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Thermal performance in single-zone occupied space ancient Myanmar multistage roof buildings

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Abstract. Multistage roofs are dominant features in the ancient Myanmar buildings. They describe the cultural context, social status and are a response to the local climates. However, little is known about the thermal performance of multistage roof buildings. The authors believe that this is the first study to access the thermal performance of multistage roof buildings taking into account their typologies, ventilation modes and roof materials. The findings revealed that the three-stage roof buildings received a shorter duration of a year for thermal discomfort compared to the single gable roof buildings. However, there were insignificant improvements in annual mean air temperature by using three-stage roofs. On the other hand, the roof space of three-stage roof buildings received a very high indoor air temperature that caused abandon roof spaces apart from acting as a response to the local climate contexts. The study highlights that the beautiful use of Le-baw allows adding the gable vents easily for better ventilation performance. The results from this study substantiate the findings of another computational fluid dynamic simulation and support the conclusion with a discussion that the three-stage roof buildings have more potential to improve a better thermal performance if they have gable vents.

1. Introduction

A tropical roof with large eaves acts as a barrier to protect the intense solar heat gain and serves as a rain tight layer to prevent the ingress of precipitation. It is also built to provide ventilation in removing humid, stale air from the building to promote passive cooling. The roof is a defensive element for tropics to strengthen the thermal performance of a building. The roof design for the tropics is thus received critical attention for the thermal comfort; however, there is a clear lack of research for Myanmar multistage roof buildings.

Multistage roofs are dominant features in the ancient Myanmar buildings [1]. They describe the cultural context, social status and are a response to the local climates [1, 2]. One recent case study reports that vernacular roof ventilation practices are not fully able to provide the required thermal performance both for a typical weather year and future climate change scenarios in Myanmar [3]. Another recent case study reports that the higher the u-value, the better for Myanmar climates if the roofs have low solar absorptivity, high reflectivity, and high thermal emissivity. [4]. Both studies are based on a generic single-gable roof building with a size of 5m length and 5m width, which can be assumed as a small-scale academic model. On the other hand, little is known about the thermal performance of large-scale multistage roof buildings in Myanmar. It is also not clear which building parameters have substantial impacts on the indoor thermal performance of the ancient Myanmar multistage roof buildings. This study accesses the thermal performance of multistage roof buildings taking into account their typologies, ventilation modes and roof materials. This study attempts to clarify what continues to be of direct and what to be modified in the multistage roof buildings.

2. Myanmar multi-stage roof buildings

A wealth of ancient Myanmar architecture reflects the continuity of Buddhist tradition that responses to essentially tropical climate contexts. It embraces a range of structures from monasteries for religious communities to monasteries for ordination procedures for monks. Continuous traditions in monastery architecture are tiered roofs, which are also known as 'Pyatthat' or multistage roofs. Multistage roofs are composed of either three or five or seven stages, up to eleven stages, but numbers of stages are always uneven. The typology is very similar to a fixed kind of 'parasol' concept because a roof can be thought of as a broad umbrella over the occupied spaces. Curve rafters with decorative features on large pediments are dominant design features for the Thai buildings. In contrast, separated roof structures are dominant features for the ancient Myanmar multistage roof buildings. In Myanmar, the multistage roofs are made of successive gabled rectangular roofs in an exaggerated pyramidal shape that consists of Le-baw. Le-baw is an intermediate box-like structure to insert between each roof stage [2]. The roof height of a multistage roof building is somehow predominant. Having a long and rich woodcarving tradition, ornate wooden carvings and floral arabesques are decorated at the Le-baw. Gable vents are added at the Le-baw to facilitate the air exchange. The centre of a Pyatthat is recognized as the hallmark of monastery architecture, for instance, either the image of the Buddha or throne room of a king is located under the crown of a Pyatthat.

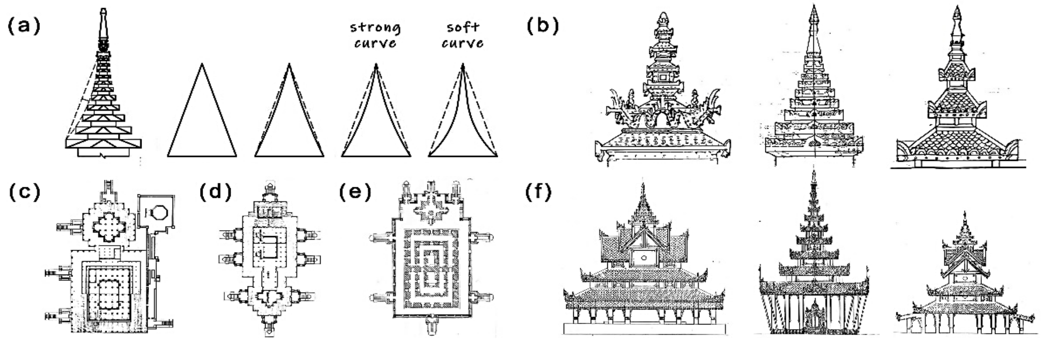

Figure 1. (a) Proportion of Pyatthat [5]; (b) Evolution of Pyatthat [5]; (c) Plan of Bargayar Monastery [2]; (d) Plan of Shwe-In-Pin Monastery [2]; (e) Plan of Mal-Nu Monastery [2]; Elevations of the Kanbawzathardi Palace's buildings [6].

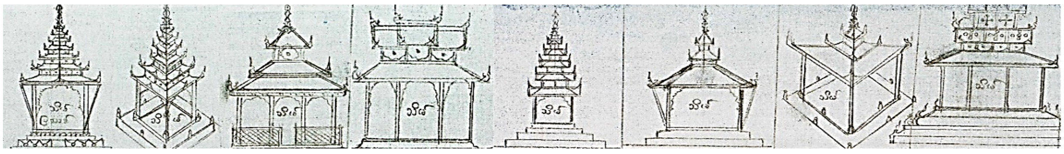

Figure 2. Multistage roof in monasteries for ordination procedure [7].

The evolution of the ancient multistage roof buildings from the Bagan era to KongBoung era shows evident changes in plan, height, size, roof form and roof decoration [2, 5], which can be seen in Figure 1 and Figure 2. One of the obvious changes in Pyatthat design is the use of an imaginary roof curve that gives a guide to developing an aesthetic consideration and presentation of religious symbols. The conceptual design of Pyatthat is developed from either a strong curve or soft curve to define the roof form [5]. Many of Myanmar's splendid wooden monasteries have sadly fallen victim of fire and war. Some of the surviving multistage roof buildings are Bargayar monastery, Mal-Nu monastery, Shwe-Nan-Taw Monastery, and Shwe-In-Pin monastery[8]. Despite the difference in basic geometric figures and decoration, certain basic principles in those buildings are their dominant multistage roofs. Monasteries for ordination procedure, on the other hand, have a similar multistage roof, but their scale is smaller than above-mentioned monasteries. There are countless duplications of multistage roof buildings over the country.

As socioeconomic influences and building technologies are often linked, the design features of those multistage buildings in Myanmar have transformed in many ways. The alternatives of the original thatch roof become reflected zinc and other metal roofs. The use of gable vents is not clear in the renovated buildings as some are blocked by adding false ceilings. One of the obvious changes is the use of a single gable roof that changes not only the aesthetic sense but also the thermal performance. However, research about the thermal performance consideration in Myanmar multistage roof buildings seems to be a secondary approach rather than the primary concern of the fine art and symbolic representation. Hence, it is important to access different impacts of built forms, ventilation modes and materials on the thermal performance of multistage roof buildings.

3. Methodology

The objectives of this study were to differentiate the thermal performance of multistage roof buildings from three roof typologies, four ventilation modes and two roof materials in three main climates of Myanmar. IESVE ApacheSim dynamic simulation program was used in this study.

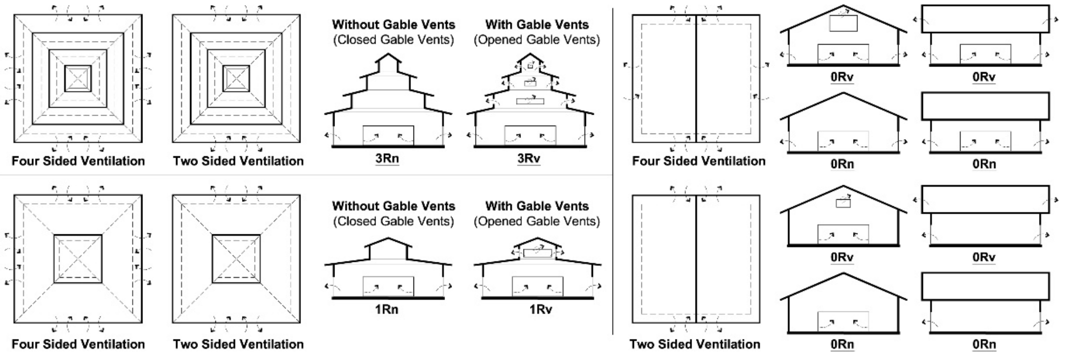

Figure 3. Three multistage roofs buildings in the study.

Table 1. Abbreviation, internal air volume and height of studied buildings in this study.

Building Type	Internal Air Volume (m^3)	Building Total Height (m)
Three-stage roof building (3R)	2425.67	15.0
One-stage roof building (1R)	1887.55	9.5
Single gable roof building (0R)	2420.44	9.5

Table 2. Material properties for simulation models.

Building Elements	U Value (W/m^2K)	Solar Absorptance
Roof Type-1	0.1801	0.90
Roof Type-2	3.1652	0.25
Timber wall	2.5503	0.70
Timber raised floor	2.0935	0.55
Window and vents	3.2308	-

Firstly, the size of the geometry was fixed as 18m length, 18m width, and 5m height for a single-zone occupied space, but the total building height of three-stage roof buildings was higher than the others. In the predefined building typologies, the window-to-wall area ratio (WWR) for the occupied zone was assigned as 30% of the total wall area of the occupied zone, which was equivalent to 108 m^2 that separates into four windows at four sides. Additional vent area 23.92 m^2 was equally separated for gable vents of a roof. The window opening time was from 06:00 a.m. to 06:00 p.m, but the gable vents were opened continuously. The infiltration was set as 1.0 ACH for all models. There was no internal gain consideration from occupants and equipment.

Secondly, four ventilation modes were introduced to compare the impacts of ventilation on the predefined models. The ventilation modes were-

1. Four-sided ventilation with gable vents opened mode (108m^2 for window and 23.92m^2 for vents)
2. Four-sided ventilation with gable vents closed mode (108m^2 for window and 0m^2 for vents)
3. Two-sided ventilation with gable vents opened mode (54m^2 for window and 11.96m^2 for vents)
4. Two-sided ventilation with gable vents closed mode (54m^2 for window and 0m^2 for vents)

It is important to note that 50% of the vent areas were reduced in the third and fourth ventilation modes. There were no false ceilings when the gable vents were opened. There were two roof finishes: roof type-1 for thatch roof with high insulation and roof type-2 for a reflective metal roof with low insulation. Three cities were selected in this study in order to cover the different climate contexts of Myanmar. Yangon presents tropical monsoon climate Am; Mandalay presents equatorial winter dry climate Aw; Myitkyina presents mixed humid subtropical climate Cwa. ASHRAE typical year weather files 22 years' worth of data spanning 1991 to 2013[9] were used in this study. In order to access the impacts of defined parameters on the thermal performance of buildings, the duration of a year above internal air temperature 36°C was used to measure the duration of thermal discomfort. The annual mean air temperature (AMAT) was used as an indicator to access the differences between the occupied space and the roof space.

4. Results

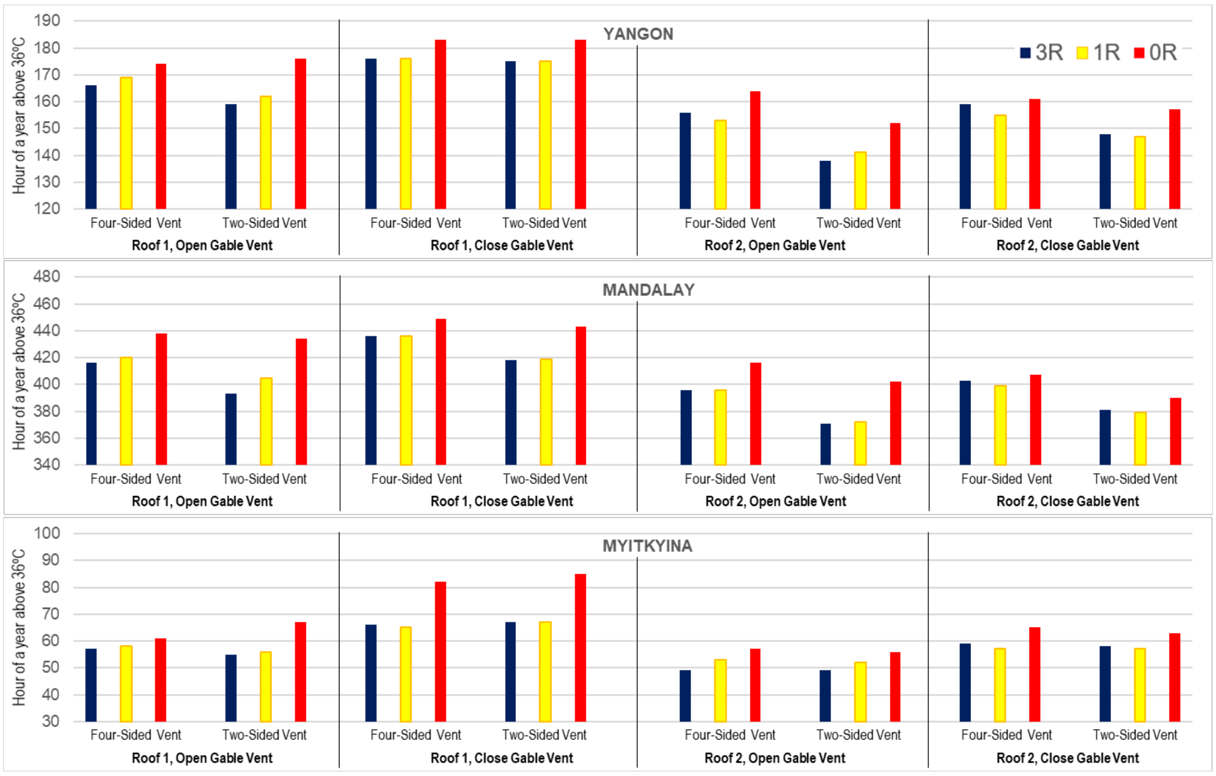

Figure 4. Duration of a year about 36°C in different roof typology, ventilation mode and roof material

In Figure 4, it can be clearly seen that the buildings 0R received a longer duration for thermal discomfort in all scenarios. For instance, when the gable vents were opened, 44 hours of a year were increased by changing from the three-stage roof to the single gable roof in Mandalay at the two-sided ventilatoin mode. When the gable vents were closed, it was found that 57 hours of a year were reduced by changing roof type-1 to roof type-2 in Mandalay at the two-sided ventilatoin mode. The duration of thermal discomfort was reduced when the gable vents were opened. The buildings with four-sided ventilation recevied slightly longer duration of thermal discomfort than the buildings with two-sided ventilation.

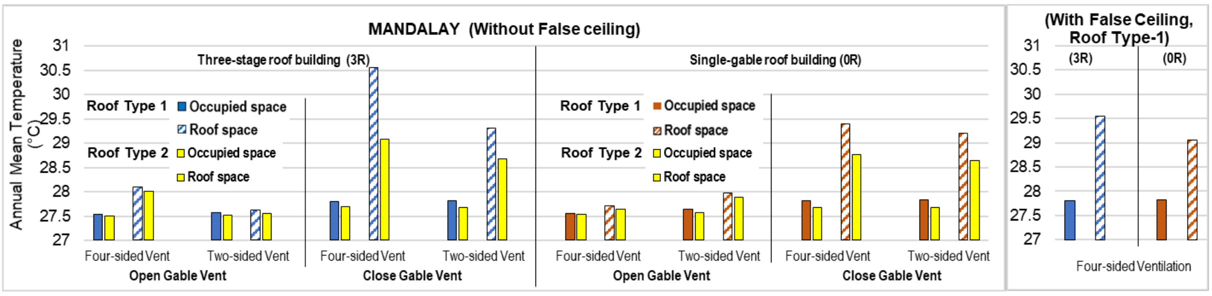

Figure 5. Annual mean temperature of building 3R and 0R in different ventilation modes in Mandalay

It was found that longer durations for thermal discomfort were in Mandalay; therefore, Mandalay was selected to access the differences between the occupied space and the roof space in Figure 5. The results showed that the AMAT of roof spaces was considerably higher than the occupied space especially when the gable vents were closed. On the other hand, the AMAT of the occupied spaces was increased if the false ceilings were added. The AMAT differences between the occupied space of the buildings 3R and 0R were very minimal. The buildings with roof type-2 received lower AMAT compared with the buildings with roof type-1.

5. Discussion

The IESVE dynamic simulation study revealed the following findings.

- The buildings 3R received a shorter duration of a year for thermal discomfort above 36°C and a slightly higher AMAT compared with the buildings 0R.
- If a roof had higher insulation with low U-value and low reflectivity value, for instance, roof type-1 in this study, the presence of gable vents was critical to reduce the thermal discomfort duration.
- The buildings with larger WWR received higher ventilation heat gain that caused the longer duration of the thermal discomfort at the occupied spaces and higher AMAT at the roof spaces.
- The indoor air temperature differences between the occupied spaces and roof spaces were more obvious if there were no gable vents in the roof or if there were false ceilings.
- The duration of thermal discomfort was greatly varied by the climate contexts rather than the building parameters and ventilation modes.

The simulation results showed that higher internal air temperature in a roof space is one of the main barriers to use it as an occupied space in Myanmar multistage roof buildings. Therefore, the functions of the roof spaces are used to remove the hot air and to represent the aesthetic and semiotic values of a religious symbol rather than occupied spaces. The needs to leave as abandon roof spaces allow freedom to design various shapes of Myanmar multistage roof buildings defining the strong or soft imaginary roof curves shown in Figure 1. Regarding the building design parameters, the use of non-vernacular materials and the introduction of false ceilings need to be aware of their impacts on thermal performance.

The study [8] investigates the ventilation performance of the same building typologies set in this study by using computational fluid dynamic simulations in ANSYS Fluent. The study [8] shows that the presence or absence of gable vents causes significant differences for indoor air movement, but the indoor air temperature differences in all scenarios are very minimal at an isothermal situation with selected climate variables. In contrast to the study [8], the IESVE simulation results show that the duration of a year above 36°C can be reduced by changing roof typologies from single gable roofs to three-stage roofs if the AMAT is negligible. The results were different due to time-step simulations in IESVE and isothermal setting in CFD in which small nocturnal natural ventilation and seasonal variation caused impacts on thermal performance. On the other hand, the area of gable vents in the buildings 0R is questionable due to its impossibility in the real-world design practices although all vent openings remain constant in the studies. Apart from the simulation settings, it is important to highlight that relocating the gable vents to the centre of the building with the use of Le-baw has potential benefit to removing the hot air instead of relying on large pediments at both ends of the gable roof.

6. Conclusion

This paper presents the thermal performance of the three-stage roof typologies varying ventilation modes and roof materials. In the tropical contexts, the natural ventilation brings both passive cooling and ventilation heat gain depending on the total response of typologies and fenestration. The outside wind conditions are stochastic in tropics; however, once a critical airflow rate and optimum fenestration area are reached, no further improvement is notable with natural ventilation alone. If still wind speed is expected in a building with a large floor plan, the height of a roof with gable vent is crucial in removing the hot air inside by the use of buoyant air exchange function. When a large scale building needs some degree of roof pitch, the height of the roof varies greatly by the use of single or multiple modules. Responding to different aspects of the tropical climate contexts, the composition of many parts of building features is necessary to use to fulfil the comfort expectation. Especially for a religious driven ancient Myanmar architecture, the form of the building varies greatly by the climate contexts and sociocultural influences. The latter is more pronounced creating the abandoned roof space as a dominant feature in the ancient Myanmar buildings. When the alternatives of the original thatch roof become reflected zinc and other metal roofs, there are positive improvements in indoor air temperature of large-scale multistage roof buildings if the finishes of the roof have higher reflectivity. On the other hand, it is important to highlight that there is a need to maintain the gable vents opening rather than blocking them with false ceilings. Beautiful use of Le-baw, on the other hand, allows adding the gable vents easily. From the results of the simulation study, it can be expected that the three-stage roof buildings have a substantial impact on the indoor thermal performance although the less distinct results were found compared to the single gable roof buildings.

Perhaps here we should contemplate the potential use of multistage roof typology for better ventilation performance and thermal fabric performance. If the grandness of ancient Myanmar multistage roof is to be appreciated, its aesthetic and semiotic values would be a secondary consideration for thermal performance. What should be honoured is its capability to avoid the thermal discomfort duration from the use of simple building physics with geometry management that brings both better thermal and ventilation performance.

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