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Simulation Modelling of Roof Design of Indonesian Airport Terminal For Optimal Utilization of Cooling Energy

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ABSTRACT

The airport terminal is one of buildings with complex energy needs. Most of the airport terminals in Indonesia are designed with regional architectural features, such as pitched or joglo roofs and exterior wall materials made of brick with paint finish. The new airport is designed with modern architectural characteristics with flat and curved roofs and outer walls made of Aluminum Composite Panel (ACP). The difference of shape, material, and the size of fenestration affects the thermal performance of the building and affects the cooling energy used. The purpose of this study is to evaluate the influence of roof designs on airport terminals in Indonesia that have different characteristics on the use of cooling energy. The effect of roof design on cooling energy analyzed by using Design Builder simulation. The simulation results show that the combination of red tile pitched roof and flat concrete roof with insulation in airport terminal building with Indonesian characteristics has the lowest cooling energy performance.

Key Words: Airport, Building Envelope, Cooling Energy, Roof Design, Simulation Modelling.

1. INTRODUCTION

The International Energy Agency reports that global improvements in energy efficiency have declined by 2015 (IEA, 2021). Direct and indirect emissions from commercial electricity and heat used in buildings rose to 10 GtCO2 in 2019, the highest level ever recorded. As a result, the intensity of energy normalization only increased by 0.8% in 2020, for 2019 (1.6%) and 2018 (1.5%).

One of the buildings with complex energy requirements is airport. Air conditioning systems, lighting, electrical equipment and other energy are needed to accommodate the facilities and comforts in airport area. Previous research at Seve-Belleros Santander airport, Spain on energy needs at airport explains that the number of air operations over the last 20 years has increased rapidly and lead to an increase in energy demand [1]. (Alba & Mañana, 2017). The airport terminal area (land side) is the largest energy consumer because of its function as a point for processing passengers and cargo as well as many facilities required for its operation. Previous research on HVAC system at Soekarno Hatta airport explained that the usage of energy for chillers at Soekarno Hatta airport terminals 1A, 1B, and 1C in the check-in and arrival areas of terminals 1A, 1B, and 1C was allocated to reach a temperature of 24.3 - 26 ^{o} C and humidity 51.7-72.5% [2]. (Husodo & Siagian, 2014). One of the key aspects of airports energy efficiency is through building envelope [3]. (R Lau et al., 2010). Poorly designed building envelope will affect occupant comfort and heating, cooling and ventilation. The "smart" building envelope is the outer layer of the building which is designed through a special process for the ability to adapt the challenges posed by interior and exterior conditions using a minimum of energy [4]. (Olgyay, 1963).

The design of airport building envelopes in Indonesia has different sizes, shapes, areas, and characteristics in each region. Most airports in Indonesia were designed with regional architectural characteristics that characterize tropical architecture, such as pitched or joglo roofs, with painted plaster brick wall facades and red tile roof coverings and hallways at the front with wider and higher building size . The last few years PT. Angkasa Pura has made changes and develop new airports, such as: Soekarno Hatta airport terminal 3 (Tangerang), Kualanamu airport (Deli Serdang), Mozes Kilangin airport (Timika), Sultan Hasanuddin airport (Makassar), Juanda airport terminal 2, and others. New airport is designed with shape, materials, and building envelope which have modern international architecture characteristics with a flat or curved roof, large glass wall facade, Aluminum Composite Panel (ACP) material, and a wider and higher building size.

The heat transfer in the building envelope may occur through walls, roofs and glass/ windows [5]. (Hall & Allinson, 2010). Therefore, dfferences in roof design and material can affect the thermal performance of buildings and eventually affect the requirement of cooling energy. The effect of roof shape and material on building thermal performance and cooling energy has been studied by (Al-Saadi, 2006), (Čanda & Kopecký, 2021), (Akbari & Konopacki, 1998), (Dixit et al., 2018) [6-9].. Previous research on the design of building envelopes for thermal comfort and reducing cooling energy in residential buildings by comparing various types of concrete roofs in hot-dry and hot-humid climate in Riyadh and Dhahran, Saudi Arabia explained that the roof should be painted with smooth and light color to reflect the solar radiation (Al-Saadi, 2006). Another research on thermal performance of roofs that is suitable in tropical climate was conducted by comparing experimental models metal roofs with different colors and natural insulation, such as reed insulation board and unburn earth board explained that the roof with ventilated air gap and white paint are the best combination to reduce heat [7]. Similarly, the research on impact of reflectivity and emissivity of roofs on building cooling and heating energy used, explains that the white reflective roofs reduce cooling energy consumption by 18-26% and by 28-35% in peak demand [8]. The other research to evaluate thermal performance of roof slabs with different insulating material (Coconut Shell, Fly Ash, Jhama, Brick Bats) explained that roof slab with glass fibre could provide temperature reduction in the room about 6.17^{o} C [9]

This study aims to determine the influence of airport terminal roof design in Indonesia which has regional and modern characteristics on cooling energy by comparing different roof shape and material. Three simulation model, V1 (Pitched or joglo roofs with red roof tiles material and flat concrete roof), V2 (metal roof with 5^{o} angle), and V3 (curved metal roof) were simulated to evaluate the thermal performance and cooling energy.

2. RESEARCH METHOD

This research is an experimental research using computer-based simulations strategy [10]. The simulation software used in this research is Design Builder.

2.1. Base case model

The base case model in this study is Juanda airport terminal 1 which represents an airport terminal building that has Indonesian characteristics. The simulation is limited to the departure terminal with the size of the main building outside the corridor 150 x 68 m. In Design Builder simulation, the pitched and joglo roof were simplified. Figure 1 shows the picture of Juanda airport terminal 1. Figure 2 shows the site plan of Juanda airport terminal 1. Figure 3 shows the perspective of the arrival terminal at Juanda airport.

Figure 1: Juanda airport terminal 1
Source: researcher and google.com (2022)

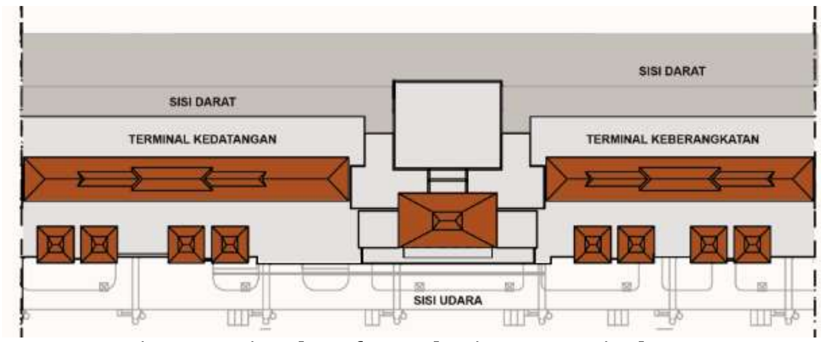

Figure 2: Site plan of Juanda airport terminal 1

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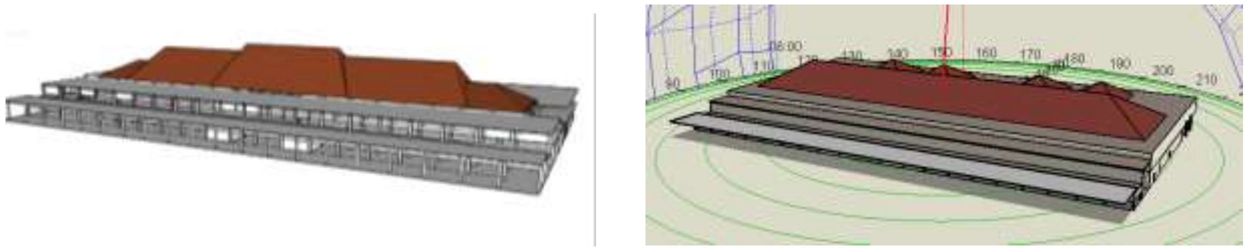


(a) (b)

Figure 3: The perspective of the existing arrival terminal (a), simplification of the basic model in the Design Builder (b)

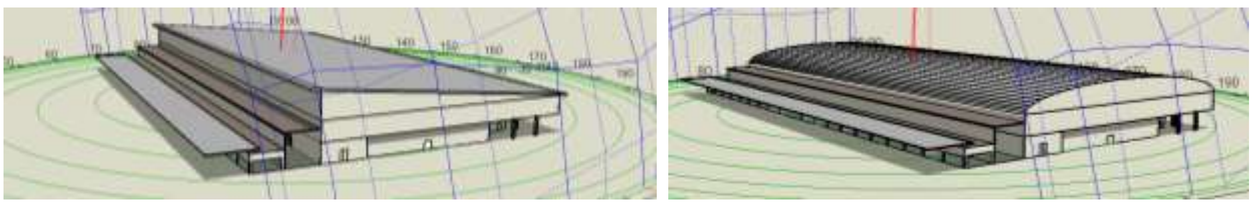
To determine the energy performance of the building envelope, the internal heat gain data are set to be same in each simulation model. The number of airport visitors per day is set at 8837 people/day according to the data from Central Statistics Agency/ *Badan Pusat Statistik* (BPS) in January-February 2022. The density value per m^2 (occupation density) is 0.83 people/day. Activities carried out by terminal visitors are check-in activities, standing, walking, and doing light work, 160 W/m^2 with metabolic factor value of 0.9. Internal heat gain obtained from lighting for airport terminal check-in area is 12 W/m^2 and gate lounge area is 15 W/m^2 and from electronic equipment is 5 W/m^2 [11]. Air conditioning machine in simulation is set to a temperature of 25^oC and operated from 04.00-21.00.

2.2 Model variations

Base case model in simulation are varied into different variations of roof. Simulation models V1 (metal roof with an angle of 5 ^{o}) and V2 (metal roof with a curved shape) which represent the characteristics of modern airport terminals. The material and thermal characteristics of the simulation model variations in the Design Builder can be seen in table 1. The roof shape of the simulation model variations 1 and 2 in the Design Builder is shown in Figure 4.

Table1. Variation simulation model

Model variation	Description	U value (W/m^2K)	Thermal Resistance (m^2K/W)
Base case (Combination of pitched roof with 30^o angle and red tile material and flat concrete roof)	Roof tile 17 mm + airgap 50 mm + bitumen felt/ sheet +plywood 15 mm + glass fibre/ wool 50 mm	0.525	1.906
	Rowel pea gravel concrete 60 mm + insulation polysterene 25 mm + waterproofing +120 mm beton/ concrete	0.634	1.577
Model variation 1 (V1): metal roof with 5^o angle	Metal roof 10 mm + glass fiber insulation 48.7 mm + metal surface 1 mm.	0.786	1.273
Model variation 2 (V2): curved metal roof	Metal roof 10 mm + glass fiber insulation 48.7 mm + metal surface 1 mm.	0.786	1.273



(a) (b)

Figure 4: Simulation model of variation 1 (a), and simulation model of variation 2 (b)

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3. RESULTS AND DISCUSSION

The simulation results shown that the changing of the shape and roof material in base case model has influence on cooling energy consumption. The simulation model of variation 2 (curved metal roof) uses the highest cooling energy. Changing the shape of the roof from the basic model to variation model 1 and 2 provides an increase in cooling energy of 0.6% and 0.7%. Figure 5 shows the cooling energy in the simulation model.

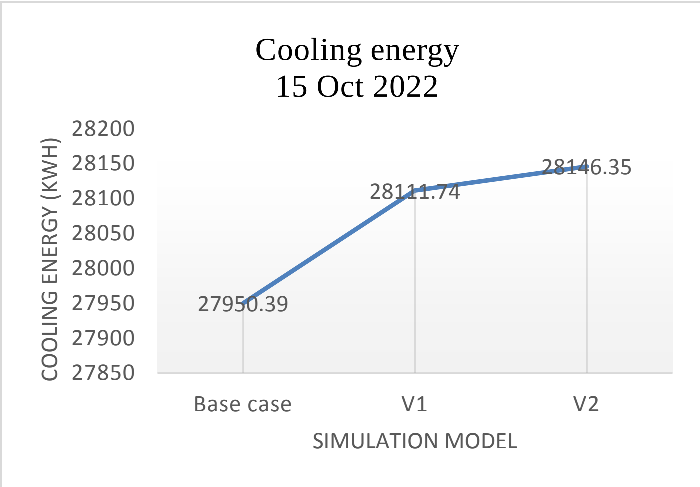
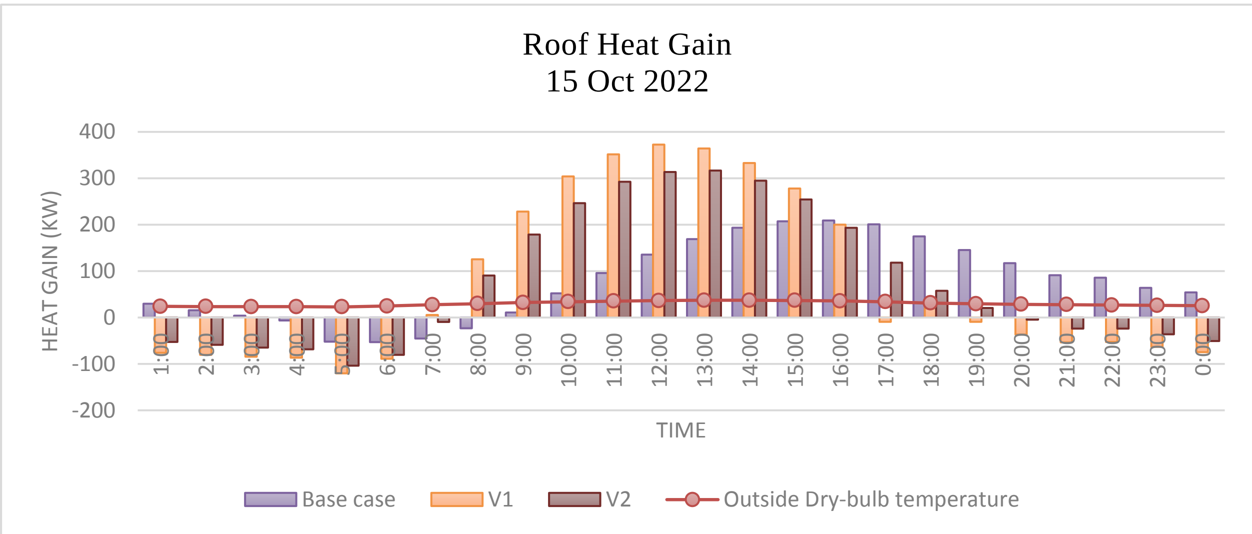


Figure 5: Cooling energy in simulation model

Roof tile material in base case model has lower U-value than metal roofing materials in variations 1 and 2, which is 0.525 W/ m2-K and a thermal resistance of 1.906 (m2K/W). Variation model 1 and 2 have a higher U-value (u value) than base case model, with U value 0.786 W/ m2-K and thermal resistance of 1.273 (m2K/W). The U-value represent the rate of heat transfer through the elements of a building material in a certain area. The lower U-value means the building material reduces heat transmission more effectively. The difference of 0.633 m2K/W in thermal resistance of base case model and variation model 1 gives a difference in energy consumption of 161.35 kWh or 0.6% per day. This is in line with previous research on the design of building envelopes for thermal comfort and reducing cooling energy in residential buildings comparing various types of concrete roofs with various U-values and thermal resistance (Al-Saadi, 2006). Base on that study, increasing the thermal resistance values of 1.5, 2.6, and 3.5 times provided a reduction in energy consumption for cooling and heating by 0.1%, 0.9% and 1.2% of buildings in Dhahran, Saudi Arabia. The result of heat gain on the roof and walls of each simulation model is shown in Figure



(a)

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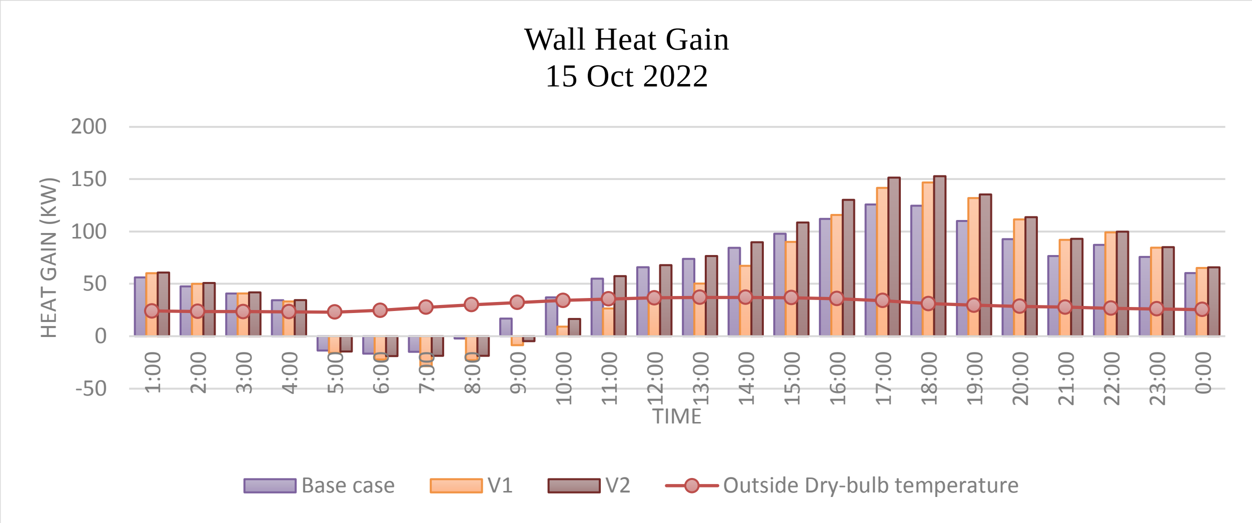

(b)

Figure 6: Heat gain on roof (a) and walls (b) of each simulation model

Changing the roof shape on variation model 1 (metal roof with an angle of 5 ^{o}) to variation model 2 (curved metal roof) provides an increase in energy use of 34.61 kWh/day. Previous research on thermal performance for non air conditioned building which compared the performance of vaulted roof and flat roof explained that vaulted roofs receive more heat gain than flat roofs, as a result of more solar radiation being absorbed by the roof surface (Tang et al., 2006). However, at night, the heat loss from an arch roof is much higher than from a flat roof, and the daily net heat gain from an arch roof is less than that of a flat roof so that such a roof shape is suitable for hot dry areas with greater fluctuations in air temperature. Although the roof heat gain in variation model 1 is higher, the higher wall heat gain on the curved metal roof (variation model 2) affects the cooling energy used.

Furthermore, the roof emissivity affects the use of cooling energy. The US Department of Energy explains that unpainted metal roofing is a poor heat generator than painted metal (US Department of Energy, 2022). Previous research on the impact of reflectivity and emissivity of roofs on building cooling and heating energy used, explains that the thermal emissivity of roofing materials can have an effect on the use of heating and cooling energy (Akbari & Konopacki, 1998). A roof with low emissivity will cause a higher roof temperature. Coating the roof with white paint will reduce cooling energy consumption by between 10% and 50%, depends on the thickness of the insulation under the roof.

4. CONCLUSION

Changing the shape of the roof from the base case model to variation model 1 and 2 provides an increase in cooling energy of 0.6% and 0.7%. The increase in cooling energy occurs due to the addition of heat from the environment that enters through the building envelope, especially the roof. The shape and thermal properties of the roofing material, U value, and thermal resistance (R) affect the cooling energy used in airport terminal buildings. The combination of red tiles roof and flat concrete roof that has lower U value and higher R value in airport terminal building with Indonesian characteristics has the lowest cooling energy. In addition, coating the roof with white paint will reduce cooling energy consumption by between 10% and 50%, depending on the thickness of the insulation under the roof.

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