. The improper use of AC increases the incidence of vulnerable groups, and at the same time, the use of AC will also increase the outdoor air temperature, even 1-1.3 °C at night (Santamouris et al., 2017).

Anti-pandemic measures also reduced people’s opportunity to obtain cooling resources. During the pandemic lockdown, most public places such as libraries, subways, shops, city parks were closed. On the one hand, people lost the privilege to join public cooling facilities; on the other hand, the outbreak modified the customary method of escaping the heat, with many choosing to stay at home rather than go out and risk illness. During the normal period, people access to public places was controlled by appointment. This results in far less public access to social cooling resources, while the public spaces are required to follow preventative laws such as maintaining a social distance of 1m or more and wearing masks. These measures also make cooling places much less effective. In informal settlements, due to inappropriate housing materials, high building density, low green coverage, economic factors, the air temperature is warmer than in other formal areas. GHHIN (2020) suggested that in Johannesburg, informal houses in settlements experienced indoor temperature 4–5°C warmer than outside, and informal settlements in Ahmedabad, India, were typically 2–3°C warmer than surrounding areas.
are also limited measures to adapt to high temperature, often by setting up public taps and temporary drinking points. However, during the pandemic, public water may increase the virus transmission risk.

On medical services (Bose-O'Reilly et al., 2021), in addition to responding to COVID-19, the medical and health department must also respond to the emergency system of the urban heat, which leads the medical load during the high-temperature pandemic seriously to exceed the standard. Due to the measures and guidelines of the pandemic, when inadvertently suffering from heat-related diseases, timely medical assistance cannot be obtained.

3.3. Mitigation measures changes
The impact of short-term lockdowns on mitigation measures is negligible, but once the pandemic becomes the normal and the duration becomes long, the mitigation measures will be adversely affected in three aspects. First, it delays mitigation strategies implementation, especially for greening needs to go through four stages of seedling cultivation, purchase, planting, and maintenance to achieve the cooling effects. However, the sudden outbreak of the pandemic had a profound impact on the gardening, where sales of seedlings were stagnant, production was paralyzed, procurement risks were increased, transportation and construction were difficult, and maintenance costs increased. In the long run, the cumulative time effect of these factors will lead to the slowdown of the greening cooling measures. The next is water bodies. The pandemic increased difficulties in later operation and maintenance of urban fountains and pools and naturally did not have expected cooling effect. Some restrictive measures introduced by government authorities and people's self-protection also made it difficult for people to go to public places with cooling strategies. Therefore, places that include these cooling measures could no longer continue to play a role of cooling center.

4. Conclusion
The dual impact of the COVID-19 and urban heat increased heat stress, reduced the way to cool down, reduced the public's ability to cope with high temperature, and further enhanced social inequality. The inequality was relevant to air quality, energy, economy, illness risk of vulnerable groups, and the ability of the public to adapt to and mitigate the heat. The novelty of this paper is to connect the pandemic and high temperature more comprehensively, which can provide references for urban heat mitigation and adaptation during pandemic periods, especially a new normal of the pandemic. As epidemic control measures continue to be loosened and city departments progressively return to normal, it is critical to strengthen the urban heat response system in light of the epidemic's current situation. Implementation of community-based adaptation and mitigation should be prioritized. During the pandemic, community-based containment methods will expose communities with insufficient cooling infrastructure to severe heat dangers. In community management, it is critical to have adequate human and material resources to respond to sudden outbreaks and high temperatures, to actively disseminate information about high temperatures, and to fully utilize the Internet to visit vulnerable groups online, and provide effective online diagnostic services. Individually, learn about heat prevention and epidemic prevention, and call for assistance in an emergency. As a result, rebalancing and coordinating COVID-19 and heat policies, as well as establishing a solid system to deal with extreme heat in large-scale public health events, requires the full cooperation of the society, including governments, policymakers, and urban planners.

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