Canyon effects in urban configurations: tropical context study

Lin Yola
Department of Urban Studies, School of Strategic and Global Studies, Universitas Indonesia, Jakarta, Indonesia
lin.yola@ui.ac.id

Abstract. The increase of the Urban Heat Island (UHI) is a continuing phenomenon in dense cities. Technically, the building of heat gain generated from modified solar radiation in tropical urban spaces requires the scientific solution. The investigation on the behavior of urban microclimate, especially solar radiation in the urban canyon, was comprehensively investigated by early urban energy studies. However, the solar radiation trapping effect as the behavior of solar radiation in different type of urban configurations is still unclear. This study, therefore, aims to investigate the impact of urban configurations on the solar radiation performance in Kuala Lumpur tropical context. By using ENVI-met V3.1, this study simulates four urban configurations situated in two scenarios of canyon directions; East-West and South-North. The results recorded that the short wave and long wave solar radiation varies in a different type of urban configurations. It concludes that besides the Sky View Factor (SVF) and Height to Width (H/W) aspect ratio, the direction of urban canyon towards the exposure of the source of solar radiation significantly influences the solar radiation trapping effect. This finding will be a significant reference to strategies for the urban configuration to improve the microclimate in the urban spaces and mitigating climate change.

Keywords: Canyon Effects, Urban Configurations, Urban Heat Island, Urban Microclimate, Solar Radiation

1. Introduction
The rapid urban development contributes to a positive impact on the economics of the countries [7], but a continuing pressure on environment protection. The globalization had created environmental change [12]. One of the environmental change consequences is climate change. Climate change is a real threat to the environment, as the global air temperature has increased up to 0.6 °C for the past century [9]. The construction of the built environment plays a vital role in this context, where the urban development contributes to the primary cause of global warming. The actual implication of this issue is the Urban Heat Island (UHI) phenomenon, where the night surface temperature in urban areas develops up to 5 - 6 °C compared to rural areas [8]. The UHI technically causes energy demand, thermal discomfort, air pollution, and health issue. Mainly, a UHI effect develops intensively in hot and humid region cities as it receives the maximum direct solar radiation. This situation could be seen from the phenomenon in Kuala Lumpur, where the UHI intensity in the year of 2004 increased 1.5 °C higher compared to year of 1985 [6].

The increase of the UHI intensity was formed by the diverse of the urban surface roughness, which in this context is identified as vertical obstruction. The emerge of the high-rise buildings and lacking of the open spaces in the dense cities cause the change of the short wave and long wave solar
radiation. The trapped and stored solar radiation within the urban spaces is the primary source of heat gain in urban areas [4]. The process of the radiation absorption and reflection effect within the urban spaces called ‘urban canyon effect’ was technically investigated by Oke T.R in the street canyon scenario [13]. The urban canyon effect closely stresses that the geometry of urban canyon results in a significant impact on the level of heat gain in urban spaces. Therefore, this study seeks to pinpoint the impact of urban configurations on solar radiation performance.

2. Solar radiation performance in urban canyon

As the source of heat energy, solar radiation is the most complex system in urban energy balance. Technically, the higher intensity of absorbed and stored radiation within the urban canyon spaces, the higher the air temperature increase [4]. Net radiation is the main factor distributing heat gain in urban spaces. Net solar radiation (Equation 1.1) is the sum of net short wave (K* = K↓ – K↑), the surface albedo (α), and the longwave (L* = L↓ – L↑) [5, 10, 13].

\[
Q^* = K_\downarrow - K_\uparrow + (1-\alpha) + L_\downarrow - L_\uparrow
\]

The Equation 1 presents that the net radiations include short wave radiation, long wave radiation, and albedo. Short wave radiation is defined as the reflected radiation influenced by the albedo and surface geometry. The longwave radiation is absorbed and reemitted downward from the surface [5,13]. In this context, the configuration of the urban spaces significantly influences the long wave radiation. This situation occurs due to the trapping effects that cause the failure to reflex the radiation flux to the atmosphere during the day. Therefore, this study analyses the performance of both short wave and longwave radiations in the urban configuration. The urban canyon effects strongly correlate with urban configuration and climate features, especially UHI intensity. Oke T.R pioneered this study from the 1970s [3]. The study emphasized that the maximum intensity of UHI, which occurs in the urban canyon is strongly influenced by the increase of Height to Width (H/W) aspect ratio and the reduction of Sky View Factor (SVF) value (Equation 2 and 3).

\[
\frac{dT_{max}}{dT_{max}} = 7.45 + 3.97 \times \ln (H/W)
\]

\[
\frac{dT_{max}}{dT_{max}} = 15.27 - 13.88 \times SVF
\]

The discussed study (Equation 2 and Equation 3) was performed in the urban canyon. This study, however, emphasized that Equation 2 and Equation 3 should be investigated in other non-canyon urban configurations. Urban canyon, besides street canyon, is widely applied as generic form of urban spaces. However, there are some other types of urban configurations in modern urban design, such as U, Courtyard, and Courtyard Canyon. Urban canyon, is defined as a linear space constrained on two sides by vertical obstructions like buildings [5]. Urban canyon features could be found in non-canyon urban configurations. This argument is the fundamental of this study to examine the solar radiation performance in four basic urban configurations; Courtyard, U, Courtyard Canyon, and Canyon. As those urban configurations physically set with different scenarios of vertical obstruction arrangement, this study further investigates the behavior of solar radiation in different types of urban configurations.

Besides the H/W aspect ratio and SVF value, the solar radiation performance in the canyon spaces also depends on the radiation sources. Specifically, the urban canyon direction, either parallel or perpendicular with the sun path, defines the modification of solar radiation in the canyon spaces. Studies [1, 2, 11] reported that East-West canyon direction generates a maximum solar radiation, while North-South is an effective approach to reduce maximum exposure to solar radiation. An earlier study also confirmed that the canyon direction impacts the direct and diffused solar radiation [15] but
weakens the urban wind [14]. Thus, to fulfill the findings, this study also examines the comparison of solar radiation performances in two scenarios of canyon directions; East-West and North-South.

3. Urban configuration simulation in residential area of Kuala Lumpur

This paper is one part of the significant study on the concept of the ‘Climatically Responsive Urban Configuration”. The scope of this paper includes the simulation of urban configurations, which examines the four urban configurations: Courtyard, U, Courtyard Canyon, and Canyon. Two case studies of high rise residential building blocks in Kuala Lumpur situates in Flat Bandar Tasik Selatan and Surya Magna. The existing building block is Courtyard Canyon. The canyon in Flat Bandar Tasik Selatan faces East-West while in Surya Magna faces South-North direction (Figure 1 and 2). The SVF of the urban configuration in Flat Bandar Tasik Selatan from the biggest to the smallest is; Canyon (0.676), Courtyard Canyon (0.438), U (0.39), and Courtyard (0.275). In Flat Surya Magna, the SVF are Canyon (0.793), Courtyard Canyon (0.707), U (0.694), and Courtyard (0.611). From this data, it is clear that the reduction in the SVF value was identified from the development of the building blocks’ vertical obstruction.

![Figure 1. Four Urban Configurations with Canyon Direction Facing East-West at Flat Bandar Tasik Selatan Site (highlighted in red)](image1)

![Figure 2. Four Urban Configurations with Canyon Direction Facing North-South at Flat Surya Magna (highlighted in red)](image2)
The simulation of the urban configurations uses ENVI-met V3.1, which investigates the short wave and long wave solar radiations. An early study [15] validated that ENVI-met V3.1 as numerical modeling is an effective and reliable approach to investigate the urban microclimate and thermal comfort. This study presents 24 hours of solar radiation data. In order to investigate the impact of urban configuration on the trapping effect, this study evaluates the mean of diurnal and nocturnal solar radiation. The urban configuration simulation was held on 21st June 2015. The ENVI-met configuration editor includes the physical and climate data, as follows:

- a. Albedo: 0.3 (wall) and 0.5 (roof)
- b. Initial temperature: 303.15 °K
- c. Indoor building temperature: 293 °K
- d. Wind: 1.4m/s speed, 225 or South-West to North-East direction
- e. Relative humidity: 83%
- f. Heat transmission: 1.94W/m²K (wall), 6W/m²K (roof)

The 250 x 250 x 30 setting was chosen as the output simulation section. Generally, the analyzed output data in this study were the 24 hours solar radiation data. The short wave solar radiation ranges from 7 am to 7 pm, while the long wave solar radiation data is derived from 7 pm to 7 am. The analysis of the results consists of the comparison of the short wave and longwave solar radiation trends in four urban configurations and the comparison between the solar radiation performances in two canyon directions; East-West and North-West.

4. Results discussion

This study presents the 24-hour solar radiation data, which was elaborated by both diurnal/short wave and nocturnal/long wave. Furthermore, a comparison of the two scenarios of canyon directions facing East-West and North-South further discusses the solar radiation trapping effects. In the East-West Canyon direction scenario at Flat Bandar Tasik Selatan, solar radiation recorded varied in each urban configuration. In this scenario, short wave radiation indicated widely ranging in different urban configurations (Figure 3). As sun altitude rises from 8 pm, the short wave develops mainly in Canyon configuration. There is a significant gap of short waves between 10 am to 1 pm, in urban configurations with and without canyon. While from 1 pm to 5 pm, the short wave consistently reaches the highest intensity (up to 1430 W/m²) in all urban configurations. Lastly, the longwave radiation is always low (450 W/m² and below) from 7 pm until 7 am.
Table 1 presents the mean of solar radiation in four urban configurations. Generally, the mean of solar radiation averagely presents a small gap between the four urban configurations, which ranges from 647.88 W/m² (Courtyard) to 828.84 W/m² (Canyon). The results show that the Canyon indicates the highest while the Courtyard indicates the lowest solar radiation. Both U and Courtyard Canyon configurations recorded low solar radiation due to the shadow effect from blocking vertical obstruction from the East-West direct solar radiation. In this context, the U configuration receives higher evening solar radiation.

Table 1: Mean of Solar Radiation in East-West Canyon Direction of Urban Configuration

| Urban Configuration        | Diurnal/Short Wave (W/m²) | Nocturnal/Long Wave (W/m²) | Mean (W/m²) | Remarks                                |
|---------------------------|----------------------------|-----------------------------|-------------|----------------------------------------|
| Courtyard (SVF: 0.275)    | 812.70                     | 483.06                      | 647.88      | Lowest radiation intensity, fully enclosed urban configuration that caused a shading effect |
| U (SVF: 0.309)            | 905.64                     | 483.99                      | 694.82      | The slightly high mean of solar radiation as the longwave radiation is high |
| Courtyard Canyon (SVF: 0.438) | 935.86                  | 453.67                      | 694.76      | High solar radiation, as the space is exposed to East and West solar radiation exposure. |
| Canyon (SVF: 0.676)       | 1204.90                    | 452.78                      | 828.84      | Highest intensity of solar radiation from East and West |

When canyon direction is facing South-North at Flat Surya Magna, the development trend of solar radiations is almost identical even though a gap was identified among the four urban configurations (Figure 4). In this context, Courtyard generates almost equal solar radiation performance with Canyon, as the two configurations set with a vertical obstruction that shades the...
spaces from East and West sources of radiation. The short wave solar radiation rises from 9 am and reaches the highest intensity at 1 pm (4350 W/m²). The solar radiation starts to reduce from 4 pm in all four configurations. The long wave radiation (7 pm to 7 am) remains constant in all urban configurations, with Courtyard Canyon leading with the highest intensity.

**Table 2: Mean of Solar Radiation in East-West Canyon Direction of Urban Configuration**

| Urban Configuration       | Diurnal (W/m²) | Nocturnal (W/m²) | Mean (W/m²) | Remarks                                                                 |
|--------------------------|----------------|------------------|-------------|-------------------------------------------------------------------------|
| Courtyard (SVF: 0.611)   | 998.49         | 495.10           | 746.79      | Low solar radiation, urban blocks shaded four cardinal directions from East-West solar exposure |
| U (SVF: 0.694)           | 2077.23        | 492.08           | 1284.66     | Exposed to North indirect solar exposure, it was significantly influenced by high June solar radiation |
| Courtyard Canyon (SVF: 0.707) | 3075.72       | 987.18           | 2031.45     | Enclosed but also partially exposed to North solar exposure             |
| Canyon (SVF: 0.793)      | 1005.82        | 485.40           | 745.61      | Lowest solar radiation, urban blocks shaded the open space from East and West solar exposure |
The comparison of the two scenarios of canyon directions (East-West and North-South) emphasized that the setting of urban configuration towards the source of solar radiation fundamentally impacts the solar radiation trapping effects. In the scenario of East-West canyon direction, the trapping effects indicated low, but the effect of direct East-West solar radiation exposure dominated the trend. This situation is indicated in the Canyon configuration as it is open to morning and evening radiation. Therefore, the Courtyard configuration performs the best performance of solar radiation as it shades the spaces from East-West direct solar radiation. Meanwhile, in the South-North canyon direction scenario, Canyon performs the lowest, and Courtyard Canyon performs the highest intensity of solar radiation. The influence of North direct radiation contributes to the significant development of solar radiation in Courtyard Canyon. In this context, the Courtyard configuration indicates better performance as it creates the shadow effects to the spaces. Canyon configuration, however, shows better solar radiation than Courtyard as it has the ventilation effect that releases the trapping effects in the spaces between the building blocks.

A. CONCLUSION

This study stresses that the solar radiation trapping effects in urban spaces found resulted in the setting of the urban configurations. The building blocks as vertical obstruction play roles of creating shadow effects and space boundaries in creating the solar radiation trapping effects. This study was performed in Kuala Lumpur, a tropical context dense city with high intensity of solar radiation and low urban wind. Therefore, the setting of Courtyard configuration mostly suits the Kuala Lumpur context as the building blocks physically shade the spaces between the buildings. Theoretically, the Courtyard Canyon would develop the solar radiation trapping effects as it is an enclosed configuration that would collect the heat gain. On the contrary, this situation does not fully apply as the urban wind is extremely slow in the city center of Kuala Lumpur. However, as Kuala Lumpur situates at 3°08’N, the results in this study were scientifically influenced by the North solar radiation. This situation is the essential background behind the lowest solar radiation performance indicated in Canyon configuration in South-North canyon direction.

The findings of this study could be applied to strategies for the alternatives of urban configurations in tropical contexts. When the canyon direction faces East-West, where the direct solar radiation is high in the morning and afternoon, the Courtyard configuration is recommended. Meanwhile, if the canyon faces the South-North, Canyon configuration would be the best alternative. This urban configuration strategy is a significant contribution for architects, urban planners, stakeholders, and policy-makers to achieve the concept of Climatically Responsive Urban Configuration in tropical context. In future, the investigation on the impact of urban configuration on other features of urban microclimates is highly recommended to further this study.
REFERENCES

[1] Algeciras, J. A. R., Consuegra, L. G., Pérez, M. C. et al (2016). Spatial-temporal Study on the Effects of Urban Street Configurations on Human Thermal Comfort in The World Heritage City of Camagüey-Cuba. Building and Environment. 101 (2016), 85-101.

[2] Ali-Toudert, F. and Mayer, H. (2006). Numerical Study on the Effects of Aspect Ratio and Orientation of an Urban Street Canyon on Outdoor Thermal Comfort in Hot and Dry Climate. Building and Environment. 41(2), 94-108.

[3] Arnfield, A. J. (2003). Two Decades of Urban Climate Research: A Review of Turbulence, Exchanges of Energy and Water, and The Urban Heat Island. Int. J. Climatology. 23, 1–26.

[4] Environmental Protection Agency (EPA). (2013). Reducing Urban Heat Islands: Compendium of Strategies, Urban Heat Island Basics. Climate Protection Partnership Division US.

[5] Erell, E., Pearlmutter, D., Wiliamson, T. (2011). Urban Microclimate: Designing the Spaces between Buildings. Earthscan.

[6] Elsayed, I. (2012). A study on the urban heat island of the city of Kuala Lumpur, Malaysia. Journal of King Abdulaziz University-Meteorology, Environment and Arid Land Agriculture Sciences, 23(2), 121–134. doi:10.4197/met.23-2-8.

[7] Fatwa, N., Sarita, B., Saenong, Z., et al (2016). The Influence of R & D Investment & Human Capital towards Indonesian economic Growth Rate to Address the ASEAN Economic Community. Scientific Research Journal (SCIRJ), Volume IV, Issue XI, ISSN 2201-2796.

[8] Lauwaet D., Hooyberghs H., Maiheu B., et al (2015). Detailed urban heat island projections for cities worldwide: dynamical downscaling CMIP5 global climate models, Climate, 3(2), 391-415.

[9] National Oceanic Atmosphere Administration (NOAA). (2016). Exploring climate events and human development- the past 100 years: the 20th century's human climate conundrum <www.ncdc.noaa.gov> accessed 25.08.2019.

[10] Newton, T., Oke, T.R., Grimmond, C. S. D., et al (2007). The Suburban Energy Balance in Miami, Florida. Journal compilation 2007 Swedish Society for Anthropology and Geography.

[11] Qaid, A. (2015). Asymmetrical Street Aspect Ratios and Sky View Factor Orientation on Urban Canyon Microclimates in Hot Humid Regions. Ph. D. thesis. Universiti Teknologi Malaysia.

[12] Tairas, D.R., Kadir, A.R., Muis, M., et al (2016). The Influence of Strategic Leadership and Dynamic Capabilities through Entrepreneurship Strategy and Operational Strategy in Improving the Competitive Advantage of Private Universities in Jakarta, Indonesia. Scientific Research Journal (Scirj). Volume IV, Issue II, February 2016 Edition. ISSN: 2201-2796.

[13] T. R. Oke. (1987). Boundary Layer Climates. New York: Routledge.

[14] Yola, L. and Siong, H.C. (2018). Impact of Urban Canyon Direction on Solar Radiation and Airflow in Hot and Humid. Asian Journal of Behavioural Studies, Vol 3, No 13 (2018). DOI: http://dx.doi.org/10.21834/ajbess.v3i13.146.

[15] Yola, L. and Siong, H.C. (2017). Computer Simulation as an Alternative Approach in Climatically Responsive Urban Configuration Study. Chemical Engineering Transactions, 56 (2017). pp 505-510 DOI: 10.3303/CET1756085. ISSN 2283-9216.

[16] Yola, L. and Siong, H.C. (2016). Solar Radiation and Urban Wind Effect on Urban Canyon in Hot, Humid Regions, Environment Behaviour Proceedings Journal (E-BPJ), V1n4, September 2016 (Pp. 220-229). DOI: http://dx.doi.org/10.21834/e-bpj.v1i4.384.