Cities 116 (2021) 103240

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Reshaping the concept of transit-oriented development in response to public space overheating near the transit nodes of Tokyo

Anvar Mukhamedjanov *, Tetsuo Kidokoro, Fumihiko Seta, Yi Yang

International Development & Regional Planning Unit, Department of Engineering, Graduate School of Engineering, The University of Tokyo, Faculty of Engineering, Bldg 14, Room 914, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

A R T I C L E I N F O

Keywords:
Overheating
Transit-oriented development
Public space
Urbanisation
Urban heat island

A B S T R A C T

In Tokyo, the overheating of public spaces in summer is a challenging issue that needs to be resolved for the vibrant social life in this city to be sustained. The urbanisation of Tokyo is based on transit-oriented developments (TODs); this study focused on understanding the correlation between the urban heat island (UHI) effect and public spaces within TODs and on providing solutions for mitigating the overheating of such spaces. The onsite microclimatic data of 30 public spaces near transit nodes were compared with average daily weather forecast data to identify the overheating levels. The spatial structures of the selected areas were then analysed to identify possible planning issues that led to the overheating. Public spaces with high-overheating levels tended to have a lack of vegetation and to be small, dry, and blocked from the wind flow. Public spaces that were not overheated tended to be wide, green, and shaded. These spaces had a microclimate similar to the daily weather forecast. These findings were used to develop new planning guidelines for improving TODs, developing overheating mitigation strategies for public spaces, and identifying future directions for sustainable improvement of the urban structure.

1. Introduction

Urbanisation is the concentration of the population in urban areas such as towns and cities, and it is a result of economic and social shifts around the globe that lead to changes in land use (Gu, 2019; Wang et al., 2015). Such a transformation drives the economy as well as the lifestyle and social values of citizens. Because large cities provide more amenities and chances for a better life, the labour force tends to migrate from rural to urban areas. Approximately 55% of the global population already lives in cities, and this proportion is set to rise to 68% by 2050 (Bocquier, 2005). However, the better amenities and economic activity of city life come with trade-offs, such as a lack of natural elements (Corcoran et al., 2017), the development of urban heat islands (UHIs) (Oke, 1987; Radhi et al., 2015; Yokohari et al., 2001), and CO_2 emissions (Zhang, 2016). To reap the benefits of cities as well as make them more compact and less car-dependent, many large Asian cities such as Tokyo have based their urban planning on transit-oriented developments (TOD), which are focused on maximising the residential, business, and leisure spaces within walking distance of public transit (Bernick & Cervero, 1997). In Japan, TODs have led to the growth of new towns around suburban rail stations so that residents can commute to employment hubs like central Tokyo. However, the relationship between TODs and the UHI effect has not been adequately studied (Kamruzzaman et al., 2018). Although many guidelines have been developed to mitigate summer heat (Bureau of the Environment, 2005), cities are still often considered as harmful and stressful environments (Corcoran et al., 2017) that reduce the wellbeing and quality of life (QoL) of citizens. In addition, TODs often neglect to ensure provision of green spaces for health-related benefits and instead focus on increasing economic activity and land value. This has a negative impact on citizens' health (Rydin et al., 2011). The Tokyo Metropolitan Area (TMA) is one of the best examples of TOD implementation in the world, and thus is ideal for investigating and addressing the factors that lead to overheated public spaces.

The objective of this study was to understand the functions of public spaces near transit nodes in Tokyo and their overheating issues. Often, these spaces are urban squares and plazas surrounded by buildings (Moughtin, 2003). They usually have different levels of greening and sizes, and they provide a living space for creating a healthy sense of community (Gehl, 2006; Lennard, 2019). Understanding the relationship between the development of public spaces and their overheating

* Corresponding author.
E-mail addresses: anvarsan1988@gmail.com (A. Mukhamedjanov), kidokoro@urban.t.u-tokyo.ac.jp (T. Kidokoro), seta@urban.t.u-tokyo.ac.jp (F. Seta), yangyi930611@gmail.com (Y. Yang).

https://doi.org/10.1016/j.cities.2021.103240
Received 18 April 2020; Received in revised form 14 January 2021; Accepted 30 April 2021
Available online 20 May 2021
0264-2751/

levels can be extremely useful for reshaping these spaces to adapt to the summer heat and creating new planning principles for TODs. The rest of this paper is structured as follows. A literature review on the overheating of public spaces is presented together with a hypothesis. The methodology and data compilation are described next. The results of the microclimate analysis of public spaces near different transit stations of Tokyo are presented, along with the functions and locations of these spaces. Then, the relevance of the findings to urban science is discussed, and solutions are proposed for reshaping the TOD concept to mitigate overheating of public spaces near transit nodes in the summer. The paper ends with the conclusions.

2. Public space overheating due to TODs: literature review and hypothesis

There are various theories in the literature on the positive economic and social impacts of TODs, the influence of public spaces on public health, and the causes of the UHI effect. The following literature review can be divided into three broad categories: the influence of urban spaces, the importance of public spaces within the TOD concept, and the causes behind overheating in Tokyo. This discussion was used to develop the hypothesis that guided this study.

2.1. Influence of urban spaces

In urban design, understanding the relationship between society and space is necessary; spaces may be manipulated to promote necessary, optional, and social activities. Gehl (2006) argued that open public spaces should have multiple uses by offering recreational opportunities, wildlife habitats, venues for special events, and an opportunity to breathe. He also developed a list of 12 key quality criteria for evaluating urban spaces according to if they are safe, comfortable, and enjoyable. Many studies on urban QoL have highlighted the importance of 'greening' (Jennings et al., 2016; Villanueva et al., 2015), which is key to ensuring sustainable development (Carmona et al., 2010). High-quality urban spaces are often popular and busy, while poor-quality spaces are the least utilised (Gehl, 2006). To support a sustainable urban environment, the concept of mixed-use areas was promoted, where a space is required to serve more than one primary function (Jacobs, 1961). However, it is unclear how to mix these functions correctly for public spaces to support environmental sustainability in the context of TODs. Because developers are eager to maximise the utility of their properties, public spaces tend to become single-function areas (Carmona et al., 2010). Thus, market forces and urban design have a significant influence on the environment and sustainable development of a city.

2.2. Importance of public spaces within the TOD concept

Urban spaces are traditionally divided into two groups: those that encourage citizens to move, and those that encourage citizens to stay. However, modern urban spaces (e.g. streets and plazas near a train station) may be designed to offer many functions and uses. Gehl (2006) argued that the potential of spaces near transport hubs have still not been realised; these spaces are often dominated by traffic, and their functional monotony tends to make them boring and unsafe at night. They could be made more pleasant if they had other uses. In recent decades, substantial research has been focused on the socioeconomic benefits of the TOD concept. The application of the TOD concept has been very successful in Tokyo; while railway companies secured substantial profits from the integrated rail and neighbourhood development, citizens also benefitted from a sustainable pattern of urban growth and efficient low-cost travel. Thus, the TOD concept promotes dense, profitable, and mixed-use development while maximising walking accessibility. However, it also leads to the growth of transit villages, where the design principles for leisure spaces are unclear. The rapid urbanisation of Tokyo probably affected public spaces by making them smaller in scale; in the summer, they are also extremely hot and thus often empty.

Calthorpe (1993) proposed another approach to the TOD concept, where the land area is divided into zones; public spaces should comprise at least 5–15% of a TOD. Calthorpe argued that public parks and plazas used to be a fundamental feature of liveable and enjoyable high-density communities, and they are needed for stimulating pedestrian activity and providing an economic incentive for mixed-use development. However, it is unclear how green these spaces should be and for which climate these values were estimated for. This lack of clarity may have led to the creation of unsustainable urban environments, which motivated Kamruzzaman et al. (2018) to study the thermal increase caused by TODs in Brisbane, Australia. They found that people living in TODs are likely to experience higher temperatures than those living in non-TOD areas. In the case of Tokyo, the temperature and electricity consumption increased dramatically several decades after the implementation of the TOD concept in urban planning (Yamamoto, 2005). However, Kamruzzaman et al. did not focus on the side effects of TODs that could be caused by a lack of public spaces.

2.3. Consequences of the TOD concept in Tokyo

Many studies have focused on the UHI effect, in which the urban temperature exceeds that of areas outside the city (Hanaki, 2008). The UHI effect was first discovered in 1820 by Luke Howard (Priyadarsini, 2009). Several studies have shown that urban temperatures are considerably higher than rural temperatures (Kleerekoper et al., 2012; Oke, 1987; Yokohari et al., 2001); this is because cities are darker and less vegetated, and thus, they have a lower solar reflectivity and considerably higher heat capacity (Kaloustian & Diab, 2015). Overall, the TOD concept may have led to several major consequences that have increased the UHI effect in Tokyo, as discussed below.

2.3.1. Lack of natural land

In Tokyo, a major reason for altering the land type from green to urbanised areas was to satisfy the rapidly increasing housing demand. Presently, 56.6% of Tokyo's land area is covered by buildings; 21.1% is covered by roads; 8.5% is unused land and land meant for other purposes; and only the remaining 13.8% is covered by urban forests, waterways, farmland, bare wilderness, and parks (Hanaki, 2008). This land use pattern is very similar to the TOD concept described by Bernick and Cervero (1997) and Calthorpe (1993). Because the ground is covered largely by concrete and asphalt, it easily absorbs heat from the Sun, and its temperature can reach 60 °C at midday. Considering the land use pattern of Tokyo and the lack of TOD planning knowledge when TOD was implemented, there are few opportunities for cooling even at night because of the thermal mass of residential buildings and roads and the lack of open green spaces.

2.3.2. Wind flow

The wind flow, together with the roughness of the urban landscape, plays an important cooling role in cities. In Tokyo, buildings cover most of the ground and are three storeys tall on average (Hanaki, 2008). The reason for such a dense development in Tokyo is that the TOD concept promotes development of land within walkable distance to the station, in accordance with the land value capture and specific land use development policies. The development area becomes extremely expensive and dense, and wind flow is usually blocked. The aforementioned measures necessitate the construction of taller buildings to justify development costs in comparison with, for example, auto-dependent development. Here, heat emissions from urban surfaces and air conditioning units dramatically increase the temperature at the pedestrian level. Fernández et al. (2015) demonstrated that tall buildings can distribute heat within an urban area because their surfaces absorb and reflect solar radiation. Akashi (2008) observed the same effect for newly

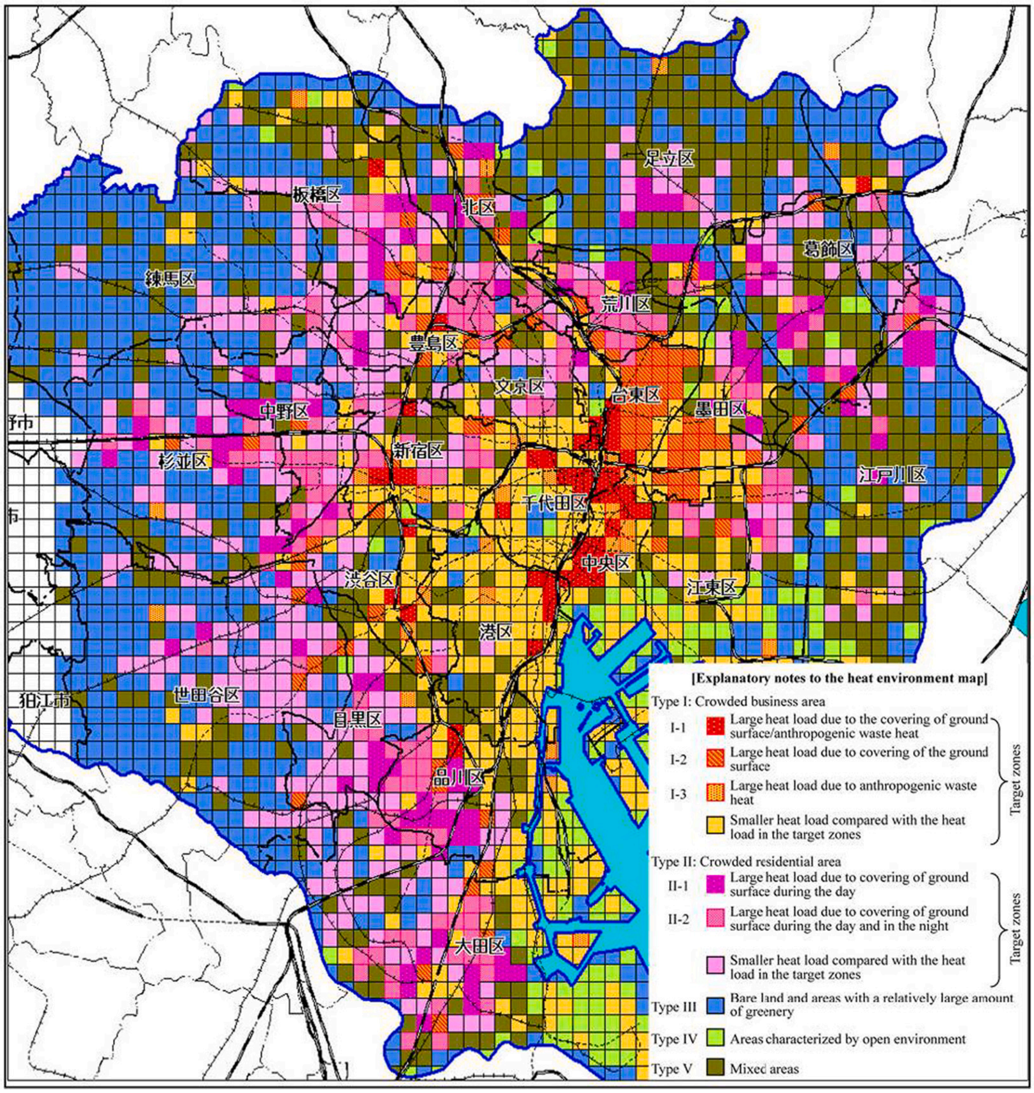

Fig. 1. Study area in August 2019; Source: Bureau of the Environment (2005). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

developed high-rise buildings around Shiodome Station. This development also blocked the cooling wind from Tokyo Bay. However, Akashi also noted the positive effects of high-rise buildings; they can capture higher-altitude air, which travels downward and cools the space. No study has yet described acceptable wind flow conditions for mitigating heating within a TOD.

2.3.3. *Ecosystem*

Numerous theoretical and empirical studies have focused on developing UHI mitigation strategies. Santamouris et al. (2011) identified appropriate materials for reducing energy consumption and improving the comfort of urban spaces. UHI mitigation strategies usually rely on modifying the surface energy balance of overbuilt terrains; the local climatology, geography, and surface typology are very important for successful implementation of such strategies. For example, pavements with a low albedo reflect more solar radiation, while greening redistributes more energy for heat vaporisation (Wang et al., 2012). However, few studies have described UHI mitigation strategies within the TOD concept. In response to the increasing urban temperature, the Bureau of the Environment (2005) of the Tokyo Metropolitan Government developed guidelines for UHI control that included a heat map of Tokyo as well as measures such as greening of developed areas (e.g. roadway painting, rooftop greening, watering, planting trees). However, these guidelines did not focus on how green, windy, and humid such spaces should be. Huang et al. (2009) performed numerical simulations to analyse the UHI mitigation effects of greening for an actual street block in Marunouchi District, but the results showed that adding several trees had an insignificant effect. Nevertheless, parks and paddy fields clearly have significantly lower temperatures than urban areas in summertime (Yokohari et al., 2001). Researchers from the National Institute for Land and Infrastructure Management (NILIM) studied the potential importance of wind paths for different parts of Tokyo. However, the results indicated that, even if helpful, the wind is not a panacea (Akashi, 2008).

2.4. *Hypothesis*

Multiple research initiatives have been undertaken to combat the summer heat in Tokyo (Oke, 1987; Yokohari et al., 2001). However, the effectiveness of these initiatives remains undetermined (Akashi, 2008). It is hypothesised that the planning principles of the TOD concept unintentionally promote public space overheating in Tokyo. This study focused on understanding the causes of overheated public spaces in TODs of Tokyo and on developing possible solutions for mitigation of

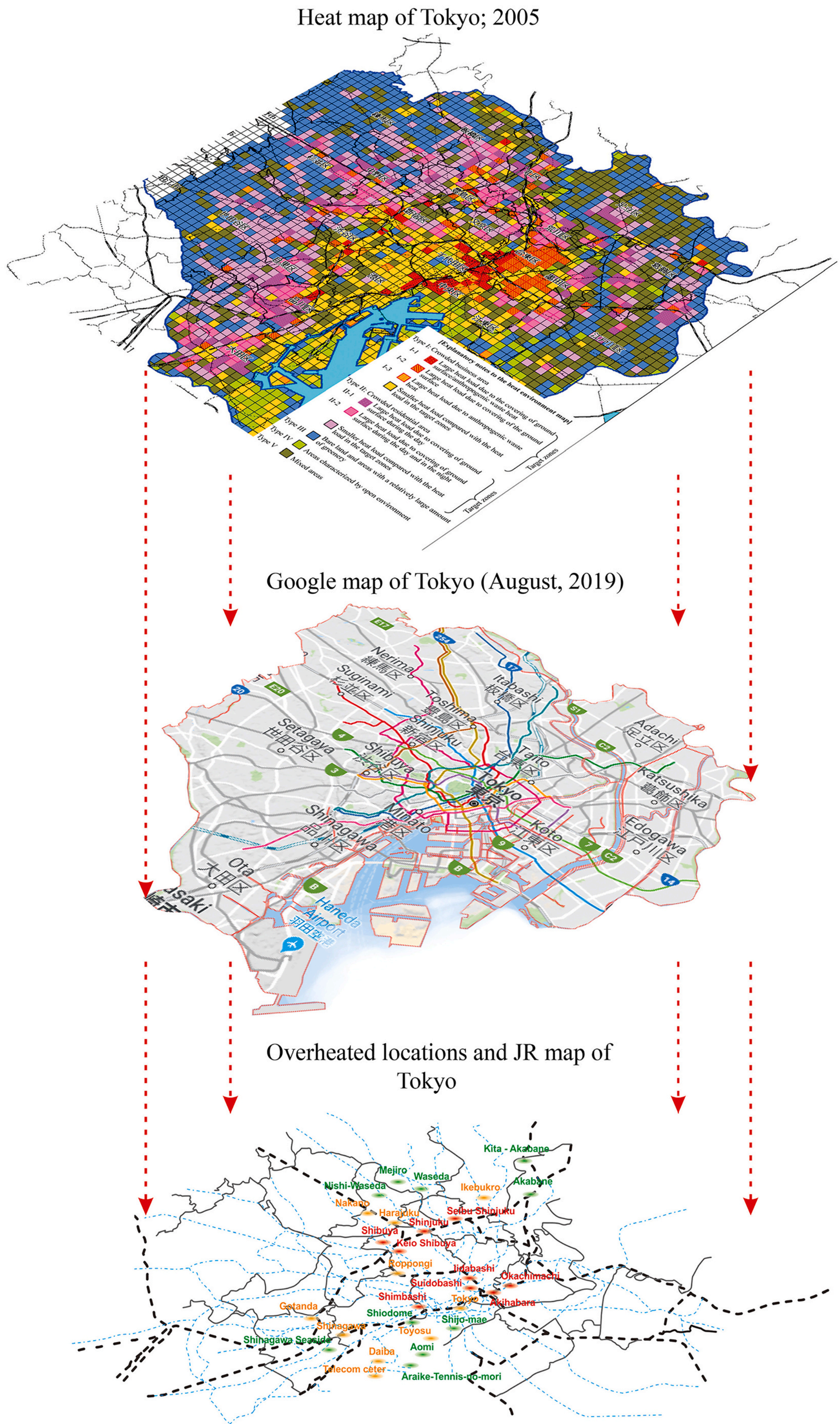

Fig. 2. Search for overheated locations along the Tokyo rail network.

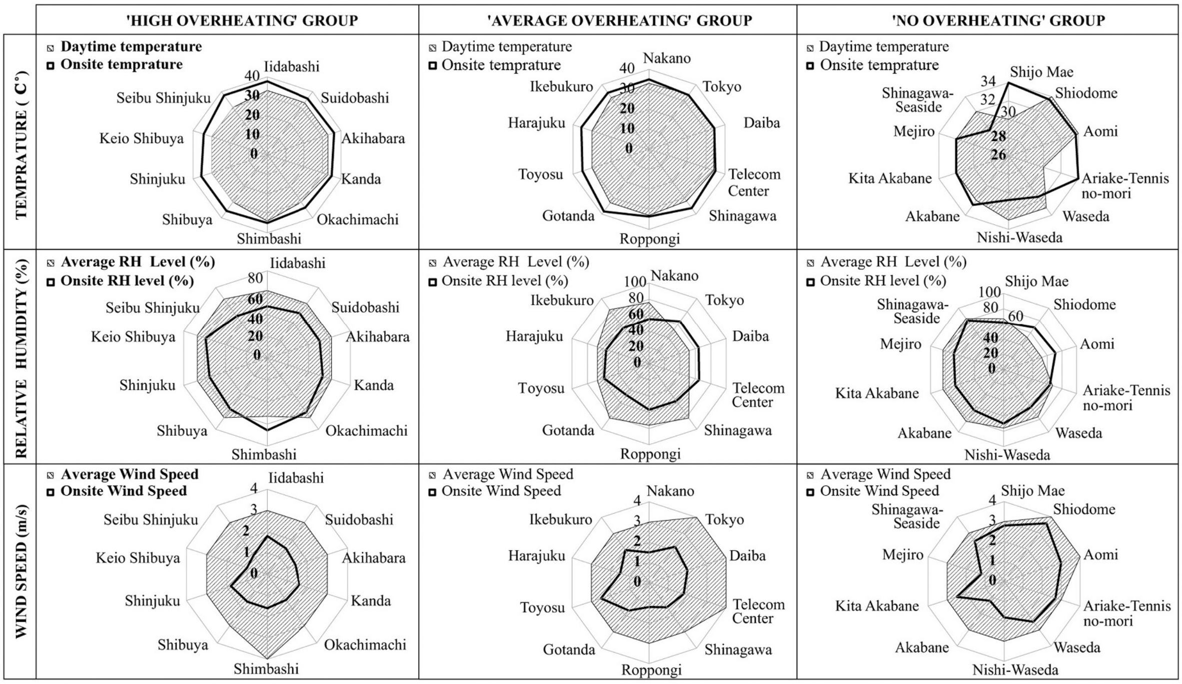

Fig. 3. Differences between onsite measurements and daily weather forecast data.

overheating. However, the problem of global climate change was beyond the scope of this study; hence, the climatic standards for the human comfortability zone proposed by ASHRAE were ignored. The daily weather forecast data were selected to represent normal liveable environmental conditions.

3. Materials and methods

Because the TOD concept promotes dense, economically profitable, and mixed-use development, public spaces in urban cores tend to be small (Calthorpe, 1993), hot (Kleerekoper et al., 2012), and thus often empty during the summer (Gehl, 2006). It is still unclear how to design these public spaces to make them vibrant and liveable during summers. In this study, a field survey was performed to measure the microclimatic conditions at selected public spaces in Tokyo and classify them according to the typology devised by Carmona (2010). Spatial planning analysis and onsite measurements were performed to identify the causes and impacts of public space overheating at selected transit nodes. A similar method was first applied by Luke Howard in 1818 to study the UHI effect in London and has since been used by many scholars (Kolokotroni et al., 2006).

For research transparency, public spaces were selected throughout the entire TMA, located both close to and far from Tokyo Bay by considering various heat environment types.

3.1. Case study: locations and microclimate characteristics of selected areas

As shown in Fig. 1, public spaces near 30 stations with different heat levels were visited. The heat distribution from anthropogenic waste heat and ground surface cover for the 23 wards of Tokyo are mapped as a 500 m mesh. All meshes were divided into five types, and they are represented with different colours. Type I (red to orange) had the highest overheating level and indicated crowded business areas. Type II (pink) included crowded residential areas with large heat loads during the day and occasionally at night. Types III (blue), IV (light green), and V (green) represented areas with large amounts of greenery, open environment, and mixed areas, respectively. The Tokyo Metropolitan Government selected Type I and II areas for UHI mitigation.

Datasets on the temperature, wind velocity, and humidity at a standard height of 1.5 m above the ground surface were analysed together with thermal images and the spatial design of structures in this study.

3.2. Methods and instruments

This study involved two steps of independent analysis. First, the measured field temperature, wind velocity, and humidity level data of selected areas were compared with the daily weather broadcast (DWB) data. Second, thermal image analysis was performed to measure the surface overheating of selected areas and their surroundings. The differences in the design approaches used for the selected public spaces, the locations of these spaces relative to transit nodes, and the functional characteristics of these spaces were also compared. To analyse the locations of stations in terms of the overheating level, the heat map of Tokyo was matched with the rail network from Google Maps (Fig. 2).

Next, 30 TODs were divided according to their level of overheating: high, average, and none. The public spaces nearest the stations (e.g. plazas, squares, promenades) were selected and visited for the field survey in August 2019. The temperature and humidity were measured using a GM 1362 m (Benetech), which has an accuracy of ± 1 °C and $\pm 3\%$ (range of 30–95%), respectively. The wind speed was measured using a GM816 anemometer (Otraki), which has a wind speed accuracy of $\pm 5\%$ (precision of ± 0.1 dgt) and a temperature accuracy of ± 2 °C. Images were captured using a FLIR ONE Pro thermal camera for Android Gen 3, and a Redmi 4× mobile phone was used. Subsequently, the thermal images were analysed using the free 'FLIR ONE' application on the mobile phone and on a PC.

3.3. Data analyses

3.3.1. Climatic data compilation and analysis

Understanding overheating behaviour may help with developing measures to mitigate the UHI effect and improve the QoL in cities. Climatic data were measured at the no-overheating public spaces in an attempt to identify indices for cooling down high-overheating spaces.

Table 1
Urban space types.

Space type	Distinguishing characteristics	Examples
	Positive spaces	
Natural/semi-natural urban space	Natural and semi-natural features within urban areas; typically, under state ownership	Rivers, natural features, seafronts, canals
Civic space	Traditional forms of urban space; open and available to all, and catering to a wide variety of functions	Streets, squares, promenades
Public open space	Managed open space; typically, green and available and open to all, even if temporarily controlled	Parks, gardens, commons, urban forests, cemeteries
	Negative spaces	
Movement space	Space dominated by movement needs; largely for motorised transportation	Main roads, motorways, railways, underpasses
Service space	Space dominated by modern servicing requirements	Car parks, service yards
Leftover space	Space left over after development; often designed without function	SLOAP (space left over after planning), Modernist open spaces
Undefined space	Undeveloped space; either abandoned or awaiting redevelopment	Abandoned space, transient space, redevelopment space
	Ambiguous spaces	
Interchange space	Transport stops and interchanges whether internal or external	Metros, bus interchanges, railway stations, bus/tram stops
Public 'private' space	Seemingly public external space; in fact, privately owned and controlled to some degree	Privately owned civic spaces, business parks, church grounds
Conspicuous space	Public spaces designed to make strangers feel conspicuous and potentially unwelcome	Cul-de-sacs, dummy gated enclaves
Internalised 'public' space	Formally public and external uses; internalised and often privatised	Shopping/leisure malls, introspective megastructures
Retail space	Privately owned but publicly accessible exchange spaces	Shops, covered markets, petrol stations
Third-party space	Semi-public meeting and social places; public and private	Cafes, restaurants, libraries, town halls, religious buildings
Private 'public' space	Publicly owned but determined by function and user	Institutional grounds, housing estates, university campuses
Visible private space	Physically private but visually public	Front gardens, allotments, gated squares
Interface space	Physically demarcated but publicly accessible interfaces between public and private spaces	Street cafes, private pavement spaces
User-selected space	Spaces for selected groups; determined (and sometimes controlled) by age or activity	Skate parks, playgrounds, sports fields/grounds/courses
	Private spaces	
Private open space	Physically private open space	Urban agricultural remnants, private woodlands
External private space	Physically private spaces; grounds and gardens	Gated streets/enclaves, private gardens, private sports clubs, parking courts
Internal private space	Private or business space	Offices, houses, etc.

Source: Carmona (2010) and Carmona et al. (2010).

Fig. 3 graphs the differences in climatic data of the three groups. Each vertex represents the public space of a station, and the hatched areas show the DWB data. The black bold lines represent the onsite measurement. The high-overheating spaces had significantly higher temperatures than the no-overheating spaces, but the wind speed and relative humidity were significantly lower. However, two spaces in the no-overheating group (Shijo-mae and Ariake-tennnis-no-mori) showed abnormal results with high temperatures.

The onsite data were compared with the DWB data to calculate the average climatic conditions for each group. The onsite data (Dm) usually indicated greater human discomfort than the DWB data (Dw) did. The average of each data type (DA) (i.e. temperature, wind speed, or relative humidity) was calculated by subtracting the statistical data (Dw) from the measured data (Dm) and dividing this by the number of public spaces in each overheating group (Ln):

$$DA = \frac{Dm(L1 + L2 + \ldots Ln) - DW(L1 + L2 + \ldots Ln)}{Ln} \quad (1)$$

3.3.2. *Analysis of spatial design and surface overheating in selected areas*

Thermal and spatial design analyses were performed for the selected areas, and high-overheating and no-overheating public spaces were compared. As per Carmona's system, all spaces were visited, snapshotted, and subsequently analysed to understand their functions and characteristics. Table 1 presents Carmona's division of urban spaces. There are four main categories: positive, private, ambiguous, and negative. Interestingly, while positive and private spaces represent natural or public spaces mainly occupied by people, ambiguous and negative spaces represent transportation, market, and development areas. These features suggest that positive and private spaces are greener, more comfortable, and thus less overheated than ambiguous and negative spaces. Because the TOD concept promotes mixed-use development, it is hypothesised that high-overheating public spaces have predominantly ambiguous and negative characteristics. Thus, the following analysis focused on determining whether a correlation exists between the location, function, and overheating of public spaces near different transit nodes in Tokyo.

4. Results

4.1. *Environmental characteristics for sustainable TODs*

In high-overheating spaces, the average temperature was up to 4 °C (113%) higher than the DWB data, while average-overheating spaces were 2.7 °C (108.5%) hotter. However, no-overheating spaces were up to −0.8 °C (97.6%) cooler. The average wind speeds in the high-, average-, and no-overheating spaces were 48.3%, 54.7%, and 73.8% of the DWB data, respectively. Similarly, the high-, average-, and no-overheating spaces had relative humidity values that were 87%, 88%, and 96.3% of the DWB data, respectively.

A linear correlation was observed between the temperature and the other two parameters. High-overheating spaces had the highest temperature and the lowest wind speed and relative humidity. Average-overheating spaces had relatively similar temperatures and relative humidity levels as those of the high-overheating spaces, but the wind speed was up to 6% higher. For most spaces, the wind direction was from the south (i.e. Tokyo Bay). However, the wind direction was from the west or even north for some spaces. Zero-overheating spaces showed values that were close to the DWB data, and the temperature in these spaces was even lower than the DWB data (Fig. 4). It is also clear from this figure that the wind speed in no-overheating spaces is almost the same as in the DWB data, which means that the wind needs to be sufficiently strong to provide a cooling effect. These findings should be referred to for creating wind conditions in public spaces within TODs that enhance pedestrian comfort.

4.2. *Spatial and functional characteristics of public spaces for sustainable TODs*

Representative examples of high- and no-overheating public spaces are described below. The data include the thermal analysis results along with when and where the public spaces were developed. Fig. 5 shows

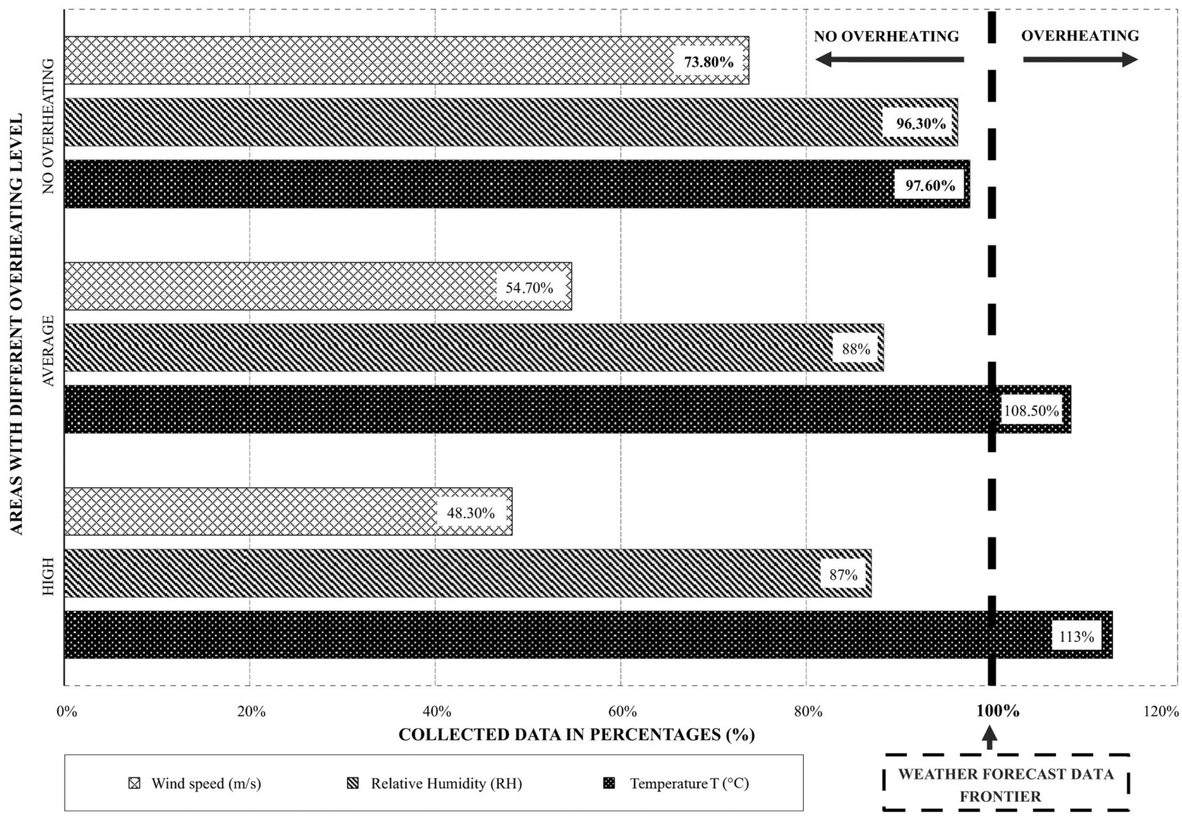

Fig. 4. Correlation between onsite measured climatic data and DWB data for three overheating locations.

that the high-overheating spaces were completely blocked from the wind flow by the station or other buildings. Additionally, the large pavement area absorbed a great amount of heat by evaporating the natural humidity of greenery and the ocean breeze. The wind was rare and slow, and greenery was only decorative. The shade from trees was usually the only place to take shelter from the Sun. In contrast, Fig. 6 shows that the no-overheating spaces were not completely blocked from the wind. Therefore, even if much of the space was covered by pavement and asphalt, the wind and shade from buildings and trees helped cool it down. Plenty of green space was available, and people could enjoy their time there. It appears that an ocean breeze was not required to cool the entire city. Mejiro Station is considerably far from the coast, but its plaza was cooled by wind from the south that passed over Gakushuin University, which has an abundance of green spaces. Trees may cool the wind as it travels towards Mejiro Station. This is supported by the results of Yokohari et al. (2001), who found that correctly positioning parks may cool the air in urban areas. The public spaces of Shiodome and Shinagawa Seaside Stations were also cooled by the surrounding high-rise buildings. These buildings may have captured wind at high altitudes that travelled downward to cool the spaces. These buildings also created shadows that covered almost all the public spaces on hot summer days. Green areas were also characterised by wooden walkways and balconies. The thermal images show that wooden walkways were cooler than pavements covered by asphalt or concrete, while the balconies cast a shade that cooled down nearby building spaces. The measured wind speed and relative humidity were almost the same as the DWB data.

The system in Table 1 was used to organise the findings of this study, which are presented in Table 2. High-overheating spaces tended to combine civic, interchange, semi-natural, movement, and retail functions and mixed positive, negative, and ambiguous characteristics. In contrast, no-overheating areas tended to have natural, civic, public, or private functions with only positive and private characteristics.

5. Discussion

The novelty of this study was identifying the climatic conditions for 30 public spaces near transit nodes of Tokyo and demonstrating how the wrong combination of functions, types, and locations of public spaces may exacerbate overheating. High-overheating public spaces are sometimes neglected or small in scale; they are often blocked from the wind, lack vegetation, and have a mix of positive, ambiguous, and negative characteristics, where the Foehn effect may occur. No-overheating public spaces tend to be broad with positive and private characteristics, along with plenty of greenery and wooden walkways. They are also located within the wind flow and are shaded by surrounding balconies or building facades, which may help lower the temperature.

Kamruzzaman et al.'s (2018) study on Brisbane, Australia, identified a relation between TODs and UHI, which raised the question of how TODs should be designed for environmental sustainability. The implementation of living walls and green roofs has been suggested; these are already in use in Tokyo (Shikata & Oimatsu, 2019). While this study focused on overheating at the microscale, it presents a fresh approach for planning cooler and healthier public spaces near the transit stations of Tokyo. For example, the findings indicate that the planning principles of the TOD concept can be reshaped by designing public spaces with only positive and private characteristics within the wind flow, which tend to be greener and socially vibrant (Carmona et al., 2010). To prevent public spaces with negative and ambiguous characteristics from overheating, they can be shaded by buildings or ventilated with wind catchers to prevent their surfaces (which tend to be covered with asphalt or pavement) from absorbing and storing large amounts of heat from the Sun (Fig. 7).

Thus, Jacobs' (1961) doctrine with the multifunctional use of urban spaces may be amended that public spaces should have the right mixture of functions. By separating functions and prioritising positive and

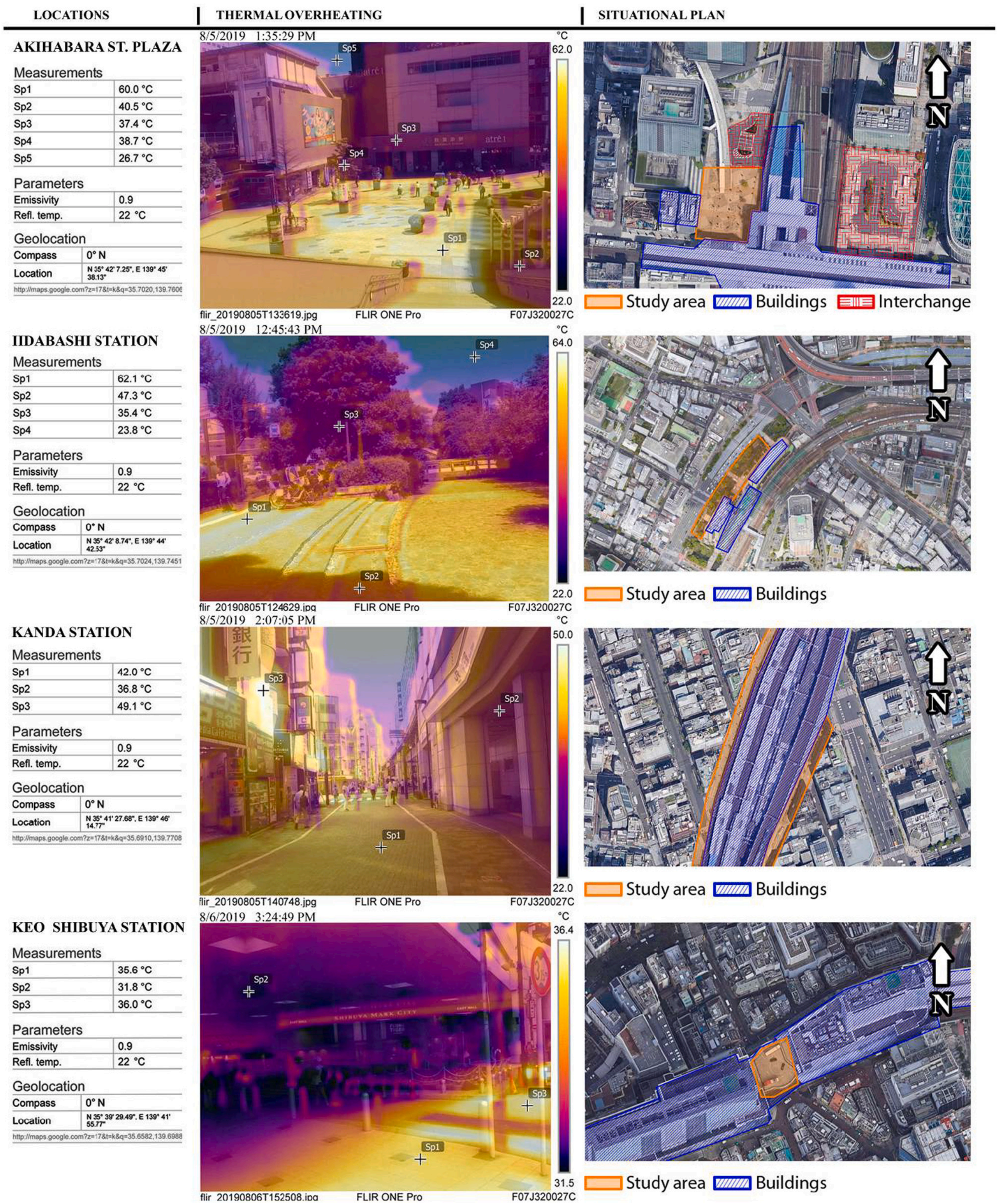

Fig. 5. Spatial and thermal analysis results of high-overheating areas.

private characteristics, the opportunities to mitigate overheating of public spaces within TODs may be increased. However, the concept of functionally separate public spaces in Fig. 7 is not universal, and the composition may vary with respect to geographical location, topography, and environmental conditions depending on the case. The planning of TODs can be improved by considering previous environmental and urban studies conducted by Japanese researchers (Kagiya & Ashie, 2009; Kidokoro et al., 2008; Oke, 1987; Yokohari et al., 2001) and Western researchers regarding the spatial and social aspects of urban planning (Bernick & Cervero, 1997; Carmona et al., 2010; Gehl, 2006; Jacobs, 1961). For example, wind has a significant role, which is even more important when it becomes less predictable (Akashi, 2008). In a recent study, Chew et al. (2017) described the importance of wind for cooling down urban areas and how implementing wind catchers can be a

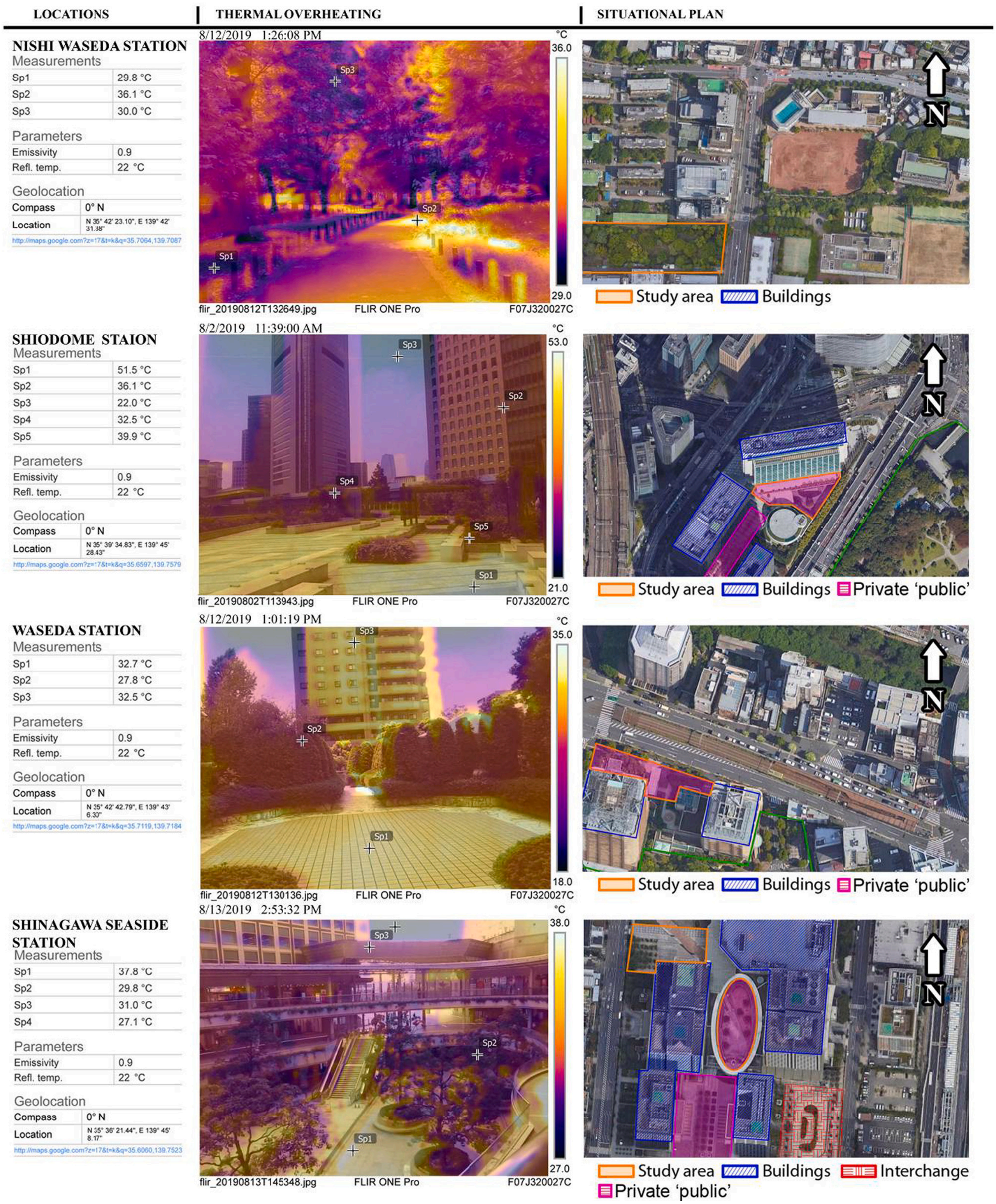

Fig. 6. Spatial and thermal analysis results of no-overheating areas.

possible solution. However, they did not consider the economic feasibility of wind catchers, which may significantly increase the costs of redeveloping existing TODs. To prevent future environmental, financial, and other issues, more research is needed on negative impacts of the TOD concept and on how it can be improved.

The first approach taken in the analysis conducted in this study was necessary to verify the reliability of the thermal data of the environmental heat map of Tokyo, as well as to clarify the contrast in the comfort conditions of public spaces in different thermal areas of Tokyo. This approach has a useful 'diagnostic value of the urban organism' to identify how to adapt overheated public spaces to comfortable conditions where the method of computer simulation may be used. Overall, it is obvious that identifying the required amount of landscaping and wind catchers can be economically cheaper to cool overheated public spaces

Table 2
Urban space analysis.

Characteristics of public spaces near the stations with HIGH overheating									
№	Station name	Environmental characteristics					Urban space types (Carmona, 2010 b).		
		Wind	Shade	Greening	Scale	Heat	Space type	Examples	Distinguishing characteristics
1	Akihabara	Bad	Bad	Bad	Bad	Bad	Civic/ Interchange space	Square/ Train interchanges	Positive & Ambiguous
2	Iidabashi	Bad			Bad	Neutral	Semi-natural/ Movement space	Canal, streets/ Bicycle/ Car road	Positive & Negative
3	Seibu-Shinjuku	Bad	Bad	Bad	Bad	Bad	Civic/ Interchange space	Square/ Underpass	Positive & Ambiguous
4	Okachimachi	Bad	Bad	Bad	Bad	Bad	Civic/ Retail space	Square/ Retail markets	Positive & Ambiguous
5	Kanda	Neutral	Neutral	Bad	Bad	Bad	Movement space	Roads/ Underpass	Negative
6	Keio-Shibuya	Bad		Bad	Bad	Neutral	Movement space	Roads/ Underpass	Negative
7	Shinjiku		Neutral	Bad	Bad	Bad	Interchange/ Civic/ Private 'public'	Roads/ Street/ User determined spaces	Positive & Negative & Ambiguous
8	Suidobashi	Bad	Neutral	Neutral	Neutral	Bad	Civic/ Movement space	Roads/ Underpasses/ Streets	Positive & Negative
9	Shibuya	Neutral	Neutral	Bad	Bad	Bad	Civic/ Interchange space	Square/ Train interchanges	Positive & Ambiguous
10	Shimbashi	Bad	Bad	Bad	Bad	Bad	Civic/ Retail space	Square/ Retail markets	Positive & Ambiguous

Characteristics of public spaces near the station with ZERO overheating (< / = DWB data)									
№	Station name	Environmental characteristics					Urban space types (Carmona, 2010 b).		
		Wind	Shade	Greening	Scale	Heat	Space type	Examples	Distinguishing characteristics
1	*Ariake-Tennis-no-Mori*		Bad	Bad	Bad	Bad	*Civic/ Movement space*	*Canals/ Street/ Bicycle & car road*	*Positive & Negative*
2	Kita-Akabane						Civic/ Public/ Private space	Promenades/ Square & park	Positive & Positive & Private
3	Akabane			Neutral	Neutral	Bad	Civic/ Public space	Square/ Park	Positive & Positive
4	Aomi		Neutral				Civic/ Public space	Promenades/ Square & park	Positive & Positive
5	Shiodome						Civic/ Public/ Private space	Promenades/ Square & park	Positive & Positive & Private
6	Waseda		Neutral		Neutral		Civic/ Private space	Square/ Park	Positive & Private
7	*Shijo-mae*	Bad	Bad	Bad	Bad	Bad	*Civic/ Movement/ Leftover*	*Canals/ Street/ Bicycle & car road*	*Positive & Negative*
8	Shinagawa seaside						Civic/ Public/ Private space	Promenades/ Square & park	Positive & Positive & Private
9	Mejiro	Neutral					Civic/ Public space	Promenades/ Square & park	Positive & Positive
10	Nishi-Waseda						Natural/ Public space	Promenades/ Square & park	Positive & Positive

Designation: **Bad** (crossed box) **Neutral** (shaded box) **Good** (empty box)

than a complete restructuring of the spatial environment at transit nodes within the TODs of Tokyo.

The second approach of filtering public places through Carmona's list of urban spaces identifies the differences in terms of functional characteristics between overheated and non-overheated public spaces. This analysis arose out of the first analysis during the field surveys. This method also may be useful to prevent the future overheating of public spaces at the design stage of the socio-spatial environment near the transit nodes of Tokyo by filtering and separating their functions. The relevance of the attempted correlation between these approaches could be clearly traced during the urban space analysis (Table 2), where the environmental characteristics were compared with the functional characteristics of selected public spaces. As is shown, the environment in negative and ambiguous spaces that are located in overheated areas are less comfortable than those located in non-overheated areas.

Further, to attract the attention of urban scientists, synthesis of these methods was necessary because both approaches support each other synergistically for one goal and solution; specifically, how to create more sustainable socio-spatial environments near the transit nodes of Tokyo within the existing built environments and how to prevent overheating in the public spaces of Tokyo at the planning stage through reshaping of the TOD concept itself.

The results of this work indicate that the climatic conditions of public spaces can be planned and controlled through computer simulations to prevent overheating. However, this approach may not be applicable around the world because the importance of different climatic factors can vary by season and be modified through landscape design (Brown & Gillespie, 1991). Implementing wind catchers and newly developed cooling materials will be extremely beneficial for mitigating the overheating of urban spaces in Tokyo during hot summers.

6. Conclusion

Much has been written on the positive economic effects of TOD, urbanisation, the relationship between public spaces and citizens' wellbeing, and the causes of the UHI effect in Tokyo. However, very few works in the literature have shed light on the drawbacks that result from these combinations. This lack of knowledge on the TOD concept may have led to public spaces near stations that become extremely hot in summer, and the appearance of the UHI effect in metropolitan areas

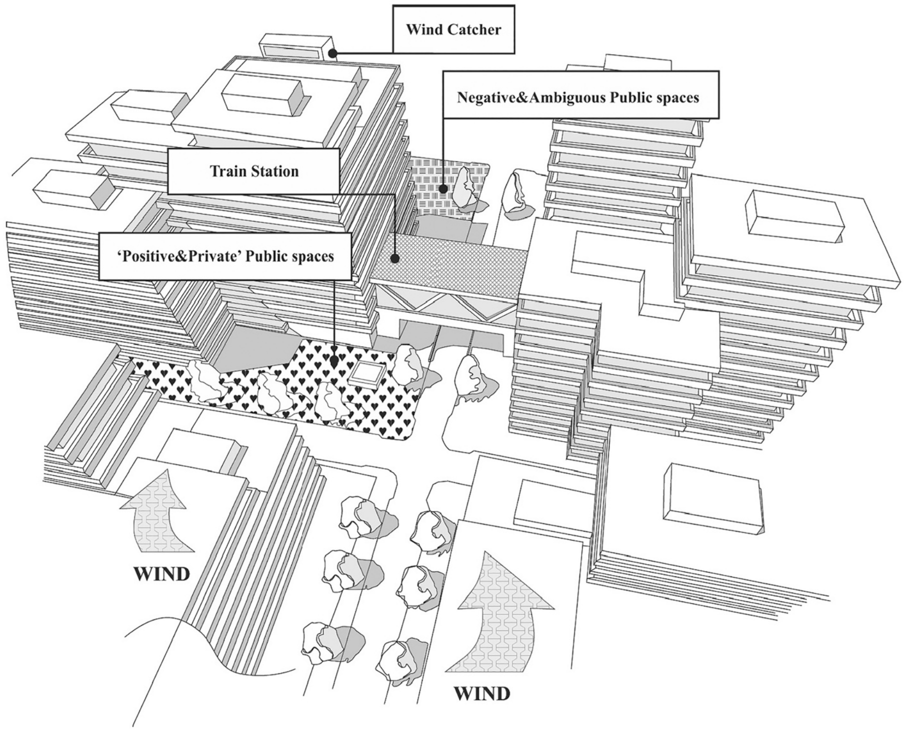

Fig. 7. Concept of functionally separate public spaces near transit nodes.

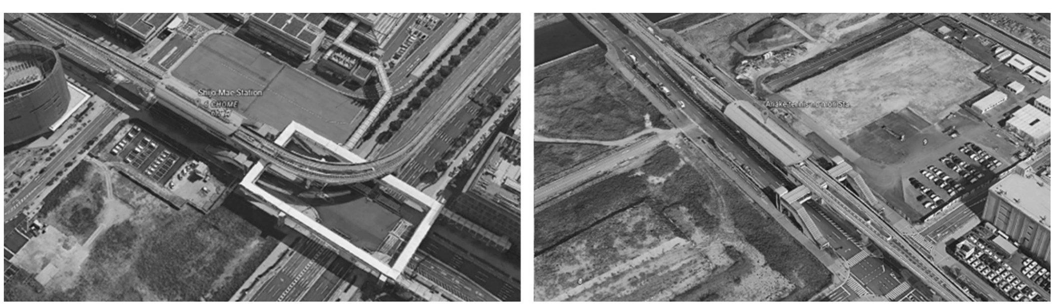

Fig. 8. Spatial characteristics of Shijo-mae Station (left) and Ariake-Tennis-no-Mori Station (right).

such as Tokyo. Reviewing the literature on the influence and importance of public spaces within TODs and the causes of the UHI effect in Tokyo inspired this study to evaluate indices for identifying environmentally sustainable public spaces. The findings can be used to develop new planning guidelines for improving the TOD concept and developing UHI mitigation strategies for spaces near the transit nodes of Tokyo. The case study showed that high-overheating public spaces are generally small, dry, and blocked from the wind with a mix of public, ambiguous, and negative characteristics. Meanwhile, zero-overheating public spaces are shaded by surrounding balconies and building facades, and they are characterised as windy and green with positive and private characteristics.

To test these findings critically, the following aspects should be considered in future research: an updated heat map of Tokyo; computer simulations to identify the recommended proportions of greenery, green pavement, and wind catchers to ensure zero overheating; separation of public space functions; and actual experiments to validate that recommended measures actually cool these public spaces.

This study had several limitations. First, the lack of an updated heat map of Tokyo did not allow deeper analysis of the overheating behaviour of the selected public spaces. Second, the results cannot explain the causes of the increased temperatures for two zero-overheating spaces. There are several potential explanations: the wrong locations were chosen during the field survey; the locations on the heat map were marked incorrectly; climate change issues; and the land development strategy around these stations increased the temperature (Fig. 8). Finally, the concept of TOD is still relatively new. More studies are needed to analyse how to integrate greening and heat reduction materials to prevent overheating of public spaces within a TOD. In addition, the climatic data were only evaluated for Tokyo, and the findings may not be applicable to other geographical locations. The results of this study increase the opportunities for improving the QoL of transit-oriented cities at the microscale through improved planning and design of public spaces near transit nodes for heat mitigation.

CRediT authorship contribution statement

Anvar Mukhamedjanov: Conceptualisation, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Software, Visualisation, Roles/Writing – original draft and review & editing. **Tetsuo Kidokoro:** Supervision, Validation. **Yi Yang:** Investigation, Methodology, Writing – review & editing. **Fumihiko Seta:** Resources; Validation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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.

Acknowledgements

This paper imparts a small portion of the author's thesis for a master's degree, which will be completed in 2020. We would like to thank our families, friends, and professors as well as the anonymous reviewers for their support, invaluable comments, and suggestions.

References

Akashi, T. (2008). Creating the "wind paths" in the city to mitigate urban heat island effects a case study in central district of Tokyo. In *COBRA 2008: The construction and building research conference of the Royal Institution of Chartered Surveyors held at Dublin Institute of Technology, 4–5 September 2008*. London, UK: Royal Institution of Chartered Surveyors.

Bernick, M., & Cervero, R. (1997). *Transit villages in the 21st century*. New York: McGraw-Hill.

Bocquier, P. (2005). World urbanization prospects: An alternative to the UN model of projection compatible with the mobility transition theory. *Demographic Research, 12*, 197–236. https://doi.org/10.4054/demres.2005.12.9.

Brown, R. D., & Gillespie, T. J. (1991). Estimating crop top microclimates from weather station data. *Atmosphere-Ocean, 29*(1), 110–132. https://doi.org/10.1080/07055900.1991.9649396.

Bureau of the Environment. (2005). Guidelines for heat island control measures. https://www.kankyo.metro.tokyo.lg.jp/en/about_us/videos_documents/documents_1.files/heat_island.pdf Accessed (04.09.2020).

Calthorpe, P. (1993). The next American metropolis: Ecology, community, and the American dream. New York, NY: Princeton Architectural Press (pp. 63–92).

Carmona, M. (2010). Contemporary public space, part two: Classification. *Journal of Urban Design, 15*(2), 157–173. https://doi.org/10.1080/13574801003638111.

Carmona, M., Heath, T., Oc, T., & Tiesdell, S. (2010). *Public spaces, urban spaces. The dimensions of urban design* (2nd ed.). Oxford, UK: Architectural Press.

Chew, L. W., Nazarian, N., & Norford, L. (2017). Pedestrian-level urban wind flow enhancement with wind catchers. *Atmosphere, 8*(9), 1–22. https://doi.org/10.3390/atmos8090159.

Corcoran, R., Mansfield, R., Giokas, T., Hawkins, A., Bamford, L., & Marshall, G. (2017). Places change minds: Exploring the psychology of urbanicity using a brief contemplation method. *SAGE Open, 7*(2). https://doi.org/10.1177/2158244017707004.

Fernández, F. J., Alvarez-Vázquez, L. J., García-Chan, N., Martínez, A., & Vázquez-Méndez, M. E. (2015). Optimal location of green zones in metropolitan areas to control the urban heat island. *Journal of Computational and Applied Mathematics, 289*, 412–425. https://doi.org/10.1016/j.cam.2014.10.023.

Gehl, J. (2006). *New city life*. Copenhagen, Denmark: Danish Architectural Press.

Gu, C. (2019). Urbanization: Positive and negative effects. *Science Bulletin, 64*(5), 281–283. https://doi.org/10.1016/j.scib.2019.01.023.

Hanaki, K. (2008). *Urban environmental management and technology*. Tokyo, Japan: Springer Japan. https://doi.org/10.1017/CBO9781107415324.004.

Huang, J., Ooka, R., Okada, A., Omori, T., & Huang, H. (2009). The effects of urban heat island mitigation strategies on the outdoor thermal environment in central Tokyo: A numerical simulation. In *Engineering, the seventh Asia-Pacific conference on wind*. Atsugi, Japan: IAWE.

Jacobs, J. (1961). *The death and life of great American cities*. New York, NY: Vintage Books.

Jennings, V., Larson, L., & Yun, J. (2016). Advancing sustainability through urban green space: Cultural ecosystem services, equity, and social determinants of health. *International Journal of Environmental Research and Public Health, 13*(2), 196. https://doi.org/10.3390/ijerph13020196.

Kagiya, K., & Ashie, Y. (2009). National research project on Kaze-no-michi for city planning: Creation of ventilation paths of cool sea breeze in Tokyo. In *2nd international conference on countermeasures to urban heat islands*. Berkley, CA: Berkeley Lab.

Kaloustian, N., & Diab, Y. (2015). Effects of urbanization on the urban heat island in Beirut. *Urban Climate, 14*, 154–165. https://doi.org/10.1016/j.uclim.2015.06.004.

Kamruzzaman, M., Deilami, K., & Yigitcanlar, T. (2018). Investigating the urban heat island effect of transit oriented development in Brisbane. *Journal of Transport Geography, 66*, 116–124. https://doi.org/10.1016/j.jtrangeo.2017.11.016.

Kidokoro, T., Harata, N., Subunu, L. P., Jessen, J., Motte, A., & Seltzer, E. P. (2008). *Sustainable city regions: Space, place, and governance*. London, UK: Springer Nature. https://doi.org/10.1007/978-4-431-78147-9.

Kleerekoper, L., van Esch, M., & Baldiri, T. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling, 64*, 30–38. https://doi.org/10.1016/j.resconrec.2011.06.004.

Kolokotroni, M., Giannitsaris, I., & Watkins, R. (2006). The effect of the London urban heat island on building summer cooling demand and night ventilation strategies. *Solar Energy, 80*, 383–390. https://doi.org/10.1016/j.solener.2005.03.010.

Lennard, S. H. C. (2019). Livable cities: Concepts and role in improving health. In H. K. M. Nieuwenhuijsen (Ed.), *Integrating human health into urban and transport planning*. Cham: Springer. https://doi.org/10.1007/978-3-319-74983-9_4.

Moughtin, C. (2003). *Urban design: Street and square*. Amsterdam, Netherlands: Elsevier Science.

Oke, T. R. (1987). *Boundary layer climates*. Milton Park, UK: Taylor & Francis.

Priyadarsini, R. (2009). Urban heat island and its impact on building energy consumption. *Advances in Building Energy Research, 3*(1), 261–270.

Radhi, H., Sharples, S., & Assem, E. (2015). Impact of urban heat islands on the thermal comfort and cooling energy demand of artificial islands - A case study of AMWAJ Islands in Bahrain. *Sustainable Cities and Society, 19*, 310–318.

Rydin, Y., Bleahu, A., Davies, M., Dávila, J. D., Friel, S., De Grandis, G., … Wilkinson, P. (2011). Shaping cities for health: Complexity and the planning of urban environments in the 21st century. *The Lancet, 379*(9831), 2079–2108. https://doi.org/10.1016/S0140-6736(12)60435-8.

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy, 85*(12), 3085–3102.

Shikata, H., & Oimatsu, H. (2019). *Station town integrated development. Charm of TOD46*. Tokyo, Japan: Nikken Sekkei Ltd.

Villanueva, K., Badland, H., Hooper, P., Koohsari, M. J., Mavoa, S., Davern, M., … Giles-Corti, B. (2015). Developing indicators of public open space to promote health and wellbeing in communities. *Applied Geography, 57*, 112–119. https://doi.org/10.1016/j.apgeog.2014.12.003.

Wang, H., Zhang, X., & Skitmore, M. (2015). Implications for sustainable land use in high-density cities: Evidence from Hong Kong. *Habitat International, 50*, 23–34. https://doi.org/10.1016/j.habitatint.2015.07.010.

Wang, Z.-H., Bou-Zeid, E., & Smith, J. A. (2012). A coupled energy transport and hydrological model for urban canopies evaluated using a wireless sensor network. *Quarterly Journal of the Royal Meteorological Society, 139*(675), 1643–1657. https://doi.org/10.1002/qj.2032.

Yamamoto, Y. (2005). Measures to mitigate urban heat islands. *Environmental and Energy Research Unit. Quarterly Review, 18*, 65–83. https://www.kankyo.metro.tokyo.lg.jp/en/about_us/videos_documents/documents_1.files/heat_island.pdf.

Yokohari, M., Brown, R. D., Kato, Y., & Yamamoto, S. (2001). The cooling effect of paddy fields on summertime air temperature in residential Tokyo, Japan. *Landscape and Urban Planning, 53*(1–4), 17–27. https://doi.org/10.1016/S0169-2046(00)00123-7.

Zhang, X. Q. (2016). The trends, promises and challenges of urbanisation in the world. *Habitat International, 54*(13), 241–252.