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Ventilation performance of single zone occupied space in ancient Myanmar multistage roof buildings

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Abstract. Roof ventilation gives passive cooling effect in removing hot air from tropical climate buildings. However, little is known about the impacts of building parameters on the passive cooling effect in ancient Myanmar multistage roof buildings. The authors believe that this is the first study to assess the ventilation performance of multistage roof buildings taking into account their typologies, ventilation modes and climatic parameters. This paper presents the ventilation performance of two roof typologies by varying defined parameters from studies in computational fluid dynamic simulations. Simulations were generated by using the 3D steady Reynolds Averaged Navier Stokes equations and k-ε turbulence models. The results of CFD studies revealed that the presence of gable vents allowed better indoor air movement although the indoor air turbulence was depended on the intensity of exterior wind speed and roof typology. It was found that the single gable roof buildings increased the indoor airspeed with insignificant indoor air temperature improvement for thermal comfort. The results of this CFD study substantiate the findings of another dynamic simulation study and support the conclusion that the three-stage roof buildings have more potential to improve a better thermal and ventilation performance if they have gable vents.

1. Introduction

Roof ventilation gives a passive cooling effect in removing hot, humid and stale air from tropical Myanmar vernacular buildings for thermal comfort. The ventilation performance depends on wind-driven ventilation and infiltration of a building if there are no gable vents in a roof. The ventilation performance depends on both wind-driven ventilation and buoyancy-driven ventilation if there are gable vents in a roof. Apart from fenestration parameters, roof pitch and roof typology play a critical role in determining the effectiveness of roof ventilation [1]. On the other hand, the shape of a roof affects the indoor airflow pattern and its intensity [2]. However, little is known about the roof ventilation of ancient Myanmar multistage roof buildings. This study investigates the ventilation performance of multistage roof buildings taking into account roof typologies, ventilation modes, and climate parameters.

2. Ancient Myanmar Multistage Roof Design

Multistage roofs are dominant features in the ancient Myanmar buildings [3]. They describe the cultural context, social status and are a response to the local climates [3, 4]. 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. They 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. Myanmar 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 [4]. 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.

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 [4, 5], which can be seen in Figure 1. In the building physics, narrowed roof excels in providing a lower mean age of air and higher air change effectiveness [6], which can be expected in multistage roof buildings. On the contrary, the air exchange in Myanmar multistage roof buildings can be expected from the use of the perforated screens and opening above the windows and doors. For instance, Kanbawzathadi Palace [7] presents high-level openings, perforated screens and decorated false ceilings. Since the relationship between the roof typologies, fenestration parameters and climate parameters is unclear in ancient Myanmar multistage roof buildings, it is important to clarify the precise role of roof typology because the fenestration parameters can be supporting factors to allow flexibility for floor plan arrangements.

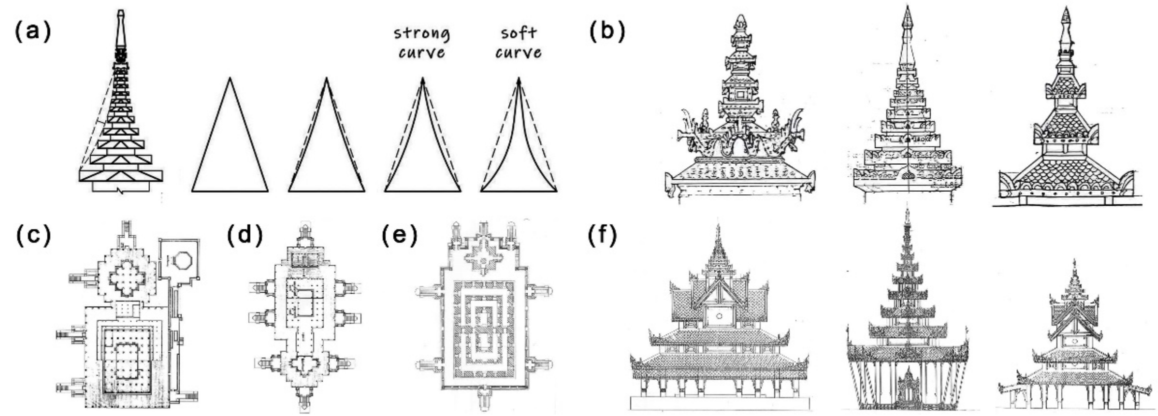

Figure 1. (a) Proportion of Pyatthat [5]; (b) Evolution of Pyatthat [5]; (c) Plan of Bargayar Monastery [4]; (d) Plan of Shwe-In-Pin Monastery [4]; (e) Plan of Mal-Nu Monastery [4]; Elevations of the Kanbawzathardi Palace's buildings [7].

3. Computational Fluid Dynamic Simulations

3.1. CFD setup, mesh characteristics and grid verification

The study was set to investigate the ventilation performance of two roof typologies by varying defined building parameters and climate parameters. 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 (3R) was higher than the single gable roof buildings (0R). In the predefined building typologies, the window-to-wall area ratio 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 internal air volume of the buildings 3R was 2425m^3; the buildings 0R was 2420m^3. In sum, the buildings 3R and 0R had same floor areas and vent areas but different roof height, slightly varied internal air volume and gable vent locations.

The 3D models for this study were firstly created in AutoCAD Revit. Then, they were imported into ANSYS by using the Solid Edge ST10 as a file exchange format. A computational fluid dynamic analysis was carried out by using ANSYS Fluent 18.1. The medium grids and the unstructured mesh were chosen to generate the simulation models in order to achieve the flexibility in conforming to the complex geometries. The average skewness from the defined meshing strategy was less than 0.26. The mesh quality parameters for all models were shown in Table 1. The simulations were performed by using the 3D steady Reynolds Averaged Navier Stokes (RANS) equations and k-ε turbulence models in order to investigate turbulent indoor air temperature and turbulent indoor airflow. The macroclimate entities in this study were presented in Figure 2 for the existence of a limit.

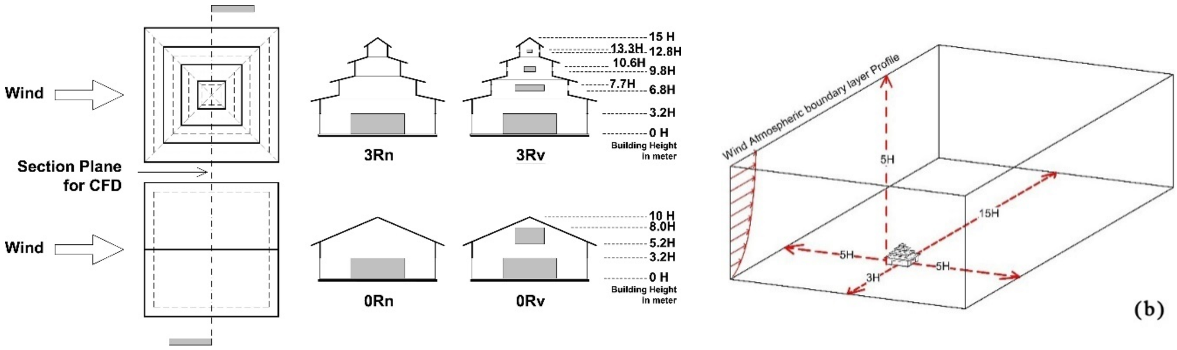

Figure 2. (a) Two building typologies; (b) Perspective view of the computational domain.

Table 1. Mesh characteristics for the simulated buildings.

	Gable Vents contained	Elements	Nodes	Average skewness	Average orthogonal quality
Three-stage roof building – 3Rv	Yes	1015111	1408084	0.25148	0.74723
Three-stage roof building – 3Rn	No	1463635	2032705	0.24186	0.75686
No-stage roof building – 0Rv	Yes	1599544	2226556	0.22755	0.77114
No-stage roof building – 0Rn	No	1556506	2168641	0.22680	0.77188

3.1.1. Boundary conditions. Firstly, all models were sited on the ground surface with the sand-grain roughness height ks=0.14m and the constant roughness Cs=7. The values of roughness were referred to Blocken et al. [8]. The inlet wind speed profile was defined according to the logarithmic law of the wall for high Reynolds numbers for turbulence flow. The fabric temperature was assumed as the same exterior air temperature. The effect of adjacent buildings and the impacts of fabric heat transfer on the ventilation performance were left in this study.

Secondly, Yangon, Mandalay, and Myitkyina were selected to check the different climate contexts in Myanmar. In this study, ASHRAE typical year weather files [9] 22 years' worth of data spanning 1991 to 2013 were chosen to review the climate data. It was found that 36.2%, 47% and 98.8% of a year was governed by the wind speed between 0m/s to 1.2m/s in Yangon, Mandalay and Myitkyina respectively. It was also found that 50.4%, 34.1% and 1% of a year were governed by the wind speed between 1.2m/s to 3m/s in Yangon, Mandalay and Myitkyina respectively. The rests of percentage were governed by the wind speed above 3m/s. Thirdly, two exterior air temperature variables, three exterior wind speed variables and two vent opening modes were considered to investigate the ventilation performance of pre-defined models. The wind direction was set parallel to the axis of the building 0R's gable roof. The incident wind angles were considered as 90°. Three variables of exterior wind speed were introduced as 0.15m/s, 1.2 m/s and 3.0m/s. It is important to highlight that ASHRAE 55-2013 states that the increased indoor airspeed above 0.3m/s can increase the acceptable operative temperature limit in an occupant-controlled naturally conditioned space for the adaptive thermal comfort [10], so the wind speed 0.15m/s is a very still condition. Two exterior air temperature variables were also selected as 26ºC and 33.5ºC. The first temperature variable, 26ºC, was based on the annual average temperature of the country. The later variable was selected from the maximum acceptable prevailing man outdoor air temperature limit reported by ASHRAE for the acceptable operative temperature ranges for naturally conditioned spaces [10].

4. Results of the CFD study

4.1. Indoor airflow differences

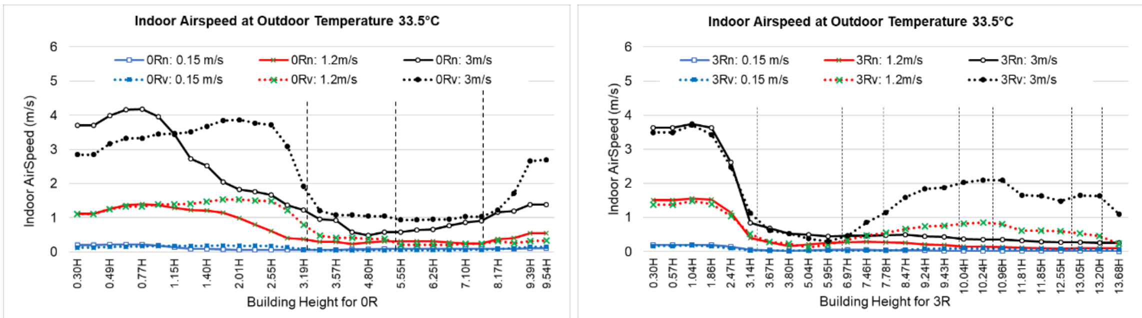

Figure 3. Indoor airspeed in numerical data at the central vertical planes.

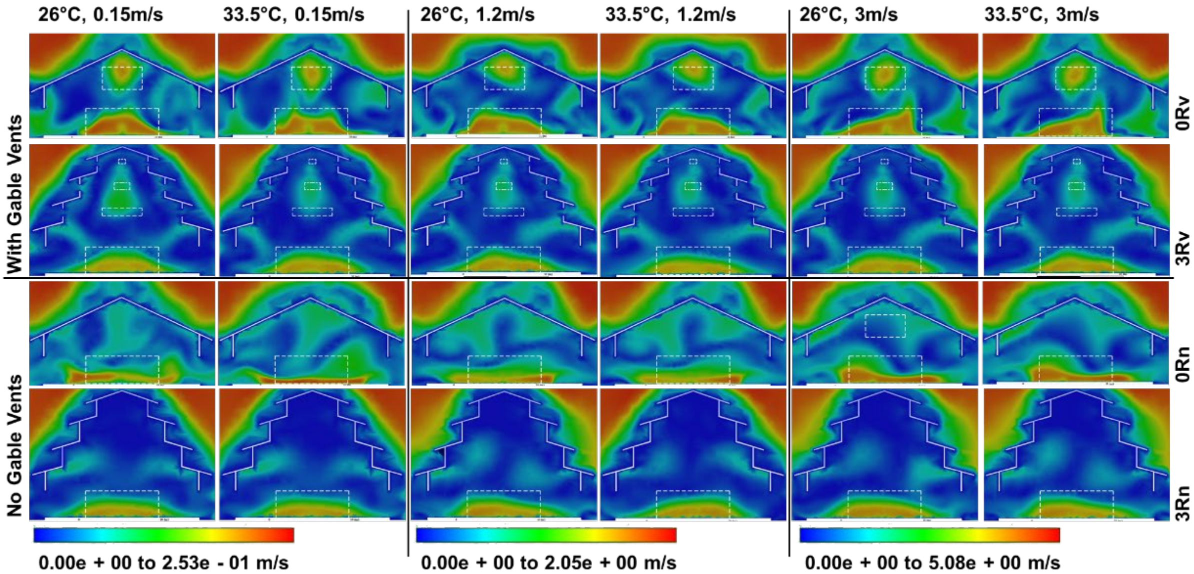

Figure 4. Indoor air movement at the observed vertical planes.

Table 2. Peak indoor air speed, location and increasement from the exterior wind speed at 33.5°C.

Building	Exterior wind speed	Maximum indoor air speed and location	% of increasement
0Rv	0.15 m/s	0.187 m/s at the height of 2.01m	24.6 %
0Rv	3.00 m/s	3.862 m/s at the height of 2.01m	19.6 %
0Rn	0.15 m/s	0.225 m/s at the height of 0.77m	49.7 %
0Rn	3.00 m/s	4.170 m/s at the height of 0.77m	39.0 %
3Rv	0.15 m/s	0.179 m/s at the height of 1.04m	19.6 %
3Rv	3.00 m/s	3.707 m/s at the height of 1.04m	23.6 %
3Rn	0.15 m/s	0.186 m/s at the height of 1.04m	31.6 %
3Rn	3.00 m/s	3.746 m/s at the height of 1.04m	24.9 %

The observed planes at the centre of the buildings shown in Figure 2 were normal to the wind direction. It was found in the observed vertical planes that the airspeed was reduced considerably at the roof space of the building 3Rn, but there were more turbulence conditions at the roof space of building 0Rn. On the contrary, a similar indoor airflow was found in the building 0Rv and 3Rv. The results revealed that the location of the peak indoor airspeed and indoor air turbulence were varied according to the gable vent opening modes. The presence of gable vents had a considerable impact on peak indoor airspeed and indoor air turbulence. It was reported in Table 2 that the buildings 0R increased a higher indoor airspeed than the buildings 3R. On the other hand, all building presented a similar location for the peak indoor airspeed although the exterior wind speed was changed.

4.2. *Indoor air temperature differences*

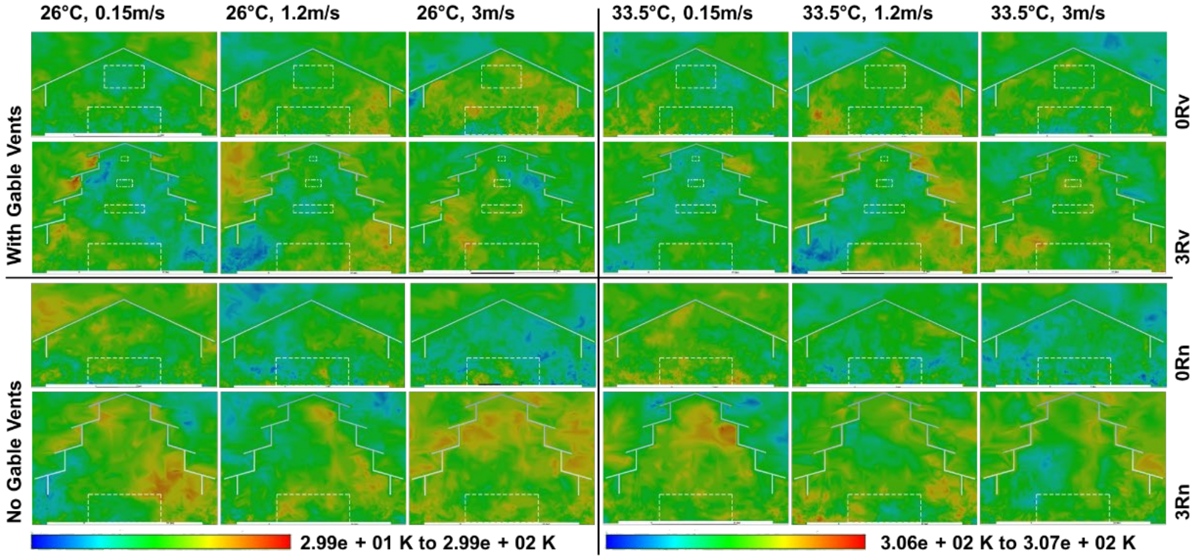

Figure 5. Indoor air temperature at the observed vertical planes.

Figure 5 observed the intensity of turbulence from the intensity of temperature. There were insignificant temperature differences between the indoor air temperature and exterior air temperature. The graphical images showed some degree of turbulence and the slightly higher air temperature held in the building with the still airspeed 0.15m/s; however, the temperature values shown in the legends presented low turbulence results. One notable result was that the higher indoor air temperature was maintained in the building 3Rn because there were no openings to remove the hot air.

5. Discussion

The CFD study presents the ventilation performance of ancient Myanmar multistage roof buildings taking into account their typology, ventilation modes and climate parameters. The main findings of the CFD results from this study were-

- The relationship between indoor air temperature and roof typologies were less distinct.
- The indoor air turbulences were very still in the buildings with no gable vents that maintained a slightly higher indoor air temperature, especially in the buildings 3R.
- The location of peak indoor airspeed was found depending on the typology of the building.

The study [11] designed to investigate the thermal performance of ancient multistage buildings from different ventilation modes and two roof materials. The results were cumulated for one typical weather year taking into account exterior air temperature fluctuation and exterior wind changes over time by using hourly offset data. The results of IESVE dynamic simulation study [11] reported that the duration of annual thermal discomfort condition was increased in the buildings with no gable vents. The result also reported that the annual mean indoor air temperature differences between the occupied spaces and roof spaces were more obvious due to the lack of gable vents in the roof. Similar results were found in this CFD simulation study although the air temperature differences between peak indoor temperature and outdoor temperature were very minimal due to their isothermal situations.

Due to the limitation of the scope of work in this study, it is important to highlight the future work in this domain in order to address the following issues.

- This study used an equally distributed gable vent area for building 0Rv and 3Rv. Although the gable vent area in the building 0Rv was unrealistic for real-world construction, the area of vent opening remained constant to avoid the impacts of window-to-wall area ratio.
- The simulations were performed at an isothermal situation with selected climate variables; therefore, the results were not addressed exterior air temperature fluctuation, natural wind direction and wind speed changes over time, and boundary surface temperature.

- Future work is necessary to address the impacts of inlet and outlet, roof height and roof pitch, and eave length on wind pressure distribution.

6. Conclusion

In the tropics, removing hot air from a naturally ventilated building is important for passive cooling. On the other hand, offsetting the radiate heat gain from the roof surface is a considerable factor for thermal comfort. The three-stage roof buildings have a benefit to avoid the radiate heat gain from their dominant height. Apart from the roof height, both this CFD study and the study [11] highlights that the use of gable vents are important for the three-stage roof buildings to remove the hot air as a huge hot air volume can lead undesirable outcomes for thermal comfort. On the other hand, relocating the gable vent to the centre of the multistage roof buildings helps better indoor air movement to remove hot air quickly instead of relying on large pediment at both ends of the gable roof. In sum, it can be expected that the three-stage roof buildings with gable vents have a substantial impact on the ventilation performance although the positive improvement is less distinct compared with the single gable roof buildings.

If the grandness of ancient Myanmar multistage roof is to be appreciated, it is not only because of its fine art and semiotic values but also what should be honoured is its capability to avoid the hot, stale air in the roof structure from the use of simple building physics with geometry management. Beautiful use of Le-baw, on the other hand, allows adding the gable vents easily for better ventilation performance. Perhaps here we should contemplate the benefit of gable vents in the multistage roof buildings coupled with better fabric thermal performance.

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