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ANALYZE THE URBAN ENERGY BALANCE OF DENSELY AREA JAKARTA USING SINGLE-LAYER URBAN CANOPY MODEL

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Graphical abstract

Abstract

Modification of surface and urban morphological changes, resulting in disruption of thermodynamic and dynamics properties in sub lowest layer of atmosphere, lead air temperature in downtown area higher than suburban. Study aims to analyze components of energy balance dense area of Jakarta using single-layer urban canopy model. H flux in solid area was dominant at noon. LE flux from dense area was very low Maximum intensity nocturnal heat island in dense areas was 2.5 °C. Higher value of *h*/*w*, S↓ received by wall and road decreases, causing H flux emitted by surface weakened. Instead L↑ emission trapped increases. The most dominant component that controls the balance of radiation and energy dense area are S↓ radiation, and H emission. Roof and road most active to respond heat during the day, and wall at night. Energy received or emitted by roof and road are greater than wall, due to shadowing effect. Surface temperature of urban areas is strongly influenced by local buildings configuration. Walls surfaces are less active emiting H at night for the *h*/*w* increasingly large. H emission from road surface decreases with increasing *h*/*w*. Increasing breadth of walls surfaces causing L↓ trapped in the canyon becomes higher, thus canyon temperatures remain high.

Keywords: Canyon aspect ratio, single-layer urban canopy, urban energy balance, urban morphology

1.0 INTRODUCTION

Urbanization led to increasingly densely city, extends up and stretched to the periphery. Land which has been built on the increase, and reduce the vegetated area. It is estimated that more than 70% of urban people will be crowded cities of the world, especially in Asia by 2050 [1], making the Asian region's fastest growing cities in the world [2]. Configuration dan geometry of urban buildings have changed urban landscape, creating more urban canyons with materials infrastructures are made of impermeable material, so easy absorb heat, that could potentially change radiative and thermal properties, and aerodynamic [3, 4, 5], leads to increased urban temperatures at downtown area through the "urban heat island" (UHI) effect. Studies of urban climate anomalies so far conducted generally in cities sub-tropical climates in industrialized countries, but very rarely performed in cities tropics, whereas tropical cities generally were facing high population growth [6]. Existing energy balance model calculates the heat conduction flux component on surface of snow-covered city. In tropical city, snow cover components need to be modified into a rain cover.

2.0 LITERATURE REVIEW

Urban climate studies related to the phenomenon of UHI has performed in many major cities in the world, both observations and modeling, among others [7] and [8]. It was found that the air temperature downtown area showed an increase compared with its suburbs area with the value varies according to geographical location of the city. Air temperatures in the downtown area Jakarta found differed by ± 0.8 °C compared with suburban areas [9]. A study has been conducted to study the effects of urbanization on temperature changes in the city of Jakarta using a numerical model MM5 [10].

Urban climate studies with modeling method using the principle of urban energy balance has evolved towards a quantitative model based on physical processes [11] and [12]. Single Layer Urban Canopy (SLUC) is a model of urban energy balance of the first using the smallest unit of urban systems, namely urban street canyon [13], [11], [14] and [15], then develop a scheme for the urban surface meso-scale atmospheric model uses concept of urban canyon geometry with parameterization of physics process which is relatively more complete [10]. The model was developed more realistic that taking into account the orientation canyon and variations in elevation angle of the sun [14].

Implementation of the model in tropical urban areas requires a slight modification in the energy balance prognostic equation. Modification of the energy balance equation enforceability tested at selected observation sites on solid business district of Jakarta.

3.0 METHODOLOGY

This study uses SLUC model that was introduced by Masson [11] and Kusaka *et al*. [14], developed by Olesson *et al*. [16] and Ryu *et al*. [17]. This physics-based models of urban areas (Figure 1) is the smallest unit of an urban system, consisting of two walls buildings surface with height *h*, flanking infinitely long road with width *w*, three surfaces; roof, road and wall [19, 14]. SLUC is coupling urban and atmospheric models, where the surface is treated as a single layer [17] through a single resistance between roof, road, walls and air [18]. Urban surface is the bottom boundary condition of the atmosphere model, which are driven by the atmospheric elements [16]. Evolution of roof, walls, and road temperature calculated based on the energy balance prognostic [11]

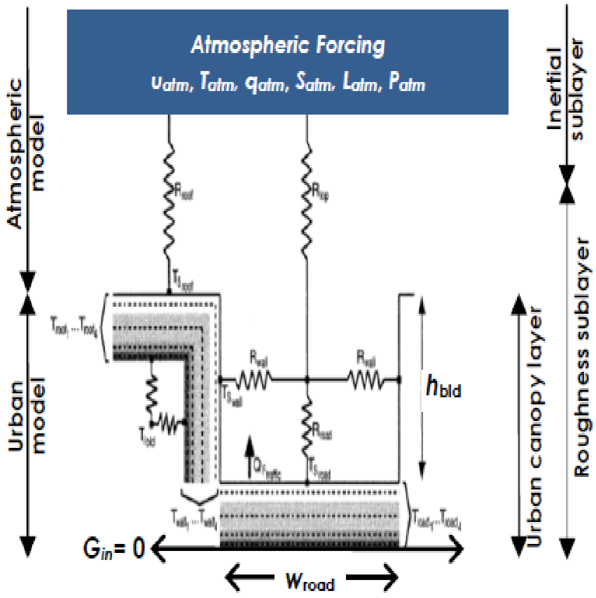
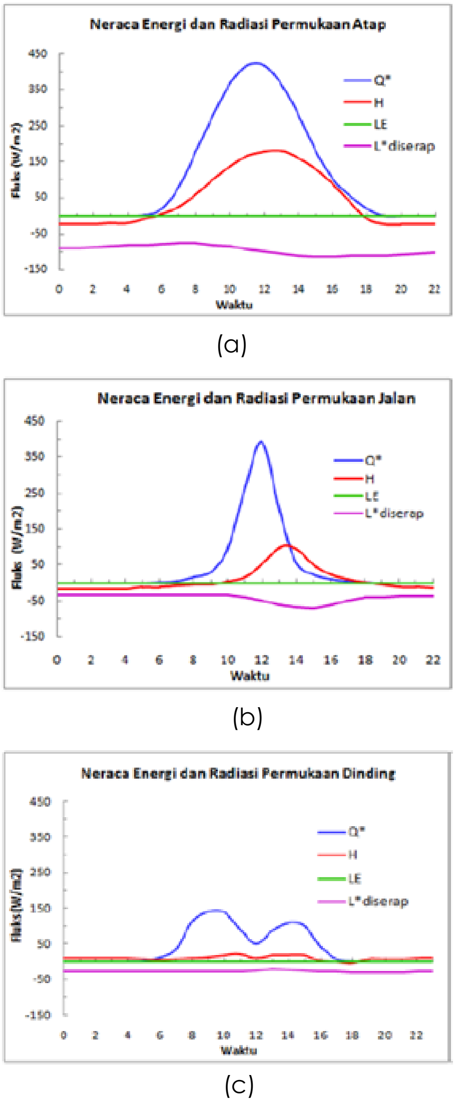


Figure 1 Scheme of coupling urban model and atmospheric model [11, 18, 19]

SLUC models run with atmospheric data at the reference height of 30 m, which are taken at two different locations (Figure 2) in summer with sampling frequency, is one hour. Data retrieval using the AWS. The instrument position at; point-1 (Pinangsia) 2 m above the road and 15 m above roof of 4-story building (15 m high); point-2 (Jagakarsa) 2 m above the grass. Canyon geometry data (building height and road width) taken at point-1. While the temperature of roof, walls and road and building material values of physical parameters was obtained from the literature.

4.0 RESULTS AND DISCUSSION

Diurnal variation of surface energy balance models shown in Figure 2. In morning-day transition period (5:00-13:00 pm) roof emit H positive earlier than road, up to a maximum of 12.00 pm. ends early afternoon although radiation intensity still relatively high. While road begin H positive phase at 12.00 pm. and ends at the evening and maximum at 14:00 pm. Road late receive optimal solar radiation due to the shadow



(a)

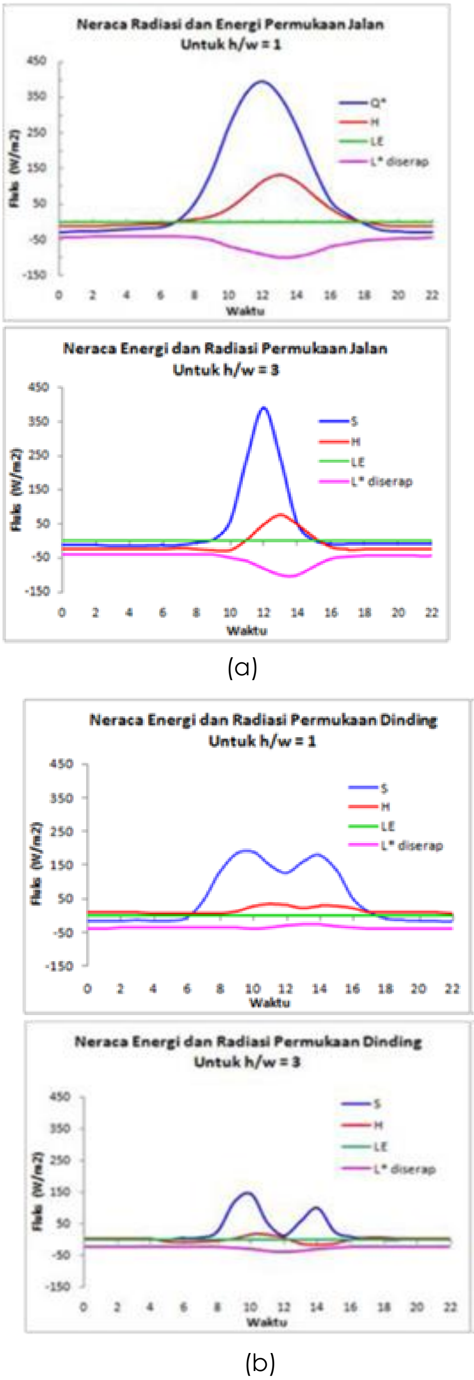
(b)

(c)

Figure 2 Diurnal variation of surface energy balance models for dense area; (a) roof, (b) road, and (c) wall at reference height

Effect of east wall (morning) and west wall (afternoon), cause the positive H period shorter than roof. In day-night transition period (13:00-18:00 pm) magnitude of net radiation decreased afternoon, the H emission from roof and road weakened, and can not keep a positive value of H until evening, probability due to increased air flow, or cloud cover (reducing emissions release of L↑) [20]. H emission from wall has strengthened evening, meaning that wall is more actively respond to heat [21].

Figure 3 shows the variation of energy and radiation balance component against *h*/*w* (canyon aspect ratio). L net radiation received by road and walls weakened by increase in value of *h*/*w*, causing L↑ trapped in the canyon strengthened (Figure 4a, b). The greater value of *h*/*w*, road surfaces receive S radiation is getting shorter, and H flux emitted is lower. This causes the emission flux L is trapped in the canyon is increasing (Figure 3a). H flux emitted by road for the *h*/*w* = 1 is maximum (115.68 Wm^{-2}) and for *h*/*w* = 3 is 75.95 Wm^{-2} (Figure 4a). Net radiation received by road of *h*/*w* = 1 is 363.74 Wm^{-2}, slightly above the *h*/*w* = 3 (392.60 Wm^{-2}). S radiation flux received by road surface is a maximum for the value of *h*/*w* small (Figure 3a).



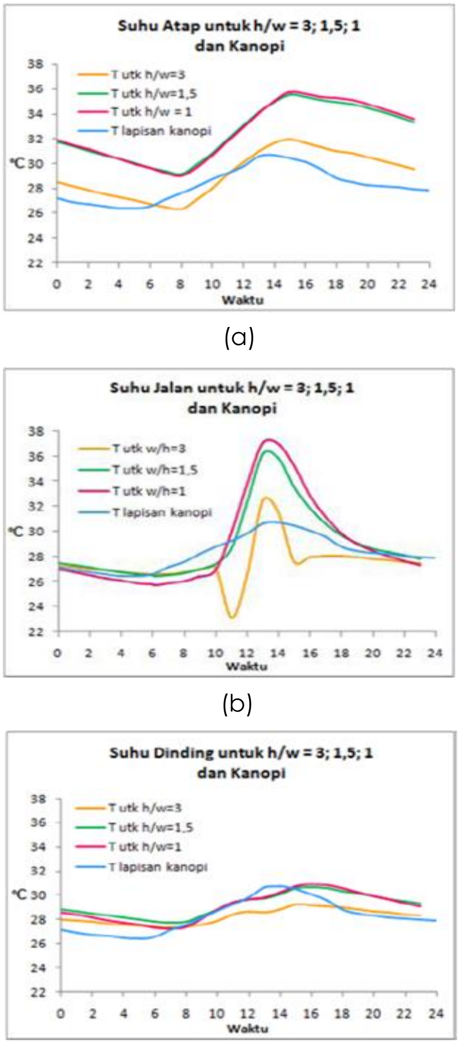
(a)

(b)

Figure 4 Diurnal variation of surface energy balance models (a) road, and (b) wall for the value of *h*/*w* = 1 and 3

L radiation received by walls is lower than road, because the sky view factor (SVF) road surface is small (Figure 3b). Seen that, the greater value of *h*/*w*, maximum duration of radiation S is getting shorter. This is due to influence of shadow (morning and evening) on both sides of walls. H flux emitted by walls to *h*/*w* = 1 is higher (35,00W.m^{-2}) compared to h/w = 3 (18.22 Wm^{-2}). H emission flux from walls to *h*/*w* = 3 looks weak in the evenings.

Figure 4a and b shows the higher temperature of roof and road surface by decreasing *h*/*w*. The hottest period of road surface temperature decreases with increase in the value of *h*/*w*. It is appropriate that shown in Figure 4b, that the greater value of *h*/*w* hence hottest period of road surface temperature decreases.



(a)

(b)

(c)

Figure 4 Diurnal variation of surface temperature; (a) roof, (b) road, and (c) wall for *h*/*w* = 3, 1.5 and 1, and temperature of canopy layer at a height of 30 m

So it shown here that the surface temperature of urban area greatly controlled by local configuration of the building. Variations in the temperature of the atmosphere layer always follow the pattern of surface temperature variations, not by changes in the value of *h*/*w* as the surface temperature.

Figure 5 is a graph of increase in the intensity of UHI dense area of Jakarta. Increased intensity of UHI seen happen with expressly after sunset (at 18:00 pm), reaching a peak at 02.00 am early days, and after that strength decreases gradually until late morning. The maximum value of temperature difference dense areas of Jakarta (Pinangsia) and suburbs (Jagakarsa) is 2.5 °C, Intensity gradually weaken as the warming of the surface of the city and suburban areas until equilibrium surface temperatures occurred before noon.

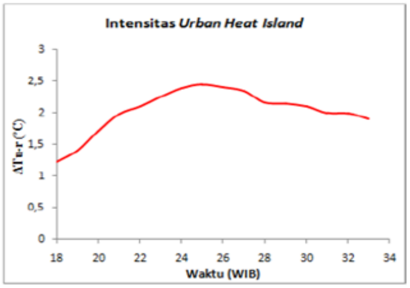


Figure 5 Night UHI intensity dense area of Jakarta

5.0 CONCLUSION

The conclusions for this research are as follows:

1. Radiation and energy balance in dense area of Jakarta are dominated by S↓ radiation, and H emission flux components during the day. While LE emission flux components from dense area is very low.
2. Roof and road surface are most active to respond heat during the day, and walls surfaces are at night. Energy received and emitted by roof and road are greater than walls.
3. The surface temperature of urban areas is strongly influenced by local configuration of building. Increasing breadth of walls surfaces causing L↓ trapped in the canyon becomes higher, so canyon temperatures remain high until early hours.
4. Walls surfaces are less active emiting H at night for the *h*/*w* increasingly large. H emission from road surface decreases with increasing *h*/*w*. H emission flux from roof surface increases due to influence of upper layer of canyon surface.
5. UHI intensity at night occurred early days with a maximum value of 2.5 °C. The reason is the difference in material properties and the geometry of building, complexity of the urban surface, thus increases the heat stored and long-wave radiation flux trapped in densly urban areas.

References

[1] United Nations, World Urbanization Prospects, The. 2009. Revision Population Database.

[2] Hung, T., Uchihama, D., S. Ochi and Y. Yasuoka. 2005. Assesment With Satellite Data Of The Urban Heat Island Effects In Asian Mega Cities. *Int. J. of App. Earth Observation and Geoinformation*. 10(96): 1-15.

[3] Trusilova, K. 2006. Urbanization Impact On The Climate In Europe. Ph.D Thesis Max Planck Institut Für Biogeochemie, Hamburg, ISSN 1615-7400.

[4] Offerle, B., Grimond, C. S. B., K. Fortuniak and W. Pawlak. 2006. Intraurban Differences Of Surface Energy Fluxes In A Central Europe City. *American Meteorological Society*. 45: 125-136.

[5] Souch, C., C. S. B. Grimmond. 2006. App. Climatology: Urban Climate. *Progress in Physical Geography*. 30(2): 270-279.

[6] Emmanuel, R. 2011. Urban Climate Design In The Equqtorial Megapolii: Key Challenges To Effective Adaptive Action. *Forum Patrimonio*. 4(1): 1-8.

~~[7]~~ Ichinose, T., K. Shimodozono, and K. Hanaki. 1999. Impact of Anthropogenic Heat On Urban Climate In Tokyo. *Atmospheric Environment*. 33: 389-3909.

[8] Chow, W. T. L., and M. Roth. 2006. Temporal Dynamics Of The Urban Heat Island Of Singapore. *Int. J. Climatol.* 26: 2243-2260.

[9] Mas'at A. 2008. Perubahan Suhu Udara DKI Jakarta Sebagai Efek Perkembangan Kota. *Bulletin Meteorologi Klimatologi dan Geofisika*. 4 (4): 392-404.

[10] Tokairin T., A. Sofyan, and T. Kitada. 2009. Numerical Study On Temperature Variation In The Jakarta Areas Due To Urbanization. *The Seventh International Conference on Urban Climate,* 29 June-3 July 2009. Yokohama, Japan.

[11] Masson, V. 2000. A Physical-Based Scheme For The Urban Energy Budget In Atmospheric Models. *Boundary-Layer Meteorol*. 94(3): 357-397.

[12] Best, M. J. 2005. Representing Urban Areas Within Operational Numerical Weather Prediction Models. *Bound. Layer Meteor*. 114: 91-109.

[13] Mills G. M. 1997. An Urban Canopy-Layer Climate Model. *Theoretical Applied Climatology*. 57: 229-244.

[14] Kusaka, H., Kondo, H., Y. Kikegawa and F. Kimura. 2001. A Simple Single-Layer Urban Canopy Model For Atmospheric Models. *Boundary-Layer Meteorology*. 101: 329-358.

[15] Nunez, M. and T. R. Oke. 1977. The Energy Of An Urban Canyon. *J. App. Meteorology*. 16: 11-19.

[16] Olesson, K. W., Bonan G. B., Feddema J. J., M. Verstenstein and C. S. B. Grimmond. 2008. An Urban Parameterization For A Global Climate Model. Part I: Formulation And Evaluation For Two Cities. *J. of App. Meteorology and Climatol*. 47: 1038-1060.

[17] Ryu, Y. H., J. J. Baik and S. H. Lee. 2011. A New Single-Layer Urban Canopy Model For Use In Mesosclae Atmospheric Models. *American Meteorological Society*. 50: 1173-1794.

[18] Lemonsu, A., C. S. B. Grimmond and V. Masson. 2003. Modelling the Surface Energy Balance Of The Core Of An Old Mediteranian Citiy: Marseile. *J. App. Meteorology*. 43: 312-327

[19] Olesson, K. W., Bonan, G. B., Fedema, J. J., M. Verteinsten and E. Kluzek. 2010. Technical Description Of Urban Parameterization for the Community Land Model (CLMU), Climate and Global Dynamics Division, National Center For Atmospheric Research, P.O. Box 3000 Boulder, Colorado (US) 80307-3000.

[20] Oke, T. R., Smith, R. A. S., E. Jauregui and C. S. B. Grimmond. 1999. The Energy Balance Of Mexico City During The Dry Season. *Atmospheric Environment*. 33(39):19-3930.

[21] Piringer, M., Grimmond, C. S. B., Joffre, S. M., Mestayer, P., Middleton, D. R., Rotach, M. W., Baklanov, A., de Ridder, K., Ferreira, J., Guilloteau, E., Karppinen, A., Martilli, A., V. Masson and M. Tombrou. 2002. Investigating The Surface Energy Ballance in Urban Areas-Recent Advance and Future Needs. *Water, Air, and Soil Pollution: Focus*. 2: 1-16.