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Influence of landscape material properties on microclimate change in a tropical area with case in Manado City

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Abstract. The objective of this research is to show the influence of thermal properties of landscape materials on microclimate change of tropical environment in the city of Manado. The microclimatic variables of this study include surface temperature, air temperature, and solar radiation. The landscape materials as object of the research were bricks, hard-soil, concrete-block, trees, and garden-pond water. The research used descriptive quantitative method. Measurement of thermo-physical characteristic of brick and paving stone were conducted by using calorimeter and quick-thermal-conductivity meter. Measurements of solar radiation, and temperatures were also performed in a commercial area in Manado city. Calculations of heat exchanges were realized by using HEAT2 computer program in order to evaluate magnitude of surface temperature of various landscape materials. The results show that a dense leaves tree can reduce solar radiation in its shade by up to 80% at a mid-daytime. The landscape materials of red brick, light concrete-block and hard soil can cause a surface temperature by up to 50 ^{0}C under a clear open sky. Water surface temperature of garden pond can also reach 50 ^{0}C, while at a depth 50 cm can decrease to 25 ^{0}C.

1. Introduction

In general, people who carry out activities in outdoor spaces feel physiologically comfortable when they are in an environment with temperatures that are not too hot and not too cold, especially with the addition of cool breezes. However, the heat of the sun which can be very hot during the day, causes thermal discomfort, so humans try to find shelter under the shade, for example under a tree or under some other shade, and also look for water for cooling. In this case, apart from atmospheric climatic factors, the morphology and physical anatomy of the outdoor landscape architecture also play a role in causing variations in the level of thermal comfort for humans who carry out activities, both at night and during the day. Landscape morphology that composed of various types of material can affect changes in microclimate, especially environmental temperature [7]. However, the thermophysical properties of landscape materials are an integral part of the morphological characteristics. Even the surface of water may also affect the microclimate [3]. The thermophysical properties of the material will affect its surface temperature and the surface take role as heat radiator to the environment when the material receives a heat penetration of solar radiation at outdoor space [9]. Radiant temperature of outdoor landscape environment mostly affected by the heat capacity and emissivity of surface material [12]. The physical morphology of the greenery also has a significant effect on the filtration of solar thermal radiation to the points under shade [5]. Since the thermophysical characteristics of the material are known, it will then be designing a landscape architecture with optimize to serve a comfortable microclimate to the user [1]. The microclimate variables that play the most role on the perception of thermal comfort in outdoor spaces are radiant temperature, air temperature and wind [2], [4]. Previous studies mostly used reference

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materials where the physical properties were be taken from literatures published in developed countries like in Japan, US, Europe, and Australia. Meanwhile in this study it used local materials, where the thermophysical properties are not mentioned in the literatures. Therefore, it should be measured in order to know the values that may be difference from the literatures. Specifically, this study aims to obtain information of the fluctuation of microclimate variables due to the application of various types of landscape materials, which include type of pavement in the location (brick, paving, soil), water and trees. The microclimate variables were the surface temperature of the material, air temperature, and penetration of solar radiation. As case study, the site is in the coastal area of the Mega Mas commercial area in Manado City, Indonesia. In this area, the landscape formation consists of pavement material, trees, and there is also a garden water pond.

2. Methodology

This research used a quantitative description method that include steps of measurements, practical calculations and computer simulations. Location of field measurements was in the Mega Mas beach area, in Manado city.

2.1. Measurement of thermal properties of materials

The selected local materials which are to be measured in this study were local red brick, and concrete-block. Measurements were to determine the value of specific heat capacity (c) in Joule/kg^{0}C, thermal conductivity in W/m^{0}C, and density in kg/m^3. The measurement instruments were Joule Calorimeter, digital balance, thermocouple, and quick-thermal-conductivity meter.

2.2. Microclimate measurement

Outdoor microclimate measurements that include air temperature, surface temperature and solar radiation, were performed in a clear day when the sun was not covered by clouds. The equipment consists of infrared thermometer (to measure the surface temperature of the material), solar power meter (to measure solar radiation) and digital thermometer (to measure air temperature). Measurements of surface temperature and radiation were carried out at a point under the shade of a dense leaves tree, and at another point that face to a clear open sky or exposed to the direct sunlight. In addition, measurements of the body of water in a garden pond were also carried out at the surface and at the bottom of 50 cm deep. Measurement of air temperature was conducted at the height of human activity, 1.5 m from the surface of the land. The activity of measurements was performed in a coastal area of Manado City (1.5 LU) on 10 January 2021.

2.3. Calculation simulation

The calculation and simulation of conduction heat transfer of the materials were performed by using the HEAT2 computer program. The objective is to determine the surface temperature of the material due to radiation penetration from the sky or by sun light. The geometrical modelling to be applied to the program is explained schematically in the Figures 1 and 2. The simulation by HEAT2, applied transient calculation mathematical model. The boundary at the top of the material was radiant temperature that varies every hour. This represents the penetration or product of sun radiation to the surface. A daily solar radiation in the tropics was estimated by using equations that refer to some references ([9],[11]) as shown in Figure.4. By approximation, a conversion calculation of solar and sky radiation to radiant temperature (*tr*) is applied (Equations (1) to (4)). This *tr* would be then as boundary on the upward of the material (Figure 2). The bottom boundary is characterized by soil at deep 10 m, where the temperature was set constant 25 ^{0}C. A research on soil heat flux in the tropics, show that in a depth of 10 m the temperature is relatively constant at 20 ^{0}C [14], while another study shows that the soil temperature is constant 28.95 ^{0}C also in a depth of 10 m [13]. Therefore, in this study the median value of 25 ^{0}C was taken.

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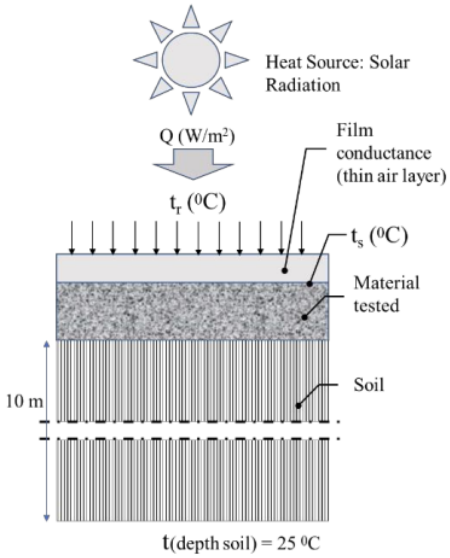

Figure 1. Material system modeling for computational simulation process

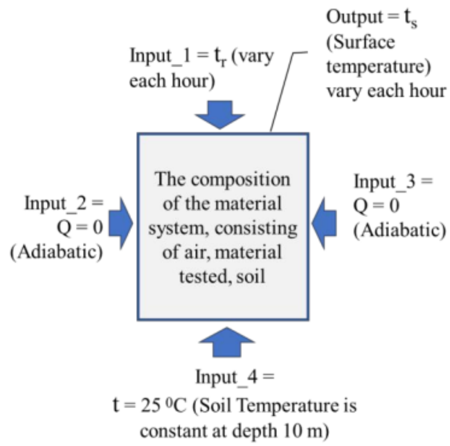

Figure 2. Input-boundary layer and output modeling for 2-dimensional heat transfer simulation using HEAT2

Figure 3 shows the modelling of the conversion from solar radiation (short wave radiation) and celestial radiation (long wave radiation) to radiant temperature, by introducing an imaginary black body that absorbs all radiation from above and transmits all heat energy downward. The radiation temperature conversion calculation process can be set by applying the general radiation equations as follows:

$$Q_r = \varepsilon \sigma T_r^4 \quad (1)$$

$$I_{dir} + I_{dif} + L_w = \sigma T_r^4 \quad (2)$$

$$L_w = h_r(t_{sky} - t_a) \quad (3)$$

$$T_{sky} = 0.0553\, T^{1.5} \quad (4)$$

Where I_{dir} is direct sun radiation, I_{dif} is diffuse radiation, and L_w is longwave radiation. Equation (4) is known as swinbank equation [10], where T is in Kelvin. t_r (in ⁰C) can be then estimated by those equations. In a situation where t_a is bigger than t_r, and impact of wind speed is neglected, tr can be then approximatively taken as same as t_a. Figure. 4 shows the variation of sun radiation (I_{dir} and I_{dif}) and radiant temperature that be applied in the simulation.

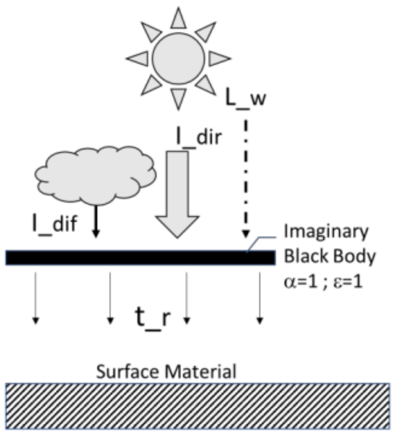

Figure 3. Heat penetration on surface

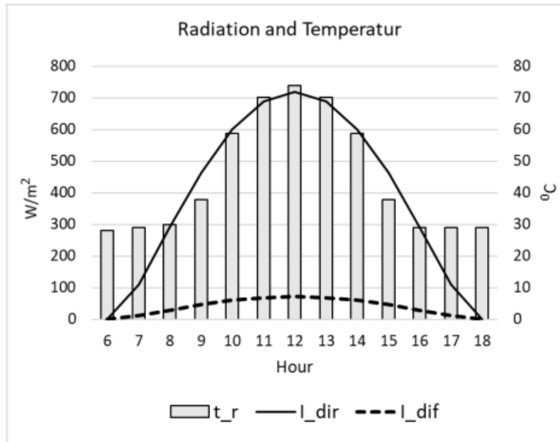

Figure 4. Solar radiation and radiant temperature

3. Results and discussion

3.1. Microclimate in the coastal area of Manado City

The measurement showed that due to hot solar direct radiation, the surface temperature of the hard and dry soil was almost reach 50 ^{0}C at the peak hottest during the day (Figure 5). Meanwhile, when under the shade of a tree (Tanjung tree species), the highest surface temperature of the material was close to 35 ^{0}C at 13.00 or about 60% compared to other point that face directly to skylight. The surface temperature of the soil from those two situations begins to differ after 08.00, when the influence of the sun has begun to make the material hotter. The pattern of heat changes, showing a curve that peaks at midday, and decreases in the morning and evening. The surface temperature pattern of the material shows the same tendency as solar radiation fluctuation that measured at the same time. The amount of solar radiation was almost 1050 W/m^2, at 12 noon at a point that face to open sky. On the other hand, at another point were shaded by the leaves, the highest value was close to 150 W/m^2 at 12 noon or reduced drastically to around 80%. Other researcher has also found the similar result. A study in tropical area, in Penang Malaysia, a dense leafy tree could reduce the soil temperature by 17% and could filter solar radiation by about 80% [8].

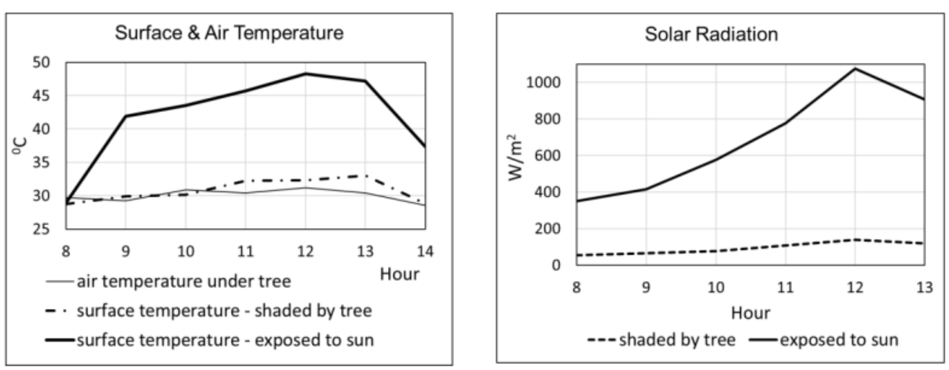

Figure 5. Results of measurement of surface temperature (left) and sun radiation (right)

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3.2. Thermophysical properties of local materials

Measurement of heat capacity and thermal conductivity of concrete block and red brick materials showed that different results from those that are generally found in several literatures. Specific heat capacity of local concrete block reaches 1423 J/kg^{0}C, with thermal conductivity of 1.06 W/m^{0}C. While the local red brick has specific heat capacity of 1090 J/kg^{0}C and thermal conductivity 0.43 W/m^{0}C (Table.1)

Table 1. Thermal properties of local materials

Properties	Unit	Concrete tile block	Local Red brick
Density[a]	kg/m3	1947	1662
Specific Heat Capacity[a]	J/kg ^{0}C	1423	1090
Thermal conductivity[a]	W/m^{0}C	1.06	0.43
Absorption coefficient from solar radiation [b]	%	60	90
Emissivity[b]	-	0.9	0.9

[a] By measurement
[b]Data from the SNI (National Indonesia Standard)

3.3. Hard surface temperature

Calculations of surface temperature of the local materials i.e. light concrete block and red brick, and dry soil were conducted by using HEAT 2. The results show (Figure 6) that at midday, the highest surface temperatures can reach in range between 45 ^{0}C to 50 ^{0}C, that occurs from 13.00 to 15.00 (Figure 6). In this simulation, the highest air temperature applied is around 32 ^{0}C at 12.00, according to the results of microclimate measurements. Peak hour of air temperature is generally following the peak heat radiation of the sun at 12.00. There are delay in peak heat flux of surface temperature due to the inertia property of materials. This is also known as time-lag of the material against the heat load. In the morning, the surface temperature can be lower than the air temperature (Figure 6). This can happen, because the air warms up faster due to the influence of human activities in the outdoor space, and also because of the influence of the sun rising since 06.00. It appears that the surface temperature of the concrete block is lower than the surface of the red brick at midday. The concrete block material has a light colour, so there is enough heat from the sun that is reflected, and the rest is absorbed which causes the heat of the material and its surface. While the red bricks are darker in colour, so more heat is absorbed by the material which also causes the high surface temperature of the material. Colour can affect to a higher or lower surface temperature.

A study in a tropical climate, in Malaysia, also showed that a white-coated asphalt can reduce temperatures by up to 60% compared to dark-coloured asphalt [16]. In addition, the conductivity of concrete is higher than that of red brick, which causes the heat flow from the concrete into the soil to be greater than that of red brick, so that less heat is retained in the concrete. The higher temperature of surface material will consequently cause a radiant heat increase of the outdoor microclimate. The results of the calculation also show that the surface temperature of the material starts to be higher than the air temperature from 08.00 until the evening. It reaches a peak close to 50 ^{0}C at 13.00. In Japan, as comparison, the surface radiation temperature of paving-concrete material can reach a peak of 40 ^{0}C even though the climate is cooler than in the tropics, as stated by Takebayashi and Kyogoku [6].

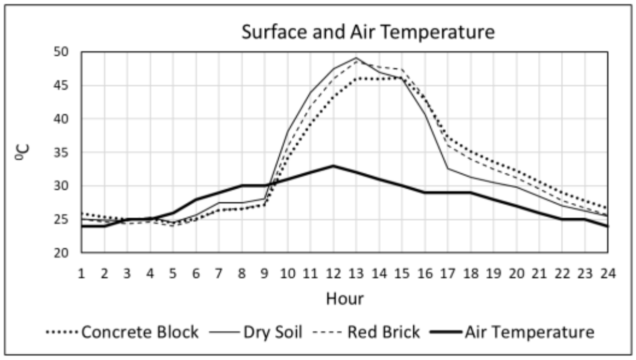

Figure 6. Simulation of surface temperature by HEAT2

3.4. Water temperature

A simulation calculation of water temperature using HEAT2 can show changes in temperature according to depth. At the surface, the surface water temperature can be almost the same as the surface temperature of other hard pavement materials, which can reach peak peaks of around 50 ^{0}C (Figure 7). However, at a depth of 20 cm, the peak temperature has decreased considerably to around 25 ^{0}C. Even at a depth of 50 cm, the water temperature can relatively constant around 25 ^{0}C as same as ground soil temperature, in period from 7.00 to 17.00. This simulation is only limited to the case of water that is not moving, there is no mixing of temperatures between the bottom and the surface, due to convective movement. To lower the surface temperature of the water, it may be necessary to mix it with the bottom, or there is a movement of flowing water. Even the surface temperature of a flowing river water in tropical climates can still be quite high and can reach almost 40 ^{0}C [15].

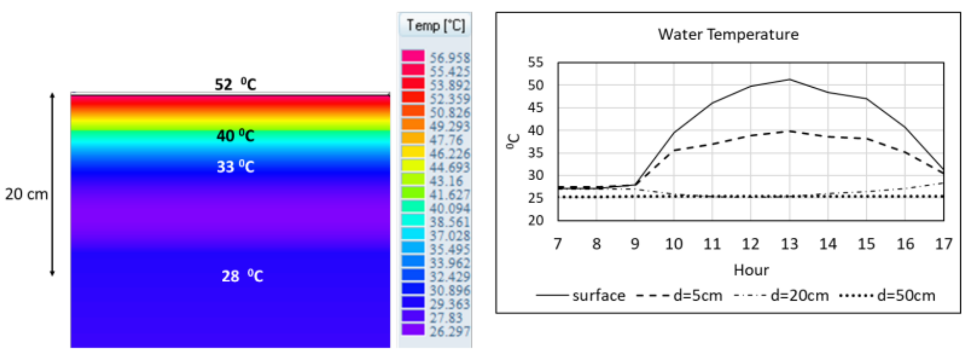

Figure 7. Water temperature

4. Conclusion

The thermophysical properties of landscape materials affect the change of microclimate, in particular the mean radiant temperature that be caused by the surface temperature of the material. The vegetation factor in the form of dense leafy trees has the potential to reduce or filter solar radiation that can up to 80% at midday. In addition, it can also reduce the surface temperature of the material under their shade by up to 30%, when the sun is vertically above it.

The surface temperature of the pavement materials, namely paving stone, brick and hard soil, during the day can reach almost 50 ^{0}C at midday. The surface temperature of the garden pond water under open sky can quite hot at midday, therefore, to cool it, it is needed an intervention to move the water in order to gain a temperature mixture with the other side which is cooler.

5. References

[1] G Y Choi, H S Kim, H Kim, J S Lee, 2021, Int.J of Clim. Ch.Str and Mgmt, **13,**2 97-119 (2021)
[2] B Givoni, Climate Considerations in Building and Urban Design, (J Wiley & Sons, New York, 1998).
[3] M Lesi, Iklim Mikro di Sekitar Permukaan Air. (Project Research Report, Pascasarjana IPB, 2017)
[4] Sangkertadi & R Syafriny, J. of Urb. and Env.Eng, **10**, 2, 177-185 (2016)
[5] FM Shahidan, E Salleh, KMS Mustafa, 2007. Effects of tree canopies on solar radiation filtration in a tropical microclimatic environment. In Proceeding of The 24th Conf. of PLEA, Singapore 22-24 Nov, 2007.
[6] H.Takebayashi and S Kyogoku, MDPI Sust. J. **10**, 337, 1-11 (2018)
[7] SKSO Thani & S M S Abdullah, Int. J of Behav. Std,. 2, **7**, 31-41 (2017).
[8] J Md Tukiran, J Ariffin J, AN Abdul Ghani, Int. J. of Geomate, **11**, 24 2275-2283 (2016)
[9] SV Szokolay S V. Introduction to Architectural Science: The Basis of Sustainable Design. Oxford: (Architectural Press , 2010)
[10] Y Qin, Jacob E. Hiller, 2011, Const & Build Mat, **25**, 3753-3761 (2011).
[11] J Widen & J Munkhammar. Solar Radiation Theory. (Uppsala University, Swedia, 2019)
[12] J Huang, J G Cedeno-Laurent, J D Spenglen, Build & Env, **80,** 84-95 (2014)
[13] A Mukhtar, MZ Yusoff, NK Ching. IOP Conf. Series: J.of Phys.**949,** 012011 (2017)
[14] W Cui, Q Liao, G Chang, Q Peng, T C Jen, Measurement and prediction of undisturbed underground temperature distribution. In Proceedings of the ASME 2 international mechanical engineering congress & exposition, IMECE2011, Denver, CO, USA, January 1 2011.
[15] G Bwire, D A Sack, A Kagrita, T Obala, A K Debes, M Ram, H Komakechi, CM George, and CG Orac, 2020. BMC Pub. Health.**20**,1128.
[16] J Md Tukiran, J Arifin, A N Abdul Ghani, Jurnal Teknologi (Sci. & Eng), **78**,5, 63-70 (2016)

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