The Influence of Surface Ground Material on the Outdoor Thermal Value

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Abstract. The provision of open space in the building for educational purposes such as university is mandatory to ensure the balance between the buildings and the environment. Besides, the availability of open space in construction projects, particularly architecture, is also listed as one of the requirements that must be included when applying for a building permit. What is more, besides its functional factor, open space planning is expected to enhance campus aesthetics. The strategy in choosing the proper material for covering open areas in the tropical climate country is still challenging. It holds a significant contribution to reducing the effect of urban heat island phenomena. This article discusses the impact of changing surface ground materials on the site radiation of an open space called “lapangan lilin,” located in Atma Jaya University, Yogyakarta, Indonesia. The research incorporated computer simulation methods, ENVI-met, to compare several types of materials and their effects on the environment. The result shows that of the four types of materials that being compared (paving, soil, asphalt, and grass), the soil material gives the best outdoor thermal value impact compared to other materials.

1. Introduction

Climate change, which also leads to global warming, indirectly affects the comfort level in the outdoor space. One of the causes of this condition is the massive development in the city center, a lot of land cover change, which affects the weather and climate in the city and creates the UHI (Urban Heat Island) effect [1]. Another cause is infrastructure development in the transportation sector, which indirectly contributes to the acceleration of climate change [2]. Urbanization and excess energy consumption are also predicted to increase further the temperature difference in urban and rural areas, which could have as dangerous an impact as the increased CO2 levels in some areas [3]. For this reason, planning for open space in urban areas that accommodate the activities of its residents is very important for the quality of life [4].

Thermal comfort is a very complex parameter and can be unlimited in arranging aspects for measurement [5]. Although PET (Physiologically Equivalent Temperature) is the model most often used in studying thermal comfort [6], the PET index of cold and hot climate areas can be different when determining a comfortable temperature [7]. This is possible because thermal comfort can also be influenced by the psychological side of the behavior and personal experiences of each person who
lives in the area [8]. Even in another study, which uses the SET (Standard Effective Temperature) index to measure comfort level, it was found that the thermal environment can also be influenced by the elements available in an open space [9]. Therefore, the factors that affect thermal comfort can be seen from various points of view to determine whether the open area is categorized as comfortable or not, including the selection of surface covering materials in open spaces.

The use of the ENVI-met program to simulate thermal comforts, such as the pedestrian design in the street corridors in downtown Phoenix USA [10], vegetation design, and its effect on the microclimate [11], can provide an overview of the impact resulting from various possible design alternatives. The simulation results like this are expected to be able to provide consideration in terms of thermal comfort as a complement to other factors to produce the best decision.

This article discusses the impact of changing surface ground materials on the site radiation of an open space called “lapangan lilin,” located in Atma Jaya University, Yogyakarta, Indonesia. The research incorporated computer simulation methods to compare several types of materials and their effects on the environment. ENVI-met, a software used to simulate sustainable living conditions in a changing environment, has been used to collect site radiation data. The results of this research can be used as consideration for campus management and as decisions making support for further campus area development.

2. Method

The method applied in this research is a simulation method using the ENVI-met program, a program that helps building, landscape, and urban designers to consider the microclimate in their design ideas. This program can also assist in improving the planning of an area to get better microclimate results. ENVI-met is a three-dimensional microclimate model designed to simulate the types of fronts, plants, and air interactions in urban environments with a typical resolution of 0.5-10m. in space and 10 seconds on time. Model simulation in the ENVI-met program is based on the basic laws of fluid dynamics and thermodynamics. Simulation models include flow around and between buildings, heat and steam exchange processes on the ground and walls, turbulence, exchange of vegetation and vegetation parameters, bioclimatology, and particle disperse (figure 1).

Before conducting simulations related to existing conditions, a survey must first be carried out to obtain vegetation layout data. There are five types of typology from the vegetation layout: less than 5 meters high with a dense crown; 10 meters high with a light canopy; 10 meters high with a medium crown; 10 meters high with a solid canopy; more than 15 meters tall with solid canopy. The classification of the tree canopy is based on how many percentages of sunlight that the tree can block.

- a. Light; < 40%
- b. Medium; 40-70%
- c. Solid; > 70%

![Figure 1. Research Method](image)
From the results of the field survey, it was found that shade trees with dense crowns dominated the existing vegetation. There is also some vegetation with medium and light crowns that serve as aesthetic plants. The data needed besides vegetation to simulate in the initial conditions is the type of ground cover (pavement) and the height of the building. The ground cover is dominated by concrete block paving, and there are grass block pavers at several points on the campus. The building around the observation site has a height of 4 floors. From this collected data, it is then entered as basic data in the ENVI-met software.

In addition to existing data, data on regional climatic conditions are also needed as input for simulations such as temperature (temperature), humidity, and air velocity data. Based on secondary data obtained from the BMKG Yogyakarta climatology station, it is known that the average temperature in Yogyakarta for one year (2019) is 28°C, and the average humidity is 60%. The wind generally blows in the direction of 220°, namely to the southwest, air velocity of 3 m/s at an altitude of 10 m from the ground.

Figure 2. Existing Condition

The existing data and secondary data are then entered into the ENVI-met software to carry out the simulation process. The results of the ENVI-met calculation will be in the form of images and graph tables of the specified hours for data analysis.

According to SNI T14-1993-03, the minimum or maximum temperature of the simulation results in the observation area is not included in the category of air temperature that is comfortable for humans (29.26°C - 29.59°C). From the simulation results, it will also be known whether the design of the open area in the observed area will have a better impact on the level of human comfort in the area.

3. Result
The focus of observing the effect of the pavement material will be on the “lapangan lilin” plaza. As a comparison, observations were made with some different groundcover materials and the influence of other elements around the pavement area. Measurement of air temperature at plaza ranges from 27.61°C - 28.95°C. Compared with other areas, which have different material ranges from 0.1°C - 1.35°C. The plaza has a temperature that tends to be high when compared to other areas because of the large surface area of the pavement material. It is not protected by vegetation and has a material composition with a low albedo value (grey concrete pavement block). Other zones have lower temperatures due to the variety of surface materials, and there are other elements, such as the shading of buildings and vegetation, which make heat absorption by surface materials lower.

3.1. Concrete Paving Block
Regarding heat absorption by the material, in general, the Mean Radiant Temperature (MRT) in the plaza is above 72.04°C. This value is the highest value among the other zones. In line with the resulting temperature value, the high MRT value is due to the plaza having a grey concrete ground
cover (pavement) and a large area. The ratio between points exposed to direct sunlight and not exposed to direct sunlight is 36.5°C at the highest temperature (figure 3). This variation in value is also observed in areas covered by trees or shading by surrounding buildings. This difference occurs due to variations in the vegetation shading points plaza.

The relative humidity is lower at the plaza because the heat generated by the ground cover (pavement) in the plaza results in higher temperatures, which results in reduced water vapor (figure 4a). Wind, the moving air, will affect the level of humidity. This is because the air movement will carry heat and humidity (water vapor). The area that is directly under the vegetation has higher relative humidity due to the evaporation process of the vegetation.

The simulation results of the wind speed performed show that each point at the plaza has almost the same wind speed. The wind speed in the observed zone has a low value (figure 4b). With a low value, it causes the heat and humidity in the observation zone to be stuck in this zone longer because it is not carried away by the wind. On the other hand, the building that covers the observed outdoor area, a four stories building, causes the wind speed to be restrained low, which can be caused by the building that can make the air turn.

3.2 Soil surface, Grass, and Asphalt as Plaza Ground Cover Material
Several simulations were carried out by replacing the ground cover material in the plaza to compare the results of thermal values with the existing plaza conditions. The first one used soil to replace the existing material, concrete pavement. It can be seen from the simulation results that this material change shows a lower MRT value. The Mean Radiant Temperature (MRT) in the plaza is 58.58 to 68.64°C (figure 5). Soil material has a high albedo that is able to reflect more solar radiation. Soil surface also affects the conditions around the plaza, which also has a lower MRT value due to the size of the plaza area. The second material uses grass as a ground cover material on the plaza. The use of grass as a ground cover material on the plaza shows that the MRT value is slightly higher (figure 6) than the use of soil as a ground cover material in the plaza with a range of 0.07 to 10.1. Grass material has characteristics similar to soil. However, because plants also need the sun for photosynthesis, they absorb more solar radiation than soil. Interestingly, asphalt material gives a similar result with the grass, both for temperature and MRT (figure 7).
Changing the material on the plaza with the soil makes the humidity in the plaza area higher than the existing material (figure 8). The difference in humidity with the existing conditions is around 15.48%. This happens because the soil material can absorb water, which then when exposed to the heat of the sun, can make more water vapor in the air. Grass material gives results that are almost like soil because, in the grass material, there is an evapotranspiration process that can release moisture and increase moisture (figure 9). In comparison, the asphalt material provides a lower moisture value and is even lower than the existing pavement material (figure 10). This is due to the nature of the asphalt material, which absorbs heat higher than pavement with a lower albedo value.
The simulations on the three materials show that the wind speeds inside the plaza are almost the same. This is because there are tall buildings that cover the plaza so that the moving wind cannot pass through the plaza. This condition is almost like the simulation of the existing conditions in the plaza.

4. Discussion

From the analysis conducted, it is known that the type of ground surface material will influence the surface temperature of the material and the temperature of the surrounding air. From the simulation results, this material change shows a lower Temperature and MRT value. The Mean Radiant Temperature (MRT) in the plaza is 58.58 to 68.64°C. Soil material has a high albedo, so that it is able to reflect more solar radiation. This also affects the conditions around the plaza, which also has a lower MRT value due to the size of the plaza area. Changing the material on the plaza with the soil makes the humidity in the plaza area higher. The difference in humidity with the existing conditions is around 15.48%. This happens because the soil material can absorb water, which then when exposed to the heat of the sun, can make more water vapor in the air. Grass material gives results that are almost like soil because in the grass material, there is an evapotranspiration process that can release moisture and increase moisture. The simulations on the three materials show that the wind speeds inside the plaza are almost the same. This is because there are tall buildings that cover the plaza so that the moving wind cannot pass through the plaza.
However, there are studies that provide data that the use of stone tile material does not really affect changes in temperature around the house [12]. This is possible because the observed area is not too large and gets a lot of development from buildings and trees. In studies with a larger area, changes in ground cover material can have an impact on changes in air temperature and wind speed but do not have a significant impact on air humidity. [13]. Therefore, in addition to choosing the type of ground surface material, it is necessary to consider the area of the open area that is protected by shadows of buildings and trees in analyzing thermal comfort. In addition, the building configuration also seems to have an important role in creating thermal comfort because it can direct the wind. The linear configuration of the building allows for better distribution of the outside wind [14]. This is in accordance with previous research, which states that thermal comfort is influenced by building height, building configuration, and floor covering materials [15]. However, this can be different for an area scale, where the irregular arrangement of buildings and variations in building height can actually encourage the creation of wind movements, especially if there are tall buildings or towers in the area [16].

5. Conclusion
This paper investigates the changing of surface ground material in “Lapangan lilin,” a plaza in University Atma Jaya Yogyakarta campus, Indonesia. Several materials such as asphalt, grass, and soil have been simulated to see their impact on surface temperature, humidity, and wind speed using simulation engine ENVI-met. Regardless of the value of each material, it can be concluded that the outdoor thermal comfort is influenced by the temperature that occurs in the area. The choice of the ground material surface has different impacts on its temperature, relative humidity, and wind speed of the simulated site.

From the results, in terms of temperature, asphalts perform lower temperature, and the two other materials, soil, and grass state lightly higher temperature. However, the three material, in general, has performed lower temperature that the existing material (concrete pavement). Similarly, the three compared materials show lower value in terms of wind speed. On the opposite, in terms of relative humidity, the three materials besides the concrete stated a slightly higher value than the existing ones.

In determining the outdoor thermal value, it cannot be only from the surface covering material. There are other factors in the role. Therefore, with the simulation, we can see and adjust the parameters in the analysis process. With the same conditions but different types of material, it will be known the effect on one element or component. More than that, to create a sense of comfort, apart from outdoor thermal value, there are other factors that need to be considered, such as human psychological aspects. There are still many opportunities for simulations/trials and further research in the future.

The simulation helps us determine and predict the phenomena in the built environment, particularly the relation of the site or buildings and its environment, in order to respond to the microclimate. There are many attributes that can make an impact on thermal comfort, not only the physical characteristic of the urban forms and material covering the surface, but also the attributes that are embodied in the human, such as clothing and metabolism. However, from the simulation carried out in this research, the three different materials that have been simulated in order to see the environmental impact compared to the existing, have shown valuable information. It is proven that in a simple setting, only
different types of material can improve the thermal condition of the site. Furthermore, the information obtained from this research can be a reference in deciding the ground surface materials.

References

[1] L. Tursllowati, “PULAU PANAS PERKOTAAN AKIBAT PERUBAHAN TATA GUNA DAN PENUTUP LAHAN DI BANDUNG DAN BOGOR,” J. Sains Dirgant., vol. 3, no. 1, pp. 43–64, 2005.

[2] P. White, J. S. Golden, K. P. Biligiri, and K. Kaloush, “Modeling climate change impacts of pavement production and construction,” Resour. Conserv. Recycl., vol. 54, no. 11, pp. 776–782, 2010, doi: 10.1016/j.resconrec.2009.12.007.

[3] M. P. McCarthy, M. J. Best, and R. A. Betts, “Climate change in cities due to global warming and urban effects,” Geophys. Res. Lett., vol. 37, no. 9, pp. 1–5, 2010, doi: 10.1029/2010GL042845.

[4] L. Chen and E. Ng, “Outdoor thermal comfort and outdoor activities: A review of research in the past decade,” Cities, vol. 29, no. 2, pp. 118–125, 2012, doi: 10.1016/j.cities.2011.08.006.

[5] R. F. Rupp, N. G. Vásquez, and R. Lamberts, “A review of human thermal comfort in the built environment,” Energy Build., vol. 105, pp. 178–205, 2015, doi: 10.1016/j.enbuild.2015.07.047.

[6] S. Coccoio, J. Kämpf, J. L. Scartezzini, and D. Pearlmutter, “Outdoor human comfort and thermal stress: A comprehensive review on models and standards,” Urban Clim., vol. 18, pp. 33–57, 2016, doi: 10.1016/j.uclim.2016.08.004.

[7] O. Potchter, P. Cohen, T. P. Lin, and A. Matzarakis, “Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification,” Sci. Total Environ., vol. 631–632, pp. 390–406, 2018, doi: 10.1016/j.scitotenv.2018.02.276.

[8] T. P. Lin, K. T. Tsai, C. C. Liao, and Y. C. Huang, “Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types,” Build. Environ., vol. 59, pp. 599–611, 2013, doi: 10.1016/j.buildenv.2012.10.005.

[9] T. Xi, Q. Li, A. Mochida, and Q. Meng, “Study on the outdoor thermal environment and thermal comfort around campus clusters in subtropical urban areas,” Build. Environ., vol. 52, no. July 2007, pp. 162–170, 2012, doi: 10.1016/j.buildenv.2011.11.006.

[10] A. Rosheidat, D. Hoffman, and H. Bryan, “Visualizing Pedestrian Comfort Using Envi-Met,” in SimBuild 2008, 2008, pp. 198–205.

[11] K. Perini, A. Chokhachian, S. Dong, and T. Auer, “Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper,” Energy Build., vol. 152, pp. 373–384, 2017, doi: 10.1016/j.enbuild.2017.07.061.

[12] Y. K. D. Mahendra and S. Y. Amijaya, “PENGARUH PENGGUNAAN MATERIAL TEGEL BATU TERHADAP SUHU LINGKUNGAN RUANG KOTA LASEM,” in SMART #2 - Seminar on Architecture Research & Technology, 2017, pp. 105–111.

[13] C. N. Octarino and Y. S. Raniasta, “PENGARUH PEMILIHAN MATERIAL PENUTUP TANAH TERHADAP KONDISI TERMAL LINGKUNGAN,” in Prosiding Seminar Hasil Penelitian bagi Civitas Akademika UKDW, 2017, pp. 130–141.

[14] E. Susanti and D. P. Damayanti, “Analisis Komparasi Kinerja Termal Ruang Luar terhadap Ragam Tipe Pekarangan (Natah) pada Permukiman Tradisional di Provinsi Bali,” J. Lingkung. Binaan Indones., vol. 8, no. 2, pp. 103–108, Jun. 2019, doi: 10.32315/jbli.8.2.103.

[15] T. M. Aziz Soelaiman, W. K. Soedarsono, and M. Donny Koerniawan, “The Study of Thermal Comfort in Transforming Residential Area in Bandung using ENVI-met Software. Case Study: Progo Street,” in IOP Conference Series: Earth and Environmental Science, Jun. 2018, vol. 152, no. 1, doi: 10.1088/1755-1315/152/1/012036.

[16] E. Johansson and R. Emmanuel, “The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka,” Int. J. Biometeorol., vol. 51, no. 2, pp. 119–133, 2006, doi: 10.1007/s00484-006-0047-6.
