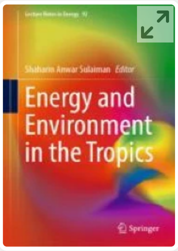

Energy and Environment in the Tropics pp 273–288

Urban Heat Island Phenomenon in Tropical Countries: Analysis of the Wake Flow Behind Slender High-Rise Building

Muhammad Arifuddin Fitriady, Nurizzatul Atikha Rahmat & Ahmad Faiz Mohammad

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Abstract

Urban Heat Island (hereafter, UHI) is a phenomenon described by an increased temperature in an urban area compared to the temperature of its surrounding (Mohajerani et al. in J Environ Manag 197:522–538, 2017).

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References

1. Mohajerani A, Bakaric J, Jeffrey-Bailey T (2017) The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. J Environ Manag 197:522–538. https://doi.org/10.1016/j.jenvman.2017.03.095

2. De Bono A, Peduzzi P, Kluser S, Giuliani G (2004) Early warning on emerging environmental threats: impacts of summer 2003 heat wave in Europe. United Nations Environment Programme, Nairobi

3. Robine J et al (2008) Death toll exceeded 70,000 in Europe during the summer of 2003. C R Biol 331(2):171–178. https://doi.org/10.1016/j.crvi.2007.12.001

4. Oke TR (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 108(455):1–24. https://doi.org/10.1002/qj.49710845502

5. Mohan M, Kikegawa Y, Gurjar BR, Bhati S, Kandya A, Ogawa K (2009) Assessment of urban heat island intensities over Delhi. In: The seventh international conference on Urban climate, 2009, no. July, pp 3–6. https://www.academia.edu/download/41337034/Delhi-UHI.pdf

6. Kim YH, Baik JJ (2002) Maximum urban heat island intensity in Seoul. J Appl Meteorol 41(6):651–659. https://doi.org/10.1175/1520-0450(2002)041%3c0651:MUHIII%3e2.0.CO;2

7. Lee SH, Baik JJ (2010) Statistical and dynamical characteristics of the urban heat island intensity in Seoul. Theor Appl Climatol 100(1):227–237. https://doi.org/10.1007/s00704-009-0247-1

8. Hirano Y, Fujita T (2012) Evaluation of the impact of the urban heat island on residential and commercial energy consumption in Tokyo. Energy 37(1):371–383. https://doi.org/10.1016/j.energy.2011.11.018

9. Vallar E, Oliveros J, Galvez MC, Bagtasa G (2015) Effect of the urbanization of metro Manila on the climate of selected urban and rural areas

using WRFV3.4.1. In: Proceedings of DLSU research congress, 2015, vol 3, pp 1–6. https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/research-congress-proceedings/2015/SEE/012-SEE_Vallar_EA.pdf

10. Wong LP, Alias H, Aghamohammadi N, Aghazadeh S, Nik Sulaiman NM (2017) Urban heat island experience, control measures and health impact: a survey among working community in the city of Kuala Lumpur. Sustain Cities Soc 35:660–668. https://doi.org/10.1016/j.scs.2017.09.026

11. Xiong Y, Huang S, Chen F, Ye H, Wang C, Zhu C (2012) The impacts of rapid urbanization on the thermal environment: a remote sensing study of Guangzhou, South China. Remote Sens 4(7):2033–2056. https://doi.org/10.3390/rs4072033

12. Aflaki A et al (2017) Urban heat island mitigation strategies: a state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. Cities 62:131–145. https://doi.org/10.1016/j.cities.2016.09.003

13. Sarrat C, Lemonsu A, Masson V, Guedalia D (2006) Impact of urban heat island on regional atmospheric pollution. Atmos Environ

40(10):1743–1758. https://doi.org/10.1016/j.atmosenv.2005.11.037

14. Kolokotroni M, Giridharan R (2008) Urban heat island intensity in London: an investigation of the impact of physical characteristics on changes in outdoor air temperature during summer. Sol Energy 82(11):986–998. https://doi.org/10.1016/j.solener.2008.05.004

15. Giridharan R, Kolokotroni M (2009) Urban heat island characteristics in London during winter. Sol Energy 83(9):1668–1682. https://doi.org/10.1016/j.solener.2009.06.007

16. Bohnenstengel SI, Evans S, Clark PA, Belcher SE (2011) Simulations of the London urban heat island. Q J R Meteorol Soc 137(659):1625–1640. https://doi.org/10.1002/qj.855

17. De Ridder K et al (2016) Urban heat Island intensification during hot spells—the case of Paris during the summer of 2003. Urban Sci 1(1):3. https://doi.org/10.3390/urbansci1010003

18. Umezaki AS, Ribeiro FND, de Oliveira AP, Soares J, de Miranda RM (2020) Numerical characterization of spatial and temporal

evolution of summer urban heat island intensity in São Paulo, Brazil. Urban Clim 32(January):100615. https://doi.org/10.1016/j.uclim.2020.100615

19. Gaffin SR et al (2008) Variations in New York city's urban heat island strength over time and space. Theor Appl Climatol 94(1–2):1–11. https://doi.org/10.1007/s00704-007-0368-3

20. Gedzelman SD et al (2003) Mesoscale aspects of the Urban Heat Island around New York City. Theor Appl Climatol 75(1–2):29–42. https://doi.org/10.1007/s00704-002-0724-2

21. Ballinas M, Barradas VL (2016) The Urban tree as a tool to mitigate the urban heat Island in Mexico City: a simple phenomenological model. J Environ Qual 45(1):157–166. https://doi.org/10.2134/jeq2015.01.0056

22. Effat HA, Hassan OAK (2014) Change detection of urban heat islands and some related parameters using multi-temporal Landsat images; a case study for Cairo city, Egypt. Urban Clim 10(P1):171–188. https://doi.org/10.1016/j.uclim.2014.10.011

23. Oke TR (1976) The distinction between canopy and boundary-layer urban heat Islands. Atmosphere (Basel) 14(4):268–277.

https://doi.org/10.1080/00046973.1976.9648422

24. Honjo T (2019) Analysis of urban heat island movement and intensity in Tokyo metropolitan area by Amedas data. J Agric Meteorol 75(2):84–91. https://doi.org/10.2480/agrmet.D-18-00026

25. Ahmed AQ, Ossen DR, Jamei E, Manaf NA, Said I, Ahmad MH (2015) Urban surface temperature behaviour and heat island effect in a tropical planned city. Theor Appl Climatol 119(3–4):493–514. https://doi.org/10.1007/s00704-014-1122-2

26. Priyadarsini R, Wong NH (2007) An investigation of the urban heat Island of Singapore. In: An investigation urban heat Island, Singapore, no 1996, p 192

27. Wolters D, Brandsma T (2012) Estimating the urban heat Island in residential areas in the Netherlands using observations by weather Amateurs. J Appl Meteorol Climatol 51(4):711–721. https://doi.org/10.1175/JAMC-D-11-0135.1

28. Steeneveld GJ, Koopmans S, Heusinkveld BG, Van Hove LWA, Holtslag AAM (2011)

Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. J Geophys Res Atmos 116(20):D20129. https://doi.org/10.1029/2011JD015988

29. Zhou B, Rybski D, Kropp JP (2013) On the statistics of urban heat Island intensity. Geophys Res Lett 40(20):5486–5491. https://doi.org/10.1002/2013GL057320

30. Imhoff ML, Zhang P, Wolfe RE, Bounoua L (2010) Remote sensing of the urban heat island effect across biomes in the continental USA. Remote Sens Environ 114(3):504–513. https://doi.org/10.1016/j.rse.2009.10.008

31. Elsayed ISM (2012) Effects of population density and land management on the intensity of urban heat Islands: a case study on the city of Kuala Lumpur, Malaysia. In: Application of geographic information systems, InTech, pp 267–283

32. Akbari H, Pomerantz M, Taha H (2001) Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70(3):295–310

33. Doulos L, Santamouris M, Livada I (2004) Passive cooling of outdoor urban spaces. The role of materials. Sol Energy 77:231–249. https://doi.org/10.1016/j.solener.2004.04.005

34. Adinna EN, Christian EI, Okolie AT (2009) Assessment of urban heat Island and possible adaptations in Enugu urban using landsat-ETM. J Geogr Reg Plan 2(2):30–36

35. Taha H (1997) Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat. Energy Build 25(2):99–103. https://doi.org/10.1016/s0378-7788(96)00999-1

36. Yavuzturk C, Ksaibati K, Chiasson AD (2005) Assessment of temperature fluctuations in asphalt pavements due to thermal environmental conditions using a two-dimensional, transient finite-difference approach. J Mater Civ Eng 17(4):465–475. https://doi.org/10.1061/(asce)0899-1561(2005)17:4(465)

37. Synnefa A, Dandou A, Santamouris M, Tombrou M, Soulakellis N (2008) On the use of cool materials as a heat island mitigation strategy. J Appl Meteorol Climatol 47(11):2846–2856. https://doi.org/10.1175/2008JAMC1830.1

38. Takebayashi H, Moriyama M (2012) Study on surface heat budget of various pavements for urban heat island mitigation. Adv Mater Sci Eng 2012. https://doi.org/10.1155/2012/523051

39. Stone B, Hess J, Frunkin H (2010) Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Environ Health Perspect 118(10):1425–1428. https://doi.org/10.1289/ehp.0901879

40. Masson V (2006) Urban surface modeling and the meso-scale impact of cities. Theor Appl Climatol 84(1–3):35–45. https://doi.org/10.1007/s00704-005-0142-3

41. Priyadarsini R, Hien WN, David CKW (2008) Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island. Sol Energy 82:727–745. https://doi.org/10.1016/j.solener.2008.02.008

42. Chen H, Ooka R, Huang H, Tsuchiya T (2009) Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation. Build Environ 44(11):2290–2299. https://doi.org/10.1016/j.buildenv.2009.03.012

43. Park HS (1986) Features of the heat island in Seoul and its surrounding cities. Atmos Environ 20(10):1859–1866. https://doi.org/10.1016/0004-6981(86)90326-4

44. Debbage N, Shepherd JM (2015) The urban heat island effect and city contiguity. Comput Environ Urban Syst 54:181–194. https://doi.org/10.1016/j.compenvurbsys.2015.08.002

45. Hamilton IG, Davies M, Steadman P, Stone A, Ridley I, Evans S (2009) The significance of the anthropogenic heat emissions of London's buildings: a comparison against captured shortwave solar radiation. Build Environ 44(4):807–817. https://doi.org/10.1016/j.buildenv.2008.05.024

46. Fan H, Sailor DJ (2005) Modeling the impacts of anthropogenic heating on the urban climate of Philadelphia: a comparison of implementations in two PBL schemes. Atmos Environ 39(1):73–84.

https://doi.org/10.1016/j.atmosenv.2004.09.031

47. Okwen R, Pu R, Cunningham J (2011) Remote sensing of temperature variations around major power plants as point sources of heat. Int J Remote Sens 32(13):3791–3805. https://doi.org/10.1080/01431161003774723

48. Zhou D, Zhao S, Liu S, Zhang L, Zhu C (2014) Surface urban heat island in China's 32 major cities: spatial patterns and drivers. Remote Sens Environ 152:51–61. https://doi.org/10.1016/j.rse.2014.05.017

49. Cheng V, Ng E, Chan C, Givoni B (2012) Outdoor thermal comfort study in a sub-tropical climate: a longitudinal study based in Hong Kong. Int J Biometeorol 56(1):43–56. https://doi.org/10.1007/s00484-010-0396-z

50. Hagishima A, Tanimoto J, Nagayama K, Meno S (2009) Aerodynamic parameters of regular arrays of rectangular blocks with various geometries. Boundary-Layer Meteorol 132(2):315–337. https://doi.org/10.1007/s10546-009-9403-5

51. Zaki SA, Hagishima A, Tanimoto J, Ikegaya N (2011) Aerodynamic parameters of urban

building arrays with random geometries. Bound Layer Meteorol 138(1):99–120. https://doi.org/10.1007/s10546-010-9551-7

52. Ahmad Zaki S, Hagishima A, Tanimoto J (2012) Experimental study of wind-induced ventilation in urban building of cube arrays with various layouts. J Wind Eng Ind Aerodyn 103:31–40. https://doi.org/10.1016/j.jweia.2012.02.008

53. Jiang D, Jiang W, Liu H, Sun J (2008) Systematic influence of different building spacing, height and layout on mean wind and turbulent characteristics within and over urban building arrays. Wind Struct Int J 11(4):275–289. https://doi.org/10.12989/was.2008.11.4.275

54. Yuan C, Ng E (2012) Building porosity for better urban ventilation in high-density cities-a computational parametric study. Build Environ 50:176–189. https://doi.org/10.1016/j.buildenv.2011.10.023

55. Abd Razak A, Hagishima A, Ikegaya N, Tanimoto J (2013) Analysis of airflow over building arrays for assessment of urban wind environment. Build Environ 59:56–65. https://doi.org/10.1016/j.buildenv.2012.08.007

56. Volik MV, Orlova NS (2020) Testing a mathematical model of air movement in a street canyon using the openfoam package. Springer Geol. I:43–50. https://doi.org/10.1007/978-3-030-38177-6_6

57. Ikegaya N, Okaze T, Kikumoto H, Imano M, Ono H, Tominaga Y (2019) Effect of the numerical viscosity on reproduction of mean and turbulent flow fields in the case of a 1:1:2 single block model. J Wind Eng Ind Aerodyn 191:279–296. https://doi.org/10.1016/j.jweia.2019.06.013

58. Ikegaya N, Morishige S, Matsukura Y, Onishi N, Hagishima A (2019) Experimental study on the interaction between turbulent boundary layer and wake behind various types of two-dimensional cylinders. J Wind Eng Ind Aerodyn 204(September 2019):104250. https://doi.org/10.1016/j.jweia.2020.104250

59. Harun Z, Reda E, Abdullah S (2015) Large Eddy simulation of the wind flow over skyscrapers. Recent Adv Mech Mech Eng 15:72–79. http://www.wseas.us/e-library/conferences/2015/Malaysia/MECH/MECH-10.pdf

60. Rahmat NA, Hagishima A, Ikegaya N (2016) An experimental study on aerodynamic

interaction between a boundary layer generated by a smooth and rough wall and a wake behind a spire. Eng Sci Reports, Kyushu Univ 37(2):19–26. https://api.lib.kyushu-u.ac.jp/opac_download_md/1560669/3724.pdf

61. Tachie MF, Balachandar R (2001) Turbulent wakes of flat plates in shallow open channel flow, pp 8–11

62. Nagawkar J, Ghosh S, Kataria R, Nashit A, Deora A (2014) Effect of sky scrapers on natural ventilation patterns and human comfort index in low-risebuildings-a CFD analysis over central Mumbai. ARPN J Eng Appl Sci 9(3):293–295. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1061.2403&rep=rep1&type=pdf

63. Rahmat NA, Hagishima A, Ikegaya N, Tanimoto J (2018) Experimental study on effect of spires on the lateral nonuniformity of mean flow in a wind tunnel. Evergreen 5(1):1–15. https://doi.org/10.5109/1929670

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Author information

Authors and Affiliations

Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang (UMP), Pekan, Malaysia

Muhammad Arifuddin Fitriady & Nurizzatul Atikha Rahmat

Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia (UTM), Kuala Lumpur, Malaysia

Ahmad Faiz Mohammad

Corresponding author

Correspondence to Nurizzatul Atikha Rahmat .

Editor information

Editors and Affiliations

Department of Mechanical Engineering, Universiti Teknologi Petronas, Seri Iskandar, Perak, Malaysia

Shaharin Anwar Sulaiman

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Editor
Shaharin Anwar Sulaiman
Department of Mechanical Engineering
Universiti Teknologi Petronas
Seri Iskandar, Perak, Malaysia

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Preface

Since the 1980s, the terms global warming and climate change were brought up to alert the whole world on an upcoming crisis. It was not well accepted at the beginning, although the awareness was slowly increasing. By now in 2022, the observed rise in temperature and greenhouse gas concentrations has been at the fastest rates in Earth's history. The consequences for these are becoming more distinct. The sea level is clearly raising, submerging certain areas of low elevations. More rains and storms can be seen than before, as well as drought. At the same time, desertification of land is expanding leading to less fertile areas for agriculture, which are needed to support the fast-growing population. By the end of the Great Coronavirus Pandemic of 2019–2021 (COVID-19), a few difficult situations emerged such as the Russia-Ukraine conflict and the early sign of food crisis. The latter could lead to famine. The world economy is also badly hit. Clearly today, the environment, which was perceived differently in the 1980s, coupled with the certain unpredicted situations is making the world's future to become uncertain.

A decade ago, the environmental problems were always expressed as a secondary matter after the mention of energy shortage issues. However, presently, the environment is regarded as a far more important issue due to the many negative effects experienced by many countries. In managing today's problems of environment and energy necessitates various efforts by various stakeholders. In the tropics, this would be unique due to diverse conditions of the areas such as climate, geographical, culture and political conditions. Mitigating the environmental problems in the tropics among others involves enhancing the potential of various types of fuels and conversion of energies. Simultaneously, how the energy is utilized must also be considered holistically. Nevertheless, awareness on the need to improve energy efficiency and to protect the environment is still lacking in many parts of tropical countries. There are plentiful of efforts required within the tropical countries in order to catch up with the vision aspired in the Paris Agreement in 2015. This book delves into studies on issues related to the environment and energy in the tropics. The chapters are contributed by authors from several tropical nations who are experts in the environment and energy topics in their respective countries. The book covers topics in relation to the present state of the environment in selected countries, mainly in Malaysia and the Philippines.

The major content of the book is on the potential energy conversion technologies that can be leveraged for different countries in order to alleviate environmental problems particularly in the tropics. Topics on indoor air quality and energy efficiency, which affect the environment of today, are also presented in this book.

The editor wishes to express his gratefulness to all the contributing authors for their strong effort in preparing the texts for this book. It is hoped that the book would serve as a useful reference to readers.

Seri Iskandar, Malaysia Shaharin Anwar Sulaiman

Contents

Chapter 17

Urban Heat Island Phenomenon in Tropical Countries: Analysis of the Wake Flow behind Slender High-Rise Building

Muhammad Arifuddin Fitriady, Nurizzatul Atikha Rahmat, and Ahmad Faiz Mohammad

Urban Heat Island (hereafter, UHI) is a phenomenon described by an increased temperature in an urban area compared to the temperature of its surrounding [1]. The impact of the UHI can be devastated, such as the loss of lives due to the heatwave in Europe; at least 30,000 lives were claimed to be killed by the heatwave in August 2003 with the fatalities of almost 15,000 lives in France alone [2], [3]. A schematic of UHI is illustrated in **Figure 17.1.**

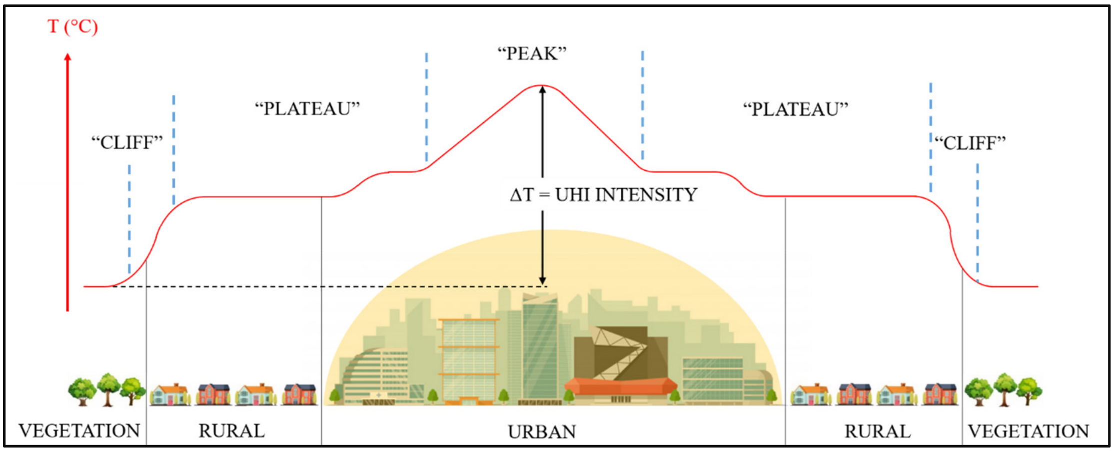

Figure 17.1 Schematic of UHI

The word ‘island’ in the term ‘UHI’ represents the area where the temperature increases uncharacteristically from a plateau to its peak. This is corresponding to densely packed buildings in the urban area sandwiched between two slopes of colder temperatures in the surrounding rural area [1], [4]. This phenomenon typically occurs in most megacities around the world. A quick glimpse of UHI intensity in Asia [5]–[12], Europe [13]–[17], America [18]–[21], and Africa [22] can be seen in **Table 17.1**. Due to this condition, the research on the factors of the UHI as well as the mitigation efforts have been extensively done throughout the globe.

The causes of the UHI phenomenon are diverse, and so are the mitigation efforts. Hence, this paper is focused on the factors of UHI which are presented in the next chapter. Moreover, the effects of city layout on the UHI are discussed in detail.

To sum up all the factors of UHI, we will divide them into five categories, namely 1) the increasing urban population and the growing city area, 2) the low albedo material usage, 3) the increasing anthropogenic heat waste, 4) the geographical & weather factors, and 5) the layout of an urban area.

17.1 Increasing Urban Population and Growing City Area

The UHI is mainly caused by the high rate of urbanization that leads to the increase in population density. The temperature difference (ΔT) between urban and surrounding rural areas, namely the UHI intensity, increases with the rise in the urban population [23], as shown in **Figure 17.2**.

Table 17.1. A quick glimpse of UHI intensity in Asia, Europe, America, and Africa

No	Author	City	Country	Max UHI intensity (˚C)	Remark
1	Kim et al. [6]	Seoul	South Korea	6.5	• The UHI intensity is at the weakest and the strongest point in summer and winter, respectively. • The maximum UHI intensity is more frequently observed in the nighttime than in the daytime. • The previous-day Maximum UHI is positively correlated with the present-day maximum UHI. • The relative humidity, cloudiness, and wind speed are negatively correlated with the present-day maximum UHI.
2	Gedzelman et al. [20]	New York City	United State	8	• The UHI intensity is stronger in summer and autumn while weaker in winter and spring. • The maximum UHI intensity is larger on clear night with low relative humidity. • The sea breeze decreases the UHI intensity due to the high-velocity wind that increases natural ventilation.
3	Gaffin et al. [19]	New York City	United State	5.5	• The UHI intensity is maximum at night while minimum during the day. • The UHI intensity is stronger during summer and fall while weaker during spring and winter. • The main factor of the increase in UHI intensity is the decrease in wind speed over the century.
4	Sarrat et al. [13]	Paris	France	7	• The maximum UHI intensity is larger at night than during the day. • The surface roughness of a city greatly influences the structure of the atmospheric boundary layer.
5	Kolokotroni et al. [14]	London	United Kingdom	8.9	• The maximum UHI intensity is larger during the day than at night. • The partially cloudy period and low albedo surface were considered as the most critical variable in UHI intensity.

No	Author	City	Country	Max UHI intensity (˚C)	Remark
6	Mohan et al. [5]	Delhi	India	8.3	• The UHI intensities observed during the afternoon (at 3 PM) and night (at 9 PM) are higher than in the early morning. • The maximum UHI intensity is mostly observed in dense commercial areas due to the anthropogenic heat generated by the increasing energy demand. • Green and forest vegetation has a greater effect in reducing UHI intensity compared to a water body.
7	Xiong et al. [11]	Guangzhou	China	2.43	• The highest UHI intensity is concentrated in the built-up area with a high-density population as well as the heavily industrialized districts. • The major contributor to the UHI is the expansion of a built-up area that generates anthropogenic heat waste.
8	Honjo [24]	Tokyo	Japan	15	• The higher UHI intensity is mostly observed in winter. • On a daily basis, the UHI intensity is at maximum during daytime in summer and night-time in winter.
9	Effat, H. and Hassan, O. [22]	Cairo	Egypt	5.7	• The UHI intensity in the desert and bare land is higher than in the high-density district due to the large area of shadow generated by the building in the dense population district. • The variation in UHI is mainly subjected to weather conditions, climate change, and anthropogenic heat waste.
10	Ahmed et al. [25]	Kuala Lumpur	Malaysia	2	• Building geometry, street orientation, building materials, hard landscape, and soft landscape play a crucial role in urban microclimate. • The nighttime UHI is higher than the daytime.
11	Priyadarsini, R. and Wong, N. H. [26]	Singapore	Singapore	2	• The UHI intensity is higher during the nighttime compared to the daytime. • Solar shade, which is generated by high-rise buildings and vegetation, decreases the temperature during the daytime. Hence, it is suggested to increase the vegetation area to provide some shade while increasing the albedo.

Wolters and Brandsma [27] measured the temperature in various urban areas during summer (June-August) in the Netherlands. It was found that there is a significant positive relation between UHI and the population density, deduced by the slopes of regression (obtained through the least square method) of 0.11°C (10^3 km^{-2})$^{-1}$ and 0.17°C (10^3 km^{-2})$^{-1}$ for the average and maximum UHI intensities, respectively. A similar statistical analysis by Steeneveld et al. [28] describes the relationship between the diurnal maximum UHI intensity and overpopulation density using an exponential relation. This relation produces the regression slopes of 0.19°C (10^3 km^{-2})$^{-1}$ and 0.38°C (10^3 km^{-2})$^{-1}$ for the median and 95th percentiles of the diurnal maximum UHI, respectively.

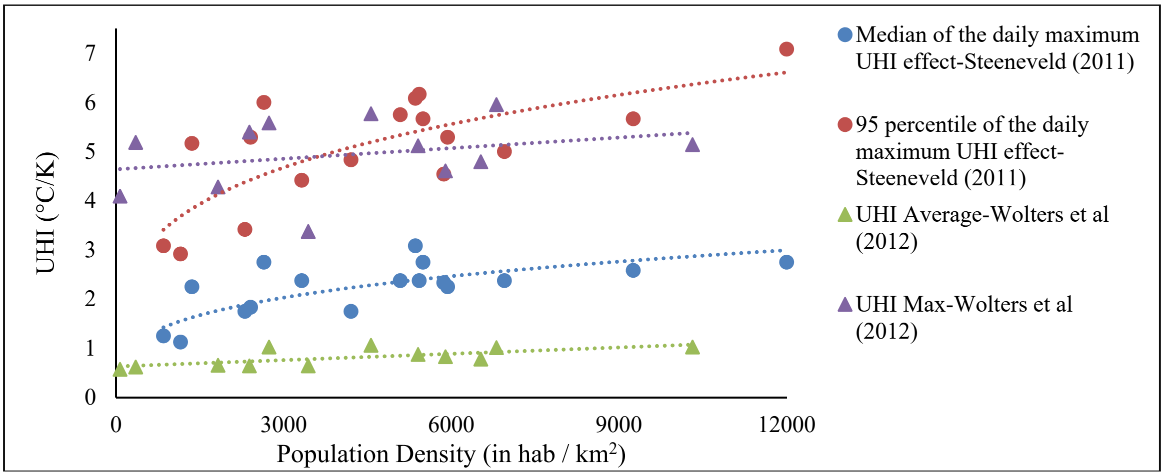

Figure 17.2 The relationships between population density and UHI intensity. Data taken from Wolters and Brandsma and Steeneveld et al.

On the other hand, the increased population density will also increase the city size area. The studies by Zhou et al. [29] and Imhoff et al. [30] achieved the same conclusion; a larger city size leads to a higher UHI intensity. Moreover, the UHI intensity increased from 1.5°C to 10°C in a city area ranging from ≤10 km^2 to ≥1000 km^2 [30]. **Table 17.2** shows a brief description of the studies on the relation of the UHI intensity with the population density and the city size area.

Table 17.2. A description of the studies on the relation of the UHI intensity with the population density and the city area

Cause	Author	Finding
Urban population	Steeneveld et al. [28]	➢ The UHI intensity increased with the increase in the population density of urban areas. ➢ A higher population density required higher a building density which can cause increased trapped radiation and thermal inertia.
	Elsayed [31]	➢ The threefold increase in population density increased the UHI intensity by 1.5°C.
	Wolters and Brandsma [27]	➢ The UHI intensity increased with the increase of population density of an urban area by 0.11°C per 10^3 people/km^2 for the average UHI and by 0.17 per 10^3 people/km^2 for the maximum observed UHI. ➢ Population density is suggested to be a promising predictor of the UHI.
City area	Zhou et al. [29]	➢ The larger city cluster size leads to the higher UHI intensity, forming a sigmoid relation on a logarithmic scale of city cluster size.
	Imhoff et al. [30]	➢ A larger city has a higher UHI intensity. ➢ The UHI intensity increased from 1.5°C to 10°C in a city area from ≤10 km^2 to ≥1000 km^2.

17.2 The Low Albedo Material Usage

With the increase in population density, the need for decent places to live is also increasing. Hence, people start to expand the city by turning the forest into a residential area. The surface of the land changes from high albedo material, i.e. water surfaces, forest, or other natural vegetation surfaces, to low albedo material [32]–[34]. The albedo of a surface is defined as the hemispherically-and wavelength-integrated reflectivity of a surface. The higher the albedo, the less solar radiation absorption and thus lower the temperature surface [35].

The low albedo condition in an urban area, including the use of dark-colored surface coating of buildings [32], the use of heat-storing materials i.e. asphalt and concrete [36], and the decrease of vegetation in the urban area [37], can increase the UHI intensity [33]. Moreover, Takebayashi and Moriyama [38] proved that normal asphalt can be up to 20°C hotter than grass during the daytime; this shows that hard and heat-absorbing materials like asphalt contribute significantly to UHI. These materials absorb heat from solar radiation during the daytime and re-radiate the stored heat at night [39]. This process can increase the outdoor temperature in the urban area. A brief description of the studies on the relation of the UHI intensity with the low albedo material usage in urban areas is presented in **Table 17.3**.

Table 17.3. A brief description of the studies on the relation of the UHI intensity with the low albedo material usage in urban areas

Author	Finding
Synnefa et al. [37]	➢ Rising the albedo level from 0.63 to 0.85 increased the temperature from 1.5°C to 2.2°C.
Doulos et al. [33]	➢ Light-colored and smooth surfaces of stone, marble, and mosaic have a high albedo. ➢ Dark-colored and rough surfaces of asphalt, paving stone, and concrete have a low albedo.
Masson [40]	➢ Applying a low albedo of 0.15 in the NARP-LUMPS model to reproduce the UHI phenomenon.
Takebayashi et al. [38]	➢ Hard and heat absorbent materials contribute significantly to the UHI, indicated by the higher temperature of normal asphalt than the grass by up to 20°C in the daytime.
Priyadarsini et al. [41]	➢ At the same wind speed of 4 m/s, black-colored aluminum has a 1°C higher temperature than white aluminum.
Adinna E. N. et al. [34]	➢ The increase in air temperature is caused by the replacement of natural environments including forests, water surfaces, and pasture, with non-evaporating and non-transpiring surfaces.
Chen et al. [42]	➢ A decrease of 1°C air temperature was simulated by increasing the albedo i.e. usage of water-retaining material and greening.

Concerning the causes previously mentioned, there is a paradoxical suggestion in the study of the UHI causes. On one hand, some detailed studies suggested that the size of a city area [29], [30], as well as the water area within the city [43], can be correlated with the UHI intensity. Moreover, the city population [43] and the population density [27], [28], [31] affected the UHI intensity. On the other hand, Debbage and Shepherd [44] statistically showed that the four parameters (i.e. city size, water area, city population, and population density) were insignificantly correlated to the UHI intensity. Instead, the author suggested that the spatial contiguity of urban development is statistically significant to the UHI intensity [44].

17.3 The Increase in Anthropogenic Heat Waste

It is a well-known fact that the need for energy increases along with the population size to create a comfortable condition around them. This need mostly peaked at unfavorable temperature conditions such as in winter or summer. The usage of energy will never be 100% in efficacy that some part of energy was turned to waste. Since the need for energy increases, the waste of energy is also increased. This waste energy was known as the anthropogenic heat waste which indubitably increases the temperature of the urban area [40], [45], [46].

The anthropogenic heat typically originates from vehicles [42], stationary sources i.e. fossil-fueled power plants [47], and the usage of air-conditioners (AC) in urban buildings [41]. The heat is released to the ABL, increasing the outdoor temperature. **Table 17.4** presents a description of the studies on the relation of the UHI intensity with the increase of anthropogenic heat waste.

Table 17.4. A description of the studies on the relation of the UHI intensity with the increase of anthropogenic heat waste

Author	Finding
Hamilton et al. [45]	➢ High-density areas produce the highest anthropogenic heat emission.
Chen et al. [42]	➢ The air temperature increases by a maximum of 1°C in the city models of Kyobashi and Otemachi due to the traffic heat.
H. Fan and D. J. Sailor [46]	➢ Anthropogenic heat emission in Philadelphia increases the air temperature up to 3°C in the nighttime of winter, which affected the nocturnal PBL stability and PBL structure in the morning transition.
Okwen et al. [47]	➢ The air temperature recorded near a fossil-fueled power plant was 10°C higher than its surrounding area. ➢ The air temperature reached the background temperature within 1200-2000 m from the power plant.

Hamilton et al. [45] stated that a higher density urban area tends to generate a greater anthropogenic heat emission. The author also reported that an area with morphometry, which is the total built volume (m^3) normalized by total area (m^2) of middle layer super output areas, of 4 - 7.8 m was predicted to generate anthropogenic heat emission as much as 400 W/m^2 during the worst winter and 173 W/m^2 during the worst summer. While the area with morphometry larger than 7.8 m generates anthropogenic heat emissions of as much as 530 W/m^2 during the worst winter and 230 W/m^2 during the worst summer. A condition of the weather indicated by a cold cloudy day with high use of energy is referred to as the worst winter, while the worst summer is indicated by a warm clear day with high use of energy [45].

17.4 The Geographical & Wheatear Condition

Daylight radiation due to different geographical locations and weather is also a significant factor in the UHI intensity [48]. The cloudiness and seasonal condition also affect the UHI intensity of an urban area [49]. A brief description of the studies on the relation of the UHI intensity with the anthropogenic heat waste increase is presented in **Table 17.5.**

Table 17.5. A brief description of the studies on the relation of the UHI intensity with the anthropogenic heat waste increase

Author	Finding
Cheng et al. [49]	➢ Developed a set of equations to estimate the outdoor thermal sensation as a function of air temperature, wind speed, solar radiation intensity, and absolute humidity. ➢ Based on the developed equations, on a summer day (air temperature of 28°C and humidity of 80%), the wind speed is required to be 1.6 m/s to achieve a neutral thermal sensation.
Zhou et al. [48]	➢ A higher surface UHI intensity in China was observed during the nighttime in the northern region and during the daytime in the southeastern region. ➢ The surface UHI intensity was also affected by the season; it has a higher intensity during the daytime in summer and during the nighttime in winter for most cities in China.

17.5 City Layout and Planning

As urbanization increases, the size of a city also increases while the size of a forest or a vegetated area decreases. The concern about the environment is rising. Skyscraper buildings were constructed to answer the need for living spaces without harming the forest. Soon, skyscraper buildings mushroom in every megacity on earth. This phenomenon leads to another problem associated with UHI, the wind velocity deficit.

There are numerous studies investigating the wake flow either in a city layout or around a building. Some of them used blocks or cubes as a representative of a building while others create a scaled-down real skyscraper building. Hagishima et al. [50] observed the effect of several arrays of woodblock layouts, representing the city layout, to investigate the three parameters to identify the aerodynamic effect i.e. drag coefficient, *Cd*, roughness length, Z_o, and displacement height, *d*. Moreover, the author also added the roughness density as the variable of study. Furthermore, Zaki et al. [51], [52] continued the experiment using the rough wall consisting of cubes that are arranged based on the Probability Density Function (PDF) based on a GIS dataset for Tokyo.

Moreover, to observe the wake flow in detail, Computational Fluid Dynamic (CFD) simulation was used in recent studies. Jiang et al. [53] studied the systematic influence of building spacing, height, and layout on the mean flow and turbulent characteristics based on CFD using the large-eddy simulation (LES) turbulence model. Various types of wake flow were observed i.e. isolated flow, wake interference flow, and skimming flow by increasing the ratio of the frontal area of obstacles to the total floor area.

Yuan et al. [54] studied the effect of the building design and city layout on the outdoor thermal comfort by predicting the wind velocity based on CFD using the *SST k-ω* turbulence model. It was found that street grid orientation in grid planning is a significant parameter in urban natural ventilation performance. The wind environment at the pedestrian level is not affected by building height but is significantly influenced by building morphology in the podium layer. Moreover, the placing of building setback, building separation, wind permeability, and the building void were discussed in detail.

Razak et al. [55] investigated the effect of urban geometry, which is characterized by the plan area ratio, building aspect ratio, and heterogeneity of building heights, on the spatially averaged pedestrian wind speed as an index of urban ventilation based on CFD using parallelized large-eddy turbulence model. A detailed profile of wake flow behind and between the block in an array was observed and discussed.

Volik et al. [56] investigate the fields of velocity and pressure during the motion of a turbulent incompressible fluid in street canyons and behind a reverse ledge based on CFD using the LES and k-ε turbulence models. A detailed discussion was made based on the vortexes generated by various turbulence models; the LES method uses both a sticking condition and a near-wall function, while for the k-ε model, both conditons i.e. using a near-wall function and without a wall function, can be used.

Some studies were also conducted to observe the wind flow profile around a block that imitates the basic shape of a rectangular building. Ikegaya et al. [57], [58] conducted a study using a single block to observe the wind profile around the model based on CFD with LES. The objective is to clarify the effect of the numerical viscosity in different advection schemes i.e. second-order central, first-order upwind, and blending schemes with ratios of 95:5, 90:10, 80:20, and 60:40. The other objective of the study is to understand the effect of the block on the probability density distributions of each velocity component and wind speed for the pedestrian level.

Meanwhile, another study uses real building shapes to observe the wind profile around the building. Harun et al. [59] investigated the wake flow generated by the Petronas Twin Tower based on a CFD using the LES turbulence model. Two types of wake flow were observed in between the tower and behind the tower. A velocity deficit is observed in the leeward area. The most interesting part is that the result reported by Harun has a similar trend with the one reported by Rahmat et al. [60] who conducted a wind tunnel experimental study using a single quarter-elliptic wedge spire to imitate an isolated, slender high-rise building.

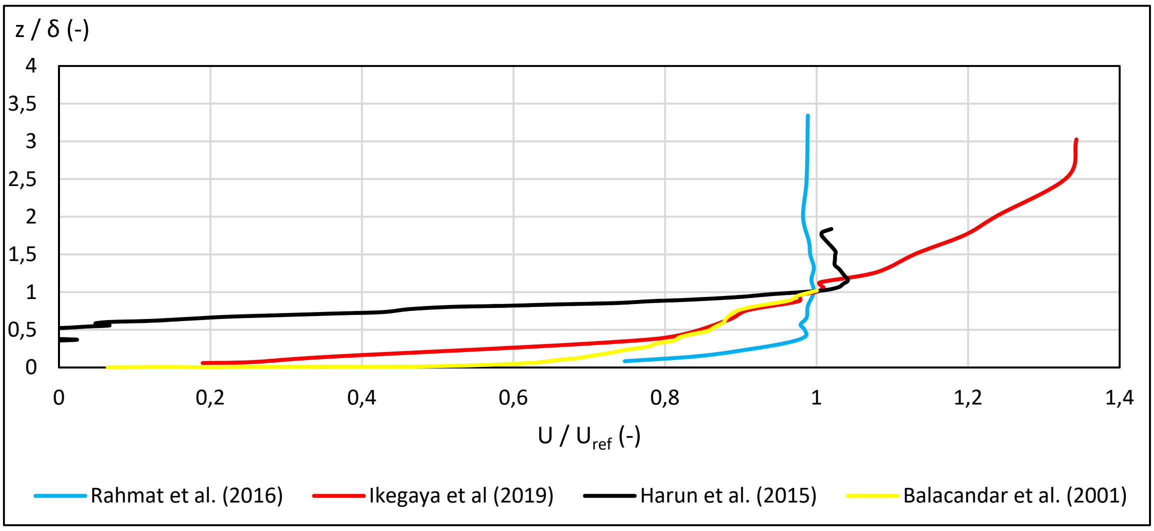

Figure 17.3 Normalized vertical velocity profiles of various studies

Figure 17.3 compares the results reported by Ikegaya et al. [57], Harun et al. [59], Balachandar et al. [61], and Rahmat et al. [60] which shows a similar vertical velocity trend. The normalized vertical velocity is at the lowest value just above the ground due to the drag coefficient and logarithmically increased as the vertical distance increased and created a turning point at around U/U_{ref} = 1. In other words, within the boundary bayer height (BLH), the normalized vertical velocity is lower than the above BLH. However, the result reported by Ikegaya et al. [57] is slightly deviate compared to the other studies.

The similarity is not only in the vertical velocity profile. The lateral velocity deficit also shows a similar trend. Figure 17.4 compare the lateral velocity deficit (ΔU_n) profile reported by previous studies where the positive peak represents a maximum velocity deficit point.

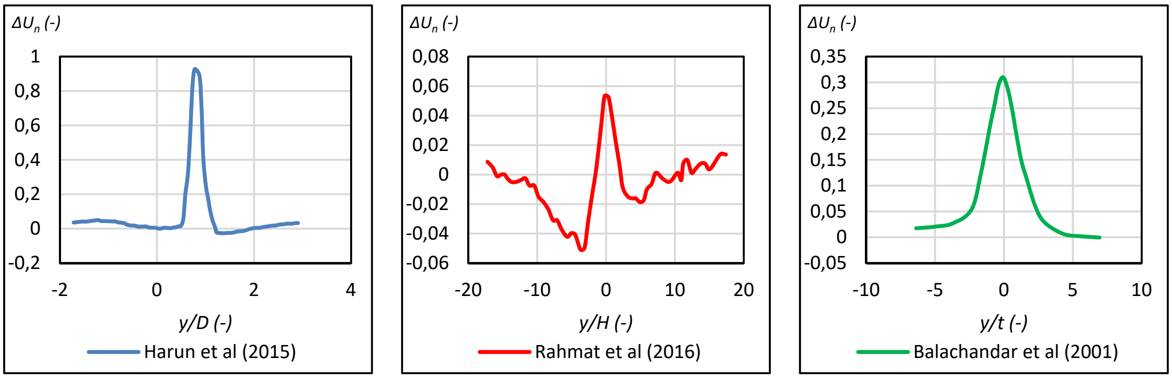

Figure 17.4 The lateral velocity deficit reported by Harun et al., Rahmat et al. , and Balachandar et al.

The lateral velocity deficit in Figure 17.4 was normalized differently based on each study case. For instant, Harun et al. [59] used the height of the Petronas Twin Tower (*D*) as the normalization value. The measurement of the lateral velocity profile was executed at streamwise distance of ($x_0=D$) and vertical distance of ($z=H$) where *H* is the height of the Petronas Twin Tower [59]. While Rahmat et al. [60] used the roughness element height (*H*) as the normalization value at $x_0=87.7H$ and vertical distance of $z=0.25\delta$ $(=1.4H)$. Moreover, Balachandar et al. [61] used the block thickness (*t*) as the normalization value at $x_0=5t$. Despite of the different normalization value, all of this data are comparable due to the similar trend of dimensionless lateral velocity deficit. The normalization value will only affect the scale of the velocity deficit in unit measurement.

Rahmat et al. [60] showed that there is a positive peak in lateral velocity deficit with a noticeable negative peak either before or after the positive peak.

Moreover, since the data was taken at the vertical distance of $z=0.25\delta$, which is very close to the surface wall, the graph is not smooth because the surface drag might be interfering. In addition, Balachandar et al. [61] did not observe any negative peak on the sides of the positive peak. Moreover, both Rahmat et al. [60] and Balachandar et al. [61] report that the velocity deficit is in the center of spanwise direction while Harun et al. [59] reported that the velocity deficit is slightly to the positive side of the spanwise direction.

This velocity deficit is very important because in some cases the velocity deficit can create a stagnation point where the velocity is very low that reduces the heat and mass transfer process significantly in the particular area as reported by Nagawkar et al. [62]. The author stated that bad city planning could create a stagnation point presented by a very low-pressure area with an almost zero wind velocity. This phenomenon leads to a UHI intensity increase [62]. Hence, it is very important to have a detailed understanding of aerodynamic interaction within the urban boundary layer, which governs the transport process of heat, moisture, and pollutants, in order to create a future green and sustainable city [63].

Furthermore, Rahmat et al. (2016) stated that the velocity deficit profiles within and above BHL are astoundingly different from each other [60]. Figure 17.5 shows the comparison between lateral velocity deficit profiles at height within the boundary layer ($z=0.25\delta$) and above boundary layer height ($z=20H$). Note: δ=BLH and H=roughness element height re-plotted based on [60].

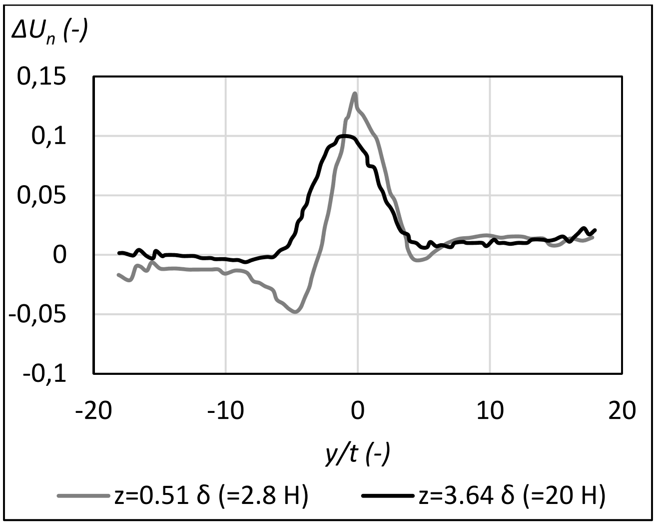

Figure 17.5 The comparison between lateral velocity deficit profiles at height within the boundary layer (*z=0.25δ*) and above boundary layer height (*z=20H*). Note: δ=BLH and *H*=roughness element height

Referring to Figure 17.5, it can be observed that the velocity deficit within the BLH is much more significant and the expansion of the wake width is much more compressed creating a long and sharp profile compared to that above boundary layer data [60].

17.6 Summary

UHI has been a worldwide major environmental issue. Numerous studies have investigated the factors that resulted in UHI. The main factor of UHI is the massive urbanization, which in turn, increases the need for decent living spaces and decreases the high albedo area due to the city expansion. Moreover, the need for energy increases as the population density increases and so does the anthropogenic heat waste. Skyscraper buildings were made to reduce the city size expansion and to preserve as many high albedo areas around the city as possible. However, this solution brings another problem to solve, the velocity deficit due to an obstacle. A well-planned city layout and building can reduce the velocity deficit and decrease the UHI effect in the city, which in turn, creates a better and healthier city to live in.

17.7 Acknowledgement

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References

[1] A. Mohajerani, J. Bakaric, and T. Jeffrey-Bailey, "The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete," *J. Environ. Manage.*, vol. 197, pp. 522–538, 2017, doi: 10.1016/j.jenvman.2017.03.095.

[2] A. De Bono, P. Peduzzi, S. Kluser, and G. Giuliani, "Early Warning on Emerging Environmental Threats: Impacts of summer 2003 heat wave in Europe," *United Nations Environment Programme*, Nairobi, Mar. 2004.

[3] J. Robine *et al.*, "Death toll exceeded 70,000 in Europe during the summer of 2003," *C. R. Biol.*, vol. 331, no. 2, pp. 171–178, Feb. 2008, doi: 10.1016/j.crvi.2007.12.001.

[4] T. R. Oke, "The energetic basis of the urban heat island," *Q. J. R. Meteorol. Soc.*, vol. 108, no. 455, pp. 1–24, Jan. 1982, doi: 10.1002/qj.49710845502.

[5] M. Mohan, Y. Kikegawa, B. R. Gurjar, S. Bhati, A. Kandya, and K. Ogawa, "Assessment of urban heat island intensities over delhi," in *The Seventh International Conference on Urban Climate*, 2009, no. July, pp.

3–6, [Online]. Available: https://www.academia.edu/download/41337034/Delhi-UHI.pdf.

[6] Y. H. Kim and J. J. Baik, "Maximum urban heat island intensity in Seoul," *J. Appl. Meteorol.*, vol. 41, no. 6, pp. 651–659, Jun. 2002, doi: 10.1175/1520-0450(2002)041<0651:MUHIII>2.0.CO;2.

[7] S. H. Lee and J. J. Baik, "Statistical and dynamical characteristics of the urban heat island intensity in Seoul," *Theor. Appl. Climatol.*, vol. 100, no. 1, pp. 227–237, Mar. 2010, doi: 10.1007/s00704-009-0247-1.

[8] Y. Hirano and T. Fujita, "Evaluation of the impact of the urban heat island on residential and commercial energy consumption in Tokyo," *Energy*, vol. 37, no. 1, pp. 371–383, Jan. 2012, doi: 10.1016/j.energy.2011.11.018.

[9] E. Vallar, J. Oliveros, M. C. Galvez, and G. Bagtasa, "Effect of the Urbanization of Metro Manila on the Climate of Selected Urban and Rural Areas using WRFV3 . 4 . 1," in *Proceedings of DLSU Research Congress*, 2015, vol. 3, pp. 1–6, [Online]. Available: https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/research-congress-proceedings/2015/SEE/012-SEE_Vallar_EA.pdf.

[10] L. P. Wong, H. Alias, N. Aghamohammadi, S. Aghazadeh, and N. M. Nik Sulaiman, "Urban heat island experience, control measures and health impact: A survey among working community in the city of Kuala Lumpur," *Sustain. Cities Soc.*, vol. 35, pp. 660–668, Nov. 2017, doi: 10.1016/j.scs.2017.09.026.

[11] Y. Xiong, S. Huang, F. Chen, H. Ye, C. Wang, and C. Zhu, "The Impacts of Rapid Urbanization on the Thermal Environment: A Remote Sensing Study of Guangzhou, South China," *Remote Sens.*, vol. 4, no. 7, pp. 2033–2056, Jul. 2012, doi: 10.3390/rs4072033.

[12] A. Aflaki *et al.*, “Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong,” *Cities*, vol. 62, pp. 131–145, Feb. 2017, doi: 10.1016/j.cities.2016.09.003.

[13] C. Sarrat, A. Lemonsu, V. Masson, and D. Guedalia, “Impact of urban heat island on regional atmospheric pollution,” *Atmos. Environ.*, vol. 40, no. 10, pp. 1743–1758, 2006, doi: 10.1016/j.atmosenv.2005.11.037.

[14] M. Kolokotroni and R. Giridharan, “Urban heat island intensity in London: An investigation of the impact of physical characteristics on changes in outdoor air temperature during summer,” *Sol. Energy*, vol. 82, no. 11, pp. 986–998, Nov. 2008, doi: 10.1016/j.solener.2008.05.004.

[15] R. Giridharan and M. Kolokotroni, “Urban heat island characteristics in London during winter,” *Sol. Energy*, vol. 83, no. 9, pp. 1668–1682, Sep. 2009, doi: 10.1016/j.solener.2009.06.007.

[16] S. I. Bohnenstengel, S. Evans, P. A. Clark, and S. E. Belcher, “Simulations of the London urban heat island,” *Q. J. R. Meteorol. Soc.*, vol. 137, no. 659, pp. 1625–1640, Jul. 2011, doi: 10.1002/qj.855.

[17] K. De Ridder *et al.*, “Urban Heat Island Intensification during Hot Spells—The Case of Paris during the Summer of 2003,” *Urban Sci.*, vol. 1, no. 1, p. 3, Nov. 2016, doi: 10.3390/urbansci1010003.

[18] A. S. Umezaki, F. N. D. Ribeiro, A. P. de Oliveira, J. Soares, and R. M. de Miranda, “Numerical characterization of spatial and temporal evolution of summer urban heat island intensity in São Paulo, Brazil,” *Urban Clim.*, vol. 32, no. January, p. 100615, Jun. 2020, doi: 10.1016/j.uclim.2020.100615.

[19] S. R. Gaffin *et al.*, “Variations in New York city’s urban heat island strength over time and space,” *Theor. Appl. Climatol.*, vol. 94, no. 1–2, pp. 1–11, Sep. 2008, doi: 10.1007/s00704-007-0368-3.

[20] S. D. Gedzelman *et al.*, "Mesoscale aspects of the Urban Heat Island around New York City," *Theor. Appl. Climatol.*, vol. 75, no. 1–2, pp. 29–42, Jun. 2003, doi: 10.1007/s00704-002-0724-2.

[21] M. Ballinas and V. L. Barradas, "The Urban Tree as a Tool to Mitigate the Urban Heat Island in Mexico City: A Simple Phenomenological Model," *J. Environ. Qual.*, vol. 45, no. 1, pp. 157–166, 2016, doi: 10.2134/jeq2015.01.0056.

[22] H. A. Effat and O. A. K. Hassan, "Change detection of urban heat islands and some related parameters using multi-temporal Landsat images; a case study for Cairo city, Egypt," *Urban Clim.*, vol. 10, no. P1, pp. 171–188, Dec. 2014, doi: 10.1016/j.uclim.2014.10.011.

[23] T. R. Oke, "The distinction between canopy and boundary-layer urban heat Islands," *Atmosphere (Basel).*, vol. 14, no. 4, pp. 268–277, 1976, doi: 10.1080/00046973.1976.9648422.

[24] T. Honjo, "Analysis of urban heat island movement and intensity in tokyo metropolitan area by amedas data," *J. Agric. Meteorol.*, vol. 75, no. 2, pp. 84–91, 2019, doi: 10.2480/agrmet.D-18-00026.

[25] A. Q. Ahmed, D. R. Ossen, E. Jamei, N. A. Manaf, I. Said, and M. H. Ahmad, "Urban surface temperature behaviour and heat island effect in a tropical planned city," *Theor. Appl. Climatol.*, vol. 119, no. 3–4, pp. 493–514, 2015, doi: 10.1007/s00704-014-1122-2.

[26] R. Priyadarsini and N. H. Wong, "An Investigation of the Urban Heat Island of Singapore," *An Investig. Urban Heat Isl. Singapore*, no. 1996, p. 192, 2007.

[27] D. Wolters and T. Brandsma, "Estimating the Urban Heat Island in Residential Areas in the Netherlands Using Observations by Weather Amateurs," *J. Appl. Meteorol. Climatol.*, vol. 51, no. 4, pp. 711–721,

2012, doi: 10.1175/JAMC-D-11-0135.1.

[28] G. J. Steeneveld, S. Koopmans, B. G. Heusinkveld, L. W. A. Van Hove, and A. A. M. Holtslag, “Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands,” *J. Geophys. Res. Atmos.*, vol. 116, no. 20, p. D20129, 2011, doi: 10.1029/2011JD015988.

[29] B. Zhou, D. Rybski, and J. P. Kropp, “On the statistics of urban heat island intensity,” *Geophys. Res. Lett.*, vol. 40, no. 20, pp. 5486–5491, 2013, doi: 10.1002/2013GL057320.

[30] M. L. Imhoff, P. Zhang, R. E. Wolfe, and L. Bounoua, “Remote sensing of the urban heat island effect across biomes in the continental USA,” *Remote Sens. Environ.*, vol. 114, no. 3, pp. 504–513, 2010, doi: 10.1016/j.rse.2009.10.008.

[31] I. S. M. Elsayed, “Effects of Population Density and Land Management on the Intensity of Urban Heat Islands: A Case Study on the City of Kuala Lumpur, Malaysia,” in *Application of Geographic Information Systems*, InTech, 2012, pp. 267–283.

[32] H. Akbari, M. Pomerantz, and H. Taha, “Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas,” *Sol. Energy*, vol. 70, no. 3, pp. 295–310, 2001.

[33] L. Doulos, M. Santamouris, and I. Livada, “Passive cooling of outdoor urban spaces . The role of materials,” *Sol. Energy*, vol. 77, pp. 231–249, 2004, doi: 10.1016/j.solener.2004.04.005.

[34] E. N. Adinna, E. I. Christian, and A. T. Okolie, “Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM,” *J. Geogr. Reg. Plan.*, vol. 2, no. 2, pp. 30–36, 2009.

[35] H. Taha, “Urban climates and heat islands: Albedo, evapotranspiration,

and anthropogenic heat," *Energy Build.*, vol. 25, no. 2, pp. 99–103, 1997, doi: 10.1016/s0378-7788(96)00999-1.

[36] C. Yavuzturk, K. Ksaibati, and A. D. Chiasson, "Assessment of Temperature Fluctuations in Asphalt Pavements Due to Thermal Environmental Conditions Using a Two-Dimensional, Transient Finite-Difference Approach," *J. Mater. Civ. Eng.*, vol. 17, no. 4, pp. 465–475, Aug. 2005, doi: 10.1061/(asce)0899-1561(2005)17:4(465).

[37] A. Synnefa, A. Dandou, M. Santamouris, M. Tombrou, and N. Soulakellis, "On the use of cool materials as a heat island mitigation strategy," *J. Appl. Meteorol. Climatol.*, vol. 47, no. 11, pp. 2846–2856, 2008, doi: 10.1175/2008JAMC1830.1.

[38] H. Takebayashi and M. Moriyama, "Study on surface heat budget of various pavements for urban heat island mitigation," *Adv. Mater. Sci. Eng.*, vol. 2012, 2012, doi: 10.1155/2012/523051.

[39] B. Stone, J. Hess, and H. Frunkin, "Urban Form and Extreme Heat Events : Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities ?," *Environ. Health Perspect.*, vol. 118, no. 10, pp. 1425–1428, 2010, doi: 10.1289/ehp.0901879.

[40] V. Masson, "Urban surface modeling and the meso-scale impact of cities," *Theor. Appl. Climatol.*, vol. 84, no. 1–3, pp. 35–45, 2006, doi: 10.1007/s00704-005-0142-3.

[41] R. Priyadarsini, W. N. Hien, and C. K. W. David, "Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island," *Sol. Energy*, vol. 82, pp. 727–745, 2008, doi: 10.1016/j.solener.2008.02.008.

[42] H. Chen, R. Ooka, H. Huang, and T. Tsuchiya, "Study on mitigation measures for outdoor thermal environment on present urban blocks in

Tokyo using coupled simulation," *Build. Environ.*, vol. 44, no. 11, pp. 2290–2299, 2009, doi: 10.1016/j.buildenv.2009.03.012.

[43] H. S. Park, "Features of the heat island in seoul and its surrounding cities," *Atmos. Environ.*, vol. 20, no. 10, pp. 1859–1866, Jan. 1986, doi: 10.1016/0004-6981(86)90326-4.

[44] N. Debbage and J. M. Shepherd, "The urban heat island effect and city contiguity," *Comput. Environ. Urban Syst.*, vol. 54, pp. 181–194, 2015, doi: 10.1016/j.compenvurbsys.2015.08.002.

[45] I. G. Hamilton, M. Davies, P. Steadman, A. Stone, I. Ridley, and S. Evans, "The significance of the anthropogenic heat emissions of London's buildings: A comparison against captured shortwave solar radiation," *Build. Environ.*, vol. 44, no. 4, pp. 807–817, 2009, doi: 10.1016/j.buildenv.2008.05.024.

[46] H. Fan and D. J. Sailor, "Modeling the impacts of anthropogenic heating on the urban climate of Philadelphia: A comparison of implementations in two PBL schemes," *Atmos. Environ.*, vol. 39, no. 1, pp. 73–84, 2005, doi: 10.1016/j.atmosenv.2004.09.031.

[47] R. Okwen, R. Pu, and J. Cunningham, "Remote sensing of temperature variations around major power plants as point sources of heat," *Int. J. Remote Sens.*, vol. 32, no. 13, pp. 3791–3805, 2011, doi: 10.1080/01431161003774723.

[48] D. Zhou, S. Zhao, S. Liu, L. Zhang, and C. Zhu, "Surface urban heat island in China's 32 major cities: Spatial patterns and drivers," *Remote Sens. Environ.*, vol. 152, pp. 51–61, 2014, doi: 10.1016/j.rse.2014.05.017.

[49] V. Cheng, E. Ng, C. Chan, and B. Givoni, "Outdoor thermal comfort study in a sub-tropical climate: A longitudinal study based in Hong

Kong," *Int. J. Biometeorol.*, vol. 56, no. 1, pp. 43–56, 2012, doi: 10.1007/s00484-010-0396-z.

[50] A. Hagishima, J. Tanimoto, K. Nagayama, and S. Meno, "Aerodynamic parameters of regular arrays of rectangular blocks with various geometries," *Boundary-Layer Meteorol.*, vol. 132, no. 2, pp. 315–337, 2009, doi: 10.1007/s10546-009-9403-5.

[51] S. A. Zaki, A. Hagishima, J. Tanimoto, and N. Ikegaya, "Aerodynamic Parameters of Urban Building Arrays with Random Geometries," *Boundary-Layer Meteorol.*, vol. 138, no. 1, pp. 99–120, 2011, doi: 10.1007/s10546-010-9551-7.

[52] S. Ahmad Zaki, A. Hagishima, and J. Tanimoto, "Experimental study of wind-induced ventilation in urban building of cube arrays with various layouts," *J. Wind Eng. Ind. Aerodyn.*, vol. 103, pp. 31–40, 2012, doi: 10.1016/j.jweia.2012.02.008.

[53] D. Jiang, W. Jiang, H. Liu, and J. Sun, "Systematic influence of different building spacing, height and layout on mean wind and turbulent characteristics within and over urban building arrays," *Wind Struct. An Int. J.*, vol. 11, no. 4, pp. 275–289, 2008, doi: 10.12989/was.2008.11.4.275.

[54] C. Yuan and E. Ng, "Building porosity for better urban ventilation in high-density cities - A computational parametric study," *Build. Environ.*, vol. 50, pp. 176–189, 2012, doi: 10.1016/j.buildenv.2011.10.023.

[55] A. Abd Razak, A. Hagishima, N. Ikegaya, and J. Tanimoto, "Analysis of airflow over building arrays for assessment of urban wind environment," *Build. Environ.*, vol. 59, pp. 56–65, 2013, doi: 10.1016/j.buildenv.2012.08.007.

[56] M. V. Volik and N. S. Orlova, "Testing a mathematical model of air

movement in a street canyon using the openfoam package," *Springer Geol.*, vol. I, pp. 43–50, 2020, doi: 10.1007/978-3-030-38177-6_6.

[57] N. Ikegaya, T. Okaze, H. Kikumoto, M. Imano, H. Ono, and Y. Tominaga, "Effect of the numerical viscosity on reproduction of mean and turbulent flow fields in the case of a 1:1:2 single block model," *J. Wind Eng. Ind. Aerodyn.*, vol. 191, pp. 279–296, 2019, doi: 10.1016/j.jweia.2019.06.013.

[58] N. Ikegaya, S. Morishige, Y. Matsukura, N. Onishi, and A. Hagishima, "Experimental study on the interaction between turbulent boundary layer and wake behind various types of two-dimensional cylinders," *J. Wind Eng. Ind. Aerodyn.*, vol. 204, no. September 2019, p. 104250, 2020, doi: 10.1016/j.jweia.2020.104250.

[59] Z. Harun, E. Reda, and S. Abdullah, "Large Eddy Simulation of the Wind Flow Over Skyscrapers," *Recent Adv. Mech. Mech. Eng.*, vol. 15, pp. 72–79, 2015, [Online]. Available: http://www.wseas.us/e-library/conferences/2015/Malaysia/MECH/MECH-10.pdf.

[60] N. A. Rahmat, A. Hagishima, and N. Ikegaya, "An experimental study on aerodynamic interaction between a boundary layer generated by a smooth and rough wall and a wake behind a spire," *Eng. Sci. Reports, Kyushu Univ.*, vol. 37, no. 2, pp. 19–26, 2016, [Online]. Available: https://api.lib.kyushu-u.ac.jp/opac_download_md/1560669/3724.pdf.

[61] M. F. Tachie and R. Balachandar, "Turbulent wakes of flat plates in shallow open channel flow," pp. 8–11, 2001.

[62] J. Nagawkar, S. Ghosh, R. Kataria, A. Nashit, and A. Deora, "Effect of sky scrapers on natural ventilation patterns and human comfort index in low-risebuildings - a CFD analysis over central Mumbai," *ARPN J. Eng. Appl. Sci.*, vol. 9, no. 3, pp. 293–295, 2014, [Online]. Available:

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1061.2403&rep=rep1&type=pdf.

[63] N. A. Rahmat, A. Hagishima, N. Ikegaya, and J. Tanimoto, "Experimental study on effect of spires on the lateral nonuniformity of mean flow in a wind tunnel," *Evergreen*, vol. 5, no. 1, pp. 1–15, Mar. 2018, doi: 10.5109/1929670.