Vernacular Architecture and Thermal Comfort in Warm and Humid Tropics

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Abstract. In order to change the situation of the buildings within poor thermal performance and high energy consumption, effectual and energy-saving architecture structure is nowadays an active demand. As vernacular residence with low energy consumption is strong evidence on human beings long term adaption to local environment, traditional dwellings could be feasible conceptual design and optimization for modern architecture. The previous research seemed to demonstrate the perspective mentioned above. However, there might be some flaws. This paper, based on two former typical case studies, is aimed to reveal the deficiency of the field study and questionnaire, and the probability to improve the methodology.

Keywords: thermal comfort, vernacular architecture, building operation.

1. Introduction

Thermal comfort can be defined as the satisfaction level of human thermal sense responding to surrounding environment. As people spend more time in buildings, indoor thermal comfort has paramount significance on human health and productivity. However, it is a really complicated issue, which concerns not only human behavior, such as activity level and thermal resistance of clothing, but also internal conditions, such as air temperature and relative humidity. Occupants can have different responses to same thermal conditions since sensation of warmth in the self-regulatory system varies among people. It is a relatively uncontrollable factor when pursuing thermal comfort, thus, most researchers dedicate to investigation in building thermal performance. Although adding mechanical systems can improve the indoor thermal environment, energy consumption and sustainability should be taken into account when dealing with building performance [1]. Therefore, vernacular architecture seems to be an alternative solution due to that the traditional modes are empirical results evolve over time of energy consumption reduction [2, 3]. As climate changes in different places, vernacular architecture also alters in different regions [4]. Studying typical structure of vernacular architecture in hot humid tropical zones could be a favorable start in the exploration on the relationship between indoor thermal comfort and local buildings. Case studies in Tezpur and Kerala on the thermal comfort research will be given, followed by the strengths and weakness in these cases, and further improvement for future investigation.

2. Background

It is obviously more challenging to achieve thermal comfort in extreme climates, such as tropical warm and humid climate. The main features of this climate are the high levels in humidity, temperature and solar radiation. The evaporative cooling in these places works inefficiently as the ambient air is nearly saturated. Instead, ventilation comes out mainly for natural cooling in houses [5]. As for blocking solar radiation, extensive shading is a simple but appropriate approach to keep cool [6].

Consequently, in respect of local climate, traditional dwellings are always constructed within large roof overhang and surrounded by huge trees. To maximum cross ventilation, the orientation is generally towards prevailing wind, and the internal structure is kept as simple as possible, while the external surface have numerous openings. Many houses are raised above the ground and some are supported by silts allowing air flowing beneath. High ceilings are also preferred in indigenous architecture to optimize stack effect, which provides opportunity for hot air forced by buoyancy to release through top openings [5].

All the traditional solutions mentioned above in architectural design aim at creating a comfortable thermal environment. Two common models are applied for setting current thermal comfort standards, namely Heat Balance Approach by Pro. O, Finger and Adaptive Approach by Pro. M, Humphreys [7]. The first approach brought in the concept of Predict Mean Vote (PMV) and Percentage People Dissatisfied (PPD) and was based on a large quantity of laboratory experiments in man-made climatic chambers, which meant heating, ventilation and air-conditioning (HVAC) systems were required for keeping thermal comfort [7, 8]. It considered both internal conditions and human behavior. The second one was relied on the survey of field studies and external environmental situations performed predominantly in indoor thermal condition estimation. Humphreys found that in fully natural ventilated houses occupants felt more comfortable than the suggested result from PMV method and it was more reasonable to apply adaptive method in unconditioned dwellings [2]. Other developments on thermal comfort assessment methods were normally depended on these two basic models and they were presented in following case studies

3. Literature References

Two case studies in warm and humid tropics were emphasized in following content. Description for Case 1 was based on Singh et al's study [8, 9], while Case 2 was Dili et al's study [11, 12].

3.1 Case 1 in Tezpur (north hemisphere) [8, 9]

The selected vernacular residential houses were located in Tezpur (hot and humid tropical zone). Figure 1 showed the external views of a representative building. It was a single story domestic house with openings evenly distributed on external walls. Inclined and extended roof minimized the damage due to heavy rainfall and also served as the shading to block solar radiation. In addition, false ceiling structure reduced the heat gain during daytime. Figure 2 presented the natural ventilation in the vernacular architecture and Table 1 summarized the climatic design characteristics of this vernacular architecture.

Figure 1: external views of target house in Tezpur [9]

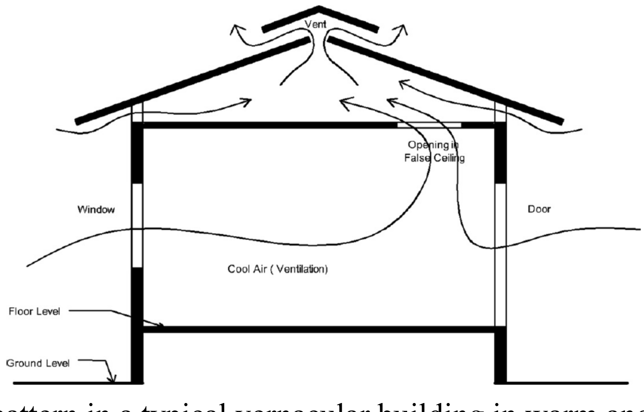


Figure 2: air flow pattern in a typical vernacular building in warm and humid tropics [10]

Table 1: climatic design characteristics of the vernacular architecture in Tezpur [8, 9]

Openings	Even distribution of windows and ventilators on exterior walls (ventilators located above windows but below the ceiling)
Window to wall ratio	0.216
Wall (material and thickness)	Brick, cement and sand (0.127m)
False ceiling and roof type	Asbestos sheet/wood. Galvanized tin sheet and tilted on two sides
Ventilation	High ventilation
Layout	Open layout with courtyard
Prominent passive features	Air gap in ceiling, shading, extended roof used as overhang, chimney arrangement for effective ventilation

In this field study, both objective and subjective aspects were taken into account. Indoor and outdoor parameters, including temperature, relative humidity and illumination level were measured at an interval of 30 minutes for 25 days (from 6.00 to 19.00) in each season (January: winter, April: pre-summer, July: summer/rainy and October: pre-winter). It was necessary to carry out the long-term data measurement since that the buildings spent some time to response to weather and seasonal variation. One data logger was placed in the center of the house and the other one was outside to record the indoor and outdoor parameters respectively. 100 people attended the thermal comfort test in 50 similar vernacular houses with detailed information shown in Table 2. The participants were asked to sit still for 20 minutes before giving the thermal sensation vote and answering the questionnaire survey.

Table 2: comfort survey indicators [9]

Clothing level (clo)	0.3
Metabolic rate (met)	1
Number of participants	100
Number of houses	50
Respondent age (%)	
<20 years	11
20-40 years	77
>40 years	12
Respondent gender (%)	
Male	65
Female	35

Table 3: estimated comfort temperature and thermal comfort range from survey [8].

Month	Comfort temperature (°C)		Range of comfort temperature from comfort survey (°C)
	Humphreys	Auliciems	
January	20.9	19.9	22.8 - NA
April	25.1	25.1	24.0 - 28.4
July	26.9	27.3	NA - 29.1
October	25.7	25.0	23.7 - 28.4

NA: not available.

Table 4: percentage of time in thermal comfort range [8]

Month	Percentage of time in thermal comfort range (%)	
	Humphreys	Auliciems
January	3	8
April	5	15
July	NA	15
October	23	23

NA: not available.

Adaptive model by Humphreys was used in this case study since the building was fully natural ventilated (without permission of fan operation) and responders tried to be more comfortable and tended to adapt to environmental changes. The thermal comfort temperature could be obtained simply from mean monthly outdoor temperature with a standard error of 1℃. Another method by Auliciems, which was improved to delete the incompatible information in Humphrey's data, considered active and passive climate control. It estimated thermal comfort temperature by using mean indoor and outdoor temperatures. All the results from these two method and comfort survey were listed in Table 3. Besides, Table 4 presented the percentage of time in thermal comfort range by different methods.

3.1 Case 1 in Tezpur (north hemisphere) [8, 9]

Kerala was regarded as a warm and damp region since the annually temperature was between 21℃ and 33℃, and the relative humidity generally exceeds 70%. This case study was to compare and contrast traditional and modern architecture in Kerala. Therefore, two groups of buildings were under testing.

The well-known traditional dwellings in Kerala, named as Nalukettu at the age of 200 – 300 years, were always constructed in rectangular or square shape in plan. One photo of a typical vernacular Kerala house and a common plan layout were illustrated in Figure 3. It had the similar structure with the buildings in previous case study. Inclined roofs with angle up to 45° had the gables to facilitate stack ventilation. Sufficient ventilators were installed throughout the external walls and false ceiling. Figure 4 provided a section view for air movement in Nalukettu and Table 5 listed the design features of this type of vernacular architecture.

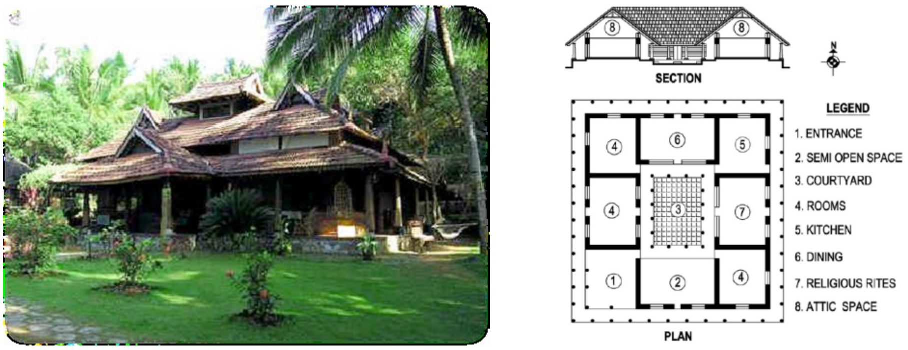


Figure 3: a photo of a typical vernacular Kerala house and a basic plan layout [11]

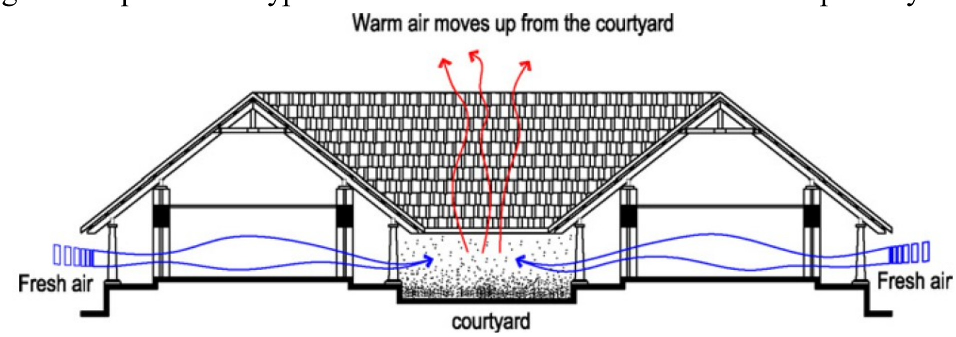


Figure 4: air flow pattern in Nalukettu [11]

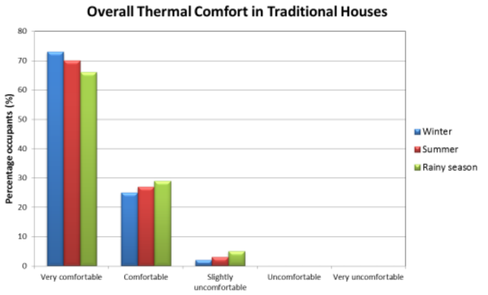
Table 5: climatic design characteristics of the vernacular architecture in Kerala [11]

Openings	Gables at the end of roofs, decorative ventilators on false ceiling, large openings on external walls
Roof type	Sloping roof on four sides (angle up to 45°)
Orientation	Entry on South or East, space for daytime activities on North and South, space for nighttime activities on West
Wind capture	Wind from South-West direction, kitchen located at North-East corner
Construction material	External wall thick up to 750 mm with double layer of laterite masonry with a gap in between filled with fine sand (high insulation)
Layout	Rectangular or square plan with open courtyards, verandahs open to courtyards

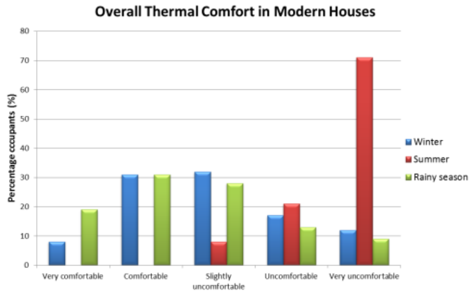
Another group is newly built houses with age of less than 20 years. There were no special design principles or passive control methods for these buildings. Brick masonry walls were plastered with cement mortar. Window openings were fixed together with glass paneled shutters.

The case study was based on questionnaire. It asked participants about the direct sensation of indoor thermal environment in terms of temperature, humidity, air movement and overall thermal comfort. There was no estimation calculation method applied in this case study. 50 families about 200 people was one sampling size for one type of buildings. All of the participants were well-educated by the relevant knowledge on thermal comfort. The survey periods were the first week of January (winter peak), last week of April (summer peak) and last week of July (monsoon peak) in the year of 2009. During the testing, all the buildings were natural ventilated.

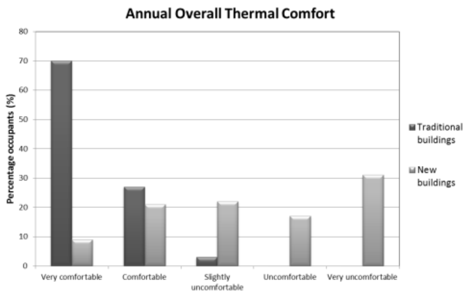
The key results were shown in bar charts in Figure 5. It revealed that residents were in favor of living in vernacular buildings. In traditional houses, thermal discomfort occurred more frequently in rainy season, while in new houses, it took place more frequently in summer.



(a) overall thermal comfort in traditional houses



(b) overall thermal comfort in modern houses



(c) annual overall thermal comfort

Figure 5: overall thermal comfort in traditional and mordern houses [12]

4. Discussion

Case study 1 used two methods to estimate the thermal comfort temperature and conducted a survey on human direct sensation of thermal comfort. Since the vernacular architecture was unconditioned and responders were free to do some activities in order to feel comfortable, the basic method, Humphrey's adaptive model, was utilized since it only concerned the mean outdoor temperature. The other method, Auliciems adaptive model, was developed to take mean indoor temperature into account for prediction. Thereafter, generally speaking, the percentage of comfort time reasonably expanded, evidently in Table 4, especially in January and April, from 3% to 8% and 5% to 15% respectively. In terms of thermal comfort survey, it was appropriate to record the comfort vote after the participants stayed in the target building for a while. In Table 3, the range of comfort temperature has only lower limit in January and upper limit in July, which means in the survey the indoor temperature failed to reach the limit on the other side during these periods. It is logical that no occupants experience extreme hot sensation in winter time or hot sensation in summer time.

However, there were some weaknesses in the methodology part. The comfort criteria in human body vary among people at different age or gender. Females or the elder would probably feel cool in the situation when males or the young satisfy the thermal condition. In Table 2, the percentage showed that the gender and age were not even distributed in responders sampling. More detailed statistics can be made according to different groups of people. The improved data could have reference value for temperature target setting in special space, such as kindergarten, elderly home and partition baths. In addition, participants should be required to stay near the data logger location since the house had different room types. As for the analysis part, results and discussion were raised individually in terms of different methods. Nevertheless, there were some gaps between the two methods. The comfort temperature from adaptive models in April, July and October were located in the interval of comfort temperature range based on survey. While in January (winter period), comfort temperatures from Humphreys and Auliciems were 20.9℃ and 19.9℃ respectively, and both of them were less than the lower limit 22.8℃ in the real comfort survey. Hence, it seemed adaptive model required further improvement in this case since the residents in tropical zones were more used to warm climate, which meant they had less tolerance ability in cold weather.

As for Case study 2, it compared the thermal comfort in traditional and modern buildings under natural-ventilated condition. The questionnaire method was fairly straightforward. It collected the immediate information of human sensation in terms of temperature, humidity, air movement and overall thermal comfort. It was also admirable to educate the participants about the survey purpose and relevant knowledge. Thus, the questions in the survey were comprehensively understood, leading to that the answers would be more realistic. Even though the concept and methodology were simple without any utilization of estimation methods, the outcome was clear and easy to compare and contrast.

However, the diversity in gender and age should be considered since the sampling size was quiet large. The duration of testing was only one week for each season. It was hard to say whether the collected data was adequate for analysis because of the slow building response to climate change. Therefore, it might be better to extend the monitoring period to gain more sensible results.

From the survey statistics, transparently, most occupants preferred to live in traditional dwellings rather than new built houses in all seasons. Since it was warm and humid region, ventilation performed as the chief method to keep cool in houses when the mechanical systems were switched off. However, in fact, most modern buildings nowadays were installed with HVAC systems, which would functioned during the occupancy hours to create favored indoor environment. Hence, another survey can be conducted for further improvement when HVAC systems were allowed to operate. Moreover, Heat Balance Model, and PMV and PPD would be used for indoor thermal comfort prediction. Energy consumption would be evaluated. The financial issue, between the energy consumption in running HVAC systems and the capital investment in design a building with traditional passive methods, was worthy of assessment to see to what extent traditional ways still deserved to follow in future building design.

5. Conclusion

Vernacular architecture was formed by a series of trial and error over generations and finally suited the local climate. Research in these buildings was raised to assess the indoor thermal comfort. In hot and wet tropical area, traditional residential houses were quite open to ambient environment to maximize the ventilation cooling.

Case 1 in Tezpur used adaptive models to estimate the indoor comfort temperature and conducted a survey for the range of comfort temperature. It was lack of analysis on the relationship between the predicted results and test results. Humphreys and Auliciems adaptive models were not actually ‘adaptive’ in this climate during the cold period due to that the natives were used to warm condition.

Case 2 in Kerala used comparative trial on thermal comfort exploration in traditional and modern buildings. A detailed survey was delivered to educated participants. Testing period should be extended to avoid the problem caused by slow climatic response in building construction. It was transparent to see more occupants were pleased staying in traditional dwellings. However, HVAC system can assist modern building in thermal comfort control but high energy consumption should be taken into consideration for economic aspect. Further improvement can be made to conduct another thermal comfort survey in modern buildings with allowance for HVAC system operation. Heat Balance Model with PMV and PPD would be an alternative solution for estimate the indoor thermal comfort.

Both cases should consider the gender and age distribution in sampling subjects since the thermal sensation varied in different group of people. Nevertheless, these cases provided a new concept of the correlativity between ancient vernacular architecture and thermal comfort, which probably bring more ideas and inspiration to building designers.

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