RESEARCH ARTICLE OPEN ACCESS

Reinventing Vernacular's Passive Design for Thermal Comfort in Equatorial Tropical Climate

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ABSTRACT : The relationship between architecture and climate is always a hotspot, interesting in the recent architecture studies, especially in corelation with thermal comfort in equatorial tropic climate, such as Indonesia vernacular dwellings. Such researchs has shown the principle of climate-oriented architecture, focus on qualitative description of passive design in getting thermal comfort. The result, it is difficult to evaluate accurately thermal performance of the vernacular buildings by qualitative approach, therefore some incorrect conclusions are easily to be drawn in general result, also incorrectly. A detailed field, empirical study of Baduy Jero's vernacular dwellings at Kanekes village, Lebak regency, Banten Province, Indonesia, has been done in the four seasons of 2015. it's aim is to get the passive design exploration in vernacular architecture, by quantitative approach, which is supported by empirical-field measurement. The result is hoped to get better understanding about the uniqueness of passive design of vernacular architecture in Indonesia, especially in adapting with the local climate, which in turn reinventing such wisdom in modern context.
Key words: Reinventing, thermal comfort, vernacular's passive design

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I. INTRODUCTION

Passive design is referred to a way of designing built environment, especially buildings which takes advantage of the prevailing climate, to achieve a comfort environment. Such approach is indicated by minimizing mechanical system, which have been implemented by vernacular architecture, within thermal comfort assesment. Equatorial tropical climate region, such as Indonesia is characterized by combination of hot and humid climate. Consequently, there is a need for acquiring generic design within control principles in maximizing passive design for providing thermal comfort. Reinventing vernacular passive design in controlling climate are required to solve contemporary thermal problem, which in turn minimizing building‟s energy consumption. Such principle is approached by employing passive environmental solutions, in order to adapt local climate appropriately, which has been implemented by Baduy Jero (Inner Baduy), Kanekes village, Banten Province, Indonesia. Usage of natural-local materials, treated by natural techniques is the main character of vernacular architecture, as Amos Rapoport describe vernacular architecture as lack of theoretical or aesthetic pretentions, working with the site and micro-climate. The Baduy is an ethnic group living in an isolated inland area in Kanekes village, Banten Province, Indonesia. Taboos and prohibition order has separated this group from nearby living Sundanese [I]. Historically, the Baduy is part of the nearby living Sundanese who has isolated themselves [II]. The presence of the Baduy people is keeping Mount Kendeng as sustainable natural area, especially the Ciujung river, which played an important role in Banten‟s agriculture area. Such wisdom is the expression: 'teu wasa'(forbiden), supported by a local custom under the guidance of Sunda Wiwitan religion [III]. Nature is God‟s gift to the next generation, therefore the implementation are: techniques for cooling, dehumidification, and heating, and acclimatisation which makes comfort perception in equatorial tropic climate.

The study aims mainly to measure the thermal performance of the kampong and the Baduy's dwelling, to see how indoor thermal environment‟s parameters like air temperature, humidity, etc, are affected by physically built environment, within the four different seasons, such as: Wet season, transition season 1 (wet to dry), hot season, transition 2 (hot to wet season). Ther result hopefully can contribute to understending in enhancement of local wisdom in curent context, especially thermal environment in modern life.

Method of collecting data is got from field measurement, is analized in discussion. The discussion is the elaboration of macro and micro climate which indicate thermal performance of village, kampong,finally the building.

II. METHOD

This researh consist of two types of data which were collected. The first data, consisted of macro climate, which was collected during four seasons from BKMG (Climatology, Meterology and

Geophysics of Indonesia). The second data, consisted of micro climatic parameters inside and outside of the dwellings, which is used to examine how the dwellings performed thermally against the micro climate. This data was collected during four season, such as: a) the rainy seasons in December-February, b) transition 1(rainy to dry) season in March-May, c) the dry season in June-August, d) transition 2 (dry-to rainy) in September- November. Location of research is in Cikeusik Kampong (Inner Baduy), Kanekes village, Banten Province, Indonesia.

III. DISCUSSION

3.1. The Physical Character of Kampong and Dwelling (House)

General physical condition of kampong, can be described such as: 1) the existing of the kampong is in southern part of the village, the highest position in the village, close to the mount of Kendeng. Northern part is Rangkasbitung city, the capital of Lebak regency (fig.1). The topography relatively is rather flat, rather down to the north, 2) the axis of the kampong is north-south, as the sacre-axis. The sum of the dwellings is about 70 houses. The green area is located in the centre of the kampong. At the northen-end of the kampong is located the Bale (customary meeting building), the southern part is puun house, 3) environment around the kampong is forest-kampong and rice swidden field. The position of the river in the western part of the kampong. The location of the kampong which close to the river is the main character of the Baduy Dalam, meanwhile the river is in the western part and northen part of the river. The research location is shown by figure 1.a, the green character dominate the kampong (fig.1.b).

Figure 1.b. The location of research

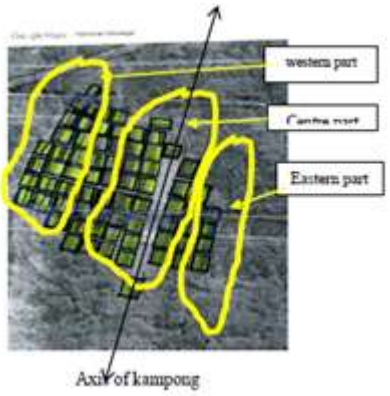

Figure 1.b.the map of Cikeusik Kampong (Google earth,2013)

Building include dwelling (imah) and rice field‟s cabin (saung). Basically, Baduy people, especially in Cikeusik (inner baduy) live in two places such as imah (dwelling) and saung (swidden‟s cabin). In certain seasons, especially in harvest season Baduy people live in saung. The size of the dwelling is about 50-60 m^2, with the height of floor is 80-120 m above the earth surface. The roof's cover is made of kiray, leaves from local tree. Bamboo is used as wall's material and floor's material. Wood is used as the main structure's material. The house's opening is quite little (fig.2). The detail of the size can be seen in the table 1. The dwelling character of the sample is based on the measurement, which is indicated by building's elements, such as: 1) floor's heigth, 2) building volume, 3) wall's celah, 4) door and window, 5) sofi-sofi (ventilation‟s opening), 6) the thickness of material, 7) teritisan (ovehang).

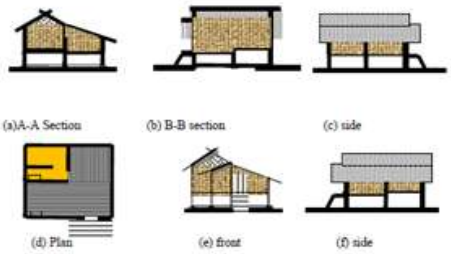

Figure 2(a)-2(f).The specification of house (building)

Tabel 1 Physical character of dwelling

(source: field measurement)

Building element	Number of dwelling										
	West-side			Centre					East-side		
	B1	B2	B3	TC 1	TC2	TC 3	TC 4	TC 5	T1	T2	T3
The height of floor (cm)	80	110	90	114	110	113	120	115	110	111	120
Volume (m^3)	50	52	51	50,6	51	50,8	52,5	56	53,5	61	70
Post-part wall-reserves (%)	7,6	7,5	7,65	7,59	7,6	7,61	7,75	7,8	7,66	7,7	7,9
Opening: door and window (m^2)	1,5	1,52	1,51	1,6	1,62	1,61	1,69	1,68	1,66	1,67	1,79
Opening: ventilation (cm^2)	9	9,8	9,2	10,6	11	10,7	10,9	11	11,2	11,3	11,6
The thickness (mm)	4,5	5	4,9	6	6,5	5,5	4,8	7,2	4,9	4,8	7,2
Overhang (m)	1,39	1,5	1,4	1,5	1,59	1,48	1,48	1,6	1,5	1,6	1,77

3.2 The Thermal Environment Performance: Kampong and Dwelling

The character of macro climate in ten years period is a reference in indicating the village's thermal environment (fig.4-fig.6):1) the rainfall is relatively moderate, local rainfall often happen because of mountainous topography condition, which is indicated by valley wind and mountain wind. Such aspects give effect to high humidity, especially in rainy season such as December, January, and February (60 %-90%), also in the transition period (dry season to rainy season), 2) Monsoon wind such as west and east monsun wind blow in Cikeusik area, but local wind is dominant. The local wind is mountain wind and valley wind. The mountain wind give effect to low temperature and high humidity. The wind velocity is between Beafort scale 0-3 in the rainy season, which indicated physically by felt on the face until the tree branches move. The scale beafort 4-5 indicated with movement of litle trees in the transition-season (dry to rainy season), 3) The level of radiation is quite high, as effect of monthly percentage‟s sunlight-duration. In the rainy season, daytime temperature is between 27-28^{0}C, the radiation temperature (MRT) is 25-30^{0}C. In the transition period (rainy to dry season) and dry season, in the day time the normal temperature between 28-31 ^{0}C, the radiation temperature is between 30-38^{0}C, 4) the temperature gap between daytime and night time is rather wide, between the lowest temperature in the night and highest temperature in midday, especially in the dry season and transition period 2 (rainy to dry season). Such gap is 8^{0}C, it's between 21^{0}C-31^{0}C,. In the rainy season and transition period 1 (dry to rainy season), the gap between the lowest temperatur in the night and the highest temperature in the daytime is quite moderate.

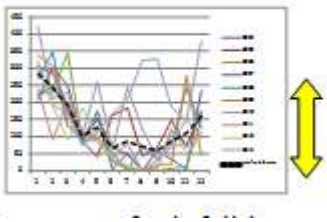

Figure 3. The curve of rainfall in ten years period
(source:elaborated from BMKG data)

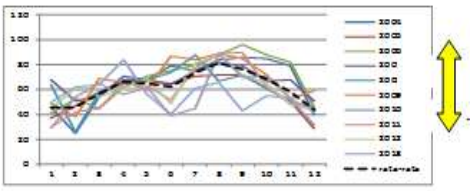

Figure 4. The curve of rainfall in ten years period
(source:elaborated from BMKG data)

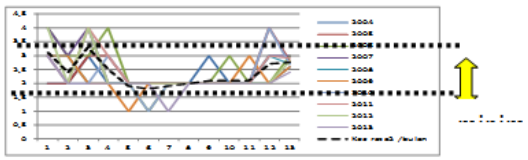

Figure 5. The curve of monthly sunlight's duration in ten years period
(source:elaborated from BMKG data)

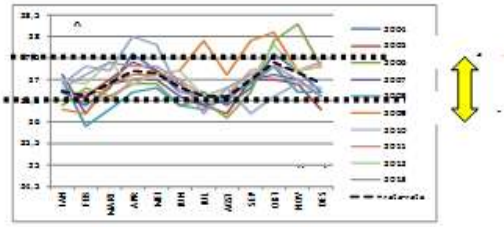

Figure 6. The curve of wind velocity in ten years period
(source:elaborated from BMKG data)

Kampong thermal environment‟s performance, consist of: 1) the air temperature between dwellings and the field temperature has been indicated that the average temperature of space between dwellings is lower than the field's average temperature. In dry-season-daytime, temperature between dwellings is relatively lower than temperature of field. In the rainy season-day time, the temperature between dwellings and field temperature not far, 2) sun radiation between dwellings is lower than the field radiation, because it is influenced by vegetation and building shading, In general, the performance of thermal environment is influenced by topography of the mountain region, the axis of Cikeusik kampong is south-north which is paralel to mountain-valley wind's direction. The vegetation around the kampong influence shading and thermal environment, especially by the stilt-dwellings configuration, and wind movement under the dwellings. The open space in the kampong, close-access to river give enhancement of shading. Such aspects influence the cooling effect of the kampong, especially in dry season and transition 2 (rainy to dry season), the close between dwellings and stilt dwellings form decrease the humidity and wind velocity in the night, 3) the humidity between dwellings and the field's humidity not to far even in night time and daytime. Such condition is influenced by the airflow which goes under the building, also moves through the space between dwellings, 4) the velocity between dwellings is quite lower the wind which blows in the field. The axis of the building is paralel with wind's direction of mountain-valley wind, therefore creating airflow, which support thermal comfort in kampong.

The vegetation which dominate the village, especially kampong of Cikeusik give shading, spesific air flow in the kampong, can lower air temperature, through evaporative cooling, around the dwellings. Therefore reducing the conductive and infiltration of heat gains, which in turn can be regulated into the comfort level of activity. High temperature and radiation in certain seasons, such as dry season can be overcomed by configuration of dense-buildings. High humidity and low temperature in certain seasons, such rainy season, the thermal enviroment conditioned by heating which is provided by firestone in the dwellings. In the extrem weather, such as the rainy season, the level humidity is high in night-time which is sometimes indicated by fog. In the dry season generally the temperature is low in night time, but it is quite high in the day time. Vegetation, particularly in the form of shade giving trees and ground cover, should be part of bioclimatic design in tropical climates, especially in Baduy area. Data relating vegetation and high stilt dwellings show providing shade and reduce solar heat, gain with relatively small blockage of wind [3]. High shrubs next to kampong providing shade, reduce appreciably the wind speed next to the kas is a area of large expanses of open and green areas, its village and particularly the outskirts of village are devoid of important vegetation. Studies have identified no heat islands in most Kanekes area, related to an abundance of vegetation and natural areas.

The thermal environment of building has characteristic such as: 1) the indoor's span of humidity is below outdoor's humidity (60%-70%) in the daytime, especially in dry season. In the night time, the indoor‟s humidity span is close to outdoor's humidity span, especially near to morning-time especially in dry season and transition 1 (dry-to rainy season), 2) wind velocity is about 0-1 Beafort scale, with indication physically felt on the face. Such condition is in the span of humidity comfort. Such wind character disturb the human comfort in rainy season and transition season-2 (rainy to dry season) and dry season, 3) radiation level is in the comfort zone, is about 20-27 ^{0}C which is indicated by globe temperature. The maximum radiation is in transition 2 (dry season to rainy season), 4) the temperature level is the comfort zone is about 23^{0}C-27^{0}C in the day-time, but not-comfort the night time, there is heating by firestone.

The detail building thermal environment in four seasons is indicated by aspects, such as: 1) in the dry season, the centre part zone's dwellings are easy to be hot because of being close to open space. Northen part easy to be hot than southern part because of valley-wind. in the centre zone, especially eastern part hotter than westtern-part, 2) In rainy season, the diferentiation of climate element lower than dry season, such as: humidity, temperature, radiation. Centre part is easy hot, close to open space, northen part easy to be hot than shorten part because of valley-wind. Eastern part easy to be hot than western part, because of duration of sun-radiation, 3) transition 1 (dry to rainy season), the diferentiation of climate elements of transition 1 is bigger than rainy season. Centre zone easy to hot close to open space, northen part easy to be hot than southern part because of valley's wind. Eastern (centre) part easy to be hot if it's been touched by sun-radiation, eastern part easy to be hot because it‟s touched by sun radiation relative longer, 4) transition 2 season, the diferentiation of climate elements is bigger than rainy season. Centre is easy to be hot because of closeness to the open space, the northen part is easy to be hot than southern part, because of valley's wind. The centre‟s eastern and eastern part is easy to be hot than western part.

The overall characteristic of thermal environment of kampong is indicated by the significant distance between aspects such as: a) day's maximum temperature and night‟s minimum temperature, b) day's minimum humidity and night‟s maximum humidity, c) day's maximum radiation and night‟s minimum radiation, especially in dry season. d) in the rainy season the humidity-level is quite high, especially in the night. The diferentiation of temperature, humidity, radiation, wind in the night-timt less than the day-time. Such characteristic can be seen by figure 7 (a)- (d).

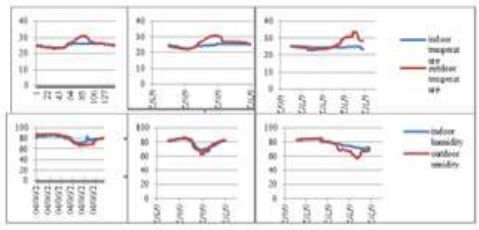

Fig 7 (a). Dwelling's thermal performance in June 2015(dry season)

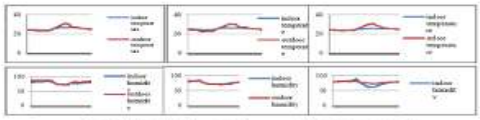

Fig 7(b). Dwelling's thermal performance in May 2015 (transition 2)

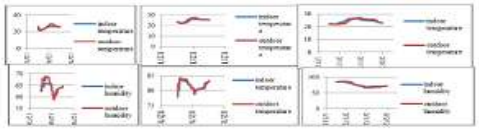

Fig 7(c). Dwelling's thermal performance in December-February 2014/15 (rainy season)

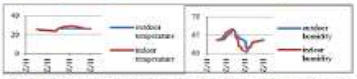

Fig 7 (d). Thermal performance in transition 1 November 2014 (transition 1)

Fig 7 (a-d) Dwelling's thermal performance in four seasons by 2014/2015 (source: field measurement)

Such condition show that: a) protection from sun-radiation, conductancy low, not storage the heat, b) in the night, there is mountain‟s valley which cold character enter the wall‟s hole and floor‟s hole, so the influence the closeness of indoor‟s and outdoor‟s thermal environment, c) the diferentiation of temperature, radiation, wind in night-time in rainy season is the least in compare with transition-1, transition-2, dry-season. In the rainy season, the building envelope‟s perfomance toward humidity is weakest, because of celah. Such condition is overcomed by floor‟s natural cover and fire-stone. The diferentiation of temperature, humidity, radiation in day's time in rainy season is the least, in comparison to transition-1, transition-2, and dry season. In the rainy season, the humidity is high, the globe's temperature is quite same with normal temperature.

Building's thermal environment performance indicate the response of dwelling to kampong's thermal environment, which indicate, such as: a) in dry season, especially daytime, there is a gap of element of outdoor-indoor, such as temperature, humidity, radiation. The surface temperatur close to indoor temperature, which indicate that the indoor has been controlled since the inner surface, b) in rainy season, especially in the day-time, there is no gap between indoor climate-outdoor climate, but especially there is a gap between indoor's wind and outdoor's wind, which indicate that the configuration of building mass and thickness can regulate the wind velocity significantly.

Thermal-environment's performance indicates that: 1) the ability of kampong's environment in regulating the kampong‟s thermal, indicated by the diferentiation between macro climate and kampong‟s thermal environment, 2) building envelope's ability in regulating building thermal environment, indicated by the diference between outdoor‟s and indoor's thermal environment.

3.3 Passive Design of Kanekes

Small openings, long overhangs and local materials used in tropical vernacular constructions play an important role in optimizing ventilation rate and indoor thermal quality. The form of the vernacular Indonesian houses are considered to be a prime example of environmental design to response the regional climate conditions. It has a low thermal mass, extensive solar shading, and a large number of ventilation openings**.** The environmental condition which produced by these housing types are generally considered to be thermally unsatisfactory, and there has been a recent move towards the development of designs which offer the thermal performance of the vernacular house[IV], whilst using modern construction technique and low cost material Indonesia, an archipelago nation in South-East Asia contains more than 13,000 islands is located in the tropical region (8° North and 13° South). Because of its equatorial position, Indonesia is endowed with a tropical climate, aired by the monsoon winds. With a high pluviometry annual average. Indonesia is then characterized by a hot and humid climate. December, January, and February cover the rainy season in most areas in Indonesia. March, April and May represent the transition from the rainy to the dry. June, July, August represent dry season. Finally, September, October, November represent ther transition from dry season to rainy season. In Indonesia, most of modern societies look vernacular societies as backward and their houses as old fashion. Although some who admire these houses were then just copying them to build similar shapes of buildings in urban areas but for different function other than dwellings.

This study was conducted in four seasons: the rainy season, the dry season, transition-1 and transition 2 in 2014/ 2015. In most areas of Indonesia, especially in kanekes area during the rainy season outdoor temperatures are likely to be lower than in the dry season. The crucial condition may occure in the dry season where occupants may feel too warm since the ambient temperatures tend to be higher. This study is to examine whether occupants will feel thermally comfortable in both seasons in vernacular houses. Vernacular houses in one locations, namely Baduy dalam (inner baduy) were taken as samples for the study. In many vernacular buildings, both primitive and vernacular, some ingenious solutions to the architectural problems of resisting extremes of weather and maintaining a comfortable indoor climate can be seen. Vernacular shelters of tropical region (hot humid climate) are usually lightweight in order to allow rapid cooling down and has larges openings to allow the maximum possible breeze penetration. These openings are fully protected from the sun and from penetration by driving rain. In Indonesia, the existence of a wide variety of vernacular village and house styles as the product of the cultural groupings; the country consists of many islands, many worldviews, languages, ways of life and social culture. Building technology is largely dictated by the nature of available materials. Traditionally one of building components, which epitomizes shelter and which perhaps, dominates all buildings is the roof. The importance of the roof as a major architectural form is underlined by the need to shelter from the hot sun and the rain. The Kanekes builders, for instance, have applied what they term as payung, or the umbrella principle to develop roof forms. From the view of general form, we can see the Kanekes village shelter has basic form as stilted

construction, which other Java and Bali regions. Their vernacular houses are elevated about only 50-180 cm from exterior surface.

Detail of unique character of Baduy dwelling, such as: 1) The golodog (veranda) is singled out as a significant Kanekes‟s building element to attain environmental comfort for the type of climate present in Banten region, Indonesia. The veranda can be shown to be a fairly constant element in the development of the Kanekes house, which is generated from ancient times, as the rural house of Sunda ethnic‟s house. The Kanekes counterpart may have a narrow bamboo‟s terrace sitting and neighbouhood gathering, as an extension of the house‟s front. Golodog provides transition from public to private spaces, also protect the house from sun‟s radiation and rain. Golodogs integrate the house with the public's way of the kampong. The golodog improves thermal comfort of the house in hot and humid climates, dominant in Kanekes and provides shaded, useful space for a number of domestic activities. As stated in Givoni (1998), the outdoor climate in hot and humid regions is more pleasant than the indoors. Furthermore, basically the house can not accommodate all household activities, many functions have to be carried our outdoors. In this respect, outdoor areas protected from rain‟s radiation and sun can be very useful, therefore the golodog was once a regular feature of the house. Most golodog are narrow strips of roof extensions. These golodogs do not act as a true outdoor space for family gatherings and relaxation activities. The length is primarily related to the design of the dwelling. The population recognizes the veranda's importance as a shading element, but selfbuilders today seldom incorporate this knowledge into the house design, 2) thermal comfort. The design of stilt houses with bamboo-woven creates a enhancement to obtain adequate air currents to mitigate heat gains in indoor spaces and cool.

This combination of such passive design gives proper ventilation conditions in houses. Furthermore our investigations have shown that self-built houses, due in part to their small functional spaces are not provided by furniture, 3) this condition enhance air flow and access to windows which are not manipulated optimally. A certain natural environmental can also be aceessed, where users do not adjust small window openings in favor of their own thermal comfort. Analysis of self-built settlements in the region of Banten province shows that house orientation which is north-south, gives significant influence to thermal comfort, 4) the axis of kampong is also paralel to the direction of mountain wind, which is south-north direction, movement and natural ventilation are main tools to sustainably provide the comfortable, thermal environment in hot humid climate [V]. Adequate ventilation brings in fresh outdoor air then the air is passed over people to increase evaporative cooling on the skin [VI], 5) Cross ventilation also must be provided to achieve comfort thermal environment. Cross ventilation assures the constan movement of the air inside a building [IV], house occupant must consider their designs to provide buildings with comfort thermal environment. Different types of climate requires different types of design strategies. Koenigsberger et al (1973), 6) The thickness of roof material (kiray) which is formed by layers of bamboo(usuk,reng,kiray) enable insulation,which can trap/catch cool air into the building and enable stratify,which is supported by overlay roof materials,more roof-layers encable the increase of insulation,which in turn the roof have high-insulation, 7) the space under building which relatively high,enable the infiltration of air-flow.The overhang enable to cool the building structure from sun radiation in the dry season [IV]. Such condition as form of roof‟s protection toward buliding structure‟s material, especially column and beam. Air flow with velocity of 1,0 m/s will give relief satisfactory for all the time, give decrease the efeciency of skin evaporation, to avoid uncomfortability of skin evaporation. Such that, opening and porousity of wall support that [VIII]. The thermal comfort in equatorial tropic must regard aspects, such as: a) the availability sunradiation to human and building body must be minimized, b) dissipation heat from human body must be maximized by ventilation and evaporative cooling

The passive design of Baduy Jero‟s kampong is paralel to design passive hot humid tropical climate [VII], especially related to layout. The strategies are: 1) Long thin elongated plan shapes, with a single row of rooms to allow cross ventilation, 2) Elevate main building on stilts to avoid the stagnant or slowly moving air at the ground surface, thus capturing air movements of a higher velocity, 3) With low rise building, orientation for wind is more advisable. 4) Wide –big area of openings for natural ventilation, especially for the living aren (up to 2 m above the floor). This condition is suitable for air change as well for air flow which will pass the air over the people to increase evaporative cooling. 5) Spacious veranda covered with roof or shading to lower the outdoor air temperature before entering the building.

IV. CONCLUSION

The vernacular‟s passive design of Kanekes village, especially Cikeusik kampong, Banten province, Indonesia, as commonly vernacular's Asia housing which indicated by stilt house (rumah panggung), has specific thermal performance. The specific form of house has enable airflow under the dwelling, which principle give

natural air conditioning, it is supported by air penetration into porous-wall. The dense housing also give protection from mountain-wind, especially cold-wind in the night-time. Shading is also result from height of dwelling, stilt house and overhang, also supported by vegetation.

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