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The Relation between Effective Temperature and Thermal Sensation Vote in Tropical Vernacular Houses

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Abstract:- ***One of the factors to enable energy efficiency in buildings is creating thermal comfort for the occupants of buildings so that the artificial vaporization is not required. The thermal sensation vote (TSV) is an indicator in analyzing the occupants' satisfaction on the thermal comfort of their buildings. Some climate variables that relate to the TSV include air temperature, humidity, and wind speed. The three variables can be combined into a variable using a psychrometric chart. The combined variable is known as an effective temperature. The present research aims at analyzing the connection between effective temperature and TSV in vernacular houses in the tropical mountain and beach locations and comparing the results of the analysis. The quantitative method was employed in the research by measuring the variables of climate using a thermal measuring instrument. The TSV was measured with ASHRAE (American Standard of Heating, Refrigerating, Air-Conditioning Engineer)'s seven-point sensation scale. The measurement was carried out in transitional periods from the dry season to the wet season. Interpretation of graphs and charts was made for analysis based on the variable of effective temperature. The results of the research indicated that there was a connection between effective temperature and TSV. The effective temperature in vernacular houses in tropical mountain locations tended to be lower, and therefore the cool thermal sensation had the greatest percentage of TSV. Meanwhile, the effective temperature in tropical beach locations tended to be high, and therefore the warm thermal sensation had the greatest percentage. In a neutral scale, the percentage of TSV in tropical mountain locations was greater than that of TSV in tropical beach locations. Therefore, it is concluded that the occupants of vernacular houses in tropical mountain location felt more comfortable than those of vernacular houses in tropical beach locations.***

Keywords: thermal comfort, field measurement, vernacular house

I. INTRODUCTION

Climate change leads to thermal discomfort for humans and buildings. The thermal discomfort has made humans use artificial instruments to create thermal comfort in their buildings, bringing about energy wastage [1]. At present, theories about thermal comfort are occupant-oriented. A building will be able to create thermal comfort if the occupants feel comfortable. Thermal comfort is defined as the human paradigm towards their environment. The theory is known as adaptive thermal comfort. Studies on adaptive thermal comfort have resulted in more models of adaptive thermal comfort [2].

Studies on adaptive thermal comfort have been conducted on various objects, one of which is a house. Houses have been examined less frequently than offices due to higher costs and more attempts required. In the world of architecture, a house is a building built for human habitation, and therefore further studies should be carried out to assure that humans are comfortable and feel like home. Several studies of which research objects are houses indicate that vernacular houses are capable of creating thermal comfort for the occupants [3]. One of the studies demonstrates the great influence of thermal comfort on the occupants of wooden houses and energy efficiency [4].

An indicator of thermal comfort is the human thermal sensation vote (TSV) [5]. TSV is defined as a thermal sensation perceived by the occupants. At present, the standards of the thermal sensation refer to the ASHRAE standards. The TSV includes a seven-point sensation scale (very hot, hot, warm, neutral/ comfortable, cool, cold, and very cold). Variables influencing thermal comfort are climate and persons [6]. The variables of microclimate comprise temperature, humidity, and wind. The three variables can be combined into a variable of effective temperature by using a psychrometric chart.

Climate is influenced by the topography of an area. The higher the elevation of an area is, the lower the temperature is. Tropical areas have two areas with extreme climate: mountains and beaches. There are vernacular houses in both areas, built in such a way that they can get adapted to the environment. In mountain location, vernacular houses are built from either exposed stones or wood. Meanwhile, in beach locations, they are built from either exposed bricks or wood. The present study analyzed the connection between effective temperature and Thermal Sensation Vote (TSV) in such tropical areas as mountains and beaches. The two areas were compared to result in more comfortable vernacular houses.

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II. METHOD

The study was conducted using variables of climate and TSV. The variables of climate consist of air temperature, humidity, and wind speed. The three variables were measured using a thermal measuring instrument set for an elevation of 1.1 m [7]. Then they were combined into a variable of effective temperature using a psychrometric chart. The TSV was obtained from the use of seven-point sensation scale (very hot (+3), hot (+2), warm (+1), neutral/ comfortable (0), cool (-1), cold (-2), and very cold (-3)). Also, there are personal factors in adaptive thermal comfort comprising activities and clothing. The activities were limited to the range of 1-1.1 met, while the clothing was limited to the range of 0.9-1.2 clo for mountain location and 0.5-0.7 clo for beach locations. The study was carried out during transitional periods from dry to rainy season. Every period will create occupants' thermal responses [8]. The periods were selected based on the belief that the periods will create unique responses. Data had been collected for 5 days. The data of variables of climate were collected every hour from 06:00 to 22:00, while those of variables of TSV were collected in the morning, afternoon, evening, and at night. The TSV data were minimally taken three times a day [9]. The mountain location has exposed stone houses and wooden houses, while the beach location has exposed brick houses and wooden houses. The spaces observed are kitchens, guest rooms, terraces, and outdoor spaces. Graphs and diagrams were used in the analysis to describe the connection between the two variables. The comparison of the connection between effective temperature and TSV of both mountain and beach locations was then made. The flowchart of the method is depicted in Figure 1.

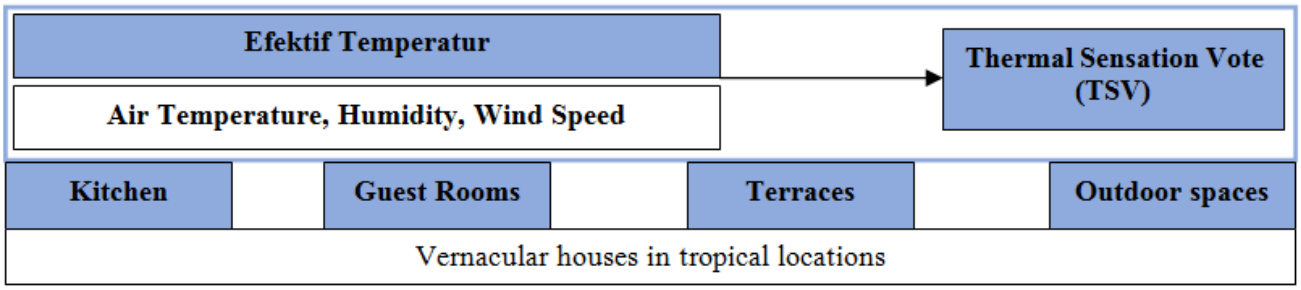

Fig. 1.Research method chart

III. RESULTS AND DISCUSSION

The connection between effective temperature and thermal sensation vote (TSV) in vernacular houses in tropical mountain location during the transitional periods from the dry season to the wet season is seen from Figure 2.

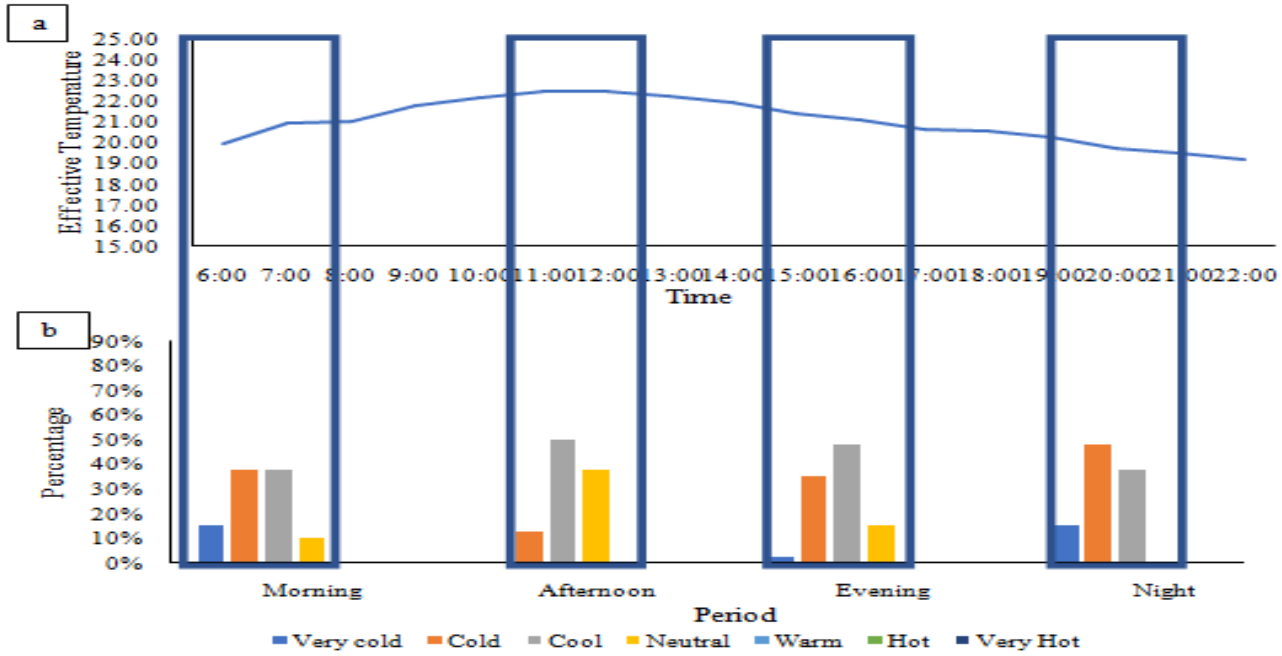

Fig. 2.a.The effective temperature in kitchens in vernacular houses in tropical mountain location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in kitchens in vernacular houses in tropical mountain location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

The occupants were found to feel such thermal sensation as very cold (15%), cold (38%), cool (38%), and neutral (10%) in the kitchens in vernacular houses in mountain location in the morning. The thermal sensations had an effective temperature of about 19.95ºC. When the effective temperature was about 22.4ºC in the afternoon, the occupants felt cold thermal sensation by 13%, cool thermal sensation by 50%, and the neutral thermal sensation by 38%. In the evening, such thermal sensations as very cold (3%), cold (35%), cool (48%), and neutral (15%) with an effective temperature of 21.05ºC were perceived. At night, the effective temperature was 19.45ºC with such thermal sensations as very cold (15%), cold (48%), and thermal sensation by 38%.

The connection between effective temperature and thermal sensation vote (TSV) in kitchens in vernacular houses in tropical beach locations during the transitional periods from the dry season to the wet season is seen from Figure 3.

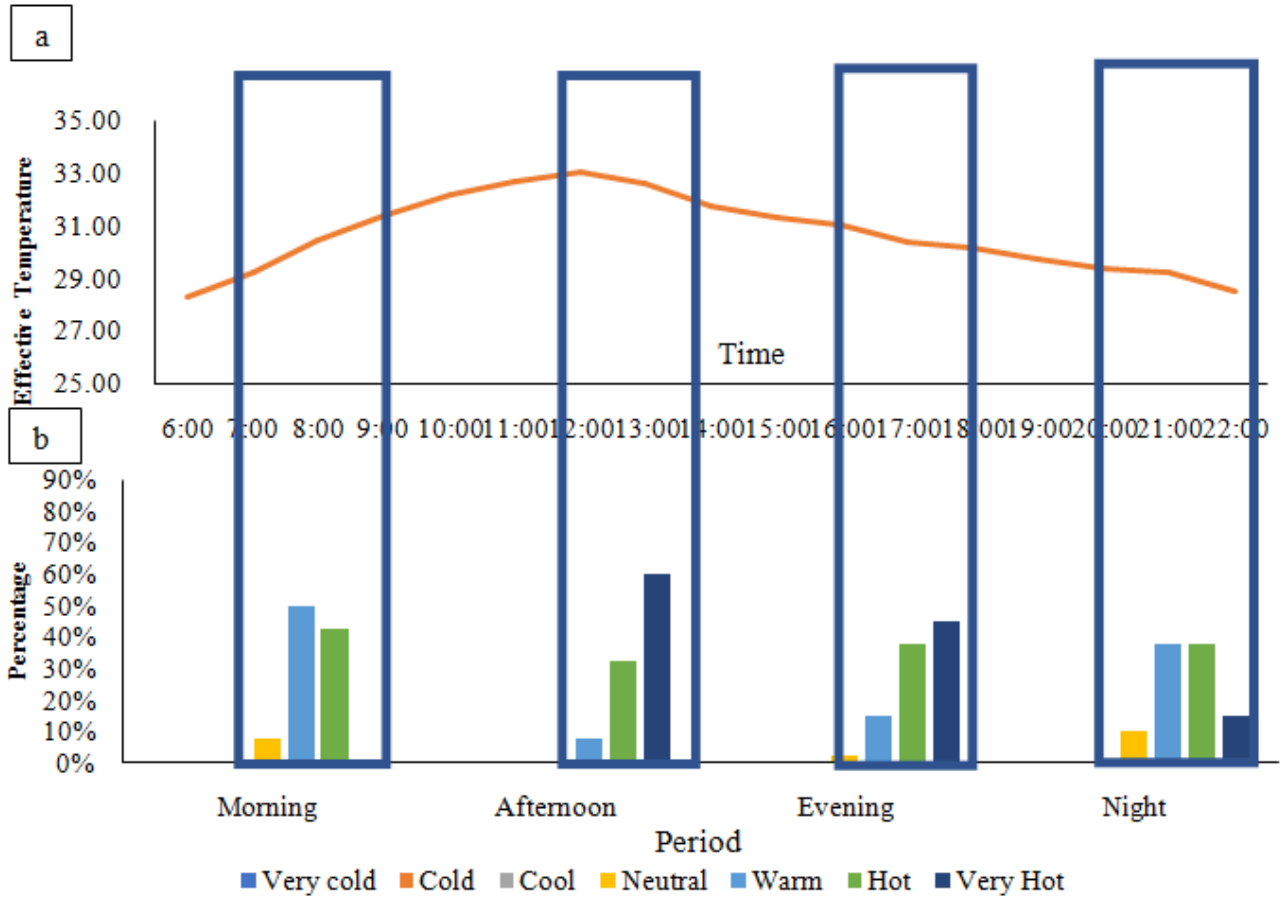

Fig. 3.a. The effective temperature in kitchens in vernacular houses in tropical beach location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in kitchens in vernacular houses in tropical beach location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

In the morning when the effective temperature in the kitchens was 28.3ºC, the occupants on average felt the neutral thermal sensation by 8%, the warm thermal sensation by 50%, and the hot thermal sensation by 43%. In the afternoon when the effective temperature was 33.05ºC, the occupants felt the warm thermal sensation by 8%, the hot thermal sensation by 33%, and the very hot thermal sensation by 60%. In the evening, when the effective temperature reached 31ºC, the occupants on average felt the neutral thermal sensation by 3%, the warm thermal sensation by 15%, the hot thermal sensation by 38%, and the very hot thermal sensation by 45%. Meanwhile, at night when the effective temperature was about 29.25ºC, the occupants felt the neutral thermal sensation/ comfortable by 10%, the warm thermal sensation by 38%, the hot thermal sensation by 38%, and the very hot thermal sensation by 15%.

The comparison has proved that the connections between effective temperature and TSV in the kitchens in vernacular houses in both tropical beach and mountain locations are different. The connection between effective temperature and TSV in vernacular houses in tropical mountain location is weaker than that in vernacular houses in tropical beach locations. In tropical mountain location, the TSV is not influenced by the effective temperature. Meanwhile, in tropical beach locations, the influence of the TSV is stronger. Another factor from the occupants exerts an influence on this.

The occupants of vernacular houses in tropical mountain locations are more adaptable than those of vernacular houses in tropical beach locations. The kitchens in vernacular houses in mountain locations are seen to be more comfortable. This finding is in line with the finding of the previous study, which explains that vernacular houses in tropical mountain location can provide comfort for the occupants to start a fireplace in the kitchens [10].

The connection between effective temperature and thermal sensation vote (TSV) in guest rooms in vernacular houses in tropical mountain locations during the transitional periods from the dry season to the wet season is demonstrated in Figure 4.

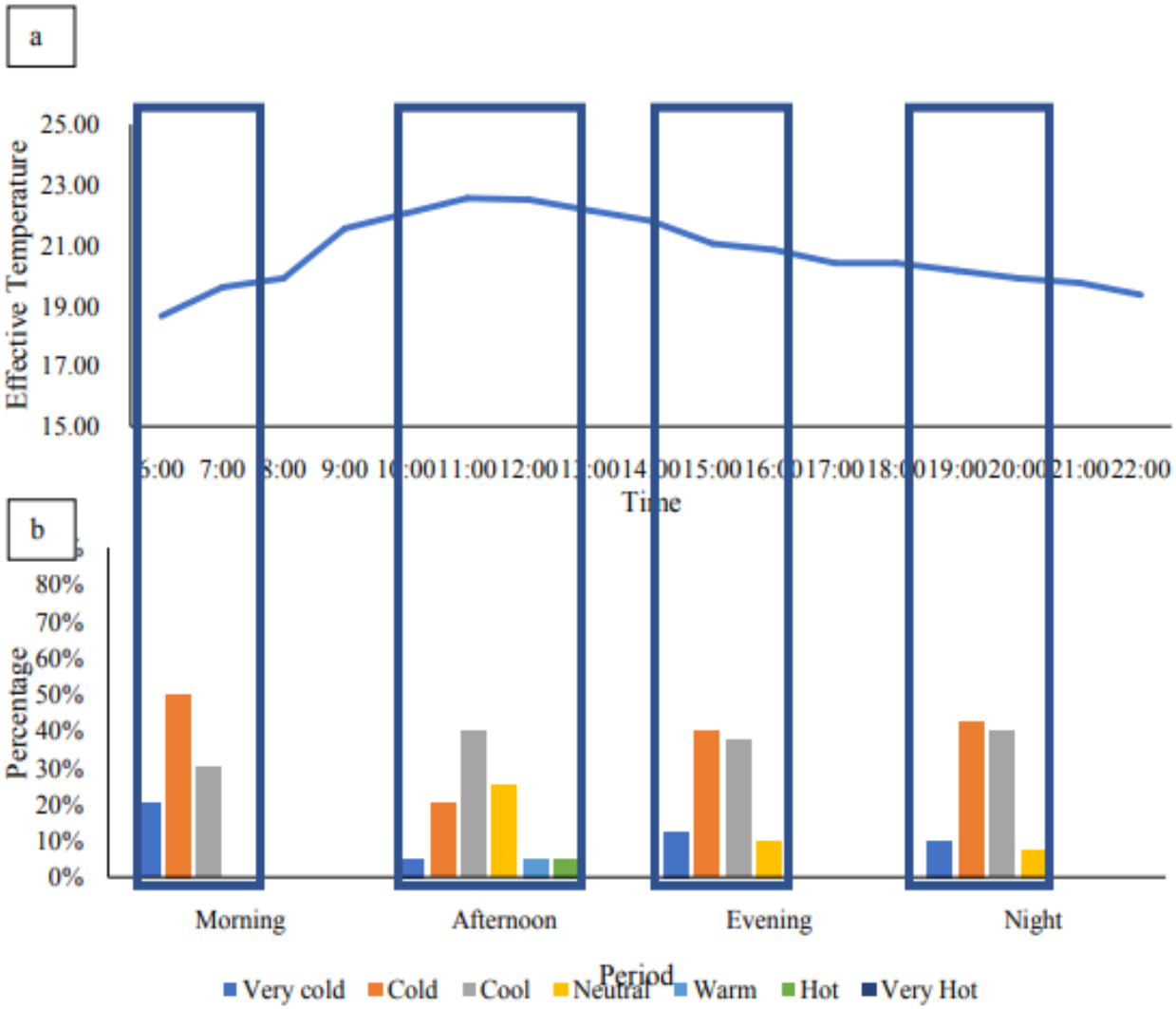

Fig. 4. a. The effective temperature in guest rooms in vernacular houses in tropical mountain location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in guest rooms in vernacular houses in tropical mountain location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

When the effective temperature of about 18.65ºC occurred in the morning, the occupants on average felt the very cold thermal sensation by 20%, the cold thermal sensation by 50%, and the cool thermal sensation by 30%. Meanwhile, when the effective temperature reached 22.5ºC in the afternoon, the occupants felt the very cold thermal sensation by 5%, the cold thermal sensation by 20%, the cool thermal sensation by 40%, the neutral thermal sensation/ comfortable by 25%, the warm thermal sensation by 5%, and the hot thermal sensation by 5%. When the effective temperature was 20.85ºC in the evening, the occupants on average felt the very cold thermal sensation by 13%, the cold thermal sensation by 40%, the cool thermal sensation by 38%, and the neutral thermal sensation by 10%. Meanwhile, when the effective temperature at night reached 19.75ºC, the occupants felt the very cold thermal sensation by 10%, the cold thermal sensation by 43%, the cool thermal sensation by 40%, and the neutral thermal sensation by 8%.

The connection between effective temperature and thermal sensation vote (TSV) in guest rooms in vernacular houses in tropical beach locations during the transitional periods from the dry season to the wet season can be seen from Figure 5.

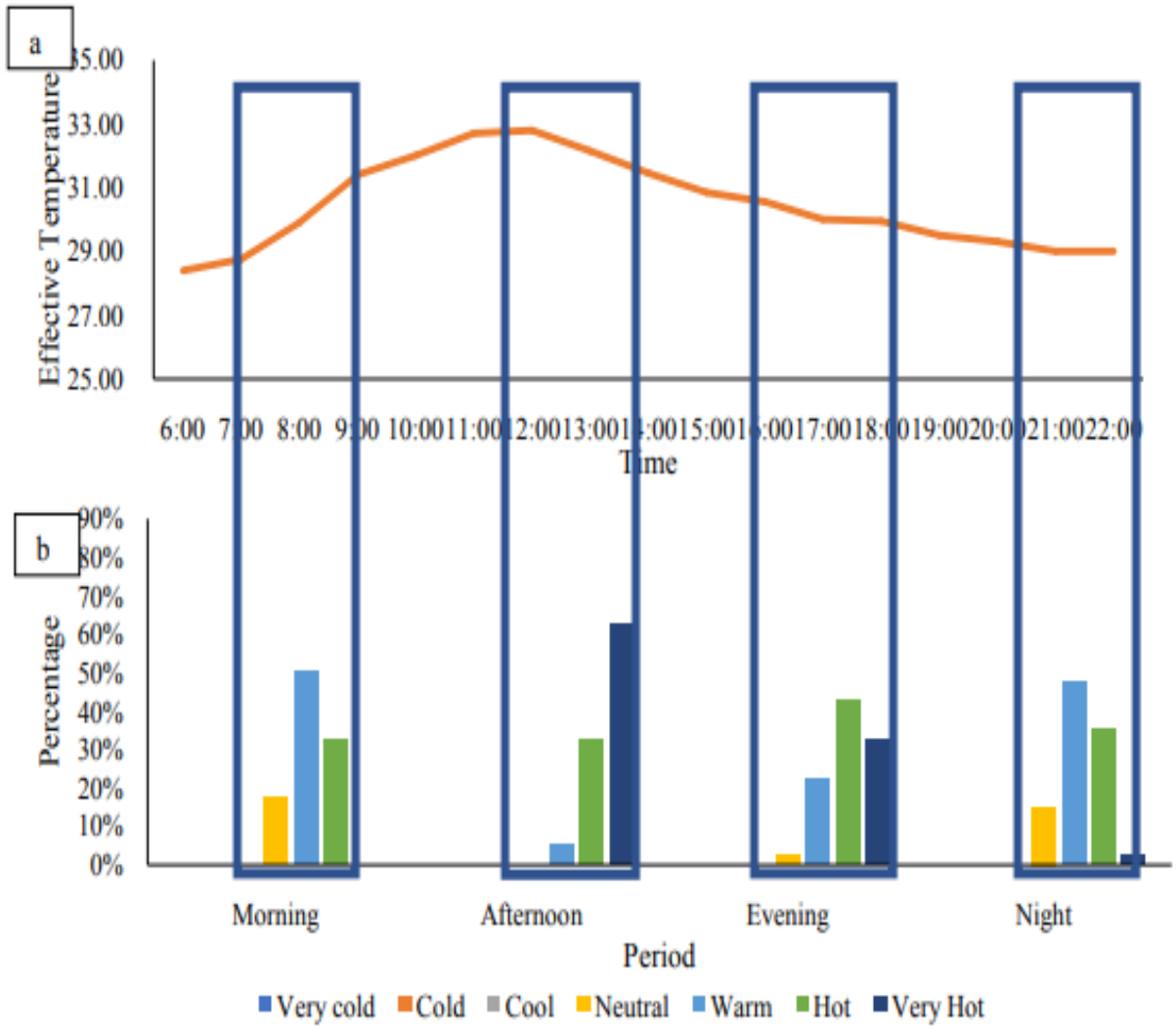

Fig. 5.a. The effective temperature in guest rooms in vernacular houses in tropical beach location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in guest rooms in vernacular houses in tropical beach location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

When the effective temperature of about 28.4ºC occurred in the morning, the occupants on average felt the neutral thermal sensation by 18%, the warm thermal sensation by 50%, and the hot thermal sensation by 33%. When the effective temperature reached 32.8ºC in the afternoon, the occupants felt the warm thermal sensation by 5%, the hot thermal sensation by 33%, and the very hot thermal sensation by 63%. Meanwhile, when the effective temperature was 30.5ºC in the evening, the occupants on average felt the neutral thermal sensation or comfortable by 3%, the warm thermal sensation by 23%, the hot thermal sensation by 43%, and thermal sensation by 33%. When the effective temperature of about 29ºC occurred at night, the occupants on average felt the neutral thermal sensation by 15%, the warm thermal sensation by 48%, the hot thermal sensation by 35%, and the very hot thermal sensation by 3%.

When the effective temperature of about 28.4ºC occurred in the morning, the occupants on average felt the neutral thermal sensation by 18%, the warm thermal sensation by 50%, and the hot thermal sensation by 33%. When the effective temperature reached 32.8ºC in the afternoon, the occupants felt the warm thermal sensation by 5%, the hot thermal sensation by 33%, and the very hot thermal sensation by 63%. Meanwhile, when the effective temperature was 30.5ºC in the evening, the occupants on average felt the neutral thermal sensation or comfortable by 3%, the warm thermal sensation by 23%, the hot thermal sensation by 43%, and thermal sensation by 33%. When the effective temperature of about 29ºC occurred at night, the occupants on average felt the neutral thermal sensation by 15%, the warm thermal sensation by 48%, the hot thermal sensation by 35%, and the very hot thermal sensation by 3%.

The connection between effective temperature and thermal sensation vote (TSV) in terraces in vernacular houses in tropical mountain locations during the transitional periods from the dry season to the wet season can be seen from Figure 6.

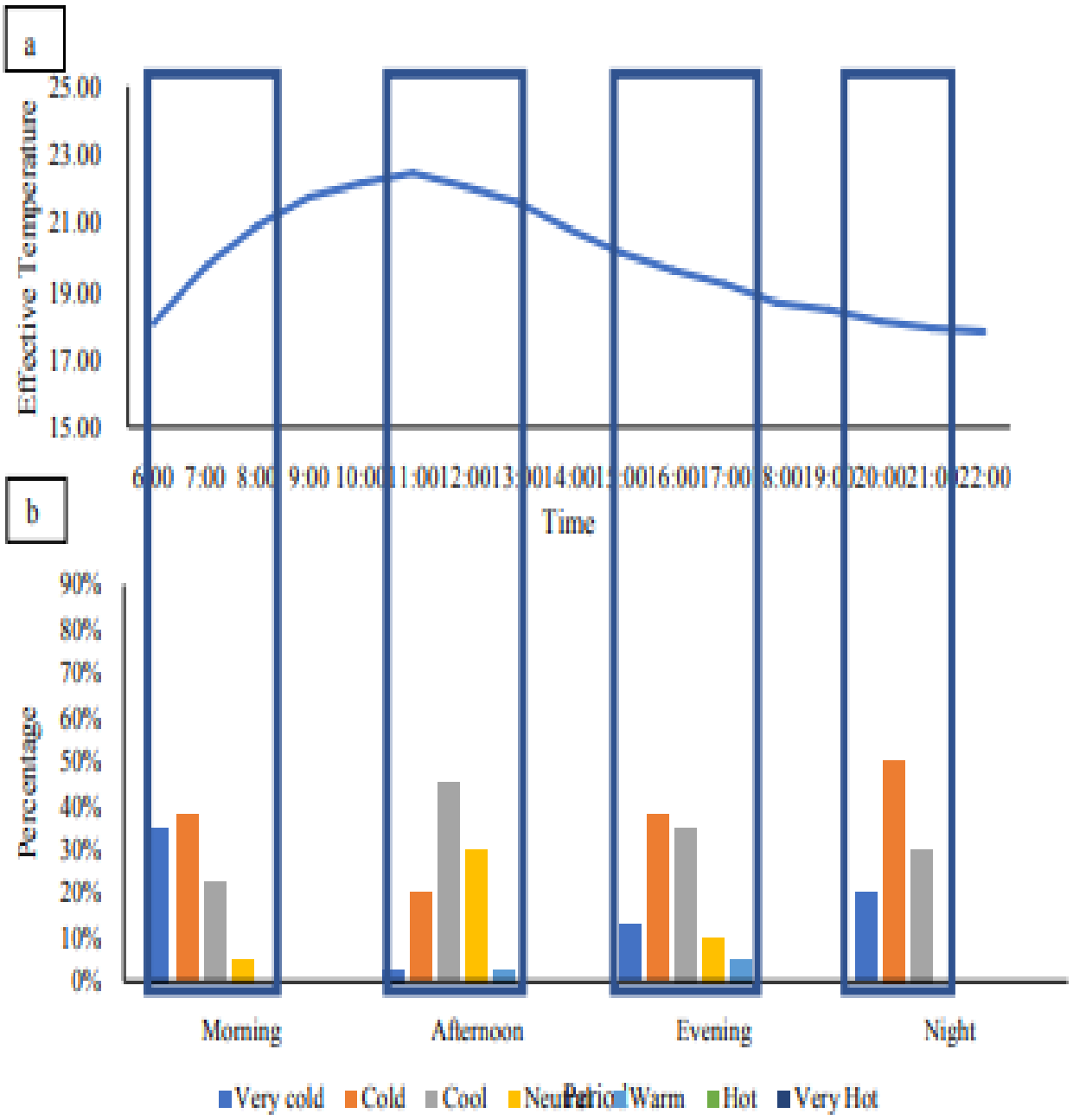

Fig. 6.a. The effective temperature in terraces in vernacular houses in tropical mountain location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in terraces in vernacular houses in tropical mountain location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

When the effective temperature of 18.05ºC occurred in the morning in vernacular houses in tropical mountain locations, the occupants on average felt the very cold thermal sensation 35%, the cold thermal sensation by 38%, the cool thermal sensation by 23%, and the neutral thermal sensation by 5%. When the effective temperature reached 22.05ºC in the afternoon, the occupants on average felt the very cold thermal sensation by 3%, the cold thermal sensation by 20%, the cool thermal sensation by 45%, the neutral thermal sensation by 30%, and thermal sensation by 3%. Meanwhile, when the effective temperature was 19.6ºC in the evening, the occupants felt the very cold thermal sensation by 13%, the cold thermal sensation by 38%, the cool thermal sensation by 35%, the neutral thermal sensation by 10%, and the warm thermal sensation by 5%. When the effective temperature of 17.9ºC occurred at night, the occupants on average felt the very cold thermal sensation by 20%, the cold thermal sensation by 50%, and the cool thermal sensation by 30%.

The connection between effective temperature and thermal sensation vote (TSV) in terraces in vernacular houses in tropical beach locations during the transitional periods from the dry season to the wet season can be seen from Figure 7.

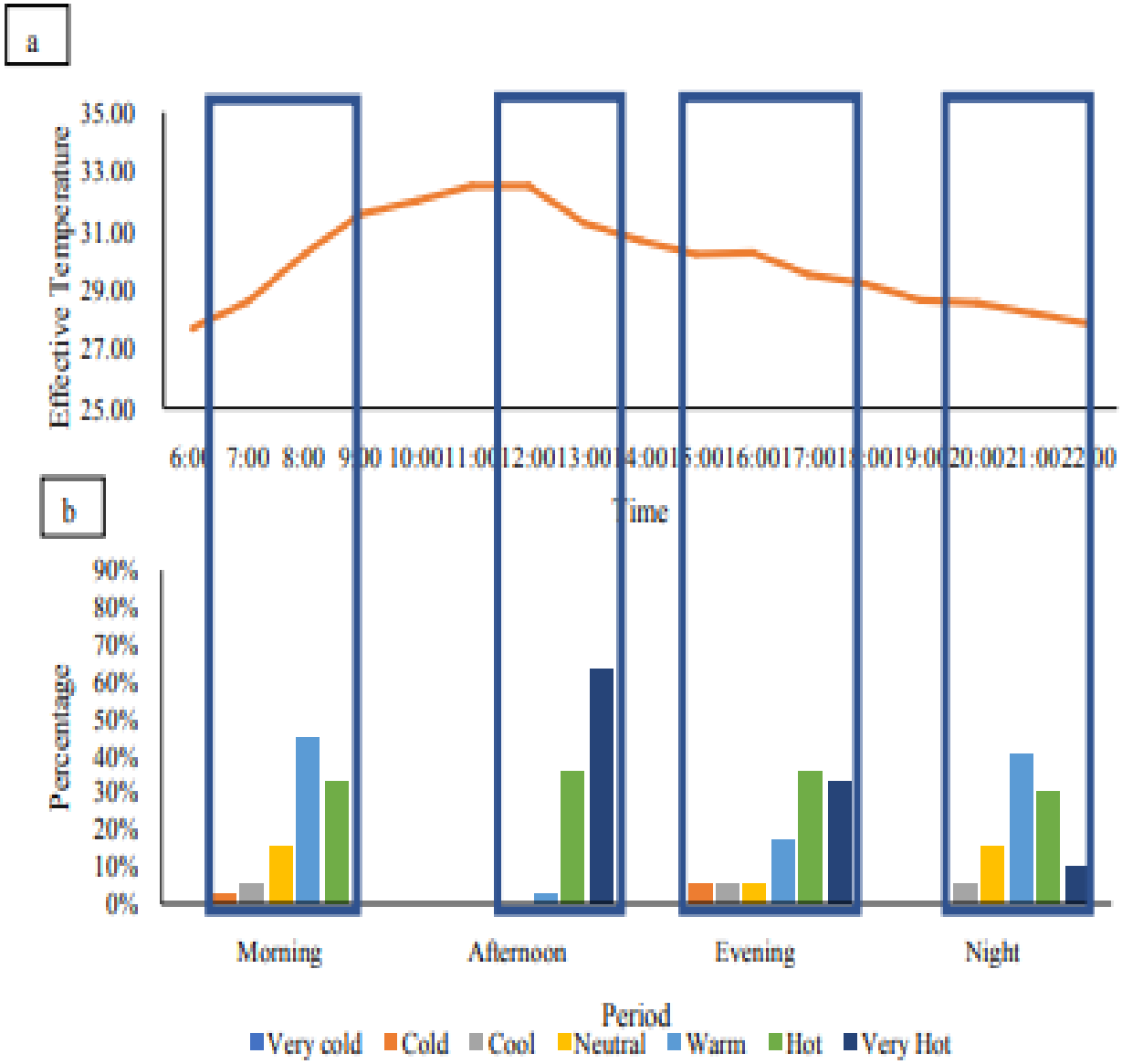

Fig. 7.a. The effective temperature in terraces in vernacular houses in tropical beach location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in terraces in vernacular houses in tropical beach location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

hen the effective temperature of 27.7ºC occurred in the morning, the occupants on average felt the cold thermal sensation by 3%, the cool thermal sensation by 5%, the neutral thermal sensation by 15%, the warm thermal sensation by 45%, and the hot thermal sensation by 33%. Meanwhile, when the effective temperature reached 32.5ºC in the afternoon, the occupants felt the warm thermal sensation by 3%, the hot thermal sensation by 35%, and the very hot thermal sensation by 63%. When the effective temperature was 30.25ºC in the evening, the occupants felt the cold thermal sensation by 5%, the cool thermal sensation by 5%, the neutral thermal sensation by 5%, the warm thermal sensation by 18%, the hot thermal sensation by 35%, and the very hot thermal sensation by 33%. When the effective temperature of 28.2ºC occurred at night, the occupants felt the cool thermal sensation by 5%, the neutral thermal sensation or comfortable by 15%, the warm thermal sensation by 40%, the hot thermal sensation by 30%, and the very hot thermal sensation by 10%. The comparison between effective temperature and thermal sensation vote (TSV) in terraces in tropical mountain and beach locations is influenced by the sunlight conditions in each area. When the sun shone a light on tropical mountain locations, the occupants of the vernacular houses felt comfortable in the afternoon and the evening. In tropical beach locations, the occupants of the vernacular houses felt comfortable in the morning and at night since the presence of sunlight brought forth heat all over the location. The connections between effective temperature and TSV in the two locations are not far different. Both have strong connections when it comes to terraces.

The connection between effective temperature and thermal sensation vote (TSV) in outdoor spaces in vernacular houses in tropical mountain locations during the transitional periods from the dry season to the wet season can be seen from Figure 8.

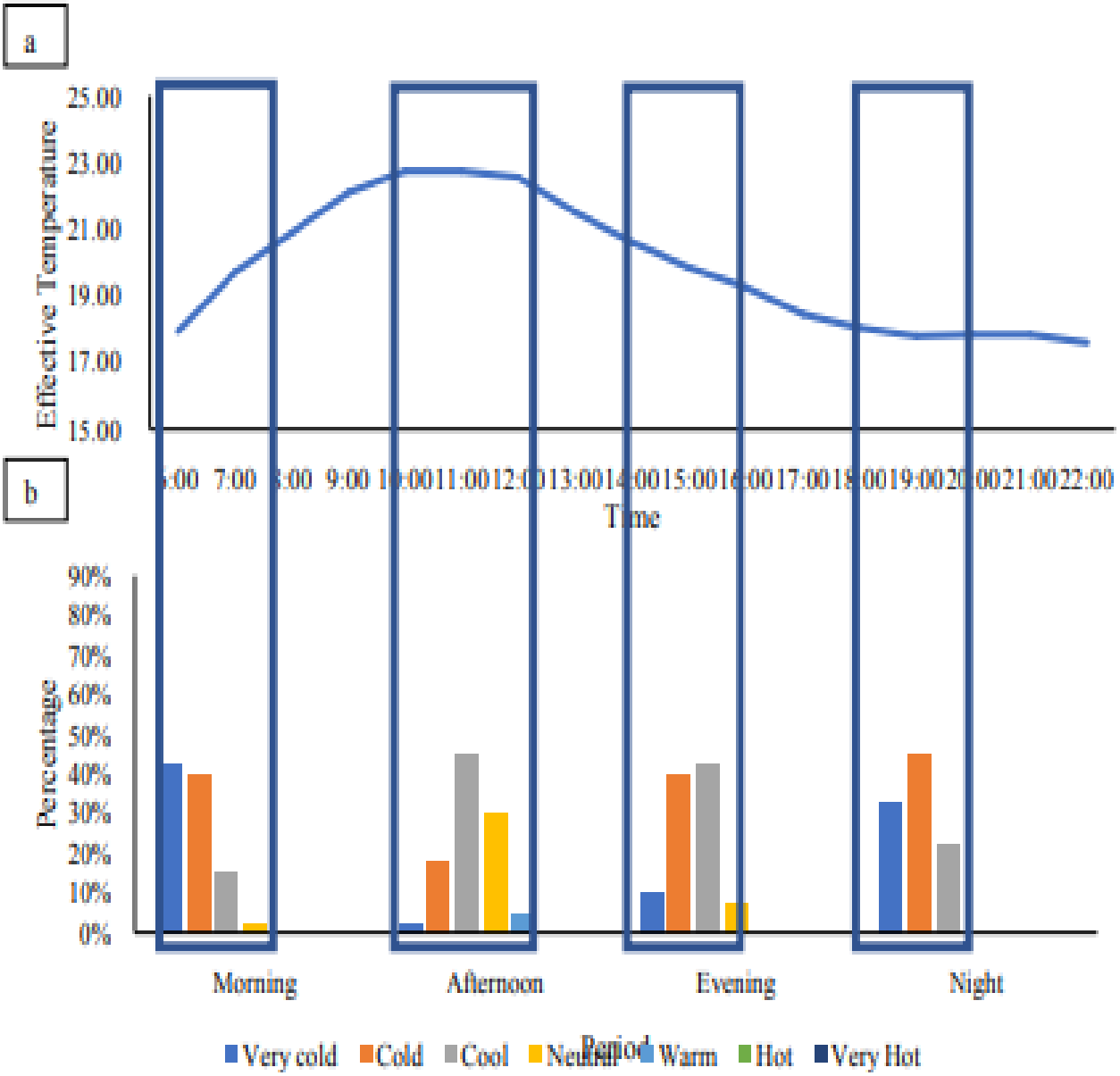

Fig. 8.a. The effective temperature in outdoor spaces in vernacular houses in tropical mountain location at 6:00-22:00 during transitional periods of the dry season to the wet season, b. TSV of occupants in outdoor spaces in vernacular houses in tropical mountain location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

When the effective temperature of about 17.95ºC occurred in the morning, the occupants on average felt the very cold thermal sensation by 43%, the cold thermal sensation by 40%, the cool thermal sensation by 15%, and the neutral thermal sensation by 3%. When the effective temperature was 22.5ºC in the afternoon, the occupants on average felt the very cold thermal sensation by 3%, the cold thermal sensation by 18%, thermal sensation by 45%, the neutral thermal sensation by 30%, and the warm thermal sensation by 5%. Meanwhile, the effective temperature reached 19.25ºC in the evening, the occupants felt the very cold thermal sensation by 10%, the cold thermal sensation by 40%, the cool thermal sensation by 43%, and the neutral thermal sensation or comfortable by 8%. When the effective temperature was 17.85ºC at night, the occupants felt the very cold thermal sensation by 33%, the cold thermal sensation by 45%, and the cool thermal sensation by 23%.The connection between effective temperature and thermal sensation vote (TSV) in outdoor spaces in vernacular houses in tropical beach locations during the transitional periods from the dry season to wet season can be seen from Figure 9.

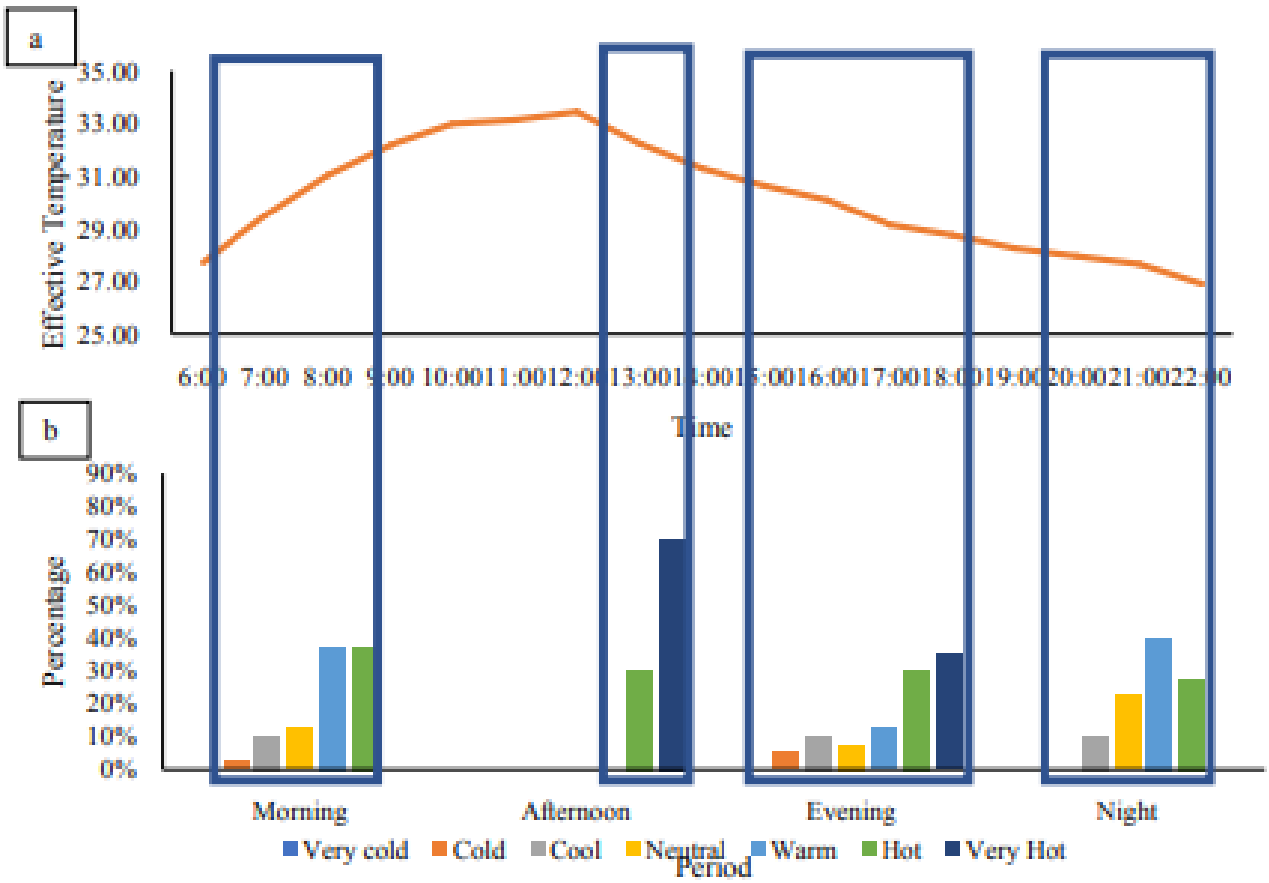

Fig. 9.a. The effective temperature in outdoor spaces in vernacular houses in tropical beach location at 6:00-22:00 during transitional periods from the dry season to the wet season, b. TSV of occupants in outdoor spaces in vernacular houses in tropical beach location at four periods (morning, afternoon, evening, night) during transitional periods from the dry season to the wet season

When the effective temperature of 27.7ºC occurred in the morning, the occupants felt the cold thermal sensation by 3%, the cool thermal sensation by 10%, the neutral thermal sensation or comfortable by 15%, the warm thermal sensation by 38%, and the hot thermal sensation by 38%. When the effective temperature reached 33.45ºC in the afternoon, the occupants on average felt the hot thermal sensation by 30% and the very hot thermal sensation by 70%. When the effective temperature was 30.1ºC in the evening, the occupants in average felt the cold thermal sensation by 5%, the cool thermal sensation by 10%, the neutral thermal sensation by 8%, the warm thermal sensation by 13%, thermal sensation by 30%, and the very hot thermal sensation by 35%. When the effective temperature was 27.65ºC at night, the occupants on average felt the cool thermal sensation by 10%, the neutral thermal sensation by 23%, the warm thermal sensation by 40%, and the hot thermal sensation by 28%. The comparison of the connection between effective temperature and TSV is similar to that in terraces due to the factor of sunlight. Terraces were not exposed by direct sunlight, but the heat effect was perceived. In tropical beach locations, the occupants of vernacular houses felt comfortable in the afternoon, while in tropical beach locations, they felt most comfortable at night. The connections between effective temperature and TSV in both locations are not far different TSV is believed to be influenced by not only effective temperature but also persons. Therefore, further study, which examines the influence of effective temperature on persons [12], is required. In addition to persons, building performance should also be revealed. The connection between temperature and buildings can determine the thermal performance of buildings so that the occupants feel comfortable to stay in the buildings [13,14].

IV. CONCLUSION

The effective temperatures in the two locations fit the elevation of the locations. Tropical mountain location with the elevation of greater than 1,000 m.a.s.l. has lower effective temperature than tropical beach location with the elevation of less than 400 m.a.s.l. The thermal sensation vote of each occupant in both locations varies according to the microclimate of the locations. The connection between effective temperature and TSV is considered strong, although other factors such as persons and artificial devices for comfort. Individual adjustment is done by doing activities that make the occupants comfortable, while adjustment using devices is done by starting a fireplace for those residing in tropical mountain location and turning on a fan for those residing in tropical beach locations. It is finally concluded that the effective temperatures in both locations can influence thermal perceptions of the occupants during transitional periods from the dry season to the wet season. The occupants of vernacular houses in tropical mountain locations have higher levels of comfort than those of vernacular houses in tropical beach locations.

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