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Effect of Vegetable Garden in the Vertical Indoor Thermal Comfortability

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ABSTRACT

This study investigates levels of thermal comfort and indoor air quality meeting room (*Balai*) *RT.11. RW.IV Rungkut Menanggal Harapan* Surabaya-Indonesia after applied vertical vegetable garden at the building. Setting the vertical vegetable garden arrangement is with a slope of 60 degrees by using the loose system. This garden installed on the west side of the building with a meeting room conditions when there are activities that people encounter with the condition of all open windows and doors closed the West. Objective measurements associated with dry air temperature, relative humidity, wind speed and solar radiation on pre-existing conditions and a garden after garden, while opinion surveys involve questions about the perception of the thermal environment and indoor air quality for the user meeting. The analysis showed that even though the air temperature in the chamber decreased 0.5º C during the dry season and 1.1º C in the rainy season, while decreasing CO2 content in the air of 2.22 ppm to 0.22 ppm dry season and the rainy season, also an increase in the O2 content in the space of 0.4% during the dry season and 0.1% in the rainy season. After the neutral temperature that occurs the park none have conditions meeting the thermal conditions within the comfort zone of ASHRAE Standard 55, and in all temperature conditions more neutral than the requirements of ASHRAE standard. The results revealed that users have subjective thermal comfort levels higher than predicted PMV (Predicted Mean Votes)
KEYWORDS: vegetable garden, vertical, Neutral temperature, perceived comfort, air quality

INTRODUCTION

Surabaya - Indonesia lies at 7.21º LS (-7.21) with altitude ± 6 meters. According to the Meteorology and Geophysics Bureau (BMG) Surabaya, Surabaya climate showed a trend micro extreme climatic conditions (climatic conditions in general than in Indonesia), and for five years (2001-2005) the maximum temperature reached 34.5º C. In the last 15 years Surabaya ambient air temperature rose to 36.4° C, resulting in an increase in the average temperature of more than 1.5º C [1]. As a comparison, neutral summary of temperature and thermal comfort range, according to some researchers in the hot-humid climate in some areas can be seen as shown in Table 1. With a relatively high temperature will be difficult to create a natural comfort room, so it takes a mechanical air conditioning, especially in an environment that has been formed.

To create space thermal comfort can be done by mechanical and natural. Mechanical way more practical and effectively implemented, but does not have a negative impact on the economy and the environment, while the natural way the results are not yet certain natural optimal thermal comfort desired but more friendly to the environment. Naturally thermal comfort can be done through architectural approaches, which designed the building with respect to: 1) orientation to the sunlight and the wind direction, 2) the use of architectural elements and building materials, and, 3) the use of landscape elements.

For new environmental approach to architecture by first and second way can be done, but for the environment that has been developed cannot use the first and second architectural approaches, it should be done in a third approach, namely the use of landscape elements with the arrangement of vegetation [2]. The purpose of this study were a) to identify and evaluate the conditions for thermal comfort and air quality in the meeting room after being given an organic vegetable garden vertically at the west side of the building at the front of the building opening, b). To determine the neutral temperature in the meeting room after being given a vertical garden at the front of the building opening, c) Comparing the results of thermal comfort to those specified by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) standard of 55 [3], and d) to occupant perception (PMV = Predicted Mean Votes) than the level of thermal comfort in the meeting through opinion approach.

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Table 1 The study of thermal comfort for naturally ventilated buildings and air-conditioned in Southeast Asia region.

Researcher &Year Publication	Location	Building Type	Form Study	Number of Subject	RH %	Neutral Temp T_n (°C) =TE
(Sh. Ahmad & Ibrahim, 2003) [4]	Shah Alam	Classroom MSRB	Filed study		72.5	27.6
(Feriadi et al, 2004) [5]	Jogja,Indonesia	Residential		525	79	29.2
(Sabarinah. & Ahmad. 2006) [6]	Klang valley	Residential Classroom	Field study Thermal chamber		85	26.1 28
(Rilatupa, 2008) [7]	Jakarta, Indo	Residential	Thermal chamber			25.2 – 27.5
(Roonak et al, 2009) [8]	Malaysia	Residential	Thermal chamber			27.8
(Rahman, 2010) [9]	Banjar, Indo	Residential	Thermal chamber			28.3
(Sulaiman et al, 2011) [10]	Malaysia					29.2
(Nugroho, 2011) [11]	Malaysia					

Description:
MSRB: multi storey housing. TO: prevailing temperature Ta: Ambient temperature N / a: Not available, NV: Natural ventilation RH: Relative humidity (Humidity)

Most of the previous studies (Table 1) which relate to thermal comfort ventilation openings configuration at the building facade, whereas in this study there is a novelty in the form of the use of a vertical vegetable garden arrangement configuration as a medium for creating thermal comfort space and improve air quality (CO2 uptake and release O2)

MATERIALS AND METHODS

The research was conducted on July 1 to 6, 2012 (the dry season) and on November 6 to 11, 2012 (rainy season) in the meeting room (*Balai*) *RT.11, RW.IV Rungkut Menanggal Harapan, Kelurahan Rungkut Menanggal, Kecamatan Gununganyar* Surabaya - Indonesia. The dimensions of the room are: length 7.00 m, width 6.00 m with a height of 3.20 m (Figure 1b and 1c).

a. Measuring indicators of indoor air Meetings with the air measuring devices

b. Existing building (façade facing

c. Plain overlooking meeting to the South

Figure 1 The space of meeting room (*Balai) RT.11 RW.IV Rungkut Menanggal Harapan* with air gauge (Thermo-Higro, Lux meter digital, Impanger and Oxygen meter)

Volume was 134.40 m3 space and floor area is 42 m2. Building stand-alone meeting the situation as follows: (Figure 2) building layout longitudinal North-South direction, so that the long side of the building facing East and West Eastern border attached to neighbouring buildings, the West border was opened fields, vacant lots and North border and South border were neighbourhood roads. Meeting room is space that restricted by two plane / solid wall (the East and North) and two plane / wall with window openings / vents (the West and South). Western side of the window opening with leaves 5 leaves plain glass windows that can be opened / closed with a height of 80 cm from the floor with an area of 4.20 m2 aperture (openings) consisting of 3.50 m wide and 1.20 m high, while 6 ventilation holes above the window plain glass closed off and within 60 cm from the ceiling with an area of 1.72 m2, consisting of 4.20 m wide and 0.40 m high, so the sunlight can directly enter into the space. The west corridor connecting door to door in the form of plywood the size of 0.80 x 2.00 m. Southern

openings form consist of 2 plain glass shutters that can be opened / closed with an area of 1.68 m2, and 4 ventilation holes above the window / glass doors closed off vast plain with 1.20 m2 and 2 plywood doors measuring 3.20 m2 are not facing to direct sunlight. Ceramic floor and ceiling covered ceiling asbestos, and asbestos roofing waves. Capacity 40 people meeting space devoted to the activities of sitting on the floor and at no events opening doors and windows are always open and the door was closed.

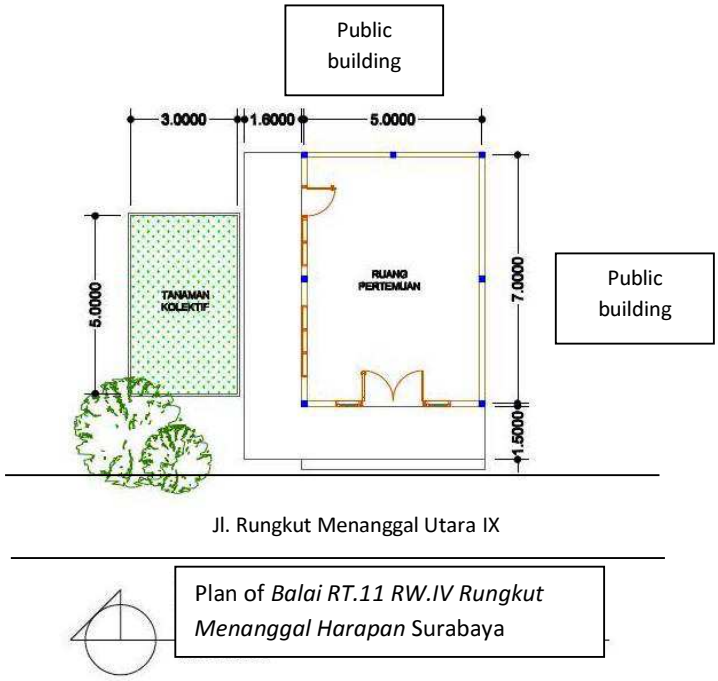


Figure 2 Building lay out of meeting room (*Balai*) RT.11 *RW.IV Rungkut Menanggal Harapan*

Vertical Garden

The garden is well laid out vertically on a pole, fence or wall. Garden in either free standing wall or part of a building, which partially or completely covered with vegetation, called the Green wall. [12]. There are two categories of green walls are:

a. Facades green living wall system is a plant that grows beside the building with the entrance to the ground and plant roots to climb into the building.
b. Loose wall system is "ground-in-the-shelf" or, using soil media packed into shelves or polybag then mounted to the wall. This system requires the replacement of the media at least once a year on the exterior and the interior of every two years.

Green wall can help reduce the temperature of the surface and the course will also affect the temperature of the air in the chamber. Based on the results of research at the National University of Singapore showed a vertical garden that can reduce the surface temperature of 12º C compared to ordinary wall in the afternoon at 12:00 to 13:00 pm. Normal wall surface temperature during the day reached 38.5º C, while the average of 8 gardens tested temperatures reached 26.5º C. The difference in day and night temperatures on the wall with a vertical garden is more stable, just 1º C, while the difference in day and night temperatures on the surface of the plain wall to reach 10º C.

Pattern of vegetable garden arrangement

In this study, using a vertical garden planted with vegetation / vegetables is capable of living in the study sites (Surabaya) were selected based on their ability to absorb CO2 vegetable plants, release O2 and have the same period of growth and composition resulting an interesting aesthetic, but for aesthetic goals should be selected plant species that provide good aesthetic and therefore should be planted in urban adapted to the urban environment, particularly related to the plant growing conditions. Productive plants are easy to arrangement in the tendency to use vegetable garden, with consideration of age harvested relatively quickly so that it can be changed and rearranged adjust wishes, cropping media production can be relatively small and not depending on the season. Of the ten types of vegetable crops under study selected three types of vegetables each Sawi / caisim / Brassica few cv caisim (CO2 uptake rate = 83.00 µmol/CO2/m2/det) curly lettuce / Lactuca sativa (CO2 uptake rate = 79,40 µmol/CO2/m2/det), and red spinach / Amaranthus sp (CO2 uptake rate = 76.60

μmol/CO2/m2/det) [13]. The pattern of plant arrangement using a Loose system (placed on the shelves with organic growing media placed in polybag) on slope of 60 degrees (allowing plant faster to get sunlight for photosynthesis, and the land needed for the garden is relatively small), horizontal distance for each plant 25 cm and a vertical distance of 30 cm, resulting in a 1 m rack contains 5 plants in polybag. (Figure 3)

a. Measurements on corridor

b. Arrangement vertical garden at the building

Figure 3 Patterns of vertical garden arrangement placed at the West side building (facade of the building is an opening)

Organic Crops

Vegetable garden in this study is using organic farming because organic crops better able to bind CO2 thus have a positive impact on the environment. Plants that carry organic farming systems that rely on organic products and natural, as well as the total does not include the use of synthetic materials, [14] From the results of the study, at the Rodale Institute held for 10 years since 1990, it is known that the use of compost trial (compost and organic fertilizer) on corn with crop rotations in organic systems to absorb carbon dioxide (CO2) to 2,000 lbs / ac / yr. Means more than 7,000 pounds / ac / yr of CO2 absorbed from the air and stored in the soil. In conventional fields of land with corn plants that use chemical fertilizers, carbon dioxide (CO2) present in the soil is lost / released into the atmosphere is almost 300 pounds / ac / year.

The influence of plants on air quality

Dry air contains of a variety of gas, the quantity of these gases there is a fixed (permanent gasses) or not fixed or changeable (variable gasses) whose number depends on the micro-environmental conditions. [15]. Gases whose numbers remain the Nitrogen (N2 = 98.08%), oxygen (O2 = 20.95%), Argon (Ar = 0.93%) and other gases which are relatively small. While the amount of gases that change the Water Vapour (H2O = 0-4%), Carbon-dioxide (CO2 = 0.038%) and other gases which are relatively small. Of all the existing gas CO2 is a pollutant in the air are dangerous and difficult to disentangle the gas so that the numbers will continue to grow, especially in the event of fire activity on the Earth's surface. To maintain the balance of the composition of the air, the plants are very effective to cope with changes in the amount of CO2 through the photosynthesis process is the process of taking CO2 and produce O2 with the help of light energy that occur during the day and respiration is the process of spending CO2 at night (without the aid of light energy). The number of carbon tethered during the day due to photosynthesis and released during the night due to respiration nearly 6: 1 depending on the type of plants and the environment.CO2 gas has a density 1.5 times higher than gaseous oxygen (O2), the implications of CO2 tends to float at a height of two meters above the ground by pressing the space that should be occupied by O2 gas. The absence of adequate O2 resulted in hypoxia or difficulty breathing, so that normal function of the respiratory system, CO2 levels do not exceed the recommended air volume of 0.05% or 5000 ppm (parts per million) [15]

The research approach

This experimental study to investigate the level of indoor thermal comfort conducted by measuring the physical data (objective) using a digital meter Thermo-hygro gauge capable of measuring relative humidity and dry bulb temperature, while the digital Anemometer, capable of measuring air velocity. Through measuring the data, using diagrams Psichometry, [16] will be known wet bulb temperature, and then to determine the TE (effective temperature) or neutral temperature is done using effective temperature diagram, [17]. As for knowing air quality measurements were taken using a tool that is able to bind Imp anger CO2 and Oxygen meter capable of measuring the O2 content of the air. (Figure 1a)All measurements were made at a height of 1 m above the floor, [18] which represents the height of the occupants at the time of highest activity in the meeting room sitting on chairs. Measuring devices placed at a point in the middle of the meeting room. Then the data is

recorded every hour from 07.00 - 16.00 (a condition in which the space is more often used for activities). Users generally assumed to meeting women / mothers using light cotton skirt and blouse and bare feet with a coefficient Clo value (thermal resistance) = 0.55. In this study, the metabolic rate is regulated by the level of activity that is an activity index settled 1.2 (office, home, school, laboratory) [19]

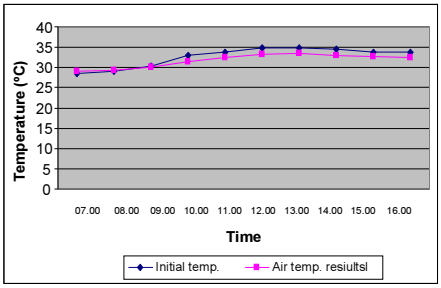
Subjectively Measurement

Survey to obtain data recorded subjective thermal comfort using a questionnaire, which was developed into four main sections: a) Demographic Information, b) The current status of thermal comfort, c) Thermal sensation and preferences, and d) The clothes worn at the time. The sample size there are 27 sample consisted of 27 women (RT.11 citizen women), and who took part in the survey sample only 24 women. The sample / respondents were given one hour to answer the questionnaire and to return it. Sex distribution of the sample is 100% female. Prior to the survey, the subject has been allowed to sit for about 30 minutes, with the majority settling activities. [5]. Sufficient time for the initial condition of the body, in any survey required respondents to maintain the metabolic rate (M) at the same level throughout the study.

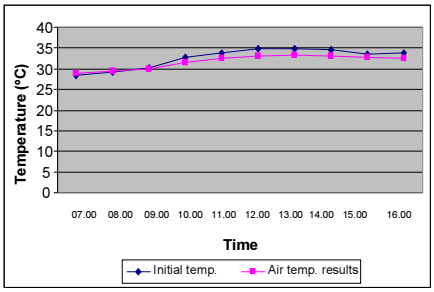
RESULTS AND DISCUSSION

.The air temperature in terms of the treatment of garden arrangement

In indoor, air temperature decreases during the dry season and the rainy season occurs after 09.00 am (Figure 3) this is the case because the effect of relatively high humidity in the morning, on average over 81%. The temperature drop is relatively a little due partly to the absence of air movement in the room (wind speed 0 m / s) (Table 2 & 3). This condition is influenced by the design of openings (no cross ventilation openings because the location is not the opposite), and is also influenced by the wind direction and air movement obstructed by surrounding buildings, but with the reduction of incoming solar radiation in space due to a vertical garden to reduce the temperature indoor air.



a. Temperature Graphic in the dry season



b. Temperature Graphic during the rainy season

Figure 3 Graphics of the average air temperature in door on space *RT.11 RW.IV Rungkut Menanggal Harapan*

Table 2 The results of measurements, humidity, air velocity and light intensity and CO_2 & O_2 Condition of ambient average in the study of indoor *Balai RT.11 RW.IV* during the dry season

Research	Time	RH %	Radiation W/m2	Air vel m/s	CO_2 ambient ppm	O_2 ambient %
Initial (Existing)	Morning	66	123	0.00	21.67	20.4
	Afternoon	40	457	0.00	12.34	19.5
	Evening	50	165	0.00	12.25	20.1
	Average	52	248	0.00	15.42	20.0
Results (After the applied garden)	Morning	75	113	0.00	16.95	20.2
	Afternoon	63	102	0.00	10.62	20.6
	Evening	67	106	0.00	12.03	20.4
	Average	68	107	0.00	13.20	20.4

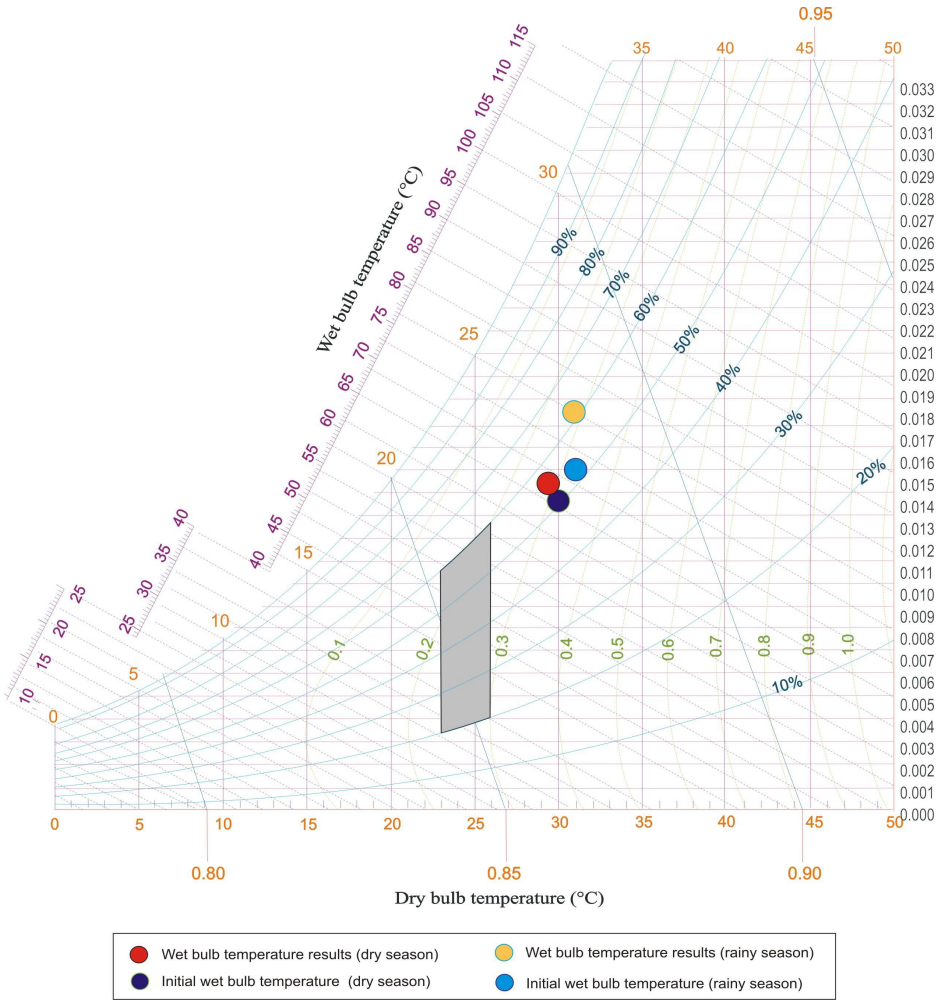
Table 3 Results of measurement, humidity, air velocity and light intensity and CO_2 & O_2 Condition of ambient average in the study of indoor *Balai RT.11RW.IV* during rainy season

Research	Time	RH %	Radiation W/m2	Air vel m/det	CO_2 ambient ppm	O_2 ambient %
Initial (Existing)	Morning	76	83	0.00	14.95	19.9
	Afternoon	55	300	0.00	13.44	20.4
	Evening	49	221	0.00	11.03	20.6
	Average	60	201	0.00	13.14	20.3
Results (after the Applied Garden)	Morning	87	24	0.00	14.74	20.4
	Afternoon	78	34	0.00	13.23	20.4
	Evening	64	32	0.00	10.80	20.4
	Average	76	27	0.00	12.92	20.4

In figure 3, the indoor air temperature in the dry season and the rainy season is not significantly decreased after the treatment is given in the form of a vertical vegetable garden at the building. The results showed that pre-existing vertical garden in the dry season temperatures average 31.4º C with the vegetable garden average to 30.9º C, a decline in average of 0.5º C, while in the rainy season the average temperature before there was a vegetable garden 31º C in the presence of the vertical garden's average temperature to 29.9° C, decreased an average of 1.1º C. Decrease in air temperature during the rainy season due to a greater influence of solar radiation is relatively small in the rainy season (solar radiation 107 W/m2 in the dry season, while in the rainy season 27 W/m2). The decrease is due to solar radiation garden next to the West building that provides shade on the walls of the western facade, besides solar radiation absorbed for photosynthesis by plants so it does not continue into space. Air quality has increased although not significant that is the mooring CO2 that occur in ambient air after a vertical crop, decreased by 2.22 ppm in the dry season, while in the rainy season decline of 0.22 ppm. The release of O2 by vertical vegetable gardens increased by 0.4% in the dry season, while in the rainy season the release of O2 by 0.1% (Table 2 and 3). Improved air quality during the rainy season is relatively small as it is influenced by solar radiation were not optimal so that the process of photosynthesis by plants is not optimal. Based on these results of air quality at the sites are still on the standard of healthy air, where CO2 levels in air ranging from 13.06 ppm and O2 levels on average 20.4%, while CO2 levels recommended no more than 5000 ppm.

Review by ASHRAE 55 using Chart

Psychometric Chart to determine the Effective Temperature (TE) analysis using effective temperature diagram [17], where it takes the variable wet bulb temperature, dry bulb temperature and wind speed. The dry bulb temperature measurement data (field measurements) are used to determine the wet bulb temperature analysis using Psychometric Charts [16].



Note: initial temperature = temperature of the air before the garden **arranging** (existing)
Temperatures result = temperature after the garden **arranging**

Figure 4 Analysis of field measurements by using Psychometric Chart

Psychometri**c** chart is used to determine the wet bulb temperature, which is a factor that affects the dry bulb temperature and humidity. Based on the analysis of the data using the Psychometric Chart with dry air temperature average (Figure 3) and average air humidity (Tables 2 and 3), the obtained temperature wet to dry season, 23.3º C, while the temperature in the rainy season wet 24.9º C. Temperatures wet during the rainy season was relatively higher than the dry season because of the humidity is high (average of above 70% RH). Furthermore, wet air temperature data analysis will be used to determine the effective temperature or temperature or thermal comfort neutral meeting.

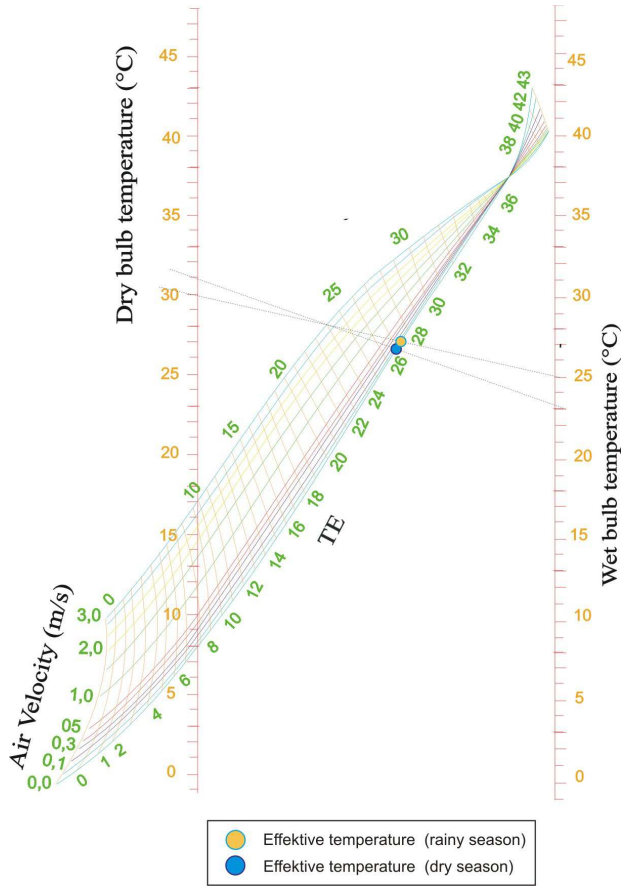


Figure 5 Thermal Comfort Analysis (TE) based on temperature measurement field Dry wet and Temperature analysis by using the Effective Temperature Chart

From the analysis using Temperature Effective Chart dry air temperature data on average (Figure 3) and wet air temperature analysis using Psychometric chart (Figure 4), because the air velocity in the meeting fairly small then ignored, in order to obtain the temperature neutral or Effective Temperature (TE) or thermal comfort for the dry season reached 26.8º C (TE) with a relative humidity of 52%, while in the rainy season 27.3º C (TE) with a relative humidity of 60%. (Table 4)

Based on the ASHRAE Standard 55-1992, it states that the summer comfort zone of thermal comfort temperatures between 20º C - 25.5º C with a relative humidity between 20% - 60% (Figure 4). The results showed that the meeting is not in the comfort zone during the on-going activity.

Review by Temperature Neutral

In some previous studies conducted in several hot humid climates (around Southeast Asia) in residential buildings resulting neutral temperatures higher than recommended by ASHRAE Standard 55 is 25.5º C. For the condition of the building with natural ventilated comfort all studies show higher temperatures between 2.2º to 3.7º C than recommended, including: Studies comfort in residential buildings in Jakarta Effective Temperatures reached 28º C - 29.2º C [7, 5], in Banjarmasin reached 27.8º C, [9] in Malaysia reached 27.5º C - 28.3º C, [8 , 10, 11] in Singapore reached 28.9º C [9]. Previous studies mostly done using configuration of openings on the building façade for thermal comfort room, but with average results beyond the standard, comfort ASHRAE 55, the adaptations made by the effort to increase the speed of the air in the room through the use of fans or adjust types of clothing with microclimate.

The equation for the probability received 90%, the recommended thermal comfort is Tn (neutral temperature) ± 2.5 TE (Effective Temperature), while 80% may be received, the recommended thermal comfort is Tn ± 3.5 TE. [20]. For possible received 80% and 90% in each of the conditions in accordance with the given in Table 4.

Table 4 Measurements result of Air Parameter and Thermal Comfort

Location	Thermal Comfort Parameters							Neutral Temperature/Effektive Temperature (TE)				
Indoor	**Initial data**			**results**				**TE**	**90 % accepted**		**80 % accepted**	
	Temp	RH	Air. vel	T d	T w	RH	Air. vel	ºC	TE-2,5	TE+2,5	TE-3,5	TE+3,5
	ºC	%	m/s	ºC	ºC	%	m/s		ºC	ºC	ºC	ºC
Balai RT												
dry season	31,4	52	0	30,9	23,3	62	0	26,8	24,3	29,3	23,3	30,3
rainy season	31	60	0	29,9	24,9	66	0	27,3	24,8	29,8	23,8	30,8

Note: Td = dry bulb temperature; Tw= wet bulb temperature; Air vel = air velocity

According to Table 4, the results showed that the neutral temperature according to standard Aluisiem (TE calculations To = ± 2.5) is acceptable in the category of 90% is acceptable, because the neutral temperatures in the dry season is still around 24.3 ° C, while in summer rainfall ranges from 24.8 ° C, while the standard ASHRAE 25.5 ° C

Review by subjectivity

Demographics of user space

Assessment of thermal comfort in the meeting by the response/perception of users on a survey was through the given questionnaires in conjunction with physical measurements in all conditions. A total of 24 respondents participated in filling the questionnaires, all of whom are women who are citizens of *RT.11 RW.IV Rungkut Menanggal Harapan* with age between 35-60 years (Table 3)

Table 5 Demographic data of respondents

Sex	Age			Number
	35 – 42 Year	43 – 50 Year	51 – 60 Year	
Female	6	11	7	**24**
Percentage	**25**	**45,8**	**29,2**	**100**

Analysis of the data predicted average voting (PMV) based on ASHRAE scale 55

Data analysis was performed based on subjective measurements were made during the public meeting activities from 09.00 am until 14.00 pm. In this study, PMV index (Predicted Mean Vote) by Finger (1972) used in the calculation and analysis. Explanation PMV index is numerically described as: cooler (-3), cold (-2), slightly cool (-1), neutral (0), slightly warmer (1), warm (2), hot (3). By using analysis of Info Gap and Microsoft Excel, micro-climate index calculation on the ground shows the range of predictions of average voting (PMV) between (-1) and (+1), while based on ISO 773-94 comfort range as favourable conditions when the PMV have values between -1 and +1, but most of the votes of respondents (over 75%) are likely to say the condition of the air temperature in the range of +1 (slightly warm) (Figure 6).

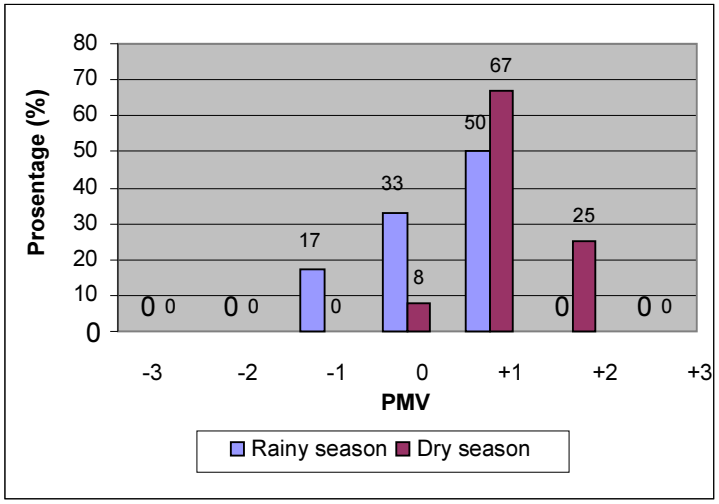


Figure 6 Analysis of PMV based on ASHRAE scale

The results of physical parameters in all conditions, the vertical garden arrangement points to the fact that is most of the respondents stated that the air temperature is acceptable. This is due to a decrease in air temperature and air movement in the room although relatively a little (as when there is activity in conditioned meeting rooms all open windows). In this condition the respondents still felt comfortable in the space; so that the subjective assessment shows that thermal comfort are still within tolerable limits respondents, although the condition is still below the requirements / ASHRAE 55-1992 thermal comfort zone. The results of this study also showed that the international standards of thermal comfort standard for ASHRAE 55 can be applied in Indonesia, **but** particularly in the city of Surabaya is difficult to be achieved only by relying on natural air system. Temperature range of thermal comfort based on the results of the study with the maximum condition showed TE (Effective Temperature) = 27.3º C, while the standard ASHRAE 55 requires a maximum 26º C, as well in several places in Indonesia with a hot humid climate showed Effective Temperature 27.4º C and 28.2º C. (Table 1)

CONCLUSION

Based on the study of the thermal comfort of meeting rooms (indoor) shows that most of the conditions PMV at public meeting activities by providing treatment in the form of a vertical garden arrangement at the buildings in the range of +1 (slightly warm) and neutral temperature between 26.8º C to 27.3º C. This shows that thermal comfort in all conditions meeting did not meet the standard ASHRAE comfort zone 55-92.

By the neutral temperature reached occupants can still tolerate the climatic conditions in the receiving meeting though beyond the limits set by the ASHRAE standard comfort zone. This study shows the receipt of the required temperature beyond comfort, then this indicates that the ASHRAE Standard 55 is not an absolute apllied on meeting people with the treatment of vertical gardens and humid tropical climate in Indonesia and especially the city of Surabaya. The results of this study indicate that more flexible range of convenience of the climate in Indonesia to be proposed by international standards, which would indicate that Indonesia can be acclimatized to the higher ambient temperatures.

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