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An Investigation of Green Roof Deployment in Bandung City, Indonesia

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Abstract: Indonesia is located in the tropics with high average temperature at daytime and relative exposure time throughout the year. Solar radiation received by the roof of a building can increase the cooling load. Green roof utilization can be one of the alternative solutions to decrease thermal rate in a building. Extensive green roof is one of green roof types which needs specific construction. Some suitable plants for the tropical zone are Amaranta, Bromelia, Euphorbia and Red Edged Dracaena which need little water. Green roof application with Amaranta and Bromelia in Bandung, using layers which consist of drainage, filter and soil have been able to inhibit heat transfer so the heat is not sentintothe room. Stable roof temperature preserves roof construction strength from the effect of cooling and heating cycle. Constructing a garden using synthetic grass is recommended if drainage is available to ease heat transfer through the roof.

Key words: Green roof, tropic, plants, synthetic grass, heat transfer

INTRODUCTION

Energy efficiency needs to be enhanced in all sectors. Energy building is one sector which has significant contribution to primary energy consumption. Energy utilization of buildings in USA is 40% (Levermore, 2008), 23% in Spain, 25% in Japan, 28% in China, 39% in Great Britain, 42% in Brazil and 47% in Switzerland (Saadatian *et al*., 2013). In a building, large energy is consumed by air conditioning system. Especially for countries in the tropical zone, such as Indonesia, energy consumption for air conditioning system reaches 63% and for Malaysia it is 57%. Energy utilization for air conditioning system can be minimized by decreasing the cooling load. Thermal energy from sunlight which enters the room through roof materials is one of the cooling loads that need to be minimized especially, for countries in the tropical zone.

Green roof has been applicable to decrease roof surface temperature. Result of a research in Japan showed that green roof can decrease roof surface temperature to about 30°-60°C (Saadatian *et al*., 2013; Wong *et al*., 2003). Liu and Minor stated that green roof can reduce sunlight which enters a building around 7090% in Summer and about 10-30% in Winter (Roche and Beradi, 2014). Indirect impact by using green roof is reducing energy consumption for air conditioning system about 5-80% (Saadatian *et al*., 2013; Wong *et al*., 2003). Another study related to this topic in Greece showed that the application of green roof can decrease energy for air conditioning system about 2-48% and temperature reduction reaching 4 K (Niachou *et al*., 2001).

Furthermore, green roof utilization has some advantages such as upgrading the air management (Mentens *et al*., 2006), decreasing air pollution (Yang *et al*., 2008), cutting back noise (Renterghem and Botteldooren, 2011), enhancing biodiversity in a city (Schrader and Boning, 2006), relieving dioxide carbon as an effect of photosynthesis (Feng *et al*., 2010; Jaffal *et al*., 2012). Green roof utilization can increase roof life as well because it can decrease thermal stress (Jaffal *et al*., 2012; Fioretti *et al*., 2010). For a comprehensive application, green roof contributes to the mitigation of the urban heat island effect (Alexandri and Jones, 2008)

The phenomenon of heat transfer in green roof is where the solar radiation into green roof undergoes several processes (Ouldboukhitine *et al*., 2011). On energy crops used for photosynthesis, water evaporates and partly reflects and emits radiation back. On the ground conduction heat transfer, thermal energy storage for the use of water evaporation, as well as most of the radiation is reflected and radiated back. The energy that enters the lower surface of the roof is forwarded to the room by convection and radiation. Of the incoming solar radiation into green roof, about 27% is reflected, 60% is absorbed by plants and soil to water evaporation process,

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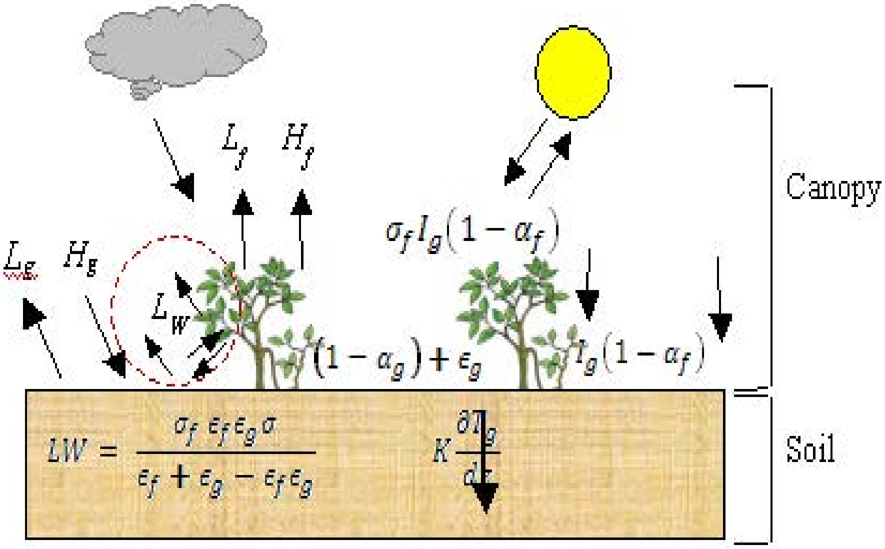

Fig. 1: Main heat flow on a green roof

and 13% are transmitted into the soil (Ayata *et al*., 2011). Energy distribution on the green roof is shown in Fig. 1. The following shows some equation of energy that occurs on green roof. Energy balance on the foliage is given by Sailor (2008) and Frankenstein and Koenig:

$$F_f = \sigma_f[I_s(1-\alpha_f)+\varepsilon_f I_{ir} - \varepsilon_f \sigma T_f^4] + \frac{\sigma_f \varepsilon_f \varepsilon_g \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g}(T_g^4 - T_f^4) + H_f + L_f \quad (1)$$

Sensible heat in plants is given by Frankenstein and Koenig:

$$H_f = (e_o + 1\times 1\times LAI \times \rho_{af} \times C_{pa} \times C_f \times W_{af}) \times (T_{af} - T_g) \quad (2)$$

Meanwhile, sensible heat flux on the ground is given by Deardoff:

$$H_g = (e_o + \rho_{ag} \times C_{pa} \times C_h^g \times W_{af}) \times (T_{af} - T_g) \quad (3)$$

The latent heat flux in the surface of the plant is given by Deardoff:

$$L_f = (LAI \times \rho_{af} \times 1 \times W_{af} \times r^n) \times (q_{af} - q_{f\,sat}) \quad (4)$$

The latent heat flux on the ground is given by Deardoff:

$$L_g = C_e^g + 1 \times W_{af} \times \rho_{ag} \times (q_{af} - q_g) \quad (5)$$

The balance of energy on the ground is given by Sailor (2008) and Frankenstein and Koenig:

$$F(T_g) = (1-\sigma_f)[I_s(1-\alpha_g) + \varepsilon_g I_{ir} - \varepsilon_g \sigma T_g^4] - \frac{\sigma_f \varepsilon_f \varepsilon_g \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g}(T_g^4 - T_f^4) + H_g + L_g + K\frac{\partial T_g}{\partial z} \quad (6)$$

The heat energy to the surface of concrete's top layer is forwarded by means of conduction heat transfer to the surface of concrete's bottom layer with the following equation:

$$Q = K\frac{\partial T_c}{dz} \quad (7)$$

Ambient temperature in Indonesia: Indonesia is located in the equator zone with coordinates of 6° North latitude 11°08' South latitude and 95° 141°45' East longitude. Climate in Indonesia is tropical. Time of solar radiation has no significant differences each month, time of day and night is relatively the same as well. Indonesian Agency for Meteorological, Climatological and Geophysics released monthly data in 2014 as shown in Fig. 2 on maximum and minimum temperature average. Jakarta and Surabaya had high monthly average temperature which could reach 31°C. While Bandung was relatively cool which had a maximum temperature of, on the average, 28° C and it could be 19.4°C at night. Generally, in rainy and dry seasons the monthly average temperature is almost the same. However the minimum and maximum temperature differences in some big cities are quite varied between 1.5 and 7°C.

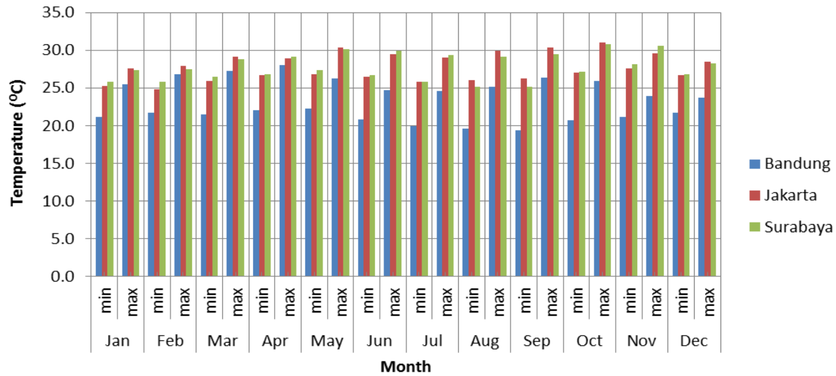

Fig. 2: The maximum and minimum ambient temperature in several cities in Indonesia

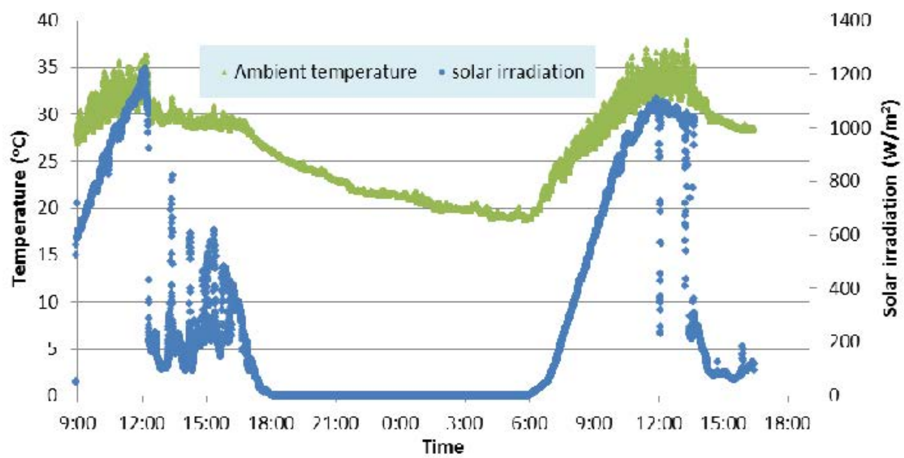

Fig. 3: Weather in Bandung from 30 September to 1 October 2015

Maximum and minimum temperature differences defined as a range between peak temperature at daylight and the lowest temperature at night. Daily temperature in Bandung during the extreme weather due to El Nino is shown in Fig. 3. Temperature difference between maximum and minimum values reached 16°C. Solar radiation at peak condition could reach 1200 Wm^{-2}.

Environmental temperature conditions influence the selection of plants suitable for green roof especially the extensive type. The choice of plants for areas of Indonesia is a plant that requires little water and stays strong at ambient temperatures ranging from 30-35°C. Some plants that can be grown, for example, are Amaranta, Bromelia, grass, Euphorbia and Red edged Dracaena.

MATERIALS AND METHODS

The equipment used for testing the green roof was two models of buildings, thermocouples, temperature data logger as well as solar power meter. The size of the building model was 1×1×1 m with 12 cm thick concrete roof. The top surface of the roof of the building walls were made of 10 cm thick styrofoam covered with plywood and painted in white color. The layer of green roof consisted of water proof, drainage, filter, soil and plants as shown in Fig. 4. Drainage was used. There were two kinds namely rubber mating Trell-link type and stone gravel. Thick drainage of rubber was 1.8 cm and of stone gravels were 2-3 cm. The soil thickness was 9 cm. Plants used were Brormelia, Amaranta. Placement of plants was also done using pots arranged on the roof. A test by using artificial turf was also conducted. Temperatures were measured using a type K thermocouple sensor and data logger Lutron brand type BTM-4208SD. Testing of solar irradiation was done by using solar power meter Lutron brand type SPM-1116SD. Data recording period is every 5 sec. Thermal properties of green roof materials to references in heat transfer calculation are shown Table 1.

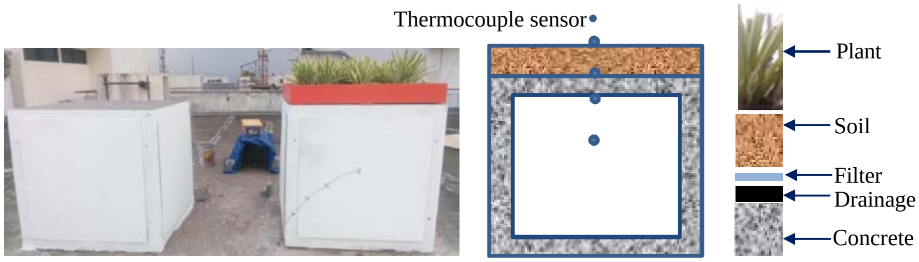

Fig. 4: Building test and green roof layers

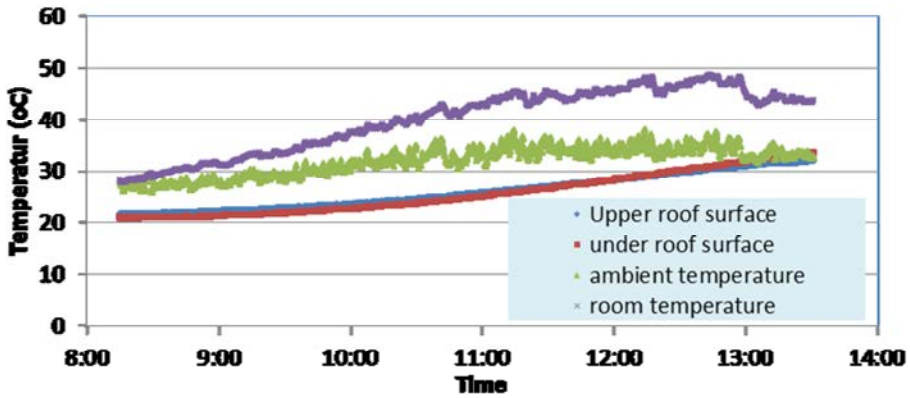

Fig. 5: Surface temperature of roof for standard building models

Table 1: Thermal properties of green roof materials

Material	Density (kgm^{-3})	Thermal ($Wm^{-1}K$) conductivity	Specificheat ($Jkg^{-1}K$)
Soil (Moody and Sailor, 2013)	825	0.64	3678
Rubber drainage (Coma *et al.*, 2016)	610	0.13	1000
Concrete (Zingre *et al.*, 2015)	2450	0.65	840

RESULTS AND DISCUSSION

Heat transfer of green roof application: Solar radiation due to direct exposure on the surface of the roof generates heat which is then passed through the roof material by conduction towards the room. Heat transfer into the room can be determined by calculating the heat transfer conduction on concrete layer of both roof types, i.e., standard and green roof type. The heat transfer into the roof layer causes increase of temperature on the lower roof surface. Standard roof surface temperature can reach 48°C when the weather is sunny as shown in Fig. 5. The lower roof surface temperature increases along with the increase in surface temperature over the rooftops. The heat energy on the surface of the underside of the roof is transferred to the room by convection and radiation. This has resulted in the rise of room temperature, too.

The use of plants on green roof has been able to inhibit the thermal energy entered in the room from the roof. From result of examination it appears that almost nothing heat transfer into the room from the roof. Instead, the heat transfer is very large standard roof during the day when solar radiation is high. That is shown in Fig. 6. The heat energy that entered in the green roof is absorbed by the water in plants and soil for the evaporation process. Some of the energy has been stored by the soil material. During the day, the heat transfer occurred from the room to the roof, and at night when the room temperature and the environment is lower than the roof of the heat transfer from the concrete roof. The thermal energy stored in the soil and concrete are released, either to the top surface and the bottom surface to the roof. Utilization of green roof can cause roof temperature to be stable which is shown in Fig. 7.

Plants on green roof receive direct solar radiation. Most are reflected, the others are absorbed for photosynthesis used to evaporate the water in plants and soil. The rest is then passed to the roof through the soil. According Lazzarin *et al.* (2005) only about 1.8% was passed onto the roofing material. Soil with a low enough thermal conductivity can slow the rate of heat to the roof. Drainage made of rubber also slows the rate of heat transfer to the roof.

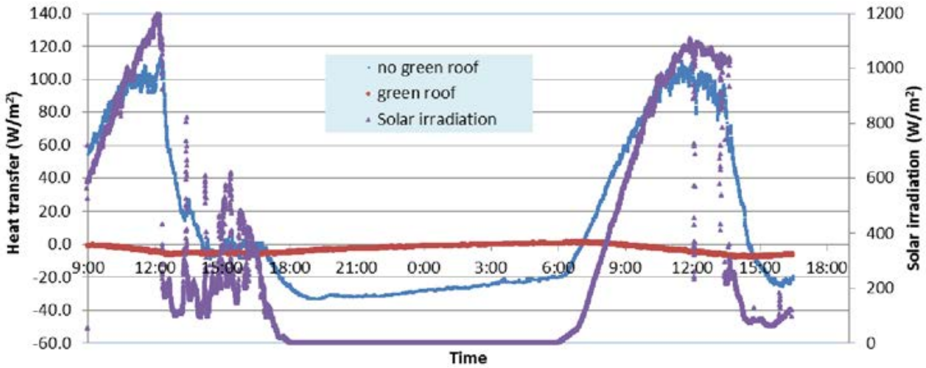

Fig. 6: Heat transfer of a standard roof and green roof using Amaranta flowers

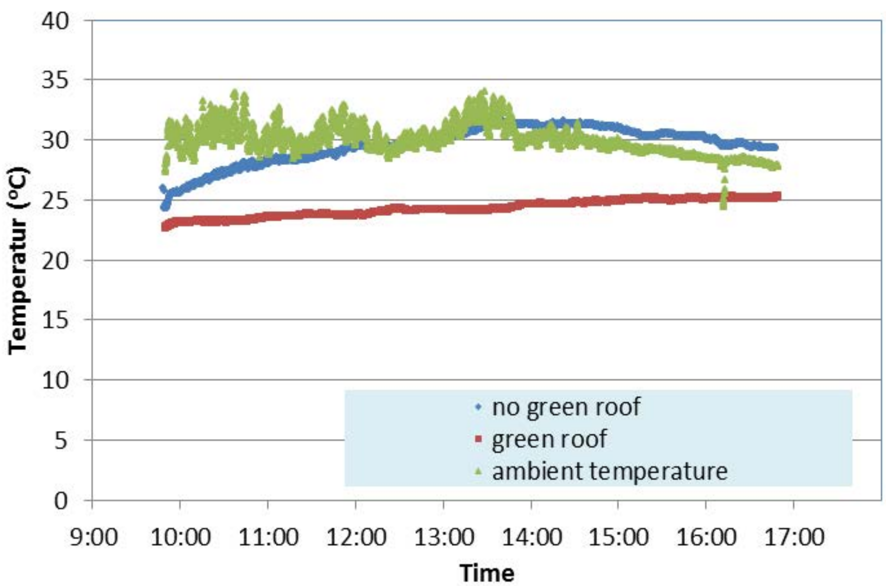

Fig. 7: The temperature of the room to use standard roof and green roof

Results of testing with several types of plants, drainage and the use of synthetic turf are presented in Table 2. Analysis has been carried out for 4 h testing time. Heat transfer of standard roof is very large. For average solar radiation of about 500 wm^{-2}, heat transfer value is around 60 wm^{-2}. While the average solar radiation above 1000 wm^{-2} produces heat transfer value above 80 wm^{-2}. The possibility of no-plant green roof to hinder the thermal energy is very significant, where the heat transfer in concrete layer is only 0.4 wm^{-2}.The use of Amaranta and Bromelia plants at green roof have been able to inhibit heat transfer to the concrete layer, so that, the thermal energy do not enter the room. The use of gravel as drainage does not give much difference on the heat transfer compared to the use of rubber. In using gravel, the strength of the roof must be considered since its density is much greater than the rubber. The placement of plants in pots also has been a positive influence on the decrease of heat transfer into the room. The heat transfer in concrete layer is 12.4 wm^{-2}. The closerthe placement of the pots, the better its effect is. This is due to the smaller surface of the roof that gets direct sunlight. The roof of the building will be hindered by plants and soil potting dam. The use of artificial turf directly on the roof turned out to not significantly gives effect of heat transfer into the room. However, by installing a drainage layer as synthetic turf mat on the roof surface, it could impede heat transfer where the value is 15.9 wm^{-2}.

Table 2: Green roof application to heat transfer reducing

Plant	Green roof layer	Average of heat transfer into the room (Wm^{-2}) Standard	Green roof	Average of ambient temperature (°C)	Average of solar irradiation ($Wattm^{-2}$)
	Soil Filter Drainage (rubber)	85.1	0.4	30.7	763.5
Amaranta	Soil Filter Drainage (rubber)	81.9	0	30.0	810.1
Bromelia	Soil Filter Drainage (rubber)	68.5	0	30.4	470.2
Bromelia	Soil Filter Drainage (gravel)	89.3	0	32.0	1028.4
Bromelia	Soil Flower pots	84.8	12.4	32.1	998.3
	Synthetic grass	81.9	78.0	32.3	1035.0
	Synthetic grass Drainage (rubber)	83.9	15.9	29.60	663.3

CONCLUSION

The average maximum temperature during the day in Indonesia is high, about 30°C and evenly throughout the year. This strongly supports the use of green roof on buildings as it can be used to reduce the cooling load of the room throughout the year. Besides that, green roof can function to overcome roofing material damage due to thermal fatigue that occurs because of differences in high maximum and minimum average temperature of around 6.8°C and repeated every day.

The application of green roof can reduce the rate of heat transfer into the room significantly. The use of Amaranta and Bromelia plants using rubber drainage can inhibit heat transfer into the room. The same is shown by the use of gravel drainage, but it is worth noting to the additional load on the roof. The use of synthetic grass as lawn on a building roof can be maintained as long as it is lined with rubber drainage. This is because the use of synthetic grass directly leads to unimpeded heat transfer in concrete layer. While the addition of rubber drainage can reduce the thermal energy into the room, where the heat transfer is only 15.9 wm^{-2}, so is the use of plants in pots. They have a positive impact on the decline of heat transfer in concrete layer down to 12.4 wm^{-2}.

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NOMENCLATURE

C_f = Bulk transfer coefficient
C_h^g = Bulk transfer coefficient for the sensible heat
C_{pa} = Specific heat transfer of air at constant pressure (J/kgK)
e_0 = Windless exchange coefficient
F_f = Foliage energy balance ($W m^{-2}$)
H_f = Foliage sensible heat flux ($W m^{-2}$)
H_g = Ground sensible heat flux ($W m^{-2}$)
I_s = Total incoming short-wave radiation ($W m^{-2}$)
I_{ir} = Total incoming long-wave radiation ($W m^{-2}$)
LAI = Leaf Area Index
K = Thermal conductivity ($W mK^{-1}$)
l = Latent heat of evaporation ($J kg^{-1}$)
L_f = Foliage latent heat ($J kg^{-1}$)
L_g = Ground latent heat ($J kg^{-1}$)
q_{af} = Mixing ratio for air within foliage interface
q_{fsat} = Saturation mixing ratio at foliage temperature
r^n = Surface wetness factor
T_{af} = Air temperature within foliage (K)
T_f = Foliage temperature (K)
T_g = Ground temperature (K)
W_{af} = Wind speed at the air-foliage interface (m sec^{-1})
α_f = Albedo of the canopy
α_g = Albedo of ground surface
ϵ_f = Foliage emissivity
ϵ_g = Ground surface emissivity
ρ_{af} = Density of air at foliage temperature ($kg m^{-3}$)
ρ_{ag} = Density of air at ground surface temperature ($kg m^{-3}$)
σ = Stefan-Boltzmann constant ($5.67\times10^{-8} W m^{-2}K^4$)
σ = Fractional vegetation coverage

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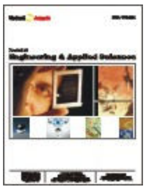

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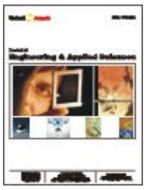

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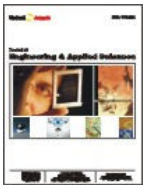

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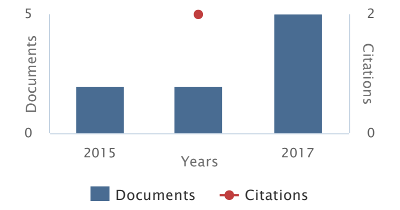

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