International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 6
ISSN: 2088-5334

Numerical Analysis of the Roof Slope Effect on the Building Thermal Comfort and the Need for Roofing Materials in Tropical Area

Remon Lapisa [a,b,*], Arwizet [a], Krismadinata [a,b], Andril Arafat [a], Aprizal Saputra [a], Zaid Romani [c]

[a] *Faculty of Engineering, Universitas Negeri Padang, Jl. Dr Hamka Air Tawar, Padang, 25131, Indonesia*
[b] *Centre for Energy and Power Electronics Research (CEPER), Universitas Negeri Padang, Padang, 25131, Indonesia*
[c] *National School of Architecture of Tetouan, Av. Baghdad, Touabel Soufla Tetouan, 93040, Morocco*
*Corresponding author: *remonlapisa@ft.unp.ac.id*

***Abstract*—Roof is the most affected building envelope element by local climate changes such as solar radiation, rain, wind, etc. The design of a building's roof will have a significant impact on the building's thermal conditions and comfort. This study aims to numerically analyze and optimize the slope of a gable roof on an 8 m × 12 m residential building with 3 m walls located in a tropical climate region. The parameter analyzed in this parametric study on galvanized steel gable roofs is the slope angle impact in the interval between 15^0 to 45^0, with an angle increment at 5^0. The thermal aspect of the analyzed building is modeled numerically using the TRNSYS simulation tool coupled with CONTAM for aerodynamic modeling. The results showed that the greater the roof slope angle, the more comfortable the room condition was due to the amount of heat release that occurred in the attic zone before penetration into the occupation zone. Otherwise, the greater the angle of inclination, the greater the roof geometry that leads to construction material addition for the frame and roof covering. Therefore, it is necessary to perform numerical analysis to determine the optimal slope of a gable roof that provides maximum thermal comfort in a room with low roofing material requirements. Analysis and optimization of convective heat dissipation from the attic zone through natural ventilation or infiltration to reduce indoor thermal gain is an outlook for further research.**

***Keywords*— Slope of gable roof; residential building; thermal comfort; roofing material; tropical climate region.**

Manuscript received 15 Sep. 2021; revised 8 Oct. 2021; accepted 24 Feb. 2022. Date of publication 31 Dec. 2022.

I. INTRODUCTION

The residential building is a significant sector in human life because 90 % of human activities are indoors [1]. Therefore, a building must be designed properly considering some requirements. Considering the geographical conditions and potential for disaster in the Indonesian region, a good building design must meet certain obligatory requirements, including safety, building function, comfort, health, economy, aesthetics, etc. [2]–[4]. In building design development, the building envelope is a crucial element that must be engineered to meet the concept of a sustainable bioclimatic building that is environmentally friendly, comfortable, and safe for residents. Compared to other envelope elements, the roof is the most affected part of the building by changes in local climatic conditions. The building roof is exposed directly to the outside air and has the most thermal interactions with the surrounding environment, such as; solar radiation, rainwater, wind, outside air temperature, etc. For reasons of comfort, the roof must consider climatic conditions. For equatorial and tropical climate regions with high temperatures and air humidity, the roof design should be able to reduce heat transfer from outside to the occupation zone.

Gable and hipped roofs have been popularly used in tropical areas like Indonesia for a long time [5], [6]. These roofs are widely used in Indonesia due to several advantages compared to other roofs, including more simple construction, faster and easier work, less material usage, reduced heat flux across the roof [7]–[9], etc. In tropical areas with high rainfall intensity, the gable roof is a suitable option to accelerate rainwater disposal to prevent leakage and help collect rainwater optimally for other domestic purposes [10], [11]. In addition, the gable roof has an attic zone that functions as a thermal resistance to reduce the penetration of solar radiation heat into the occupation zone. The higher the roof slope angle, the greater the air volume in the attic and the cooler the air in the occupation room [12]. In the gable roof type, the other two triangular sides of the roof, aside from the sloping side, are separated by wall materials such as bricks, multiplex, or zinc sheet as a cover or left open. However, to maximize the cooling effect, the vertical walls of this triangle are often left uncovered as air infiltration channels to evacuate excess heat trapped in the attic zone [13], [14].

One of the substantial materials used as roof coverings in residential buildings in Indonesia is galvanized steel/zinc - roofing. For tropical climates, roofs with galvanized steel material are very popularly used for residential houses [15], [16]. Galvanized steel roofing presents several interests, including inexpensive, simple, and obtainable on the market, easy and fast installation process, low maintenance, etc. [15], [17]. However, the use of galvanized steel harms the comfort of its high coefficient of conductivity and thermal capacity that can absorb and distribute more heat to the room below [18]. To minimize the heat penetration of the galvanized steel roofs, the air volume in the attic zone must be increased. This increase in air volume can be obtained by adjusting the roof slope to the horizontal line. The higher the slope of the roof, the greater the air volume, and the occupation zone's temperature will be more comfortable. In addition, results of previous research show that several passive cooling techniques for thermal comfort are very applicable to be implemented on roofs: installation of cool roofs [19], solar chimney [20], thermal stratification effect [21], [22], use of natural materials for roofs [23], natural ventilation through skylights [24], insulation material [25], etc.

This numerical study aims to analyze the effect of the slope of the gable roof on the thermal comfort and roofing material requirements of a residential building in a hot-humid tropical climate region. In this study, the gable roof slope varied from 15^0 (flat roof) up to 45^0 (sloped roof). The thermal comfort of the building is analyzed with indicators of operative temperature and degree hour thermal discomfort (*DH*). In addition, the material requirements for the roof are calculated based on the number of iron channel plates for the frame and galvanized steel roof covering plates required due to changes in the slope. The methodology and results of the numerical simulation analysis in this study are expected to contribute significantly to optimizing the gable roof slope design in residential buildings, especially for tropical areas with hot climates.

II. Materials and Method

A. Building Characteristics

A residential building used as the object of this numerical study is an 8 m × 12 m with a 3.5 m height. The walls of the building are made of 15 cm thick bricks, and the ground floor is made of concrete covered with ceramic tiles located directly on the clay soil. To simplify the numerical analysis, the building is considered to have a homogeneous temperature throughout the room. The roof of the building is made of a steel frame with a covering made of galvanized steel. A 3 mm thick tin roof is installed on both sloping sides facing east and west. On the main facade of the building, the walls are fitted with windows as a source of natural lighting and air ducts in the natural ventilation system. The main facade is directed toward the south to minimize the unwanted solar heat gain in the equator areas. The thermal characteristics of the reference building envelope material can be seen in Table 1.

TABLE I
THERMAL CHARACTERISTICS OF BUILDING ENVELOPE MATERIALS

Element	Material	*h*	*K*	*C*	*ρ*
Wall	Plastered clay brick	150	0.82	0.8	1,826
Roof	Zinc-steel framing	3	407.9	0.38	7,135
Ground	Concrete slab	50	5.04	1	2,350
	Ceramic tile	15	4.32	0.8	1,800
Ceiling	Plywood board	3	0.54	1.2	680

Note: *h* is thickness of material (mm), *K* is thermal conductivity ($W.m^{-1}. K^{-1}$), *C* is thermal capacity ($kJ.kg^{-1} K^{-1}$) and *ρ* is density ($kg.m^{-3}$)

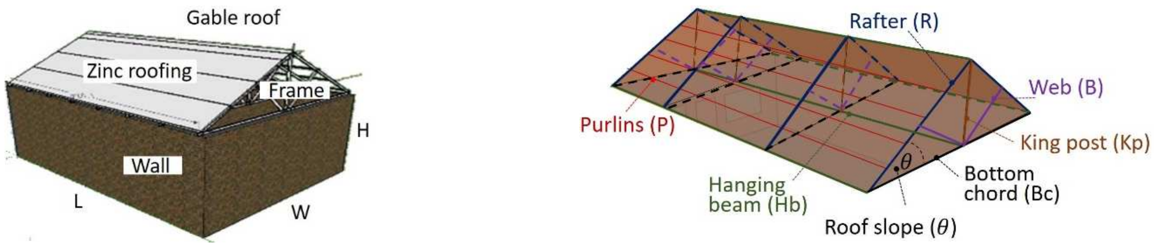
B. Gable Roof Design

The residential buildings analyzed have a gable roof type (Figure 1.a). As a reference, residential buildings often found in Indonesia have about 20^0-30^0 gable roof slopes [26], [27]. The truss framing for the gable roof is made of steel frames with several roof elements such as; (a). King post (*Kp*), the mainframe pole as a support for the overall roof load [28], (b). Bottom chord (*Bc*), the horizontal bar on which the Kingpost sits, (c). Hanging beam (*Hb*), the horizontal rod installed along with the building as support for the Kingpost, (d). Webs locking rod (*B*), to prevent the rafters from moving, (e). Rafter (*R*), a roof supporting rod installed in the direction of the width of the building depending on the angle of the roof slope [29], (f). Purlins (*P*), the rods on which the roof layer is attached. For roof construction without hanging up parts, the length of the hanging beam and purlins is identical to the length of the building (*Hb* = *P* = *L*), and the length of the bottom chord is identical to the width of the building (*Bc* = *W*). In this case, all elements of the roof frame have the same size and material, that is C75 × 0.6 mm canal steel truss rods with a length of 6 m. The distance between the kingpost rods for this building is 2 m. For a fixed building length of 12 m and a distance between frames as far as 2 m, then the manufacture of the roof truss requires 1 (one) hanging beam element and 3 (three) other rods along the hanging beam placed on the left and right walls and the rooftop, 7 (seven) kingposts, 7 (seven) bottom chords, 14 rafter pieces, 14 webs, and 10 to 12 purlins. Changes in the roof slope affect the length of all roof elements except the hanging beam and bottom chord. In addition, with a 1-meter distance between purlins, the number of purlins attached to the rafters will depend on the roof slope. The required length of the Canal C75 × 0.6 steel-bar truss (L_{FR}, in m) is calculated by: $L_{RF} = (4 \times H_b) + 7 \times (B_C + K_P + 2.R + 2\,B) + n \times P$. Where *n* is the number of purlins installed on the rafters calculated by the equation $n = \text{roundup}\left(0.5.W/\cos(\theta)\right)$. After simplifying the equation, the change in the length of L_{RF} to the θ function can be calculated using Eq. 1.

$$L_{RF} = L \times (4 + n) + 7.W \times \left(1 + 0.5.\tan(\theta) + \frac{1.5}{\cos(\theta)}\right) \quad (1)$$

$$S_{Roof} = \frac{L \times W}{\cos(\theta)} \quad (2)$$

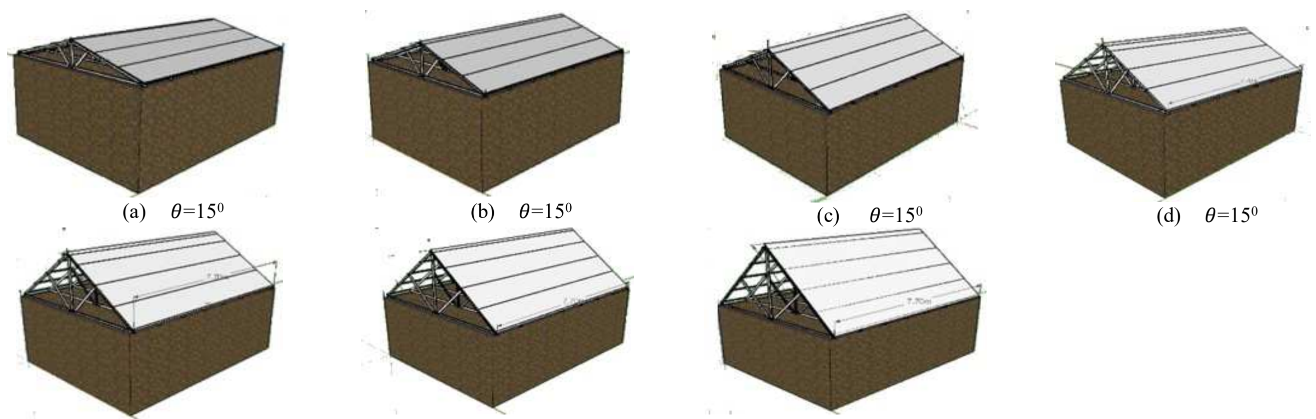
Where L is the width of the building (m), n is the number of purlins, θ is the angle of the roof slope measured from the side of the building, as shown in Figure 1.b. For example, for a reference building with a roof with a 30^0, slope angle, by using the Eq. 1 dan Eq. 2, then the required length of steel bar (L_{RF}) is 277.2 m (equivalent to 47 steel-bar trusses C75×0.6 with 6 m length) and 111 m^2 (equivalent to 66 pieces of 800 mm × 2100 mm galvanized steel sheets).



(a) (b)

Fig. 1 The prototype of the analyzed building: a. 3D building Presentation, b. Gable roof construction with truss roof framing

For a parametric study, in this research, seven types of variations in the slope angle of the gable roof are determined in Figure 2. This study analyzes the effect of the roof slope angle on the room's temperature and comfort compared to the roof weight and the amount of material required. Geometrically, changes in the roof angle will affect the roofing surface area, the number of steel frames used, etc. (Table 2). The data relating to the characteristics of each type of roof can be seen in Table 2. A roof with a 15^0 slope will look like a flat roof (Figure 2.a). With a 15^0-slope angle, the required material will be less than other roof angles (Table 2). Meanwhile, at a 45^0 angle, the demand for material will increase, and so will the volume of air in the attic zone (Figure 2.g).



(a) θ=15^0 (b) θ=15^0 (c) θ=15^0 (d) θ=15^0

(e) θ=15^0 (f) θ=15^0 (g) θ=15^0

Fig. 2 Studied residential buildings with different roof slopes

C. Building Numerical Model

This study developed the numerical model using several simulation software: Google Sketch-Up, TRNSYS, and CONTAM. Design and building geometry sizes drawings were made using Google Sketch-Up. Defining the thermal characteristics of the building envelope, such as roofs, walls, floors, windows, and others, is done using the TRNSYS software. In this software, the user can set the thermal properties of the materials, such as; thermal conductivity, thermal capacity, density, solar and thermal reflectance, thermal emissivity, etc. The building is considered to have the same thermal zone where the air temperature throughout the room is similar. In addition, by using TRNSYS, the user can set the amount of thermal gain obtained by indoor air from various heat sources such as heat from solar radiation, heat from artificial lighting, occupants, and other technical equipment. The heat transfer from the heat source to the interior air and the inner wall surface can occur by conduction, convection, and radiation. CONTAM software functions to model the aerodynamic processes between the building and the environment (infiltration, natural ventilation, air coupling between zones, etc.). The input data from the TRNSYS output (air pressure and temperature in the zone) is needed to calculate the amount of airflow that flows through openings such as windows, air leakage, doorframe jamb gaps, etc. For floors and soil, the heat transfer is solved using Type 49 in TRNSYS, which uses the Kusuda equation in determining the soil temperature profile at a certain depth [30], [31]. The coupling between TRNSYS and CONTAM can be seen in Figure 3 below:

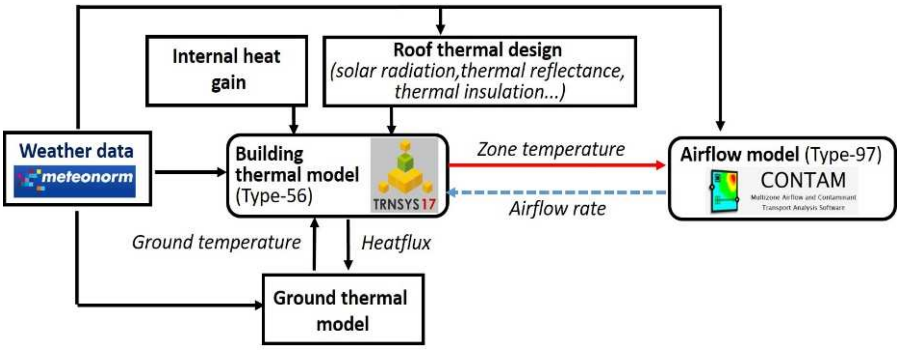


Fig. 3 Coupled simulation model between TRNSYS and CONTAM in the building model [19]

D. Parametric Study and Analysis

The analyzed parameter in this study is the effect of the roof slope angle on two aspects: the thermal comfort of the building and the amount of material used for the roof. In addition, it will also affect the construction cost. We need to check several indicators in analyzing room thermal comfort, including room temperature profile and degree hour of thermal discomfort (*DH*). In calculating Degree hour thermal discomfort (*DH*), the operative temperature depends on the indoor air temperature and the mean radiant temperature due to the influence of the entire inner surface of the building envelope. *DH* value is calculated using Eq. 3.

$$DH = \sum_{i=1}^{8760}\left(T_{Op,i} - T_{Comf}\right), \quad \text{for } T_{Op,i} > T_{Comf} \qquad (3)$$

Where $T_{Op,i}$ is the operative temperature at the i^{th} time, T_{Comf} is the maximum limit of the comfort temperature that the occupants can still tolerate, and i is the sequence of hours in one year from 1 to 8760. For areas with hot and humid climate conditions like Indonesia, the value of T_{Comf} is 27 ^{0}C as regulated in the thermal regulation of SNI 03-6197 2000 [32]. The effect of the slope angle of the roof gives the opposite effect for the two aspects above. The most reasonable roof slope angle for the tropics will be determined by considering the thermal discomfort (*DH*) conditions and the less roofing material.

E. Climate Characteristics

This research was conducted in Padang at 100.35 E and 0.95 S. Padang is the largest city in the western part of Indonesia (Figure 4.a). Based on the Köppen climate classification [33], [34], Indonesia is in an area with a tropical climate (Figure 4.b). Similar to other regions in Indonesia, Padang has wet-humid climate characteristics [35]. Therefore, Padang's average outdoor air temperature is 26.8 °C with a maximum temperature of 34.1 °C [19]. As the location is in a coastal area, the humidity and rainfall in the city of Padang are high. High humidity and rainfall intensity can affect the condition of thermal comfort in the building room. The average solar radiation in Padang is 386.5 W.m^{-2} with a maximum value of 1055 W.m^{-2}. Located at the equator, the intensity of solar radiation in this city is almost constant throughout the year [19].

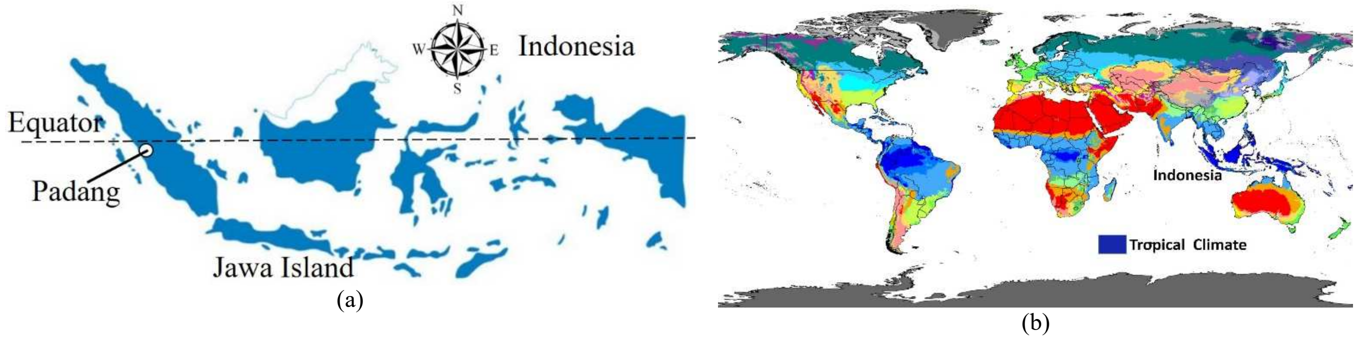


Fig. 4 Map of Padang located in the western part of Indonesia [19], (b) Köppen climate classification: tropical in blue colors [33]

III. Result and Discussion

A. Effect of Roof Slope on Building Temperatures

As the roof is in the attic zone, the air temperature in this zone is strongly influenced by the magnitude of the roof slope angle. The profile of air temperature in the attic zone for three consecutive days due to changes in the roof slope angle is shown in Figure 5. The graph shows a significant effect on changes in air temperature due to changes in the inclination angle. The bigger the inclination angle of the roof, the higher the roof position, the greater the air volume in the attic zone. The increase in air volume will reduce convective heat transfer impact from the roof to the air. Significant temperature changes occur during the day when the galvanized steel plate absorbs much solar radiation. At night the air temperature in the attic zone looks almost identical (Figure 5). For roofs with a small slope angle (15^0), the air temperature in the attic zone reaches a maximum value of 45.1 ^{0}C on April 13 at 2 p.m., when solar radiation has the highest intensity. This maximum temperature decreases intermittently, along with adding the roof slope angle. For the roof tilt angle of 45^0 (tilted roof), the maximum temperature during the day decreases by 2.6 ^{0}C and reaches 42.5 ^{0}C (Table 2). It proves that the farther the position of the heat source (in this case, the roof) from the room, the lower the room's temperature. That is why the room temperature in buildings with higher ceilings will be colder than buildings with lower ones.

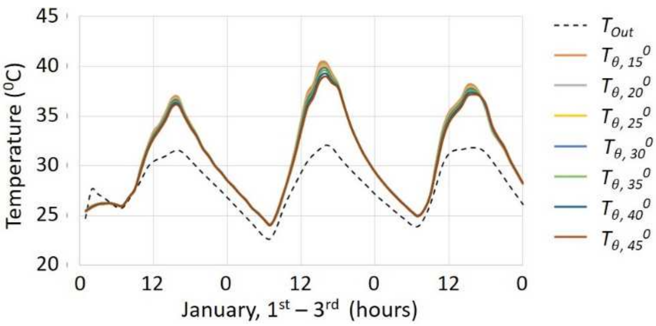


Fig. 5 Air temperature profile in attic zone based on roof slope angle for 3 consecutive days

Furthermore, it is necessary to analyze the effect of the slope angle of the gable roof on the operative temperature and thermal comfort of the occupied zone. In this study, the attic and occupied zone have a 3 mm plywood board ceiling in between (Table 1). The ceiling reduces heat transfer by radiation and convection from the building roof and another heat source with air in an occupied room. The high thermal resistance of the plywood ceiling can significantly reduce the heat penetration from the attic to the occupied zone. Therefore, the significant effect on air temperature changes in the attic zone due to changes in roof slope angle does not significantly change the operative temperature in the occupied zone of the building (Figure 6). The graph shows that the change in the roof angle from 15^0 to 45^0 reduces the maximum operative temperature of the occupied zone (T_{Op}) from 35.04 ^{0}C to 34.8 ^{0}C (-0.24 ^{0}C).

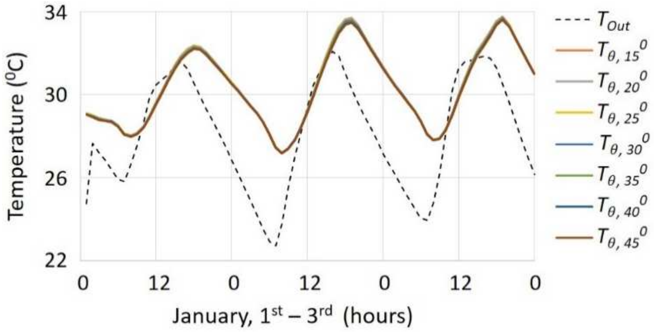


Fig. 6 Operative temperature profile of zone for different roof slope angle for 3 consecutive days

B. Effect of Roof Slope on Roof Geometry and Roofing Material Requirement

Changes in the angle of the roof slope will affect the geometry of the gable roof. Some roof truss elements that will need length adjustments are king posts (equivalent to roof height), rafters, webs, and the number of purlins. Otherwise, the hanger beam, length of purlins, and bottom chord remain constant even if the roof slope angle changes (Figure 1.b). Table 2 presents changes in roof geometry due to roof slope angle variation. When the slope angle changed from 15^0 to 45^0, then; the roof height increased from 1.07 m to 4 m, the rafter length increased from 4.14 m to 5.66 m, Web's length increased from 2.07 m to 2.83 m. The roof dimensions change the attic volume from 51.5 m^3 to 192.1 m^3, and the roof covers the surface area from 99.4 m^2 to 135.8 m^2. The increase in geometric shape causes an increase in the need for roof truss materials. The required steel-bar trusses increased from 43 bars to 54 bars. The need for the roof covering galvanized steel plates also added from 60 sheets to 81 sheets (Table 2).

TABLE II
THERMAL CHARACTERISTICS OF BUILDING ENVELOPE MATERIALS

Characteristics	**Unit**	**Roof Slope Angle**						
		15^0	**20^0**	**25^0**	**30^0**	**35^0**	**40^0**	**45^0**
Geometry characteristics								
Height of roof (King post)	m	1.07	1.46	1.86	2.31	2.80	3.36	4.00
Number of Purlins (n)	-	5	5	5	5	5	6	6
Rafter (R)	m	4.14	4.26	4.41	4.62	4.88	5.22	5.66
Webs (B)	m	2.07	2.13	2.20	2.31	2.44	2.61	2.83
L_{RF}	m	258.5	263.6	269.7	277.2	286.2	309.2	322,8
Number of steel-bar truss	-	43	44	45	47	48	52	54
Roof surface (S_{Roof})	m^2	99.4	102.2	106	111	117.2	125.4	135.8
Number of galvanized steel / zinc plate	-	60	61	63	66	70	75	81
Volume of Attic zone	m^3	51.5	69.9	89.6	111	134.5	161.2	192.1
Thermal characteristics								
Max T_{Air} (attic zone)	^{0}C	45.12	22.80	44.35	43.93	43.50	43.03	42.51
Max T_{OP} (occupied zone)	^{0}C	35.04	35	34.96	34.92	34.88	34.84	34.80
DH thermal discomfort	^{0}C.h	22.982.3	22.844.1	22.703,8	22.531,9	22.345,3	22.146,7	21.931,8

C. Optimum Slope Angle of the Roof

The slope angle of the roof has a contradictory effect on two aspects of the building: (a) building temperature-thermal comfort and geometry-material requirements for the roof (Figure 7). In the thermal context, increasing the roof slope angle will reduce the temperature in the entire building (the air temperature in the attic zone and operative temperature in the occupied zone).

The decrease in operative temperature positively impacts the thermal comfort conditions for occupants. The thermal discomfort level (*DH*) decreased from 22.982.3 ^{0}C.h to

21.931.8 ^{0}C.h (-4.6 %) when the slope angle changed from 15^0 to 45^0 (Figure 7). Although not very significant, the decrease in DH's value is enough to impact the occupants. As the *DH* value can increase the energy demand for the air conditioning system, decreasing the *DH* value can reduce the annual accumulation of hourly temperature in the occupied zone accumulatively in one year by 1050 ^{0}C.h.

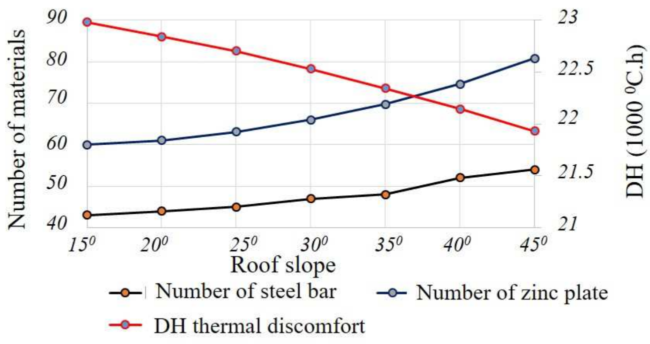


Fig. 7 The effect of the roof slope on the amount of steel rod and galvanized steel plate needed and the value of *DH* thermal discomfort

On the other hand, an increase in the slope angle will increase the size of the roof geometry. A roof with a 45^0- slope angle will be 3.7 times higher than a 15^0- angle slope. As the rooftop height increase, several other elements also need adjustments, such as rafters and webs. The increase in roof geometry causes an increase in material requirements in forming the roof frame and cover. The graph in Figure 7 shows that the change in roof geometry increases the number of trusses needed by 25.6 % and galvanized steel plates by 35 %. The additional amount of this material affects two other aspects: increasing construction costs and increasing the total roof weight. Besides, for earthquake-prone areas, it is expected that the building has a lighter roof construction to avoid the risk of falling during an earthquake shock.

Because it causes two contradictory impacts, the design of the roof slope angle needs to provide a comfortable, inexpensive, and environmentally friendly building. If occupants want a colder building, it is advisable to design a gable roof with a higher slope angle. The operative temperature in the occupied zone will be cooler due to reduced heat transfer from the building roof to the room due to the roof position from the ceiling and the large volume of air in the attic. The infiltration or ventilation in the attic zone is quite effective in releasing heat to the environment during the day. Therefore, the openings in the attic can be a solution to increase the dissipation of solar heat into the surrounding environment and minimize the heat penetration into the room. Residential buildings with gable roofs should have a ceiling with an adjustable thickness to reduce the thermal gain from the hot roof. If the occupants expect lower construction costs with lighter roof weight, a gable roof slope with a low angle can be an option.

However, it should be noted that, for tropical areas with high rainfall, flat roofs show poor performance in channeling rain flows, potentially causing rust and leaks in the zinc plate of the roof covering. From the numerical simulation results shown in Figure 7, it can be seen that the most appropriate gable roof slope angle for Padang with a hot-humid climate and high rainfall intensity is 30^0. By setting a 30^0-roof angle, the additional material for the frame construction and galvanized steel plate cover is not too much compared to 15^0 flat roofs (10% additional material), and a reasonable decrease in DH thermal discomfort.

IV. Conclusion

Setting the slope angle of the gable roof of a building will influence several aspects of the building, such as thermal (room temperature, thermal comfort), geometry (dimensions, roof area), material requirements in roof truss construction, etc. The results of a numerical study on the effect of gable roof slope angle of a residential building in a tropical area show that the higher the roof slope angle, the lower the overall building temperature, and the more comfortable it is thermally. In addition, the openings in the attic zone will speed up the heat dissipation to the environment so that the room temperature will be lower. On the other hand, an increase in the roof slope angle causes an increase in the roof geometry. Some roof truss elements have increased in size, such as roof height, roof covering the area, length of rafters and webs, etc. The increase in the roof dimensions causes the need for materials used for frame construction and roof coverings to increase. In other words, more material requirements mean an increase in construction costs and the weight of the roof itself.

Moreover, the heavier the roof, the higher the risk of falling when there is an earthquake. Therefore, it is necessary to conduct a study to analyze the optimal slope angle of the gable roof with high-cost efficiency and tolerable comfort. The optimal angle of the roof slope depends on the local climatic conditions of the building site. The methodology and results of this study are expected to provide additional knowledge in determining the slope angle of the gable roof of residential buildings in tropical areas with hot-humid conditions. In addition, infiltration in the attic zone significantly impacts decreasing room temperature. Therefore, an analysis study and optimization of convective heat dissipation from the attic zone by infiltration or natural ventilation to reduce indoor air temperature becomes an outlook for further research.

Acknowledgment

The authors thank the Research and Community Service Institute (*Lembaga Penelitian dan Pengabdian Masyarakat/LPPM*) Universitas Negeri Padang for their financial support, and Laboratoire des Sciences de l'Ingénieur pour l'Environnement (LASIE) University of La Rochelle – France for their technical support. This work was supported by the Universitas Negeri Padang under Grant number SP-DIPA 023.17.2.677514/2020 with the Contract Letter Number 893/UN35.13/LT/2021.

References

[1] S.-O. Baek, 'Assessing Indoor Air Quality☆', in *Encyclopedia of Environmental Health (Second Edition)*, J. Nriagu, Ed. Oxford: Elsevier, 2019, pp. 191–198. doi: 10.1016/B978-0-12-409548-9.11672-0.

[2] H. Simbolon and I. N. Nasution, 'Desain Rumah Tinggal Yang Ramah Lingkungan Untuk Iklim Tropis', *Educational Building Jurnal Pendidikan Teknik Bangunan dan Sipil*, vol. 3, no. 1 JUNI, pp. 46–59, 2017.

[3] I. Imran, D. M. Siringoringo, and J. Michael, 'Seismic performance of reinforced concrete buildings with double concave friction pendulum base isolation system: case study of design by Indonesian code',

Structures, vol. 34, pp. 462–478, Dec. 2021, doi: 10.1016/j.istruc.2021.07.084.

[4] K. S. Pribadi *et al.*, ‘Learning from past earthquake disasters: The need for knowledge management system to enhance infrastructure resilience in Indonesia’, *International Journal of Disaster Risk Reduction*, vol. 64, p. 102424, Oct. 2021, doi: 10.1016/j.ijdrr.2021.102424.

[5] S. Sopandi, ‘Indonesian Architectural Culture during Guided Democracy (1959–1965): Sukarno and the Works of Friedrich Silaban’, in *Dynamics of the Cold War in Asia*, Springer, 2009, pp. 53–72.

[6] I. Widiastuti, ‘Between Mountain and River: A Vernacular Settlement-Architectural Concept in Indonesian Archipelago’, in *Perception, Design and Ecology of the Built Environment*, Springer, 2020, pp. 295–309.

[7] N. Katanbafnezhad and A. Hoback, ‘Optimum roof angles of steel gable frames with pinned supports’, *International Journal of Modern Research in Engineering & Management (IJMREM)*, vol. 2, no. 4, pp. 8–17, 2020.

[8] M. Z. M. Ashhar and C. H. Lim, ‘Numerical simulation of heat transfer in a roof assembly with reflective insulation and radiant barrier’, in *Building Simulation*, 2020, vol. 13, pp. 897–911.

[9] A. Enajar, A. El Damatty, and A. Nassef, ‘Semi-analytical solution for gable roofs under uplift wind loads’, *Engineering Structures*, vol. 227, p. 111420, 2021.

[10] S. Gholami, ‘Investigations of Rainwater harvesting system from Rooftop catchment (Case study: babolrood catchment)’, *Water Harvesting Research*, vol. 2, no. 2, pp. 30–38, 2017.

[11] A. Rajendra, ‘Contemporary challenges of the Indonesian vernacular architecture in responding to climate change’, in *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 824, no. 1, p. 012094.

[12] G. N. Y. Nngague, M. L. Sagada, R. B. Tukur, and J. J. Maina, ‘Effects of building components in optimizing energy efficiency in residential buildings in the hot-dry climate of Kaduna’, in *AARCHES 2019 Cnference Proceedings*, Zaria, Nigeria, 2019, p. 145.

[13] S. Latif, B. Hamzah, R. Rahim, R. Mulyadi, and I. Idrus, ‘Computational Study of the Heat Ventilation on The Attics of Buginese Houses’, 2019.

[14] D. Zhao, A. Aili, X. Yin, G. Tan, and R. Yang, ‘Roof-integrated radiative air-cooling system to achieve cooler attic for building energy saving’, *Energy and Buildings*, vol. 203, p. 109453, Nov. 2019, doi: 10.1016/j.enbuild.2019.109453.

[15] J. I. Kindangen, L. Tondobala, and M. K. Umboh, ‘Experimental Analysis of Cooling Performance of Spraying Water Automatically on the Galvanized Zinc-Roofs’, *International Journal of Engineering and Technology, ISSN*, pp. 2319–8613, 2018.

[16] C. Y. Lee, S. Kaneko, and A. Sharifi, ‘Effects of building types and materials on household electricity consumption in Indonesia’, *Sustainable Cities and Society*, vol. 54, p. 101999, Mar. 2020, doi: 10.1016/j.scs.2019.101999.

[17] A. Amadi and A. Higham, ‘Life Cycle Costs Associated with Building Failure in Coastal Areas’, in *International Sustainable Ecological Engineering Design for Society Conference*, Leeds, 2017, pp. 72–88.

[18] A. S. Adewale, ‘Comparative study of thermal properties of some common roofing materials in Nigeria’, 2017.

[19] R. Lapisa, A. Karudin, F. Rizal, Krismadinata, and Nasruddin, ‘Passive cooling strategies in roof design to improve the residential building thermal performance in tropical region’, *Asian J Civ Eng*, vol. 20, no. 4, pp. 571–580, Feb. 2019, doi: 10.1007/s42107-019-00125-1.

[20] Y. Q. Nguyen, S. Nguyen-Tan, H.-T. T. Pham, A. Manh-Thuy, and T. Huynh-Nhat, ‘Performance of a Solar Chimney for Cooling Building Façades under Different Heat Source Distributions in the Air Channel’, *International Journal on Advanced Science, Engineering and Information Technology*, vol. 11, no. 1, pp. 158–164, 2021.

[21] R. Lapisa, M. Abadie, E. Bozonnet, and P. Salagnac, ‘Numerical analysis of thermal stratification modelling effect on comfort for the case of a commercial low-rise building’, Hongkong, Jul. 2014.

[22] N. Laghmich, Z. Romani, R. Lapisa, and A. Draoui, ‘Numerical analysis of horizontal temperature distribution in large buildings by thermo-aeraulic zonal approach’, in *Building Simulation*, 2021, pp. 1–17.

[23] R. Lapisa *et al.*, ‘Analysis of Thermal Effects of Roof Material on Indoor Temperature and Thermal Comfort’, *International Journal on Advanced Science, Engineering and Information Technology*, vol. 10, no. 5, pp. 2068–2074, 2020.

[24] R. Lapisa *et al.*, ‘Effect of skylight–roof ratio on warehouse building energy balance and thermal–visual comfort in hot-humid climate area’, *Asian Journal of Civil Engineering*, vol. 21, no. 5, pp. 915–923, 2020.

[25] G. Yildiz, B. Duraković, and A. Abd Almisreb, ‘Performances Study of Natural and Conventional Building Insulation Materials’, *International Journal on Advanced Science, Engineering and Information Technology*, vol. 11, no. 4, pp. 1395–1404, 2021.

[26] D. P. Sari, I. Gunawan, and Y. S. Chiou, ‘Investigation of Ecohouse through CFD Simulation’, *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1096, no. 1, p. 012059, Mar. 2021, doi: 10.1088/1757-899X/1096/1/012059.

[27] L. Kristianto, A. D. Rarasati, and J. Sjah, ‘Numerical modelling and cost-duration analysis of roof structure design changes’, in *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 794, no. 1, p. 012007.

[28] S. Jiang, S. Zhu, X. Guo, and Z. Li, ‘Full-scale fire tests on steel roof truss structures’, *Journal of Constructional Steel Research*, vol. 169, p. 106025, Jun. 2020, doi: 10.1016/j.jcsr.2020.106025.

[29] D. Gabriela, M. Ana-Maria, and R. Valentin, ‘Roof structures. Comparisons between traditional roof structures and industrialized ones’, *‘ Ovidius’ University Annals Constantza. Series Civil Engineering*, vol. 19, no. 19, pp. 79–85, 2017.

[30] T. Kusuda and P. R. Achenbach, ‘Earth temperature and thermal diffusivity at selected stations in united states’, National Bureau of Standards, Washington,DC, Research report 8972, May 1965. [Online]. Available: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=AD0472916

[31] N. Benrachi, M. Ouzzane, A. Smaili, L. Lamarche, M. Badache, and W. Maref, ‘Numerical parametric study of a new earth-air heat exchanger configuration designed for hot and arid climates’, *International Journal of Green Energy*, vol. 17, no. 2, pp. 115–126, 2020.

[32] I. S. SNI 03-6197, ‘Energy Conservation in the Air Conditioning System in Buildings’. Badan Standardisasi Nasional, 2000.

[33] H. E. Beck, N. E. Zimmermann, T. R. McVicar, N. Vergopolan, A. Berg, and E. F. Wood, ‘Present and future Köppen-Geiger climate classification maps at 1-km resolution’, *Scientific data*, vol. 5, p. 180214, 2018.

[34] F. J. Tapiador, R. Moreno, A. Navarro, J. L. Sánchez, and E. García-Ortega, ‘Climate classifications from regional and global climate models: Performances for present climate estimates and expected changes in the future at high spatial resolution’, *Atmospheric Research*, vol. 228, pp. 107–121, Nov. 2019, doi: 10.1016/j.atmosres.2019.05.022.

[35] R. Lapisa, ‘The Effect of Building Geometric Shape and Orientation on Its Energy Performance in Various Climate Regions’, *Int J Geomate*, vol. 16, no. 53, pp. 113–119, 2019.