

# A COMPARISON OF HEAT PERFORMANCE BETWEEN GREEN ROOFS ON CONCRETE AND GREEN ROOFS ON CORRUGATED ZINC

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## ABSTRACT

Green roofs are generally applied to concrete roofed buildings. This study compares the thermal performance of green roofs that occur in corrugated concrete and zinc to expand green roof innovation. The study experimented on a method using the 2011 Ecotect computer simulation. The results showed that the difference in temperature reduction in corrugated zinc was higher than in concrete. Changes in the heat outside the roof space on both have a number that has a relatively small difference, but the difference in heat is visible in the inner space. Based on the thermal performance of the roof, the use of corrugated zinc roofs as the base of the green roof in the building could be an alternative green roof material besides concrete.

**Keywords:** Green roof; heat performance; concrete; corrugated zinc.

## INTRODUCTION

Drawn on the tendency of green roof research at least two aspects dominate the focus of green roof research on a world scale, i.e., the criteria for building objects and determining research methods. Green roof research trends are influenced more by environmental and energy issues. This research attempts to expand the scientific discourse of architecture by comparing the materials used for green roofs with residential building objects.

The first tendency, the object of green roof research is often the focus of research on concrete roofed buildings. Concrete green roof research generally deals with commercial public buildings, such as hotels, malls, superblocks, or schools. This study presents an innovative green roof placed on the roof of a low-rise residential building with a location criterion of a high-density residential area in a tropical climate.

Second, many green roof studies use quantitative research methods. Based on the type of method, green roof research is carried out by means of experiments and computer simulations. Experimental research is research that presents experimental objects in real terms with a certain scale; whereas, computer simulations use virtual objects built on digital analysis software.

Based on practical considerations of the model and data processing process, this study focuses on the thermal performance of green roofs made of concrete and corrugated zinc using Ecotect 2011 simulations. In some previous green roof studies, software varies greatly including CFD, EnergyPlus, and other software (Yuliani et al., 2020), but few use Ecotect.

The study considers the condition of climate data in the city of Surakarta, Indonesia in the analysis tool in that the simulation results can be more accurate, as the city has a humid tropical climate. The research procedure compares the potential and constraints of the application of green roofs on concrete and corrugated zinc to determine the opportunities of green roofs on corrugated zinc. Such a comparison leads to green roof innovations that enrich the technique of implementing green roof base materials in tropical climates.

Simulation of the green roof by Envimet has been carried out by Ambrosini et al. in the scale of urban areas by considering the application of green roofs, showing a relatively small effect if only carried out on several buildings with a limited area in the metropolis because the climatic conditions of the region are still intensely dominating (Ambrosini et al., 2014), in line with (Carvalho et al., 2017; J. Scott MacIvor et al., 2016; Viecco et al., 2018). A previous study on the focus of a single building with energy considerations show that for buildings that are isolated green roofs do not provide a significant thermal impact, but for buildings that are not isolated, the thermal performance of green roofs is very beneficial for indoor and outdoor environments (HT Raktodramiarana et al., 2015). Envimet software is also used in building green performance testing (Gaspari & Fabbri, 2019). The background of this research is the impact of climate change by discussing the potential reduction in regional temperature through green elements in buildings to optimize and determine the most effective greening patterns as a solution to improve outdoor comfortable conditions.

Other researchers use EnergyPlus (Chan, 2018; Gargari et al., 2016; Owruk et al., 2015) to evaluate the thermal performance of buildings. Similar studies using Energyplus demonstrate that the energy use of semi-intensive and intensive green roofs is 60-70% and 45-60% lower than black and white roofs. A well-insulated roof does not fully utilize the cooling effect of evapotranspiration, which is particularly noticeable when compared to high reflective white roofs (Silva et al., 2016).

Testing with CFD is used by several researchers (Aly et al., 2017; Ge et al., 2019; Gromke et al., 2015; Park et al., 2016; Qin et al., 2018; Rafael et al., 2018) aims specifically to focus on thermal dynamics through air movement in buildings both indoors and outdoors. Buildings that are commonly used are ones that have problems in high-density areas with public building objects.

Building roof research is important because the roof plays a role in building energy management and evaluation can be done with simulations like the previous studies (Carbone et al., 2014; Costanzo et al., 2016; Herrera et al., 2018; Stovin et al., 2017; Van Renterghem et al., 2013).

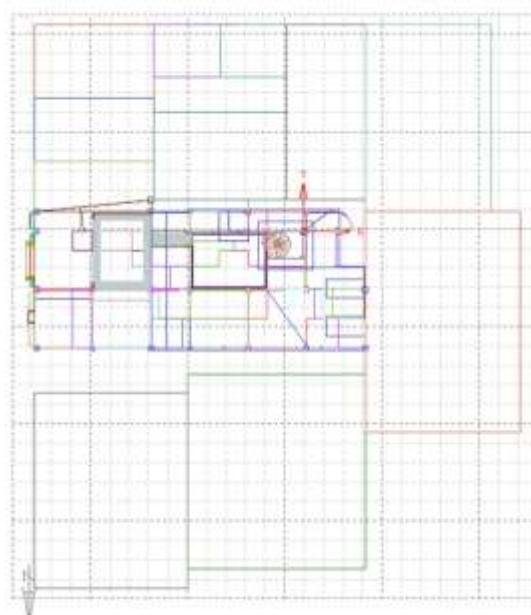
Some green roof research has been conducted with simulation methods. Apparently, there is still not much information obtained from researchers who use Ecotect, even though there is actually an analysis menu that can be processed through this software. Previous research also has a tendency to compare conventional roofed building models with concrete and green roofs placed on the top of the concrete as thermal coating elements, but information on the use of corrugated zinc has not yet been obtained. For this reason, this study presents an Ecotect simulation method that can be used as a comparison, by taking green roof building objects applied to corrugated concrete and zinc.

## METHODOLOGY

The selection of models for evaluation through simulations considers the conditions of urban problems and the characteristics of residential buildings in dense residential areas. The basis for consideration of the selection of this model is that the research findings can later become models that present actual problems in that they can become architectural solutions in overcoming building and environmental problems. The determination of the model establishes an existing residential building built in a dense low-floor residential area with a concrete roof and the corrugated zinc roof. The section of the room under corrugated iron roof is analyzed by creating a partition that divides the room into two. The building model is presented in Ecotect software

with two treatments, i.e., the roof of the existing building and the roof of a green-roofed building.

In the first stage, the model imported from Autodesk sketchup is imported into Ecotect in two versions i.e., the plant-free building model as shown in Figures 1, 2, and 3 including the floor plan and the building view. The second version, a building model with plants that includes a floor plan and looks like 4, 5, and 6. Both versions can be presented in two dimensions or three dimensions. The building model identified the characteristics of the material used, area, and position in detail.



**Fig. 1.** Building Plan without Plants in the Area around the Object.



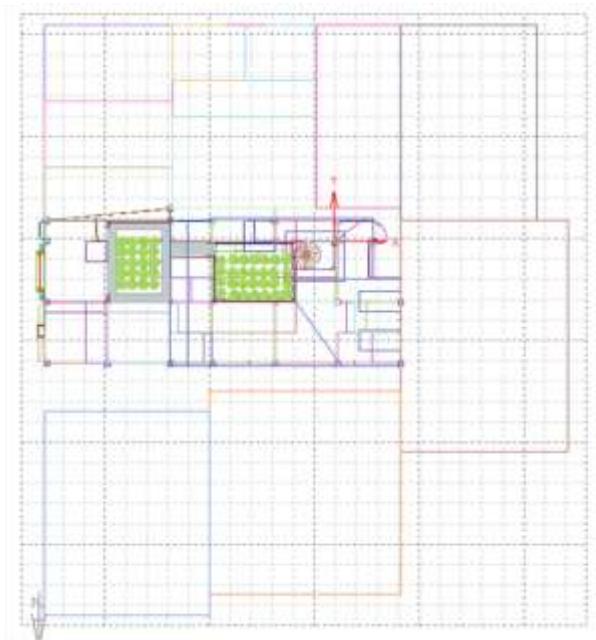
**Fig. 2.** The Southbound View of Buildings without Plants

The second stage, analyzing the simulation results using statistical processing by comparing the tested variables include one dependent variable i.e., temperature and two dependent variables i.e., the green roof on concrete and corrugated zinc measured in categories (Creswell, 2014). Evaluation of thermal performance was through simulation and calculation stages with Microsoft Excel and Origin statistical software. The results of both simulations are compared, and conclusions are related to the corrugated zinc roof opportunity. Thermal analysis

begins by inserting Surakarta City climate data. At this stage, the study received information on heat changes that occur under two conditions of green roofs both inside and outside, during one year in the dry and rainy seasons within 24 hours.



**Fig. 3.** The Northbound View of Buildings without Plants



**Fig. 4.** Building Plan with Plants in the Area Around the Object



**Fig. 5.** The Southbound View of Buildings with Plants



**Fig. 6.** The Northbound View of Buildings with Plants

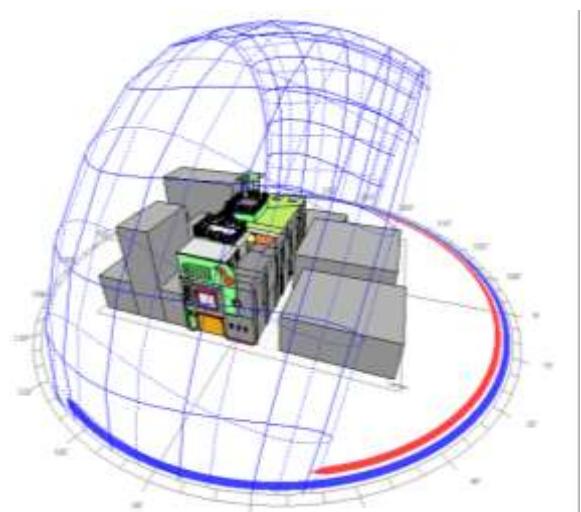
The third step, analyzing simulation data through comparative statistics with Microsoft Excel and OriginLab, to get a comparative picture as a basis for determining the conclusions from the results of research on the opportunities of green roofs on corrugated zinc.

## RESULTS AND DISCUSSION

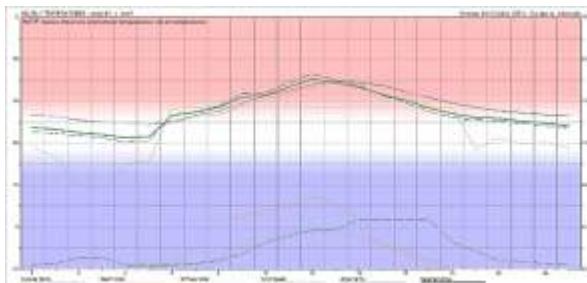
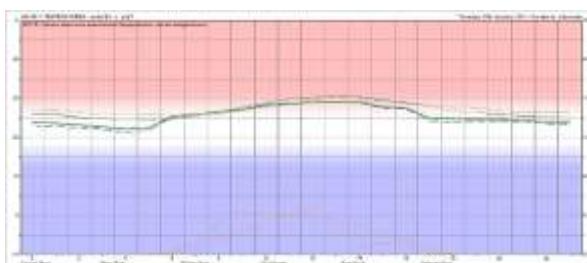
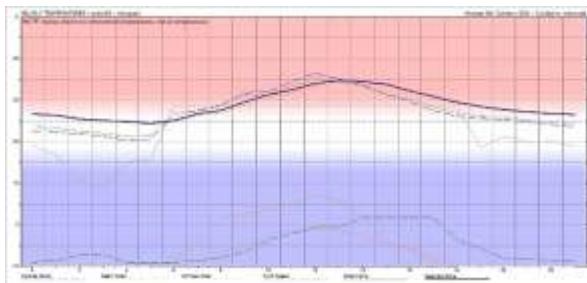
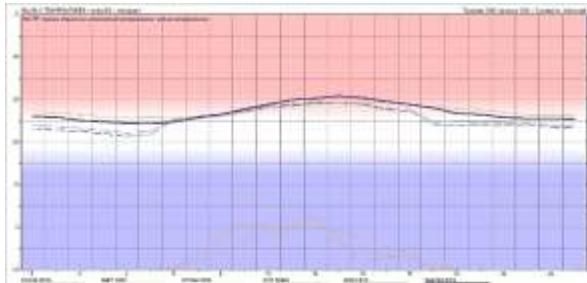
Simulation results show that there is a significant reduction in heat to the application of green elements on corrugated or corrugated zinc roofs. Both of the green roof model used peanut plant on the concrete and corrugated zinc roofs.

### Roof without plants

Model of residential building without plants is visualized in Figure 7 projected in the path of the solar orbit throughout the year. The mean radiant temperature presentation is presented in the extreme months of the dry and rainy seasons, normally in January and October. Figure 8 shows the visualization of heat dynamics occurring on a non-planted concrete roof in October as the hot peak month in the dry season. Figure 9 illustrates the change in heat on concrete roofs without plants in January. Figure 10 is a simulation result of thermal analysis on corrugated zinc roofs in October in the dry season and January in the rainy season as shown in Figure 11. The simulation results are summarized in Table 1, which explains the material criteria, the extent to the value of Roof Thermal Transfer Value (RTTV). Overall, calculation in buildings without plants obtained the value of Overall Thermal Transfer Value (OTTV) in Table 2 with the results compared to the energy efficiency benchmarks.



**Fig. 7.** Plantless Model

**Fig. 8.** Concrete roof in October**Fig. 9.** Concrete roof in January**Fig. 10.** Corrugated zinc roof in October**Fig. 11.** Corrugated Zinc Roof in January**Table 1.** Calculation of RTTV on Plantless model

Component	Zinc roof	Concrete roof	Unit
$\alpha$ (surface absorptions)	0.26	0.47	
$U_w$ (U-value on roof)	5.05	3.69	$W/m^2 K$
$A_w$ (Area)	23.99	12.00	$m^2$
$A_{wn}/\sum A_w$	0.63	0.32	
Weight/area	2.10	283.85	$kg/m^2$
$TD_{ek}$	24	16	K
RTTV opaque (conductive)	19.90	16.43	$W/m^2$
$\Delta T$ (temperature difference)	5		K
RTTV opaque (conductive)	0.00	0.00	$W/m^2$
SF	316		
Total Area	37.99		$m^2$
Roof RTTV	39.54		$W/m^2$

**Table 2.** OTTV Calculations

Section	Partial OTTV	Area of the envelope	Thermal Transmittance	WWR
East façade	16.78	20.87	350.13	0.07
North façade	26.27	24.51	643.84	0.06
West façade	17.79	12.11	215.30	0.01
South façade	29.36	27.02	793.24	0.06
Total		63.63	1,652.38	$Watt/m^2$

The value of OTTV as a whole =  $\frac{1,652,38 \text{ Watt}}{63,63 \text{ m}^2} = 25.97 \text{ W/m}^2$

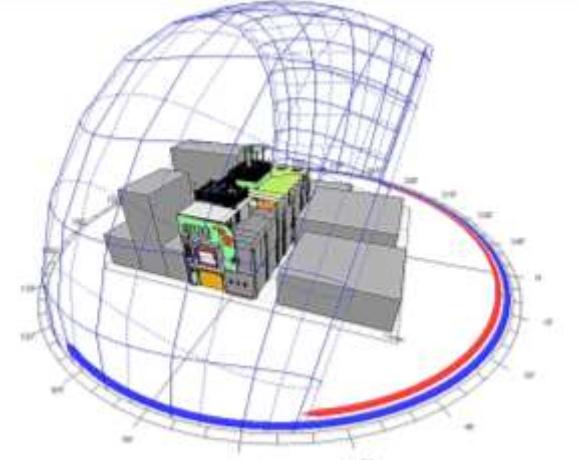
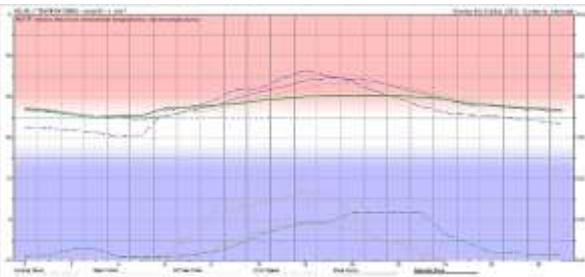
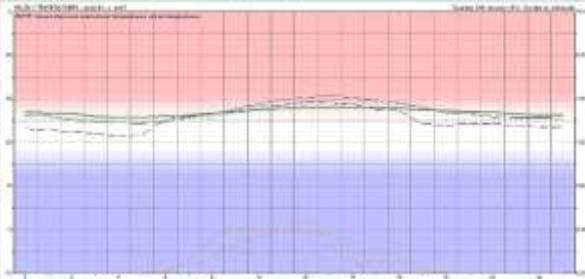
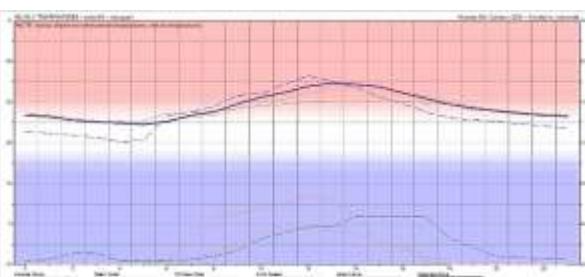
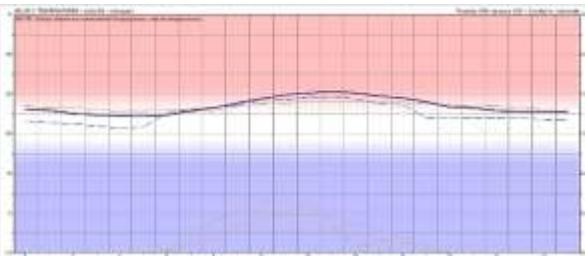
Based on SNI 6389-2011 concerning energy conservation of building envelope in buildings,  $25.97 \text{ W/m}^2$  less than  $35 \text{ W/m}^2$  so the building has an energy saving category.

RTTV opaque of  $39.54 \text{ W/m}^2$  and RTTV skylight being non-existent, the total number of RTTV objects without plants equals to  $39.54 \text{ W/m}^2$ . Based on SNI 6389-2011 on energy conservation of building envelope,  $39.54 \text{ W/m}^2$  is more than  $35 \text{ W/m}^2$  so the building has a category of not saving energy. As for the U-value of the roof with a weight per unit area of  $91.41 \text{ m}^2$  the average U-value is 4.64 and the maximum U-value is 0.80. Based on SNI 6389-2011 concerning energy conservation of building envelope in buildings, it includes the category of roof buildings that are not energy efficient.

## Green Roofs

As in the first version of the model, for this second model, the results obtained from the modeling in Figure 12 for the position of the model in solar orbit throughout the year. The summary of simulation results is presented in a representative manner based on the season, i.e., the dry season and the rainy season: the dry season (Figure 13) for green roofs on concrete and (Figure 15) for green roofs on corrugated zinc. On the other hand, in the rainy season it is presented in January for concrete roofs (Figure 14) and for green roofs on corrugated zinc (Figure 16).

The analysis of OTTV and RTTV calculations are presented in Tables 3 and 4. The resulting figures show a corroborating difference that the green roof has the benefit of reducing temperatures as the findings of previous researchers with various analysis software applications, such as ones in the literature review description.

**Fig. 12.** Model Building Planted**Fig. 13.** Green Roof on Concrete in October**Fig. 14.** Green Roof on Concrete in January**Fig. 15.** Green Roof on Corrugated zinc in October**Fig. 16.** Green Roof on Corrugated zinc in January**Table 3.** Calculation of RTTV on Green Roofs

Component	Green roof - Zinc	Green roof - Concrete	Unit
$\alpha$ (surface absorption, with plant)	0.88	0.88	
U-value(include plant)	0.62	0.57	W/m <sup>2</sup> K
$A_w$ (area)	23.99	12.00	m <sup>2</sup>
$A_{wn}/\sum A_w$	0.19	0.32	
Weight/ area	1,708.92	2,059.87	kg/m <sup>2</sup>
T <sub>Dek</sub>	16	16	K
RTTV opaque (conductive)	1.62	2.54	W/m <sup>2</sup>
SF	316		
Total Area	37.99		m <sup>2</sup>
Roof RTTV	21.44		W/m <sup>2</sup>

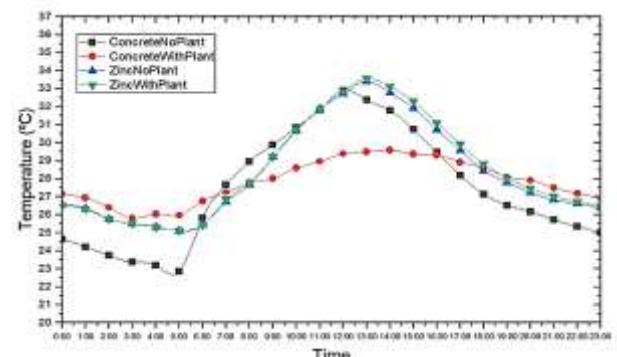
**Table 4.** OTTV Calculations

Position	Partial OTTV	Area of the envelope	Thermal Transmittance	WWR
East façade	16.78	20.87	350.13	0.07
North façade	26.27	24.51	643.84	0.06
West façade	17.79	12.11	215.30	0.01
South façade	29.36	27.02	793.24	0.06
Total	63.63		1,652.38	

$$\text{Total OTTV} = 1,652.38/63.63 = 25.97 \text{ Watt/m}^2$$

Calculation of maximum roof U-value, with a weight per unit area of 1,022.01 and U-value averaging 2.69 W/m<sup>2</sup>, then maximum U-value is 1.2 W/m<sup>2</sup>. RTTV calculations with the results are 21.44 W/m<sup>2</sup>. Based on SNI 6389: 2011 concerning energy conservation of building envelope in buildings, the values of OTTV and RTTV are below 35 Watt/m<sup>2</sup> have energy efficiency values in buildings. The thermal performance of buildings in both roof models is compared with various criteria.

The discussion begins by using the criteria for seasons in tropical climates, the difference in room temperature in the dry season shows that the peak heat occurs at 12.00-13.00 as shown in Figure. 17 and 18, where the highest temperature in the room is experienced by corrugated zinc roof without plants and the lowest temperature on the planted concrete roof.

**Fig. 17.** Dry season inside temperature

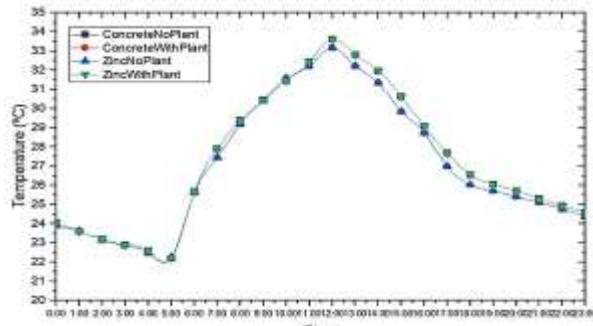


Fig. 18. Dry season outside temperature

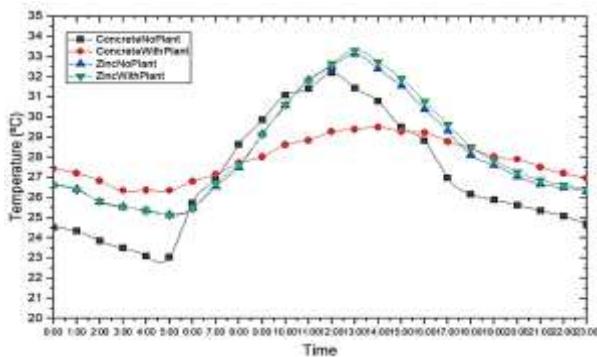


Fig. 19. Wet Season Inside Temperature

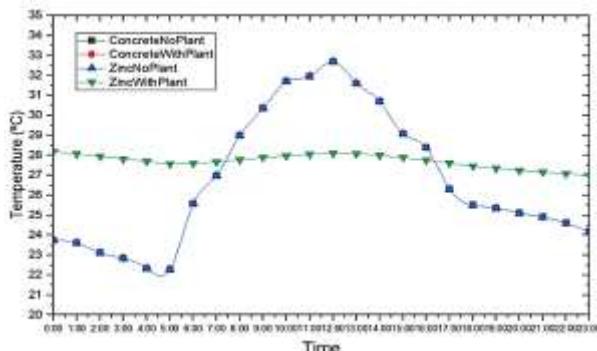


Fig. 20. Wet Season Outside Temperature

The highest temperature ratio achieved in the two models in Figure 21, shows that the trend in indoor conditions, corrugated zinc roof at high temperatures, but when it gets plant applications, corrugated zinc roof experiences a small temperature drop adrift with concrete roof, except for April. While in the outer space in Figure 22, a decrease in temperature due to the application of a green roof on corrugated zinc tends to show a graph that approaches the temperature trend on a concrete roof.

The discussion on the minimum temperature for both models shows that in the inner room, corrugated zinc roof has the fastest response to cold as in Figure 23. This condition has similarities with the dynamics of temperature changes in the outside room, as corrugated zinc has the fastest temperature decrease, as in Figure 24. As for concrete roofs, although there are relatively significant temperature changes in indoor and outdoor spaces, the temperature change

graph shows lower changes compared to corrugated zinc roofs.

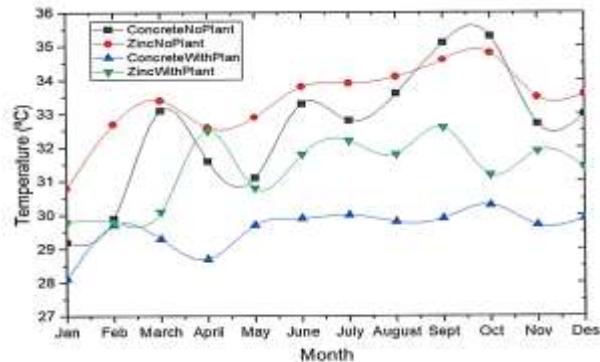


Fig. 21. Maximum Temperature of Inside

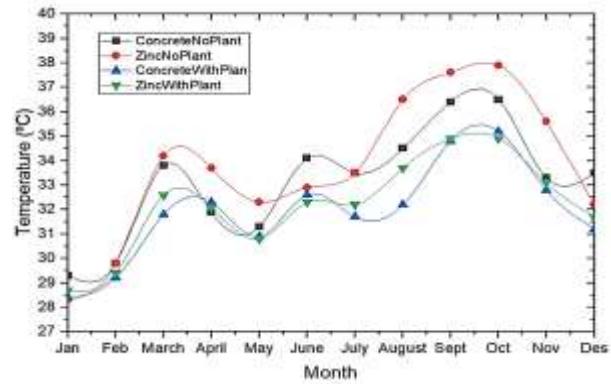


Fig. 22. Maximum Temperature of Outside

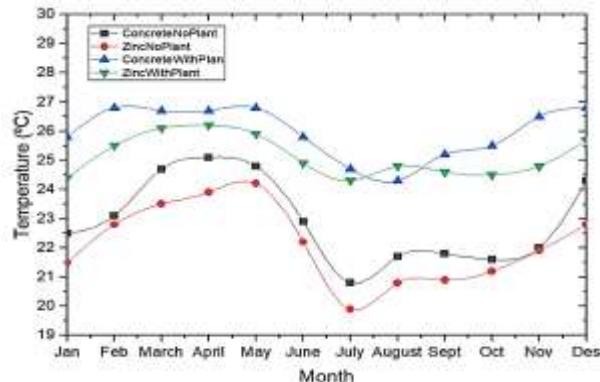


Fig. 23. Minimum Temperature of Inside

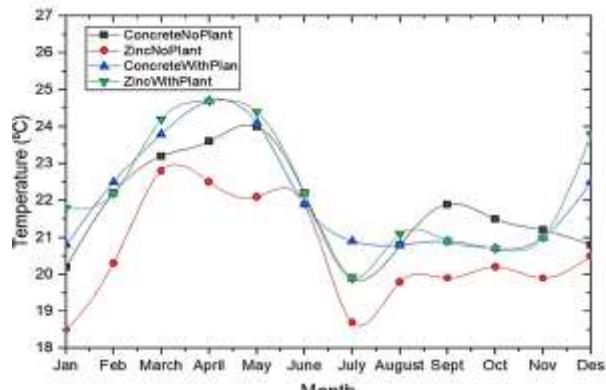


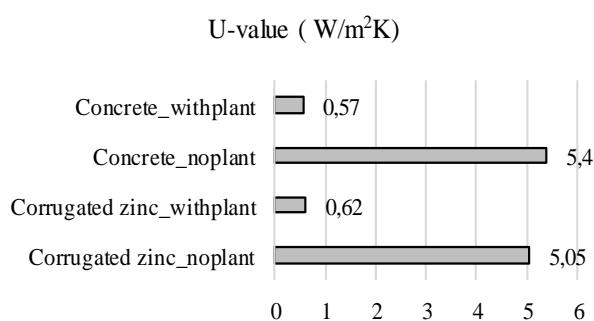
Fig. 24. Minimum Temperature of Outside

Research on the experimental model of low-rise dwelling in urban areas with humid tropical climate through simulations using Ecotect 2011 software, resulted in the finding of differences between RTTV values and U-values on the planted and non-planted roofs. Building RTTV is one of the determinants of building efficiency in several simulation tests that have been carried out on different objects (Carbone et al., 2014; Costanzo et al., 2016; Herrera et al., 2018; Stovin et al., 2017; Van Renterghem et al., 2013). The simulation test is actually not the only research method, but for the purpose of discussing energy based on obtaining RTTV values, this method feels very helpful because it is more efficient in terms of time and energy.

An important finding obtained from this study is the difference in the value of RTTV and OTTV in green roofed buildings with green or conventional roofed buildings. A significant reduction in numbers reaching almost 50% is a very useful finding. The decrease in RTTV was mainly obtained by the presence of a green element placed on the roof, so that with the decrease in the value of RTTV into an energy-efficient building according to SNI 6389-2011 standard. This study corroborates several findings that have been made by other researchers related to building energy efficiency (Altomonte et al., 2017; Baraldi et al., 2019; Shafique et al., 2018).

The benefits to the environment can be obtained from this study because the value of heat circulation that can be reduced, this study reinforces previous research on efforts to reduce regional heat or urban heat island (Ambrosini et al., 2014; Carvalho et al., 2017; MacIvor et al., 2016; Vera et al., 2018).

The simulation results show a very satisfying difference from the U-value between corrugated zinc roof, concrete roof and planting roof (Figure 25).



**Fig. 25.** Comparison of Uvalue on the roof of the model

U-values on planted roofs provide substantial reductions, on average reaching more than 80%. For corrugated zinc roof from 5.05 W/m<sup>2</sup>K down to 0.62 W/m<sup>2</sup>K, which means a decrease for up to 87.72%.

Meanwhile, the comparison between concrete roofs and planted concrete roofs has decreased to 89.44%. The results of this simulation test concluded that there was a significantly high decrease, in that further research was needed through experiments. Research with Ecotect simulation turned out to be able to show the evaluation of thermal performance in buildings with green roof applications, as well as research with other software simulations i.e., Envimet (Ambrosini et al., 2014; Gaspari & Fabbri, 2019; Rakotondramiarana et al., 2015), Energyplus Chan, 2018; Gargari et al., 2016; Owruk et al., 2015), CFD (Aly et al., 2017; Ge et al., 2019; Gromke et al., 2015; Park et al., 2016; Qin et al., 2018; Rafael et al., 2018).

## CONCLUSION

Green roofs in low-rise residential buildings could reduce heat both indoors and outdoors in a simulation test using Ecotect 2011 software. The results obtained in the research analysis concluded that the temperature difference that can be reduced by plant elements on the roof was also able to provide a decrease RTTV value of the building. Comparison of RTTV calculations obtained on a roof without plants which is 39.54 W/m<sup>2</sup> decreased to 21.44 W/m<sup>2</sup> with a gap of 18.1 W/m<sup>2</sup> as a quite significant gap. Whereas based on SNI 6389-2011, energy efficient building category is required to have a maximum RTTV 35 W/m<sup>2</sup> in that the green roof on the residential building in the experimental model carried out is influential in the energy efficiency of the building.

Research on green roofs in low-rise residential buildings in urban areas in the humid tropics with the Ecotect simulation test method reveals findings that are very useful for energy management in buildings. However, in conducting research with this simulation test method it was found that there were some obstacles in entering material data that were possible to have different values between the data from simulations and real data in the field. Therefore, the study recommends the need for further evaluations in experimental methods with measurements in the field.

## ACKNOWLEDGMENT

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