Urban Heat Island towards Urban Climate

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Abstract. The urban heat island (UHI) is defined as the temperature difference between the urban and suburban areas and rural areas in the same region. Researchers have discussed several different techniques for evaluating the phenomenon. This paper reviews some of the causes and effects of urban heat islands, mainly on urban climate. Both directly and indirectly, the UHI influences multiple sectors. According to this, it is needed to develop a strategic mitigation between government and scientists to reduce the temperature.

1. Introduction
City - where the government and center of economic activity located- always attracts people to come. The growth of the urban area with the accompanying large population will require a larger area. Various problems will accompany rapid urban development. Many cities, especially megacities, are facing problem caused by urbanization [1]. United Nation in 2014 noted that urbanization is widely acknowledged to be on an upward trend. By 2050, 66% of the global population is expected to be living in cities. The largest urbanization is anticipated to be in Africa and Asia, where some countries are expected to experience more than a five-fold increase in urban population by 2050 [2]. A recent study in Bangkok shows that urbanization during period 1984-2013 as one significant factor affecting temperature rise [3]. Urbanization could change not only the mechanism of the energy balance on urban surfaces but also sea breeze system in large coastal cities [1,4]. Because of urban sprawl, Urban Heat Island (UHI) phenomenon expanded [1]. IPCC (Intergovernmental Planetary Climate Change) publishes a global temperature trend formed from local warming of UHI. The data compiled by Climatic Research Unit (CRU), UK Met. CRU and IPCC claimed that atmosphere is warming by 0.6 to 0.8°C since the 19th century [5].

2. Understanding Urban Heat Island
Urban Heat Island (UHI) is a phenomenon as “An Island” where the hot surface air is concentrated in urban areas and will progressively decrease in surrounding temperatures in suburban/rural areas (Figure 1) [5]. UHI phenomenon, regarding an ‘urban energy balance’ based on the analysis of incoming and outgoing energy flux from an urban surface system, had been explained [2]. The energy absorbed by this urban surface system from solar radiation and generated by anthropogenic activity is, therefore, physically balanced by warming the air above the surface (convection and radiation), the evaporation of moisture, and storage of heat in surface materials. The partitioning of this energy balance defines the nature of the urban climate, which in turn affects how cities use energy and the comfort and well-being of citizens. The formation of a UHI is dependent on several climatic processes. The phenomena occurring in either the Urban Boundary Layer (UBL) or the Urban Canopy Layer (UCL) can explain this formation. The UBL is governed by processes relevant to the mesoscale with the higher altitude
thermal inversion dominant during the daytime, while the latter by those at the microscale with the lower altitude inversion dominant during night-time (Figure 2).

Temporal dynamics study of the UHI in Singapore indicated that in the urban area the peak of UHI magnitude occurs between 3-4 hours (more than 6 hours in some areas) after sunset. Maximum intensity of UHI can reach ~7°C under ideal meteorological conditions. Generally, the highest intensity occurs during the southwest monsoon period (dry season) [3]. Whereas the lowest intensity occurs during the northeast monsoon (wet season). Then intermediate UHI intensities are measured during the inter-monsoon periods [6].

3. Modelling Urban Heat Island
There were various types of models to predict UHI. The application of different scale models in the UHI studies during 2013-2015 is explained clearly in the paper “Recent challenges in the modeling of urban
heat island”. The diversity of UHI models concerning the aim of the study is divided into 3 (three) categories, namely building scale models, micro-scale models, and city scale models. Then, based on study themes, the recent UHI modeling is categorized by 1) Urban ventilation and surface material alteration, 2) Health and comfort, 3) UHI spatial-temporal variation, 4) Model evaluation and enhancement, and 5) Future temperature forecast [7].

UHI model develops both deterministic and stochastic models. Datasets from the local weather station, mobile measurement stations, radar, and satellite thermal imagery are all used to support these models [1,5,7,8]. Amongst deterministic approaches, Airflow (i.e., Meso and micro-scale CFD) and energy balanced (i.e., UCM and BEM) models are applied at different scales [9–11]. In many scenarios, a multi-scale model combined with airflow and energy balanced models is developed to enhance the accuracy of the simulation [7,12]. On the other hand, statistical models such as artificial neural network (ANN) and regression methods are widely implemented to correlate the complex and large-scale characteristic of a city to the UHI [7,8].

Building and microclimate models have higher resolution in the urban canopy layer. However, they cannot spatially be extended to cover the entire area of a city due to the extensive computational cost and complexity of the parameters. Despite the capability of mesoscale models in the investigation of the large-scale effect of the UHI, their accuracy is not sufficient to provide details about the urban canopy layer. This gap thus requires further research to develop spatially and computationally efficient models [7].

4. Causes and Effect Urban Heat Island

UHI is caused by several factors that are distinguished between urban and non-urban areas. These factors include: the release of anthropogenic energy from air conditioning systems, energy emissions from industrial activities, motor vehicles, the ratio of the number of mixed surfaces, and the difference in heat capacity of building materials with natural structure [5]. Field verifications by Effat showed that most of the hotspots in urban areas spread over metal roofs, industrial buildings, warehouses, airport runways, railways, high-density parking lots and solid waste disposal sites. Almost all hotspots have scarce or lack of green areas. Surface temperature could rise to 1.2°C [1]. In the past few decades, the daily mean air temperature in Jakarta, one of the megacities in Asia, increased by approximately 1 K as an effect of land-use changes. Furthermore, the amount of heat advected into the city was estimated to increase from −0.7 Wm−2 in the 1970s to 77 Wm−2 in the 2000s. The sensible heat flux from the ground surface into the atmosphere contributed 44% for the estimated value in the 2000s [4].

Differences in the heat on some lands are due to variation in albedo [5]. Man-made structures such as roads and buildings typically have a lower albedo than natural surfaces and absorb more visible radiation. The urban surface tends to be hotter than the natural surface that holds water. Evaporation from water releases energy from the surface and cools the surface temperature. The urban surface rapidly releases water, which contradicts the natural surfaces such as vegetation that can hold water. Anthropogenic heat sources come from heating and ventilation systems, industrial processes and internal combustion engines. Energy consumption will produce heat as a product. Mather states that the solar radiation falling on the built area (asphalt, concrete) causes the surrounding air temperature becomes higher because the heat capacity of asphalt and concrete is lower than other types of surfaces [8]. Therefore, the higher the percentage of land area, the higher the surface temperature and the air temperature will be.

Effect of the UHI is a kind of urban heat accumulation phenomenon due to urban construction and human activities. It is recognized as the most obvious urban climate characteristic. Increased land surface temperatures caused by UHI effects will inevitably affect the flow of materials and energy flows in the urban ecological system, as well as altering their structure and function, providing a series of ecological and environmental effects on urban climates, urban hydrological situations, soil properties, atmospheric environments, biological habits, material cycles, energy metabolism and population health [13].
One of UHI effects is extreme weather. The temperature will be cooler in the cool season and hotter in the hot season. This is the most pronounced during the night time and the most intensive during the dry season. It begins to rise after sunset and reaches its maximum at about sunrise during 6-7 a.m. continues to decrease to the lowest magnitude around 3-6 pm [3].

UHI intensities play an important role in the production of UHI-initiated precipitation events. This event was more common in July than in another month, with a diurnal peak just after local midnight. Even, study in Atlanta, Georgia over the past decade shows that UHI could enhance and possibly to initiate thunderstorms. However, low-level moisture appears to be the most important factor for UHI-induced precipitation. Events tend to occur under more unstable atmospheric conditions than those on no-rainy days but not unstable enough to create widespread convection. Moist air masses tend to yield UHI-induced precipitation more frequently than dry air masses do [14]. Simulations by Baik showed that increased of the UHI intensity will decrease the time required for first cloud water (or rainwater) formation and horizontally closer to the center of the heater. In a less favorable thermodynamic state, a stronger dynamic forcing, which is a stronger downwind updraft cell, was needed to trigger moist convection for the same basic-state wind speed and heat island intensity [12].

Other potential factors such as land use differences between urban and surrounding areas are needed to be considered to explain the role of urban heat islands in urban-induced convection and precipitation. In particular, surface roughness changes can affect atmospheric circulation and as a consequence, the behavior of convection and precipitation is affected. In connection with the UHI-induced circulation, it is necessary to investigate the changes systematically. The boundary layer thermal stability differences can influence the circulation of heat island significantly. The difference in the effects of atmospheric thermal stability on UHI-induced convection and precipitation requires in-depth investigation. Current studies or similar studies are expected to provide some valuable insight into dynamics for more thorough understanding of urban-induced weather and climates in complex real situations [12].

UHI plays a significant role in residential energy use, directly and indirectly. UHI has an association with the air conditioning equipment and increases monthly electricity bill [3]. The increase of air conditioning then will impact the waste of electric energy and pollution, and leads to the greenhouse effect. The use of electricity will increase sulfur dioxide emissions, carbon monoxide, nitrous oxides, carbon dioxide, known as greenhouse gases that will contribute to global warming and climate change. Furthermore, the heat island in the dry season will accelerate the formation of hazardous fog, such as nitrous oxides (NOx) and volatile organic compounds (VOCs) that react with photochemistry to produce ozone on the surface [5].

The different urban form has the significant effect on the urban microclimate and outdoor thermal effect. Compared to urban geometry; massive building area is not the main reason to affect the urban micro-climate. The average building height offered enough urban shading which is an important factor that impacts the value of temperature. Normally, courtyard building model can provide better outdoor thermal comfort, but a simulation showed that the distance between the buildings plays more important role than the building type [11]. The combination of other site-specific factors such as green space amount, anthropogenic heat, and distance to water bodies is recommended to explain the differences in intra-urban UHI intensities than meteorological conditions [7].

5. Adaptation and Mitigation

Analysis of land cover and land use that overlaid with the surface temperature distribution have seen that the built area contributing to the increase in surface temperature [8]. Due to the existence of this problem, it is necessary to arrange better development planning in urban areas, and the balance between economic, social and ecological. Sustainable development in the city is strongly associated with spatial planning. Biesbroek et al. stated that the approach at an administrative level, which is related to the spatial structure, is very effective in mitigating and adapting to climate change and warming. Spatial development planning, which controls the growth of the built area and adds green open spaces, will create a comfortable and friendly urban environment.
Adaptation strategies of the UHI phenomenon are to control the increase in built-up land area and the development of tall buildings along the coast, and to develop green and blue open spaces. Areas of high surface temperatures are a priority for the development of those space. Areas that do not enable the development of urban forest spread and clustered form can be developed by the urban forest-shaped path, garden or roof garden city. There is also an idea of developing a corridor that can throw and dilute air pollutants to the coastal and marine areas to reduce air stagnation as another mitigation action.

Later analysis points out that evapotranspiration-based green and blue space cooling effects are particularly relevant for conditions in the urban canopy layer [2]. In addition, when it is most needed, the tree-dominated green space provides the greatest heat-stress suppressor. However, the size, spread, and geometry of green spaces- with some large solitary parks found to offer a minimum cooling of boundary layer- affect the magnitude and transport of cooling experienced. Increased of green space surface roughness leads mainly to the contributing of cooling at the urban-boundary layer climate scale, and thereby, improving the efficiency of convection rather than evaporation. Nocturnal warming is highlighted during the most severe conditions even though the blue space cooling and transport during the day can be substantial. However, both of these features can offer many synergistic ecosystem benefits including cooling down when they work together [2].

To improve the thermal environment around buildings and mitigate UHI, it is suggested to use the material of lower absorptivity, higher reflectivity, and larger thermal conductivity [10]. Other than that, for the top-floor residential units can apply cool paint and roof ventilation. Both of them are highly energy efficient and cost-effective in a tropical climate [15]. Furthermore, study by Hu shows that it is workable to mitigate UHI through manipulating urban form based on SVF (Sky View Factor). SVF indicates significant potential for optimum urban form modeling to explain urban planning and design decision-making dealing with UHI while maintaining development outcomes [16]. SVF shows significant potential for optimum urban shape modeling to explain urban planning and UHI decision-making design while maintaining development outcomes.

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