Urban Overheating in Australia

Subjects: Environmental Sciences

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Cities in Australia are experiencing unprecedented levels of urban overheating, which has caused a significant impact on the country's socioeconomic environment. This study provides a comprehensive review on urban overheating, its impact on health, energy, economy, and the heat mitigation potential of a series of strategies in Australia. Existing studies show that the average urban heat island (UHI) intensity ranges from 1.0 °C to 13.0 °C. The magnitude of urban overheating phenomenon in Australia is determined by a combination of UHI effects and dualistic atmospheric circulation systems (cool sea breeze and hot desert winds). The strong relation between multiple characteristics contribute to dramatic fluctuations and high spatiotemporal variabilities in urban overheating. In addition, urban overheating contributes to serious impacts on human health, energy costs, thermal comfort, labour productivity, and social behaviour.

Keywords: climate change ; overheating ; Australia ; thermal comfort ; urban sustainability ; c

1. Introduction

The history of urbanisation is often defined as the history of human development. In the past two centuries, the urban population increased more than 100 times [1]. Today, more than 50% of the world's population lives in cities and forecasts suggest that this number will rise to 70% by 2050 [2]. The burgeoning urban population growth and subsequent urban expansion will greatly affect local and regional climates, urban environmental quality, and public life [3]. Worse, dark coloured building surfaces, roads, pavements, vehicle emissions, and reduced urban green spaces are already contributing to increased atmospheric heat, extreme temperatures, frequent and extended heat spells, and thermal stress.

In Australia, urban overheating has become an increasingly important issue, and urban residents often suffer from excess heat and frequent heatwaves [4][5]. Urban overheating is generally the consequence of the urban heat island (UHI) effect, a local phenomenon caused by city characteristics (urban density, structure, form, and land use), building and paving materials, anthropogenic heat released by vehicle exhausts and building energy use, and the loss of natural features (green areas, water) [5].

Evidence on the UHI effect is available for almost all Australian cities [4]. However, urban overheating in Australia is often triggered by the self-amplifying mechanism of synoptic weather conditions combined with the UHI effect [6]. The significant co-existence of the dualistic atmospheric systems of cool sea breeze from the ocean and hot winds from the inland desert makes the spatiotemporal characteristics of urban overheating highly variable and heterogeneous. As a result, the analysis of the behaviour and formation of urban overheating is very challenging.

Urban overheating and frequent, extreme, and extended heatwaves have significant impact on energy [7], health [8][9], thermal comfort [10], environment [11], and the economy [12]. Advanced technologies and strategies have been developed to mitigate the UHI effect and manage urban heat. The implementation of mitigation techniques and strategies, such as urban greening, green roofs, vertical gardens, cool roofs, and cool pavements, can provide a path for sustainable urban development.

2. Impacts of Urban Overheating

Urban overheating is a major local climate change phenomenon in Australia. The average UHI in Australian cities is as high as 4–6 °C, and in some metropolitan cities, it exceeds 10 °C. Consequently, this local climate anomaly may seriously affect urban sustainability and human well-being, and the interrelationship between urban overheating and its impact on various aspects of human life has been documented for major Australian cities. This section provides a comprehensive review of the impact of urban overheating on public health, energy and the economy.

2.1. Health and Well-Being

In Australia, overheating in cities seriously threatens public health. The Australian Emergency Management Agency and other government organisations have recognised that overheating poses a serious threat to health and well-being. Long-term exposure to extreme temperatures and heat may cause cardiovascular, respiratory, and thermoregulation (cramps, rashes, and heat stroke) related problems, and affect cognitive and emotional abilities [13]. The most at-risk groups include the elderly, children, pregnant women, patients with chronic diseases, people with physical and mental disabilities, and low-income communities.

A considerable body of literature has demonstrated that local climate change and higher urban temperatures, especially during heatwaves, can amplify heat-related mortality and morbidity [14][15][16][17]. In particular, existing works have found that when the ambient temperatures rise above a certain threshold, mortality and morbidity significantly increase. For example, recent evidence indicates that people living in warmer areas of Western Sydney have a 6% higher risk of heat-related death than those living in colder areas of East Sydney [18]. Furthermore, a 2 °C rise in the maximum threshold temperature (27 °C) can increase the average mortality rate by 5.3% Similar findings were also observed by [19]. In Perth, a degree rise in the temperature threshold of 30 °C increased the mortality rate of patients with cardiovascular-diseases by at least 10% [20]. Studies of a similar nature have also demonstrated a presence of strong synergies between overheating and increase in heat-related mortality in many other Australian cities, such as Brisbane [21] and Adelaide [16].

In terms of morbidity, some comprehensive studies conducted in all capital cities in Australia found that a degree rise in temperature can increase the emergency hospitalisation rate of heart-disease patients by an average of 10%, when the maximum ambient temperature is considered to be 30 °C [20][22]. However, other evidence suggests that results may vary depending on the research methods, spatial, socioeconomic, and climatic variabilities, as well as public adaptation [18]. For example, recent research has shown that Sydney's unique overheating phenomenon can be a major cause of higher morbidity in the western parts of the city [18]. It is further estimated that the incidence of all-cause heat morbidity is between 0.05% and 4.6%, and that during heatwaves, this value is between 1% and 11% [18]. Moreover, a 1 °C increase in daily maximum temperature can increase the incidence of heat-related morbidity by 1.1% to 4.6%, when the threshold temperature is regarded as 27 °C. Other studies conducted in Sydney [23] and Brisbane [24] also observed similar results.

Overall, it is evident that the risk of heat-related mortality and morbidity rises significantly with the rise in threshold temperature and during heatwaves. However, the risk gradient may depend on a variety of factors, such as local climate, age, outdoor and indoor environments, thermal quality of the housing, physiological characteristics of the population, demographic and socioeconomic factors, adaptation, and infrastructure [14][25][26][27]. For example, for low-income people living in poor and warm parts of the city with poor-quality housing, and lack of resources to maintain thermal comfort (air conditioning), the health risks are very high [28][29]. As a result, low-income people may spend more energy than others, or even live in uncomfortable indoor environmental conditions that may affect their health and well-being [18]. Despite these risks, limited research has explored the relative impact of urban overheating on low-income communities in Australia [30].

2.2. Energy Consumption and Demand

Urban overheating has severely affected the energy consumption and peak electricity demand in Australian cities. Many studies have explored the relationship between urban overheating and energy consumption, and found a positive correlation between the two [31].

Santamouris [7] found that urban energy consumption per person-year increases by 0.73 ± 0.64 kWh/m^2/°C, or 78 ± 47 kWh/°C, while peak electricity demand increases by 0.45–12.3%/°C, depending on AC penetration and setpoint temperature. Evidence from a recent experimental study conducted in Sydney indicated that urban overheating can increase indoor overheating levels by 56% and cooling energy demand by 16% per year [18]. It was further found that the cooling penalties of residential and commercial buildings were 6.4% and 15.6% per year, respectively, or about 1.8 kWh/m^2/°C and 6.7 kWh/m^2/°C per year, respectively. However, the distinct overheating phenomenon in Sydney (Section 2) can have a differential effect on the city's cooling energy demand.

According to a parametric study of the Sydney metropolis, the buildings in western Sydney consume three times as much energy as eastern Sydney [31]. Moreover, the annual cooling energy demand in western Sydney was as high as 140.2 kWh/person/°C, while the cooling penalties for residential and commercial buildings were 45.1 kWh/person/°C and 95.1 kWh/person/°C per year, respectively [18]. The higher energy penalties imposed by the commercial sector can be attributed to the increased use of commercial energy and the relative smaller population in the western region.

Similarly, in the desert city of Alice Springs, the heat island effect (Section 2) also significantly affected the city's cooling energy demand and building consumption. The energy demand, measured in cooling degree days (CDDs), was between 923–475, when the base temperature ranged between 23 °C and 27 °C [5]. This finding indicates that Alice Spring manifests three times the energy demand of Sydney [4].

In general, studies on the impact of urban overheating on energy determined that for every degree rise in threshold temperature (18 °C) increase, the average cooling energy demand will increase by 0.45% to 4.6% [32], while the annual average energy consumption will increase by 0.5% to 8.5% [25]. Worse, the cooling energy demand of urban buildings will be at least 13% higher than similar rural buildings [7]. Considering that Australia's average summer temperature is higher than 27 °C and 90% of the country is urbanised, these figures may seriously affect thermal comfort and well-being [33][34].

2.3. Economy and Productivity

Urban overheating may pose a serious threat to the Australian economy by reducing labour productivity [35]. Yet, there is not sufficient evidence on the synergies and interdependencies between local climate change and the economy. Most of the existing work on local climate change has focused on the relationship between overheating during heatwaves and indoor workplace productivity [14][35] and outdoor workers productivity [36][37].

For example, a study has shown that urban overheating will cause the Australian gross national product (GNP) to drop at least 1.3% per year [38]. A recent study highlighted that due to heat stress, 7% of the Australian population did not go to work at least one day in the year 2013/14 [35]. The study further emphasised that 70% of the population did go to work, but they felt inefficient, and on average, people were exposed to heat stress for at least 10 days a year and lost about 27 work hours per year. If the sample is extrapolated to the entire working population in Australia, the annual productivity loss from thermal stress is $7.92 billion [35]. Existing findings on the economic costs of extreme temperature events varies widely, with estimates ranging from $1.8 billion to $7 billion [35]. These economic and productivity losses make the cost of heat stress comparable to the cost of chronic health problems.

Extreme temperatures and urban overheating, especially during heatwaves [33][39], severely impact other sectors of the economy, such as transport, construction, agriculture, and tourism, in addition social behaviour (e.g., domestic violence, burglary, assault) [33]. However, evidence on the synergies between urban overheating and other sectors of the economy is also inadequate.

3. Conclusions

Australian cities are warming faster than sorrounding rural areas. The average maximum temperature of the last century has been recorded in the past two decades [40]. Even without global warming, cities are already facing the urban heat island (UHI) effect, where urban areas have become hotter than sorrounding rural areas.

In Australian cities, the intensity of UHI is very significant. The current average intensity varies from 1.0 °C to 13.0 °C. The UHI amplitude changes functionally with the measurement technique adopted. The average intensity using standard method varies between 1.0 °C and 13.0 °C, while the average intensity using non-standard methods is between 1.0 °C and 7.0 °C. Mobile transects and other non-standard measurement methods seem to capture higher UHI intensity as they are commonly used in densely populated urban areas. On the other hand, fixed measuring stations installed in the sorrounding rural areas seem to capture lower UHI intensity as they are used in thermally undisturbed areas.

Urban overheating has different characteristics in different cities and regions of Australia. Urban expansion and reduction of green coverage often lead to the UHI effect. However, the synoptic weather conditions have a greater influence on urban overheating than the UHI itself in many Australian cities. In Sydney, the absolute amplitude of overheating increases as the distance from the coastline increases. The average ambient summer temperatures in the inland western suburbs are at least 2–5 °C higher than the coastal areas of the eastern suburbs [6]. This dramatic fluctuation in the intensity of overheating in Sydney is related to synoptic weather conditions, i.e., sea breeze (cooling mechanism) and hot desert winds (heating mechanism). The sea breeze inhibits hot air advection as it interacts with the UHI circulation and contribute to the cooling effect in the eastern suburbs [6], while the stagnation region in the city canyons, coupled with warm desert winds lead to weaker penetration of cool winds in the western part of the city [4][5]. The intensity of urban overheating in other Australian cities (such as Darwin, Adelaide, Melbourne, and Alice Springs) can be explained by city-specific variables (form, layout, structure, morphology, and anthropogenic heat). Moreover, global climate change and heatwaves have exacerbated overheating in Australian cities [41][42][43].

Urban overheating has caused damage to human health and severely affected energy demand, the economy, and the overall urban sustainability. Between 1993 and 2014, extreme heat has caused more deaths in Australia than floods, hurricanes, lighting, wildfires, and earthquakes combined [44]. Increased temperatures and UHI effects can also harm public health through heat stress and other heat-related diseases. The most vulnerable to overheating are the elderly, young children, chronically ill, mentally ill, outdoor workers, and low-income or socially isolated residents. Existing evidence from different cities in Australia suggests that when the threshold temperature rises by a certain degree, mortality and morbidity will increase. Overall, a 1 °C rise in the threshold temperature (27 °C) can increase the incidence of heat-related morbidity from 1.1% to 4.6% [18][19][24][36].

In addition to causing public health problems, urban overheating also increases urban energy consumption and demand. The overheating of cities will lead to increased energy consumption to meet higher cooling requirements, which will increase greenhouse gas emissions (GHG) and air pollutants. Existing research documented that the average cooling energy can increase by 0.45% to 4.6% per degree rise in threshold temperature of 18 °C [7]. The increase in energy demand will greatly increase the financial burden on governments and may also affect thermal comfort. Worse, urban overheating can affect social behaviour, work and labour productivity, thereby affecting urban development and economic growth [35][37].

Local governments can respond to the impact of urban overheating through emergency plans, outreach activities, and resilient building. However, emergency response and adaptation actions alone cannot save the most vulnerable people. The emergency plans fail to address other interrelated aspects of urban overheating, such as energy disruptions and decreased workplace productivity. Long-term mitigation strategies must be adopted in the natural and built environment to keep residents, buildings and communities cool while also saving energy, health and economic costs.

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