Vernacular Passive Design in Myanmar Housing for Thermal Comfort

ABSTRACT: Tropical weather is characterized by high humidity, high temperature, and intense solar insolation; therefore, traditional tropical housing is predominantly dependent on natural ventilation and passive cooling for thermal comfort. In the literature and practice, however, there is a gap of knowledge on Myanmar vernacular housing, specifically with regard to the variation in weather caused by climate change. In this paper, the authors review passive design techniques used in Myanmar vernacular houses to achieve thermal comfort. Using an experimental design approach, simulation studies were carried out to compare the impact of various passive design techniques on thermal comfort in three Myanmar climates. Different passive design techniques used in the two houses were further reviewed. Fifteen models were generated through an evaluation of the latter to examine the thermal performance of Myanmar housing throughout a year, with typical weather and predicted future climate scenarios. The results revealed that the efficacy of traditional passive design techniques would not be sufficient to achieve thermal comfort in the predicted future climate scenario. For this reason, the authors suggested that the passive design techniques of Myanmar vernacular housing need to be improved, with innovative solutions in order to cope with the changing climate.

KEYWORDS: Thermal comfort; Vernacular architecture; Climate change; Tropical housing; Passive design; Myanmar (Burma).

1. Introduction

The weather in tropical climate countries is predominantly manifest in high humidity, high temperature, and intense solar insolation. In response to these climatic characteristics, traditional tropical vernacular housing is predominantly dependent on natural ventilation and passive cooling for thermal comfort [1]. In recent years, the variations in weather caused by climate change have been increasingly pronounced worldwide. As of 1998-2017 records, according to the ranking of the countries most affected by extreme weather events and long-term climate risk index, Myanmar has been ranked third out of 183 countries [2]. Those events are often beyond the normal scope of what the built environment is prepared for.

Vernacular architecture has been directly linked to locally available resources and people's skill set; however, while the built form and materiality of vernacular buildings may suggest their climatic provenance, in itself this is hardly proof of all-year environmental performance [3] and thermal performance. For instance, the indigenous Kaluli longhouse in the tropical rainforests of the Great Papuan Plateau is essentially used after dark, when the nocturnal temperature noticeably drops from daytime norms [4]. Some vernacular buildings might have constraints for perfect building physics [5], and post-colonialism and globalization have exerted significant cultural impacts and economic imperatives on tropical vernacular architecture [6]. Myanmar's 2014 Census data [7] reported that 37.74% of dwellings are made of timber and 34.22% of dwellings are made of bamboo, which is considered to be vernacular housing.

With these pressures in mind, it is necessary to review the thermal performance of Myanmar vernacular housing both for the present climate and future climate scenarios. In the literature and practice, however, there is a knowledge gap of passive design techniques used in Myanmar vernacular housing, specifically with regard to the variation in weather caused by climate change. This paper reviews the passive design techniques used to achieve thermal comfort in eight types of Myanmar vernacular houses across three cities, representing three national climate contexts. It demonstrates how the use of vernacular materials, layout, and building form can provide thermal comfort, while also identifying challenges in relation to yearly weather and predicted future climate scenarios.

2. Housing context in Myanmar

2.1. Origins of Myanmar

Myanmar, formerly known as Burma, is located at a strategic location for a trade hub near the major Indian Ocean shipping lanes. Regional climates and topography have had a tangible impact on human settlement and house design [8]. Ancient Myanmar village settlement patterns are found along the Irrawaddy rivers as a linear village type, or over the countryside as a nucleated village type [8], due to their focus on agricultural economics, fishing, and domestic animal breeding. Much of Myanmar’s art and architecture is tied to ancient Hindu-Buddhist culture that can be traced to the country’s earliest known inhabitants. Many scholars believe that the first-known human settlement in Myanmar was from the Tibeto-Burman-speaking people [9] and the Mon or Talaings [10]. From 700 AD to 1824, the Mon, Bamar, Rakhine, and Shan have been the foremost traditional habitats of Myanmar, with dispersed ethnic groups spread throughout the country [10]. When China and the Islamic world dominated, and when the first Europeans arrived in Asia, it was called ‘Burma’ in early modern times [9]. In fact, what we see and know of Myanmar today is the heritage of the British Burma period (1824–1948), the Burma Socialist period (1948–1988), and the military government period (1988-2011). Although historically Myanmar has been a land of contradictions with regard to politics, culture, and religious beliefs [11], it is important to appreciate the country's rich diversity. Despite various ethnicities and cultures, eight significant races are found in Myanmar based on their population distribution [12, 13]; therefore, it is important to review each of their house typologies.

2.2. Geography and climate

The land of Myanmar is bordered by the Andaman Sea, the Bay of Bengal, Bangladesh, India, Tibet, China, Laos, and Thailand. The country is 432.41 km wide, 1009 km long, and approximately 702 meters above sea level. Myanmar lies between the latitudes 9° to 29°N and longitudes 92° to 102°E; the latitude differences, highlands, and topography create slightly different climate zones throughout the country. Only 3.4% of the total area of the country is covered by water [13]. There are two major wind currents that run through the year. Over the Indian Ocean and the south-west Pacific, the direction of global southeast trade wind is reversed by the southwest monsoon wind due to a vast land to the east of Myanmar [14]. Cold winds come from a north-east direction in January, and strong winds come from a south-west direction in June [15]. Three seasons in Myanmar, namely the hot season, the wet season, and the cold season, are annually changed by the global trade wind.

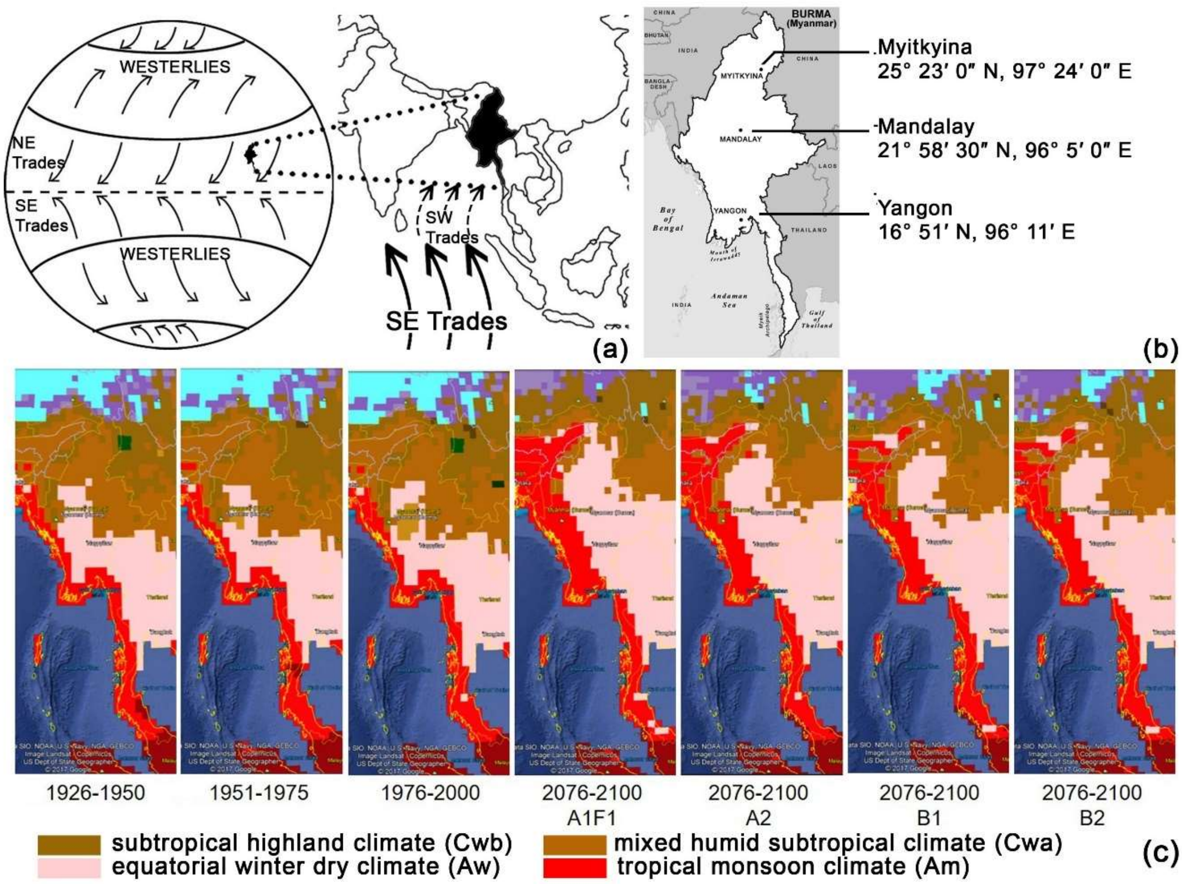

Figure 1. (a) Myanmar on the world map with trade wind direction; (b) Case study cities in Myanmar; (c) Koppen-Geiger climate shift: 1926-2100 for Myanmar [16-18]

According to the Koppen-Geiger climate classification [Figure 1] [16, 18], as of 1976-2000, there are four distinct climate zones in Myanmar: subtropical highland climate (Cwb), mixed humid subtropical climate (Cwa), equatorial winter dry climate (Aw), and tropical monsoon climate (Am). As the thermal comfort context relies on an interaction between climate, people, and building [19], it is necessary to review the influences of different climate zones on vernacular design. In this paper, three cities shown in Figure 1 were selected for comparison to cover three climate contexts of Myanmar; Yangon has the tropical monsoon climate, Mandalay has the equatorial winter dry climate, and Myitkyina has the mixed humid subtropical climate.

2.3. Climate change

Global climate change is causing climate shift in Myanmar, whereby the climate zone is moving from one place to another. The climate shift depicted by Köppen-Geiger climate classification maps [16] shows that the tropical monsoon climate and the equatorial winter dry climate are moving to the northern and eastern parts of Myanmar. As a result, the mixed humid subtropical climate and the subtropical highland climate would disappear in the northern parts of Myanmar by 2076-2100. The notable climate shift in the period 1976-2000 is compared to the predicted climate for the year 2076-2100 based on projections of future greenhouse gas emissions, which was illustrated based on the IPCC report [20]. According to the 'Assessing the Climate Risks in Myanmar' report, national annual average temperatures are projected to rise by 0.7 to 1.1°C compared with the 1980-2005 base period, while warming trends may accelerate beyond 2040, raising average temperatures by 1.3 to 2.7°C [21]. On the other hand, although the rainfall is projected a decrease in the hot season and cold season, the rainfall is projected to increase by 40% in the wet season compared with the 1980-2005 base period [21].

Deforestation is considered to be one of the main contributors to climate change. In 1990, 56% of the total land area was covered by forest; however, it is projected that only 25% of the total land area will be covered by forest in 2060 [22] due to deforestation. Population growth is also considered as one of the indirect contributors to global warming. In 1872, the population of Myanmar was estimated to be 2.7 million inhabitants; by 2014, this number had increased by 19 times to 51.5 million [7]. All the predictions and observations of climate shift, rapid population growth, and deforestation are likely to be immense and will play out in multi-dimensional ways in Myanmar and Myanmar housing. It is believed that the strength of vernacular architecture can blend buildings into various settings [23]; therefore, it is important to review traditional passive design techniques and their modern customs in vernacular housing to develop a resilient and sustainable built environment.

2.4. Myanmar vernacular houses

The National Races Village showcases eight Myanmar vernacular houses, which are replicas of significant symbolic structures characteristic of the major ethnicities residing in the country. The image shown in Figure 2 is from field study undertaken in 2016 by the first author. In this paper, based on the field observations, common features used in eight houses can be listed as described below, despite them being found in different locations.

Built form: A gabled thatch roof and bamboo or wooden structure are found in all houses as box-like forms. Most of the building components come from off-site fabrication and are assembled as a portable structure. The main houses are raised above the ground on a series of posts. An open space under the main house is either underused or used for domestic animals. Houses are either one or two-storey dwellings with a backyard and are rarely multi-storey. Room span and column spacing vary from seven to nine feet (2 metres to 3 metres). Family lifestyle patterns are usually reflected in the building size and building plan, which could serve either nuclear or extended family models. One notable feature in the Kachin house and the Chin house is the open porch that is used for a wood-burning fireplace in the winter, as these two groups mainly live in mountainous regions. Another distinctive feature in the Kayah and Chin house is the use of a hipped-roof.

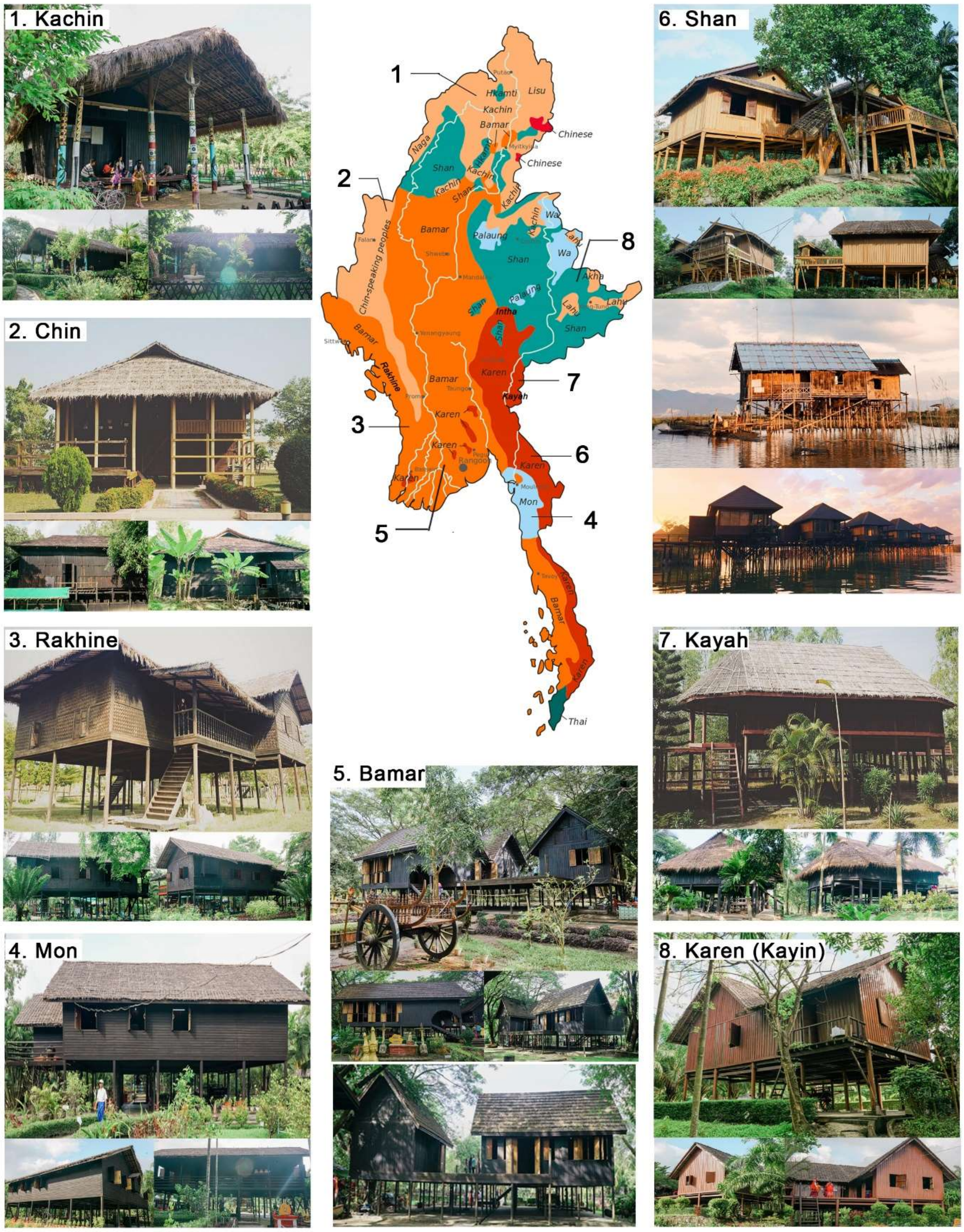

Figure 2. Ethnolinguistic map of Burma 1972[12] and Myanmar vernacular house types [24]

Building material: All buildings are assembled with a natural, rustic, unpainted wooden or bamboo envelopes and thatch roofs. Walls and floor have low thermal mass and are beneficial for small diurnal temperature ranges. Some houses are painted with coal tar epoxy, which provides protection from the weather (i.e. rain) and extends the lifespan of structures.

Nevertheless, the use of a dark colour coal tar epoxy makes the house vulnerable to fires, and increases solar heat gain. Brick is rarely used for envelopes, but it is used for the foundation of the main posts.

Roof, eave and gable vent: Thatched roofs bring insulation benefits to prevent intense solar radiation, and are combined with ventilated attic spaces. Eave projections are the main shading device in Myanmar houses that prevent heavy rain and allow no obstructions to ventilation and daylighting. The roof space is unoccupied due to the high internal air temperature near the roof surface. One notable feature in the Bamar house is its use of gable vents on the pediment and voids in wooden wall carvings, facilitating air exchange. Similar ventilation details can be found in Commander-in-Chief Minister Kinwun Mingyi U Kaung's house [25].

Raised floor and veranda: Raised floors have several functions: to protect against flood, prevent moisture penetration from the wet ground, to allow the house to be ventilated through cracks in the raised floor, and to offset the radiated heat gain from the hot-dry ground. Any gaps between different floor levels facilitates fresh air inflow. A veranda, whether narrow or large, provides some shelter and a buffer space for the main house from direct sunlight.

Layout: Building layout is strictly regulated by tradition, with a hierarchy based on gender and age. Window locations are on either side of the building; some rooms are unlit, as most traditional livelihood activities are carried on outdoors. The internal walls provide privacy; however, they are not fully attached to the roof. Ceilings are rarely built; therefore, gaps between the top of the walls and roofs allow natural light through the gable vents.

Ventilation and infiltration: Protection from strong winds and preventing the growth of mould is a priority in Myanmar housing. Therefore, the ventilation design is necessary to provide complex functions for structural stability, health concerns, and thermal comfort. Due to cultural influences and safety requirements, the windows and door openings function in different modes daily. Gable vents and openings between the roof and wall sections provide cross-ventilation and buoyancy-driven ventilation to remove smoke from cooking and hot air from houses, although windows and doors are closed. Locating at a similar distance from the Equator, most of Myanmar vernacular houses are very similar to Amazon Yagua houses [26] and Southeast Asian vernacular houses [8]. Jones et al. (1993) estimated the air infiltration rate to be above 30 air changes per hour (ac/h) in traditional Malay houses, and measured air infiltration of 15 to 35 ac/h in three Malay modern houses [27]. As outside air comes into a house through permeable walls, gable vents, floor gaps, and construction joints, all Myanmar vernacular houses can be presumed to have similarly high air infiltration rates.

Apart from the above-mentioned common characteristics, this paper further reviews different passive design techniques used in the Bamar and the Mon houses. The Bamar, the largest group in Myanmar, originally lived at the centre of Myanmar under the equatorial winter dry climate zone. The climate has a severe dry season and a short but extremely rainy wet season. In the Bamar house [Figure 3(a)], all rooms are small and located above raised floors. The roofs are broken down into small units with overlapping roofs that reduce roof height and roof size. The roof shading and roof ventilation techniques are similar to the north-east Indian houses [28] that facilitate allows the removal of removing buoyant hot air, even when the wind is still. Windows are tall and windowsills are closed to the floor; therefore, ventilation directly goes to the floor seating space. A separated kitchen is connected by an open deck.

The Mon, one of the earliest people in Indochina, originally lived in the southern part of Myanmar, where the tropical monsoon climate zone has a less pronounced dry season and an extraordinarily rainy wet season. In the Mon house [Figure 3(b)], there is a large entrance veranda with a central staircase that sets back the main house, to avoid direct solar heat gain and wind-blown rain. Although there are fewer window areas and no gable vents in the Mon house, hot air can be removed by cross-ventilation through an elongated, rectangular layout. A kitchen is attached to the main house; therefore, it is convenient to access when it is raining.

In light of this overview of traditional houses, a combination of various building components for passive design techniques is ideally suited to maintain the thermal comfort for the related tropical contexts. However, the movement of people throughout the country leads to the sharing and mixing of building styles [29], and the effect of passive design for thermal comfort might vary by regional contexts. Therefore, the impacts of various combinations of building components (e.g., in terms of orientation, window-to-wall ratio, building size, and layout) on indoor thermal performance can be different according to the three Myanmar climate zones, thus an individual study is necessary for each case.

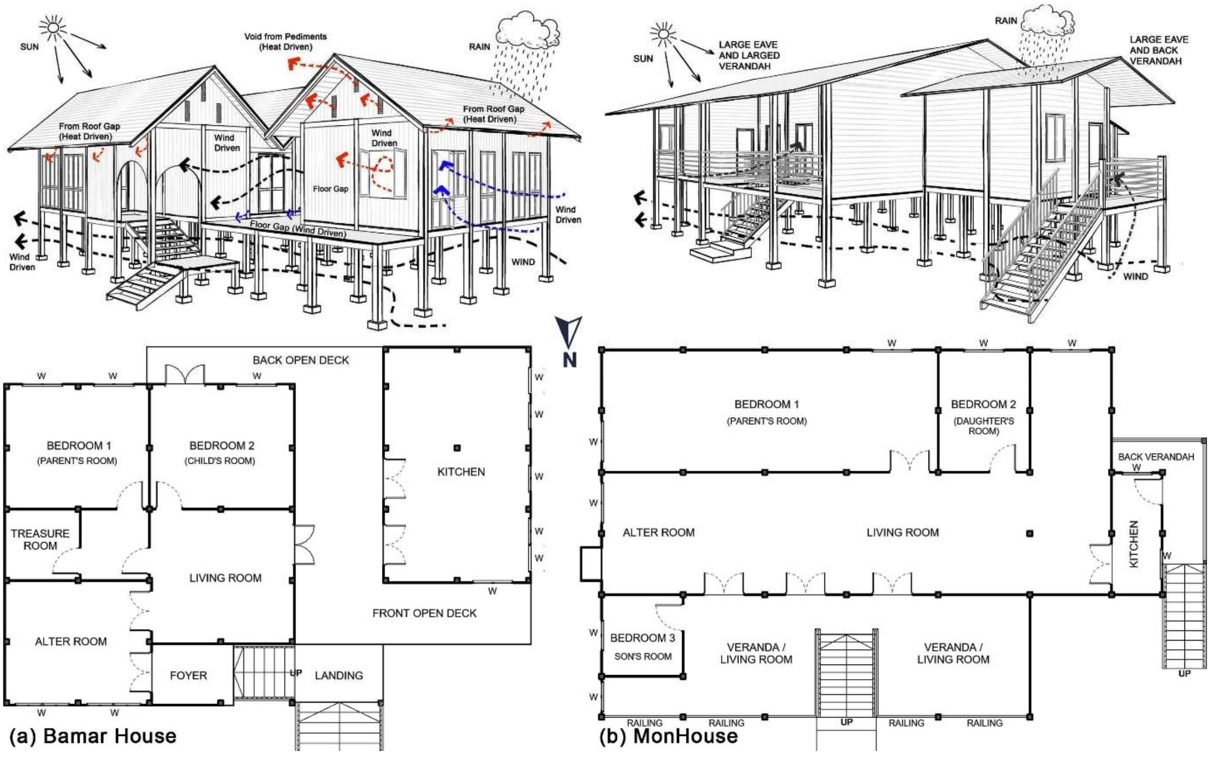

Figure 3. Built form and plan of Bamar house (left) and Mon house (right) in the study [30]

2.5. Modern customs

According to Myanmar's 2014 census data, only 15.9% of national dwellings are made of brick and concrete [7]. The practices of vernacular housing have remained remarkably resilient, while many tropical countries have fallen prey to brick and reinforced concrete housing with active cooling [29, 31]. Brick walls, concrete floors, glazed windows, and zinc or other metal roofs have become alternative choices for modern materials. In some buildings, ceiling voids are created above a flat false ceiling to remove buoyant hot air and to prevent radiated heat gain from zinc or other metal roofs. One of the popular aesthetic components for brick houses in Southeast Asia is the use of ventilation blocks, which are perforated concrete blocks, for walls and fences [32]. Ventilation blocks facilitate airflow even when windows and doors are closed. Table 1 lists modern customs in Myanmar vernacular housing that vary in terms of building materials, the presence or absence of a ceiling, gable vents, ceiling voids, and ventilation blocks. As the thermal comfort in vernacular housing can be varied by its use of vernacular and modern construction materials [33], it is important to investigate the thermal performance of modern customs in current climates.

Table 1. A possible combination of building components in Myanmar vernacular housing

	Roof	Wall	Window	Floor	Gable vent (Y/N)	Ceiling (Y/N)
1	Thatch	Timber	Timber	Timber	No	No
2	Thatch	Timber	Timber	Timber	Yes	No
3	Thatch	Timber	Timber	Timber	Yes	Yes (with void)
4	Thatch	Timber	Timber	Concrete	No	No
5	Thatch	Timber	Timber	Concrete	Yes	No
6	Thatch	Timber	Timber	Concrete	Yes	Yes (with void)
7	Metal	Timber	Timber	Concrete	No	No
8	Metal	Timber	Timber	Concrete	Yes	No
9	Metal	Timber	Timber	Concrete	Yes	Yes (with void)
10	Metal	Brick	Glass	Concrete	No	No
11	Metal	Brick	Glass	Concrete	Yes	No
12	Metal	Brick	Glass	Concrete	Yes	Yes (at gable roof)
13	Metal	Brick	Glass	Concrete	Yes	Yes (with void)
14	Metal	Brick	Glass	Concrete	Ventilation block	Yes
15	Metal	Brick	Glass	Concrete	No	Yes

2.6. Thermal comfort

Thermal comfort is a condition of mind that expresses satisfaction with a thermal environment [34]. Myanmar vernacular housing is a free-running building type that uses the adaptive comfort approach for thermal comfort. For a free-running building, the Chartered

Institution of Building Services Engineers (CIBSE) has suggested that the internal operative temperature should not exceed 30°C [35]. On the other hand, the occupants in naturally ventilated buildings are often tolerant of a significantly wide range of temperatures based on a combination of behavioural adjustment and psychological adaptations [36]. If the psychrometric charts of three cities from Myanmar are compared to the neighbourhood countries such as Singapore and Bangkok, a similar profile can be found in their typical weather years. Field experiments in naturally ventilated buildings in Singapore [37] and the study of the thermal response for the Thai office environment [38] present good agreement on the thermal neutrality of 28.5ºC for the internal operative temperature. According to the National Oceanic and Atmospheric Administration dataset, for the heat-index temperature, at the air temperature 36°C with relative humidity of 40%, the heat index temperature reaches 38°C, which is an extreme caution stage [39]. Above the air temperature 36°C with relative humidity of 40%, human health is threatened, with increased risk of heat cramps, heat exhaustion, and heat stroke [39]. Although the heat index temperature is generated for a Heat-Balance condition, it provides a limited estimate of thermal comfort, and the equations can be a rough threshold to compare the quality of thermal comfort of different indoor thermal environments [39-41]. The existing literature is limited for the Myanmar contexts; however, according to all the aforementioned factors, it could be inferred that a similar range of thermal responses can be expected in Myanmar houses as found in studies in Singapore [37] and Bangkok [38] and posited in the CIBSE guide [35].

3. Simulation studies

3.1. Research methodology

Scope of work: By applying three research stages, the simulation studies aimed to compare the thermal performance of Myanmar housing from various prescribed conditions. The first stage of the study investigated the impacts of orientations and window-to-wall ratio on indoor air temperature for a typical model. The second stage of the study investigated the impacts of building sizes and floor arrangements on indoor air temperature by comparing the Bamar house and the Mon house from Figure 2. The third stage of the study investigated the impacts of various combination of building components on indoor air temperature by comparing fifteen models evaluated as listed in Table 1. The simulation works were carried out using the ApacheSim and Macroflo programs, part of the commercially popular and well-known IESVE software. ApacheSim, a dynamic thermal simulation program of the IESVE, uses first-principles mathematical modelling for the heat transfer processes occurring within and around a building. The program also qualifies as a dynamic model in the CIBSE system of model classification. MacroFlo runs as an adjunct to ApacheSim by exchanging data at run-time to achieve a fully integrated simulation of air and thermal exchanges [42].

Weather files: The simulation studies were compared to the results of the three cities shown in Figure 1. The weather files used in this paper had 22 years' worth of data, spanning from 1991 to 2013, which were generated by Haung et al. (2014) for ASHRAE. Due to the lack of weather files for future weather scenarios, the authors created one future climate weather file for each city by adding increased value consistently to the typical weather files; the method was referred to the use of a "shift" of a current hourly weather data parameter following the study [44]; the study presented that even a single estimated expected annual change in air temperature could provide useful estimates of heating and cooling demand. The added values for the future weather files were referred to the report "Assessing the Climate Risks in Myanmar. A contribution to planning and decision-making in Myanmar", which is a technical report by World Wide Fund for Nature. The report [21] provided that the predicted temperature changes 2.9ºC in the hot season, 2.4ºC in the wet season, and 2.8ºC in the cold season, for which, the values were calculated for warming during 2041-2070 based on the baseline model of 1980 to 2006. According to the report [21], it is important to note that its reference of the

NASA NEX baseline data reflected model values averaged over 0.25 degrees; therefore, the actual observed station temperatures may differ from the model baseline.

Comparison method: Defining overheating thresholds in Myanmar is one of the challenges for this simulation study due to the limited existing literature. As the simulation models were set as a free-running building type, the indoor air temperature (AT) 30°C was considered, comparing the simulation results that can be assumed as a close value of the acceptable internal operative temperature suggested by CIBSE [35]. It is important to note that the acceptable internal operative temperature is a combination of mean radiant temperature and air temperature [45]; therefore, the AT 30°C was not the benchmark of comfort models for the Myanmar context. The simulations were worked for one-year data for different weather scenarios; therefore, the percentage of a year with different AT ranges was used for yearly profile comparisons. The AT 36°C was used in this paper in order to compare the extreme condition in the future climate scenario; however, it was not the overheating benchmark.

3.2. Model assumption and simulation input

For the first stage of the study, a single gable roof model shown in Figure 4 was first considered. The model had with 5m length, 5m width, 3m height wall, 2m height roof, and 1m height raised the floor. Firstly, the model with 20% of window-to-wall ratio (WWR) for four sides of walls was used to test the impact of orientation on the indoor air temperature. Secondly, the same model was used to test the impact of window-to-wall-ratio on the indoor air temperature; however, the window areas varied from 5% to 90% of WWR. All windows were open continuously.

For the second stage of the study, the assumption of simulation input data such as the proportion of windows area, window opening time, air infiltration rate, and internal heat gains from occupants and equipment were assigned in the simulation models of the Bamar and Mon houses. The typical models and both houses had a thatched roof, timber floor, timber wall, and timber window. For the third stage of the study, the fifteen models shown in Figure 5 were evaluated based on Table 1. The same model sizes used for the first stage of the study were used for the fifteen models. The material properties for all stages of the study were assigned in the simulation models based on the IESVE database [42] and GVA/15 CIBSE Guide A (2015). The data set for all simulations is shown in the Appendix.

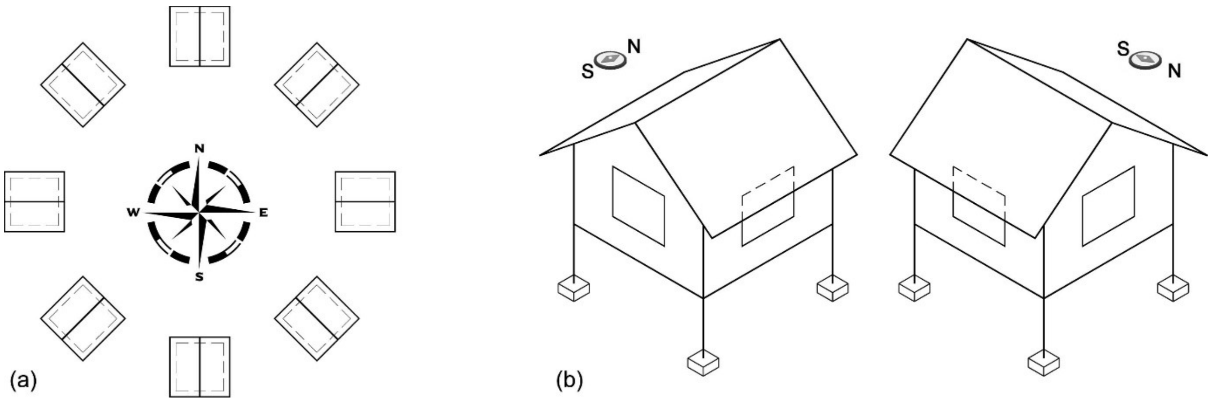

Figure 4. (a) Typical model in a plan for orientation studies; (b) Typical model for window-to-wall-ratio simulation with north-south direction gable roof

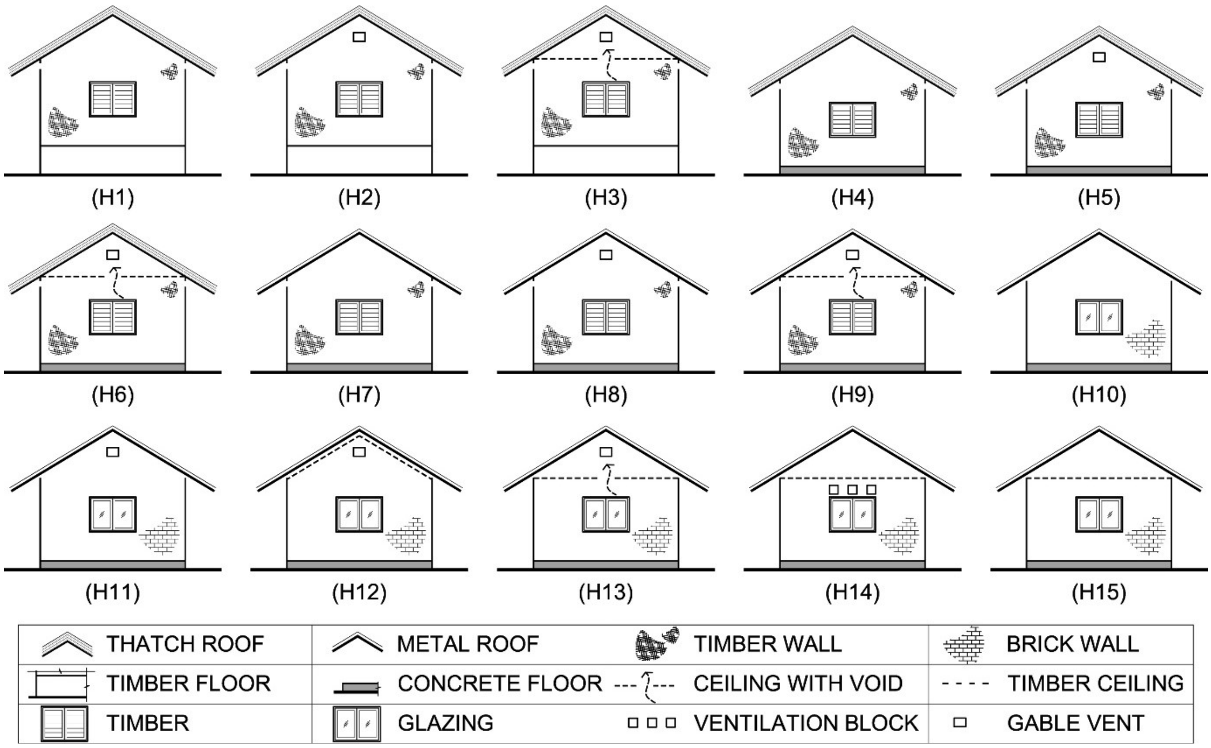

Figure 5. Model of fifteen scenarios in the study and their material use

In the third stage [Figure 5], all windows were open from 06:00 a.m. to 18:00 p.m. The ventilation block area in the model H14 was equivalent to the gable vent area. There was a ceiling in the models H3, H6, H9 and H13; therefore, a ceiling void with 0.6m width and 0.6m length was added on the ceiling. The air infiltration rate 15 ac/h was assumed for the timber models H1 to H9, which was 10 times higher than the rough assumption 1.5 ac/h for the brick models H10 to H15.

4. Results of the simulation studies

4.1. Impacts of orientation and window-to-wall-ratio

As shown in Figure 6, it was found that there were insignificant differences in AT between the four cardinal and four inter-cardinal directions. The comparison of WWR revealed that the larger the WWR, the lower the percentage of the year above AT 30°C; however, the percentage of the year was reduced by up to 5% by changing WWR 5% to WWR 90% when the window was continuously open.

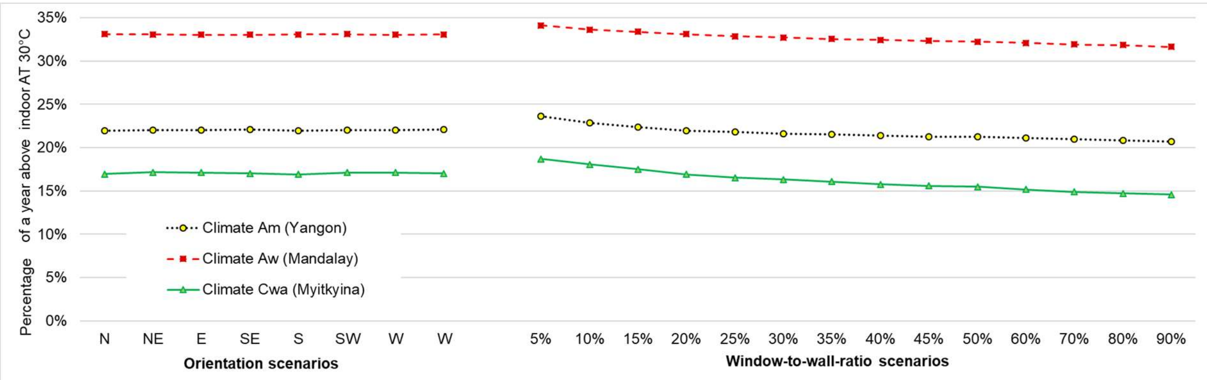

Figure 6. Impacts of orientation and window-to-wall ratio in three cities

4.2. Impacts of building size and plan

The results shown in Figure 7 indicate that there were small differences between two houses regardless of building size and floor plan arrangement differences. In the Bamar house, the kitchen received a lower percentage of the year above AT 30°C than the bedroom for the parent. In the Mon house, the veranda received a lower percentage of the year above AT 30°C than the bedroom for a daughter; the differences between the two rooms were 4.53%, 4.78%, and 4.38% in Yangon, Mandalay, and Myitkyina, respectively.

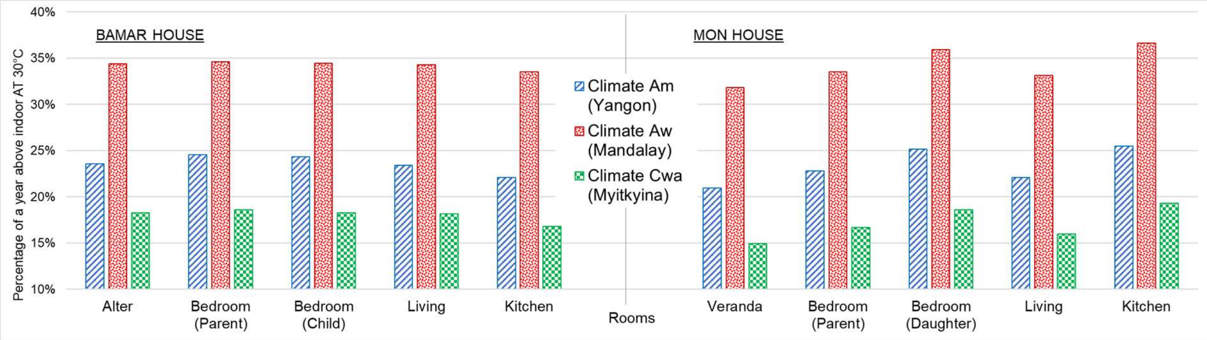

Figure 7. Comparison of Mon and Bamar houses, typical weather years in three cities

4.3. Impacts of ventilation techniques and building materials

The results of indoor air temperature ranges for the fifteen models for typical weather years of three cities are shown in Figure 8. For the timber models H1 to H9, the worst result was found in the model H7. For the brick models H10 to H15, the worst result was found in the model H10. In Yangon and Mandalay, more than 50% of a year were above AT 28ºC in models H10 to H15, while the timber models H1 to H9 maintained 60% of a year below AT 28ºC. The percentage of the year above 36°C showed the risks of heat stress in all free-running models. Similar monthly temperature variation profiles were found in all scenarios; Figure 9 presents the results of the models H1, H7, H10, and H15 for a typical weather year in Yangon. The highest peak temperature in April was decreased in the model H15 compared to the model H7; the model H7 had timber walls and no ceiling; the model H15 had brick walls and ceiling. Model H1 received the lowest peak temperature 14.15ºC in December, and values of 14.46ºC, 16.73ºC, and 17.72ºC were recorded for models H7, H10, and H15, respectively.

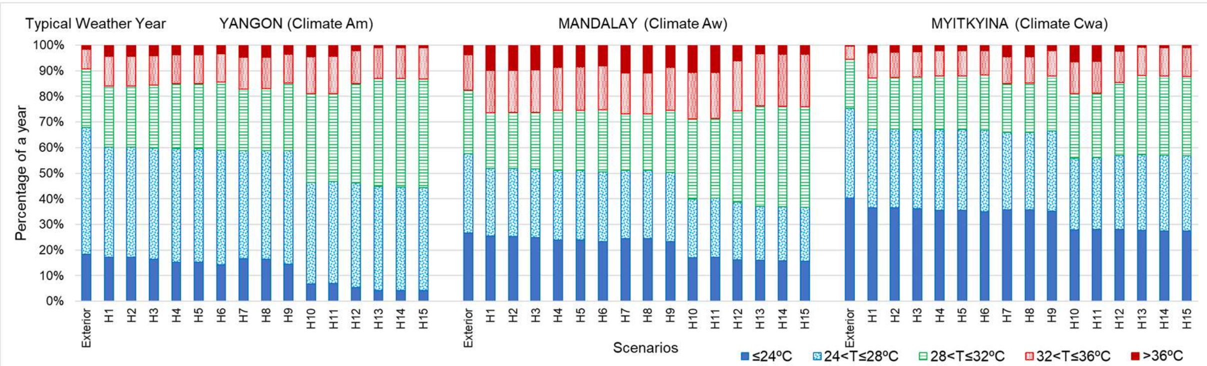

Figure 8. Indoor temperature range for fifteen models, a typical weather year

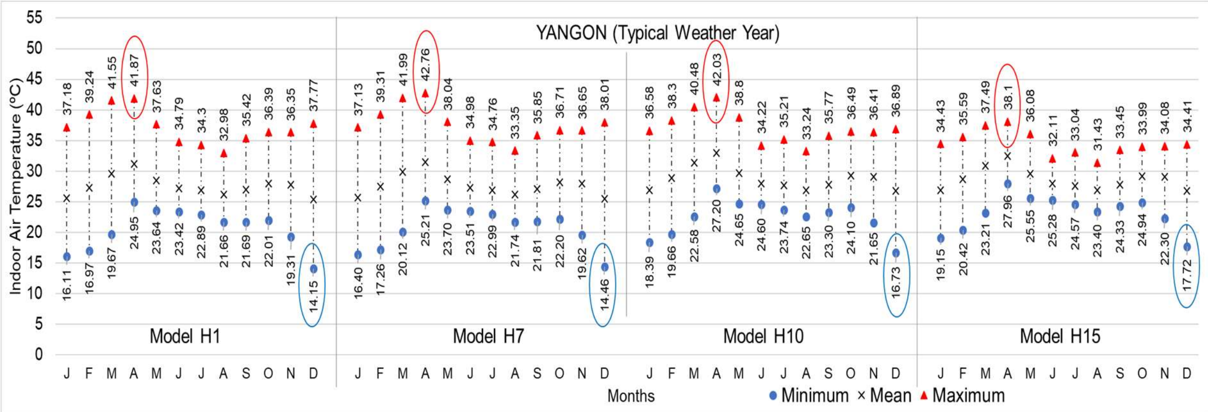

Figure 9. Monthly temperature variation in model H1, H7, H10 and H15 in Yangon

The simulation results of typical weather year and future weather scenario for three cities are compared in Figure 10. When the roofs were changed from thatched roofs to metal roofs, the indoor temperatures were significantly increased, as shown in models H6 and H7. The thatched roof model H4 performed better than the metal roof model H7. The timber wall model in H7 and the brick wall model in H10 had the same metal roof but no gable vent; however, both models received a higher percentage of the year above AT 36°C than the other models. There were minimal differences between the metal roof models H7 and H8, although the gable vent was added in the model H8; the indoor temperature of the model H9 was dropped when the ceiling was added in it. Obvious results of the ceiling and roof ventilation can be found by comparing the models H10 and H13; however, there were small differences between the models H1 to H3.

A better performance was found when the gable vents and ceilings were added in the models H12 to H15. The model with the false ceiling (H13) performed better than the model with a ceiling under the gable roof (H12). Although the ventilation blocks were replaced to the gable vent, there were small differences between the models H13 and H14. Nevertheless, the percentage of the year above 36°C was significantly increased in all models in the future weather scenario. In all simulations, the worst results were found in the models located in the equatorial winter dry climate zone, which was Mandalay.

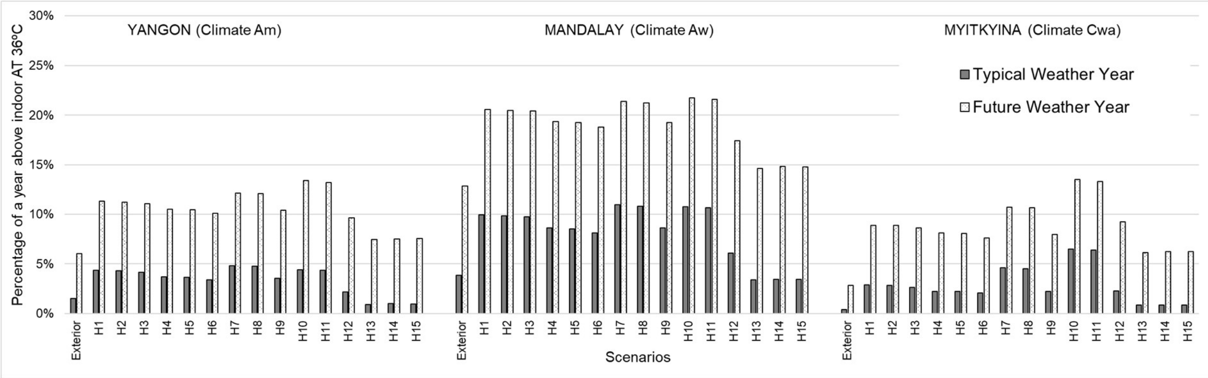

Figure 10. Comparison of a typical weather year and future weather year for fifteen models

5. Discussion

In the first stage, there were negligible differences between the eight orientations in terms of the indoor air temperature in the small-scale model. These results were in agreement with the study conducted by Morrissey et al. (2011); their ANOVA tests showed that smaller houses had significantly smaller ranges of energy efficiency ratings across eight orientations, in comparison to larger houses [46]. The simulation results of this paper showed that a model with a large window-to-wall ratio had a better result than others. Regarding the use of natural ventilation, there are five constraints: it does not work in the hot air condition; high natural ventilation is necessary for the warm air condition; the moderate ventilation is appropriate in the comfortable air-condition; natural ventilation is not appropriate in the humid air condition; and minimal ventilation will help in the cool and humid air condition [47]. Since high humid air holds a higher temperature for a long time, a complex outcome of combining high humidity and high air temperature in the tropics is the increase of warm air inside the space; therefore, higher natural ventilation throughout the day is necessary in order to remove the warm air inside. Nevertheless, further study is necessary to investigate the window size requirement for natural ventilation throughout a year to change climate conditions. Overall, the first stage of the study provided fundamental knowledge about the relationship between the Myanmar climates and the test models.

In the second stage of the study, there were difficulties describing the precise role and importance of building design features from two houses, as their simulation results were very similar. On the other hand, it can be noted that the impact of the exterior climate is more significant than the described building layouts. In the third stage of the study, it was found that there were substantial effects of roof insulation and roof ventilation on indoor air temperature. The traditional techniques presented in the models H1 to H3 have closely reflected the exterior weather. On the contrary, the modern custom presented in the models H12 to H15 had a better thermal performance than others to prevent the peak temperature; however, increments in annual mean temperature were not addressed in those models. Overall, the results of the fifteen models were in agreement with the study conducted by Samuel et al. (2017); their case study in India showed that passive architectural features in a traditional building can provide thermal comfort if employed correctly, using modern materials [33].

6. Conclusion

The paper presents the vernacular passive design techniques in Myanmar housing with a focus on their thermal performance. The paper compared the impacts of three climate contexts and passive design techniques on indoor thermal environments of Myanmar housing by using air temperature alone, with 30°C and 36°C as thresholds. Further studies are necessary to address the importance of thermal thresholds [19] in relation to the climate and people of Myanmar. Although the confidence of simulation studies indirectly relied on the accuracy of weather files, the studies provided a comprehensive body of knowledge about Myanmar vernacular housing from traditional designs to modern customs for three Myanmar climate zones.

Natural ventilation and roof shading in Myanmar vernacular architecture might have been an optimal thermal comfort performance in the past; however, the increasing outdoor temperatures and changes in rainfall caused by global warming and climate change are threatening the thermal performance of Myanmar housing. Considering the classic challenges of tropical climatic characteristics in Myanmar housing and the climate change crisis, there are demands for improvements in the Myanmar housing in order to achieve adequate thermal performance.

According to the results obtained in this study, traditional houses in Myanmar might face challenges in indoor thermal comfort; therefore, this paper suggests that new climate adaptation strategies are necessary for Myanmar housing for different climate zones. As the biggest challenge for Myanmar is the climate change risk, a concluding question of this paper is how Myanmar housing can improve thermal performance. Further studies need to include empirical and quantitative assessments, and qualitative assessment of occupant comfort in order to generate more specific scientific information for sustainable climate adaptation strategies in Myanmar housing for the political, professional, industrial, academic, environmental, economic, and media dimensions.

Appendix

Table 2. The proportion of windows areas in the Bamar house and the Mon house

	Window area		Approximate ratio window on each façade / total window area	
	Bamar House	Mon House	Bamar House	Mon House
West	11.07	2.75	20.1%	7.0%
North	8.25	7.29	25.5%	*15.7%
East	7.20	5.67	21.5%	13.1%
South	5.40	5.25	10.7%	14.6%
Total	31.92	20.96	51.46% of total floor area	29.61% of total floor area

*Note: Area of veranda opening was excluded.

Table 3. Thermal properties used in the simulations

	Nomenclature	Unit
Total thickness	T	mm
Conductivity	λ	W/(mK)
Density	D	kg/m^3
Specific heat capacity	Cp	J/(kg.K)
Thermal transmittance	U	W/m^2K
Thermal mass	Cm	$(kJ/(m^2K))$
Outside surface Solar absorptance	SA	-

Table 4. List of components used in the simulations, dataset based on [35, 42]

	T	λ	D	Cp	U	Cm	SA
Thatch roof	300	0.07	240	180	0.2881	4.32	0.70
Metal roof	15	0.19	960	837	2.6667	5.50	0.30
Timber floor	25	0.14	650	1200	2.6988	9.75	0.55
Concrete floor	500	-	-	-	0.7947	174.72	-
- Screed	-	0.41	1300	1000	-	-	-
- Sand	-	0.35	2080	840	-	-	-
Timber wall	25	0.13	900	2000	2.9240	22.50	0.55
Brick wall	250	-	-	-	1.6692	124.60	0.55
- Plaster	-	0.16	600	1000	-	-	-
- Brick	-	0.84	1700	800	-	-	-
Timber ceiling	25	0.165	650	1600	2.7295	13.00	-
Timber window / door	40	0.130	900	2000	2.1863	36	-
Glazing	12	-	-	-	5.75	-	-

Table 5. Simulation input data in the Bamar and Mon house

	Assumption	Properties	Operation
1.	Occupants (two persons)	Maximum sensible gain 60 W/p; Maximum latent gain 40 W/p	All the time
2.	Fluorescent lighting and other equipment	Maximum sensible gain 120 Watts	06:00 to 09:00 and 16:00 to 22:00
3.	Window opening	-	06:00 to 18:00
4.	Air infiltration rate	15 ac/h and 1.5 ac/h	All the time

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