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Presence and Function of Roof Ventilation in Housing Estates in the Humid Tropics

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ABSTRACT

Traditional Indonesian and Dutch colonial buildings often include an attic for ventilation and natural lighting. However, most Manado homes have corrugated zinc roofs and no attic ventilation. Zinc-roofed building roof ventilation and thermal comfort in Griya Paniki Indah, Taman Mapanget Raya, and Kharisma Koka housings are studied. We created two test cells with and without roof ventilation. A vented ceiling cools the test cell by 1.2 °C during the day. Modern, simple homes with unventilated roofs dominate the three residential districts. All responders reported daytime and nighttime discomfort or excessive temperatures. Residents were striving hard to control the room's environment due to these conditions. Air conditioning, fans, windows, and ventilation are used daily. Thus, attic ventilation benefits must be publicised. This improves building and household energy efficiency and thermal comfort.

Introduction:

The roof is a crucial element of houses and buildings as it shields them from the elements, including direct sunlight, heat, and rain. In humid tropical climates, the roof surface tends to have a higher temperature during the day compared to other building components. The surface of the roof that becomes hotter will absorb and emit heat to the surrounding environment, particularly to the space below [1]. The area between the ceiling and the roof covering acts as a barrier to keep heat from entering the living space below directly. The buffer space in question will create an intermediate area known as the attic. It is crucial to actively and passively condition this space to prevent the build-up of excessive heat and the trapping of heat in the attic.

Hot and humid climate conditions can lead to thermal discomfort, resulting in increased body temperature and perspiration. Suppression of sweat evaporation from the skin's surface can cause an unpleasant and stuffy feeling. Attaining comfort necessitates a seamless circulation of air that will effectively evaporate perspiration from the skin, resulting in a heightened sense of relaxation. One of the primary considerations is how to decrease the indoor air temperature. Strategies and methods for lowering room air temperatures revolve around creating a comfortable environment and implementing highly efficient energy-saving techniques.

Traditional Indonesian architectural styles:

Architecture is frequently perceived as the result of extensive interactions between individuals and the climate. The climate plays a crucial role in shaping the architectural features of a place, such as the choice of materials that are suitable for the local weather conditions [2]. The construction of buildings in extreme climates, whether hot or cold, requires a different approach compared to neutral climates. In these extreme conditions, the architectural design becomes more complex, and the construction materials and techniques need to be carefully chosen to ensure durability and efficiency. Architecture in temperate climates falls somewhere in the middle, taking a more discerning approach to address the specific local climatic conditions. Architecture in hot-moderate climates features open transitional spaces, while architecture in cold-moderate climates incorporates transitional and transparent spaces [3], as illustrated in Fig.1.

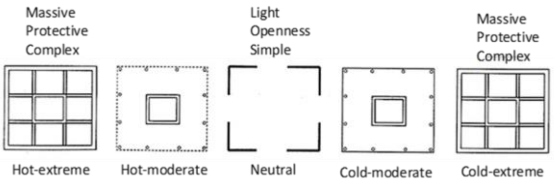


Fig 1_ The intricacy of the architectural transition functions related to different climates

Architectural designs for buildings in humid tropical climates should priorities light construction and openness. The degree of openness in building construction is determined by the porosity of the exterior walls. This refers to the ratio between the open windows, doors, or ventilation holes and the corresponding wall area. The incorporation of lightweight materials like bamboo, wood, and tree trunks exemplifies the concept of light construction [4]. Concrete and other contemporary materials can be used in a variety of settings, taking the climate into consideration. Low temperatures persisting overnight in humid tropical climates make it challenging to cool the building structure through night ventilation. The passive cooling strategy allows for the shielding of the construction area from direct sunlight and the utilisation of permanent ventilation to effectively remove the accumulated hot air within the building.

The architecture in Indonesia reflects a deep understanding of how to design structures that are well-suited for the humid tropical climate. Similarly, the utilisation of appropriate local building materials to address climatic challenges or obstacles. Traditional Indonesian architecture incorporates a raised floor area supported by wooden columns, which can be embedded in the ground or rest on stone pedestals. This type is used to prevent the building from being affected by soil moisture and to maximise the benefits of prevailing winds. Carefully designing the roof cover with a wide slit efficiently reduces rainwater splash and shields walls and large openings from rain and direct sunlight. An attic fitted with ventilation is located between the roof and ceiling covering.

This ventilation system helps to evacuate heat by absorbing solar heat on the roof surface. The external shape of the building's roof determines the shape of the attic. However, there are also traditional houses that lack attic space for various reasons. Some issues arise from the construction of the roof, which has a direct impact on the residential area, while others intentionally avoid utilising the attic in certain spaces. The Astoni tribe on the island of Timor regards the roof of a traditional house as a sacred component that holds significant symbolism. While there are different interpretations, the roof is considered a significant element in the cosmological beliefs of the Astoni tribe on the island of Timor. The Astoni tribe on the island of Timor sees the roof as a connection to the sky, where ancestral spirits are believed to reside [5]. In his book Traditional Buildings, Noble [6] explains that the attic in traditional houses serves multiple purposes. It is viewed as a cultural and religious space, reflecting people's perceptions of the larger world. Additionally, it functions as a storage or warehouse area. Howell et al. [7] have also confirmed this observation, particularly in traditional houses found in Southeast Asia. Attic ventilation is an integral component of the lighting system, enabling the entry of natural light into the attic space, as depicted in Fig. 2.

Fig 2_The traditional architecture of Indonesia, specifically the Minahasan (North Celebes) and Betang (Central Borneo) styles [8], [9]

Many researchers have conducted studies on the advantages of attic ventilation. The U.S. Department of Housing and Urban Development [10] recommends several advantages of roof ventilation, including humidity control, energy savings, the resilience of asphalt roofs, and the avoidance of frost. Researchers have extensively studied design strategies for fabricated roof ventilation. It has been found that the optimal design of roof ventilation systems varies significantly depending on the climatic conditions in different regions of the U.S. One finding from this study indicates that roof ventilation in house buildings in hot and humid climates is more financially advantageous compared to not having ventilation. Nevertheless, this study was carried out in regions of the United States that do not typically focus on examining equatorial climates, like Indonesia or Manado. In this area, the roofing material used is uncommon. In traditional Indonesian architecture, people typically source roofing materials from nature. However, zinc roofing materials are commonly used in many modern buildings in Indonesia. It is worth noting that in the province of North Sulawesi, Indonesia, an overwhelming majority of houses and other buildings, including offices, educational institutions, cultural centres, and commercial establishments, opt for zinc roofs [11].

A study conducted by Beal et al. [12] compared two types of roofing materials: a ventilated tile roof and a black shingle roof. There has been a significant decrease of 48% in heat flux observed for a ventilated tile roof. The thermal mass of the tiles and the airflow between them have the most effects on the outcomes. In order to control the humidity in the space between the roof and ceiling, Rose [13] suggests using roof ventilation.

Research conducted by Quarles et al. [14] supports the importance of roof ventilation design for humidity control and indoor heat control. Additionally, Purswell et al. [15] conducted a study on the impact of roof ventilation in cattle sheds. Their findings indicated that roof ventilation has the potential to decrease humidity levels when compared to traditional single-wall ventilation systems.

The Dutch Colonial Architectures in Indonesia:
The interior of the fort (Intramuros) is the first place where the Dutch colonial towns in Makassar resemble those found in other parts of Indonesia, according to Sumalyo [16], who was researching the impact of Dutch colonial rule on urban growth and architecture. The Fort Rotterdam building, with its mediaeval-inspired style, is one example of how European culture has influenced architecture. The Dutch colonial architecture that remains in Indonesia is a stunning example of a distinctive fusion of western and eastern styles in a humid tropical climate. As seen in Figure 3, a large percentage of the Dutch colonial architecture found throughout Java and Sulawesi is not only exquisite to look at, but it also makes excellent use of natural sunlight and ventilation.

Traditional architectural forms and patterns were incorporated with contemporary Dutch colonial architecture in a number of different buildings [19]. It is important to note that this particular style of Dutch colonial architecture was also influenced by traditional Indonesian architecture, which resulted in the formation of its identity and orientation. Wide apertures, ceiling vents, and high roofs were some of the tropically humid architectural aspects that were applied to Dutch colonial buildings. These features were designed to maximise natural ventilation during the day. Additionally, there was a foyer or gallery, and the walls were constructed with heavyweight frameworks.

Fig 3_ The cities of Jakarta and Makassar are home to several examples of Dutch Colonial architecture, such as Fatahilah Museum and Fort Rotterdam [17], [18]

The attic is designed with a large roof area and a steep incline, which can sometimes have two levels. This unique design allows for the removal of hot air from the attic space, making it a versatile component for protecting against the sun's heat. Furthermore, as depicted in Figure 4, a dormer is utilised in order to get the highest possible levels of light and air flow in the attic space. A window or a small roofed building that protrudes from the slope of the roof is referred to as a dormer house. Most of the time, they are used to create additional room.

Typically, Dutch colonial architecture incorporated attic ventilation to optimise room conditions in the humid tropical environment. In Dutch colonial architecture, attic ventilation served the purpose of expelling hot air and allowing natural light to illuminate the attic space.

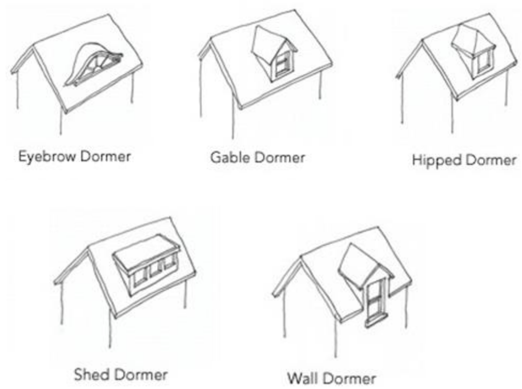


Fig 4_ Dutch colonial buildings commonly utilise various types of dormers [20]

Manado housing estates' attic ventilation:
Three residential areas were the subject of surveys and investigations: the dwellings of Griya Paniki Indah (GPI), Taman Mapanget Raya (TMR), and Kharisma Koka (KK). The first two residential projects are located inside Manado City, while the last one is located outside of Manado, specifically in Minahasa Regency. Furthermore, the study encompassed observations of all buildings within the three housing estates, as well as interviews and measurements conducted with a total of 400 respondents. This group included 200 respondents from GPI housing, 60 respondents from TMR housing, and 140 respondents from KK housing. WBGT metres

are used to conduct measurements and assess the heat stress experienced by occupants. During the interviews conducted in conjunction with these measurements, we ask occupants about their sensations, preferences, and actions taken in response to the existing comfort conditions at a specific time. In August, during the peak of the hot season in Manado, we conducted the investigation.

Manado is located at a latitude of 1.4583 °N and a longitude of 124.8260 °E. The region has a humid tropical climate, with October being the warmest month, with an average temperature of 29.10 °C, and January being the coolest month, with an average temperature of 26.90 °C. Usually, there is not a significant difference in temperature between the warmest and coldest months. During the months of November to March, there is a significant amount of rainfall, with January experiencing the highest average precipitation of 465 mm. Consequently, the daily and monthly temperature ranges are minimal. The average maximum relative humidity varies from 64% in October to 81% in January and March. Figure 5 displays the position and site layout of the three housings.

(a)

(b) **(c)**

Fig 5_ Presenting a site plan featuring three distinct housing estates: GPI (a), TMR (b), and KK (c)

The house buildings in these three housing types typically have similar types, with varying sizes ranging from small to medium. The building areas range from 36 m^2 to 60 m^2 and are proportional to the area of the building site. For instance, a 36 m^2 house would have a site area of 96 m^2. The building materials used are also the same: stone path foundations, brick walls, or hollow bricks, which are plastered and then painted. The floors are constructed with ceramic tiles, while the roof frame is made of mild steel and covered with corrugated zinc. The minor type of house features a living room that seamlessly connects to the dining room, along with two bedrooms and a single bathroom.

Most of the houses in the three housing estates being studied have a modern and minimalist design, which presents a difficulty in incorporating attic ventilation due to the distinct shape and pattern of the roofs. Furthermore, an increasing number of house buildings have chosen to eliminate roof ventilation to maintain an affordable cost that is in line with the community's purchasing power. One possible factor that is frequently taken into account is the limited understanding among homeowners and developers regarding the benefits of attic ventilation. This ventilation system has been proven to significantly reduce the temperature in the living area. Furthermore, all the existing house structures feature corrugated zinc roofs, as shown in Fig. 6.

(a)

(b)

(c)

Fig 6_ House construction types in each of the three housing estates under investigation: GPI (a), TMR (b), and KK (c)

Interviews and measurements were conducted on the original buildings, which had not undergone any restoration or additions. At GPI housing, a prominent housing estate in Manado city, the existing houses have undergone renovations and modifications based on residents' preferences, with the main goal of creating a comfortable living environment. The house construction in TMR's housing estate tends to consist of original houses, while the house building in KK housing is also prevalent.

Based on the interviews and measurements conducted on 400 houses and respondents, it was found that residents frequently experienced discomfort or excessive heat throughout the day and night. Based on the measurements taken with a WBGT metre, it appears that there are heat stress conditions present. The temperature ranges from 33 °C to 35 °C, while the relative humidity ranges from 65% to 85% throughout the day and night. According to a study conducted by [21], temperatures above 28 °C pose a significant risk of heat stress for workers or occupants. The occupant's perception of heat, as indicated by the interview results, increased from hot to very hot.

Due to the uncomfortable condition, the residents took various measures to control the room's climate. It was observed that 23% of the houses utilised air conditioning, 58% relied on fans, and the remaining 19% opted for opening windows or ventilation. Therefore, it presents a paradox as modest homes typically inhabited by individuals with a lower middle income are compelled to incur additional expenses to regulate the room temperature in an inefficient manner, such as relying on air conditioning, as depicted in Figure 7.

Fig 7_ Air conditioning is essential for ensuring the optimal thermal comfort of the house's occupants

When designing the roof, it is important to take into account the ventilation system. The roof ventilation system primarily relies on wind power. When designing a roof vent, it is important to consider air movement and ensure a proper balance between intake and exhaust airflow. Considering the construction and layout of buildings and roofs, it may be prudent to consider the use of a turbine ventilator on the roof. Ventilator turbines on the roof can be used in various types of buildings. Their use is primarily driven by climatic conditions that prevent the use of natural roof ventilation, as explored by Ismail et al. [22]. Nevertheless, the use of a ventilator turbine results in elevated energy expenses and is typically reserved for critical situations.

An investigation carried out by Ahmed et al. [23] assessed the effectiveness of roof ventilation systems in humid tropical regions with regard to thermal comfort. The system includes a solar-powered fan installed on the roof to ventilate the attic. This study closely aligns with previous research that used ventilator turbines. The findings from these studies demonstrated a notable decrease in temperature within the living area. The heat in the attic, particularly during the day, becomes the main source of warmth. Previous research has primarily focused on turbine ventilators, neglecting the exploration of natural roof ventilation systems.

The Role of Roof Ventilation:

The thermal environment is affected by various parameters, not just air temperature. However, air temperature is the main factor that strongly influences and dominates thermal comfort. In order to achieve this objective, this study necessitates the collection of air temperature data influenced by various external factors, which will serve as the foundation for the ensuing analysis.

Two test cells with identical dimensions of 1.00 m length, 1.00 m width, and 1.85 m height have been constructed for this study. The test cells were constructed with plywood walls and a galvanised corrugated zinc roof. The surface area measured 2.60 m2, with a roof slope of 30 degrees in one direction only. Furthermore, this test cell is equipped with two windows positioned on either side, measuring 25 × 50 cm, with a window sill situated 70 cm above the ground. The heat properties of the material are displayed in the table below.

Material	Thickness (mm)	Area (m^2)	Thermal conductivity (W/mK)	Density (kg/m^3)
Zinc roof	0.3	2.72	112.2	7135
Concrete floor	120	1	1.4	2300
Plywood wall	3	3.75	0.11	680
Plywood ceiling	3	1	0.11	680
Windows opening	-	2*0.125	-	-

Table 1. Material for test cells

The two test cells were strategically positioned outdoors to maximize their exposure to sunlight, from the early morning until late afternoon. One of the test models was equipped with roof ventilation, whereas the other lacked this feature. The RC4-HC data logger is used to record the air temperature and relative humidity in each test cell. Two data recorders are positioned as depicted in Figure 8.

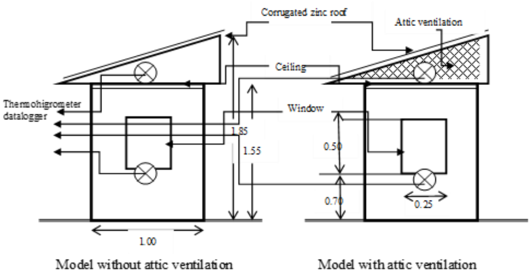
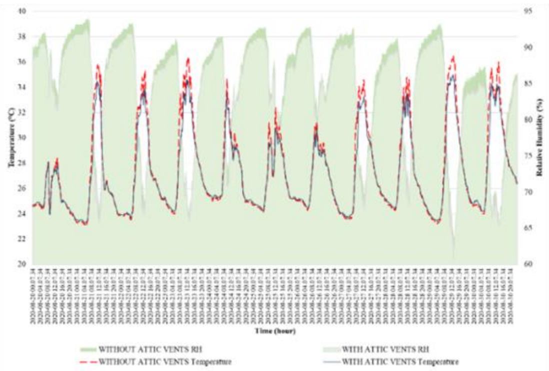
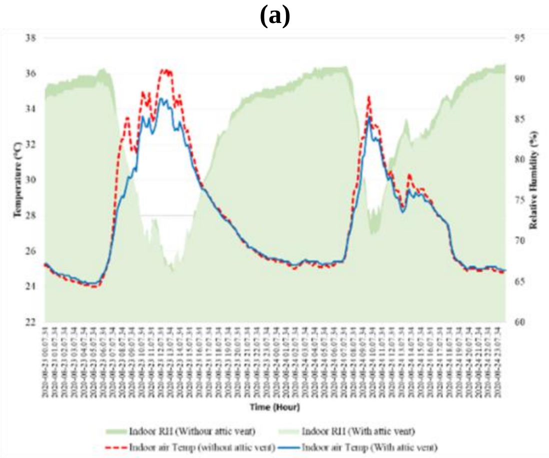


Fig 8_ Schematics of two test cells

Roof ventilation offers the benefit of maintaining a consistently lower indoor air temperature compared to cells without this feature. This temperature difference can reach up to 2.1 °C or an average of 1.2 °C, particularly during the daytime, as illustrated in Fig.9a.



(a)



(b)

Fig 9_ Test cell indoor air temperature and relative humidity measurements with and without attic ventilation

During the night, the temperature of the two cells remains constant or exhibits little fluctuation. The zinc roof surface cools quickly at night because it effectively dissipates heat. Simultaneously, the zinc roof surface will see a quick increase in temperature; it exhibits a high level of responsiveness and efficiency in terms of heating. Therefore, it has been proven that implementing daytime passive cooling techniques such as cross ventilation and attic ventilation provides significant benefits. Upon careful analysis spanning two consecutive days, the temperature patterns in the two cells reveal that between 7 a.m. and 4 p.m., the use of roof ventilation is beneficial in reducing the indoor air temperature, as shown in Figure 9b.

Conclusion:

The inclusion of attic ventilation in both traditional Indonesian architecture and Dutch colonial buildings in Indonesia exemplifies a deliberate strategy for adapting to the humid tropical climate. This design decision efficiently inhibits the buildup of warm air in the attic, guaranteeing a more pleasant living environment. The attic space fulfils a utilitarian function by integrating natural illumination and airflow through attic ventilation. The majority of houses constructed in the three residential areas being studied no longer use roof ventilation. This is because the residents experienced a high level of heat and sought ways to create a more comfortable environment by using cooling fans, air conditioners, and opening windows or ventilation. Overlooking the importance of roof ventilation can result in more affordable building costs, making it more accessible to a wider range of people, including those in the middle to lower economic communities. This is a key factor that developers take into account. Disseminating knowledge about the benefits of attic ventilation is crucial, especially among architects and developers in the community.

Measurements conducted on two similar test cells indicate that the indoor air temperature beneath the vented roof constantly remains lower than that of the non-ventilated cells, with an average temperature difference of 1.2 °C. Proposes an alternative strategy for decreasing indoor air temperature in buildings equipped with zinc roofs while simultaneously providing an energy-efficient remedy. Further study is centred on the advancement of building codes and standards for incorporating passive strategies into architectural designs in humid tropical climates with the aim of reducing air temperatures.

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