STUDY OF INDOOR AND OUTDOOR THERMAL COMFORT FOR PUBLIC SPACE AND HOUSES IN AROUND RIVER
CASE STUDY: BANJARMASIN CITY, INDONESIA

Akbar Rahman[1] and Shoichi Kojima[2]

[1]Department of Civil Engineering and Architecture, Saga University, Saga, Japan&
Department of Engineering, Lambung Mangkurat University, Banjarmasin, Indonesia
[2]Department of Civil Engineering and Architecture, Saga University, Saga, Japan

ABSTRACT

Banjarmasin city is the capital of South Kalimantan province, as well as the largest and the most populous city in Kalimantan.River into the container main activity ancient times to the present society, particularly in the areas of trade and transport. The rivers that cut through the city, pursued as a magnet economy, especially tourism.The River revitalization program has been implemented by the government. Revitalization of the building aims to increase the river potential.Thermal comfort during the day need to be considered. The research was conducted in three places: 1) Siring Tendean, 2) Sasirangan Village and 3) Bilu Village. Results regression thermal comfort of indoor and outdoor shows significant value, with coefficient of determination (R^2) between 0.5345-0.807. Conditions most comfortable outdoor environment is open space in Siringand a more comfortable indoor conditions infloating houses. This could be due to the high humidity and the wind flow was pretty good, because the open area around the river.

KEYWORDS

Indoor and Outdoor, Thermal Comfort, Public Space, Housing, Around River.

1. INTRODUCTION

Indonesian is located at 6^{O}NL to 11^{O}SL. Indonesian are grouped into characterizing humid tropical climate, with high solar radiation, high air temperatures, high humidity and high rainfall, and the state of the cloudy sky [1]. Such circumstances always occur almost throughout the year and the effect on the environment. Three things to note in the thermal control which is the duration of solar radiation, solar radiation intensity, and angle of incidence of sunlight [1][2]. Outdoor space has a significant impact on solar radiation. The impact affects thermal comfort in public spaces and house. Comfortable outdoor space is important for urban. Realizing a comfortable outdoor space is important to the urban plan. Banjarmasin is one of the cities in Indonesian (Figure.1), which is building a new outdoor space. Banjarmasin is a city that has many rivers, so it is known as the city of a thousand rivers. Banjarmasin as the city also has a variety of problems one of them slum. Urban slums occurred in a densely populated area on the riverside. The River revitalization program has been implemented by the government. Revitalization of the building aims to increase the river potential. (Figure 2).

Siring serves as a public space, a place to meet townspeople. As a public space, siring should provide comfort for visitors. Thermal comfort during the day need to be considered. The direct

sun light barrier is required in open spaces, building or house. The building is a protector of direct sunlight during the day and is a key strategy in achieving thermal comfort in hot conditions [3]. As a protector of direct sunlight, can reduce the level of heat in open space (outdoor) and houses (indoor).

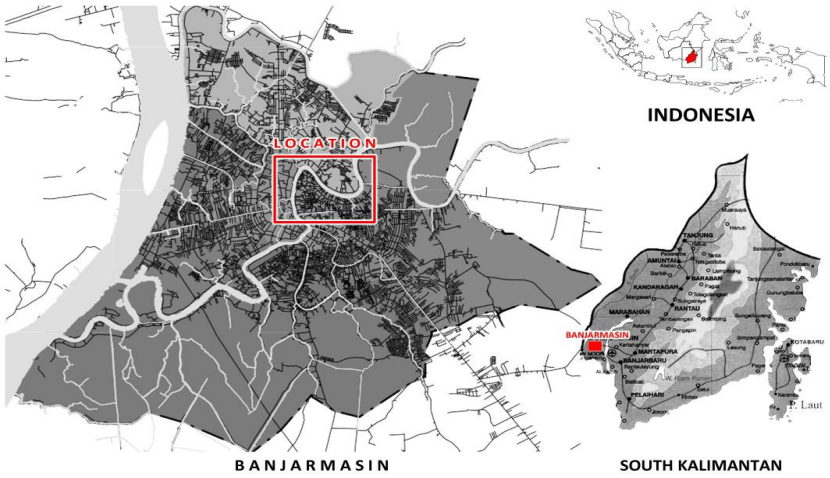

Figure 1. Research location

Figure 2. Public space and house condition in Banjarmasin (a) Housing condition before revitalization/urban slums (b) Public space in Siring Tendean after revitalization (c) Public space and housing in Sasirangan village after revitalization

2. RESEARCH METHODS

2.1. STANDARD OF THERMAL COMFORT IN INDONESIA

Indonesia is a country of humid tropical climate. Archipelago situates around the equator [1]. Surrounding countries that have similar climates are Singapore, Malaysia and Brunei. Many researchers conducted a survey of thermal comfort (Table 1). In the table thermal index consists of operative temperature (T_{op})and effective temperature (ET). T_{op} ranged between 24.1^{o}C-30^{o}C and T_{op} on average 26.1^{o}C. The effective temperature of between 20.3^{o}C-23.6^{o}C is a hospital case study in Malaysia.

The Indonesian Standardization Board (BSN) issued a national standard ventilation system and energy conservation [20][21]. Indonesian National Standard for standard ventilation systems should pay attention to thermal comfort. Indonesian National Standard (SNI) for the standard ventilation system must pay attention to thermal comfort. The thermal comfort standard is

effective temperature (ET) 20.5°C-27.1°C or operative temperature (T_{op}) 24°C-27°C (Table 2). In this study using thermal comfort SNI 03-6572, because it uses an effective temperature that has many variables: temperature, humidity and air velocity.

Table 1. Research of thermal comfort in humid tropical climate

No.	Year of Study	Principal Researcher	Location	Type of Building	Comfort Temp. (□)	Thermal Index
1	1937	Mom [3]	Bandung, Indonesia	Climate Chamber	26	T op
2	1952	Ellis [4]	Singapore	Ship	30	T op
3	1953	Ellis [5]	Singapore	House, Office	24.5 - 27.8	T op
4	1958	Webb [6]	Singapore	House	28,8	T op
5	1967	Ballantyne [7]	Port Moresby	House	25	T op
6	1979	Ballantyne [8]	Port Moresby	House	25 - 26.7	T op
7	1986	de Dear [9]	Singapore	Residential, office	24,2	T op
8	1990	de Dear [10]	Singapore	Climate Chamber	25,4	T op
9	1990	de Dear [11]	Singapore	Climate Chamber	27.6 - 27.9	T op
10	1993	Karyono [12]	Jakarta, Indonesia	Offices	26,4	T op
11	2000	Karyono [13]	Jakarta, Indonesia	Offices	26,7	T op
12	2004	Feriady-Wong [14]	Yogyakarta, Indonesia	House	26	T op
13	2005	Karyono [15]	Bandung, Indonesia	Classroom	24,7	T op
14	2011	Azizpour [16]	Malaysia	Hospital	20.3 - 23.6	ET
15	2013	Karyono [17]	Jakarta, Indonesia	Classroom	24,1	T op
16	2013	Karyono [17]	Jakarta, Indonesia	Classroom	24,9	T op
17	2015	Karyono [18]	Jakarta, Indonesia	Cathedral, Bank, Market	27.3-27.7	T op
18	2015	Siti Aisyah [19]	Bandung, Indonesia	Campus, office	24.7 - 27.5	T op

Table 2. Indonesian National Standard for thermal comfort

No.	Year	Number SNI	Location	Type of Subject	Thermal Condition	Comfort Temp. (□)	Thermal Index
1	2001	03-6572 [20]	Indonesia	Indonesian people	Cool comfort	20.5 - 22.8	ET
					Optimal comfort	22.8 - 25.8	ET
					Warm comfort	25.8 - 27.1	ET
2	2011	6390 [21]			Optimal comfort	24 - 27	T op

2.2. DESCRIPTION OF LOCATION AND PLACES OF RESEARCH

Banjarmasin city is the capital of South Kalimantan province, as well as the largest and the most populous city in Kalimantan. Banjarmasin city located on the 3° 15'to 3° 22' SL and 114° 32' EL, ground altitude is at 0.16 m below sea level and almost the whole area is flooded at high tide. It is located in the east of the river of the Barito and cleaved by the river of Martapura tipped in Meratus Mountain. The river has become a major point of community activities since the first[22]. The rivers that cut through the city, pursued as a magnet economy, especially tourism [23].The research was conducted in three places: 1) Siring Tendean, KelurahanGadang 2) Sasirangan Village, KelurahanSeberangMesjid and 3) Bilu Village. Kelurahan Sungai Bilu(Figure 3).

Figure 3. Places of Research

2.3. RESEARCH VARIABLES AND MEASUREMENT PROCEDURE

The purpose of this study was to determine the thermal comfort in public space situated around the river in the city of Banjarmasin. For that reason, the independent variable research is a public space and housing around the river, while the dependent variable is the thermal condition. Public space and housing around the river, it is a) Siring Tendean, b) Sasirangan Village and c) Bilu Village. While the thermal performance assessed between indoor and outdoor. Temperature, humidity, air velocity and solar radiation are used to determine the condition of indoor and outdoor thermal comfort at a particular time. And the control variables are comfort zone with psychometric charts, diagrams effective temperature and standards of SNI 03-6572 on thermal comfort. Scheme of research variables is shown in Figure 4, below:

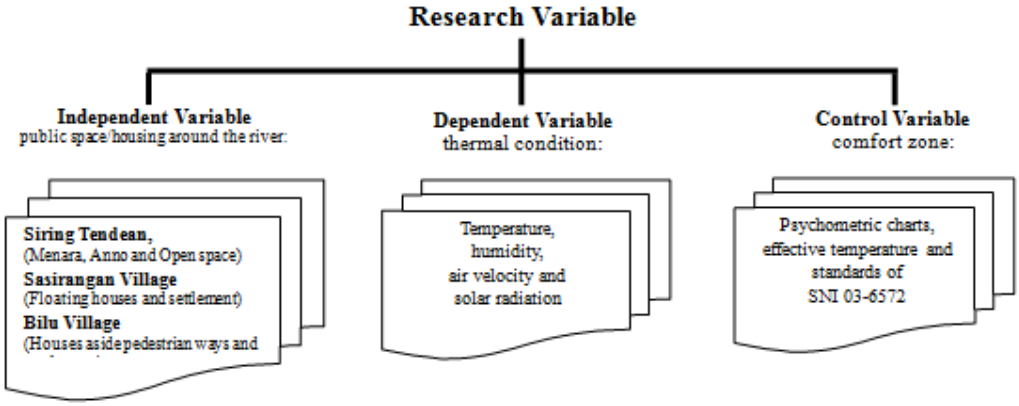

Figure 4. The Scheme of Research Variable

Field measurements conducted in three locations from 11th - 27th September 2016 with the following details: Bilu Village from 11th - 15th September 2016, Sasirangan Village of 18th - 21th September 2016 and Siring Tendean from 25th - 27th September 2016. Measurement period and instruments can be seen in Table 3 and Figure 5.

Table 3.Measurement period and instruments

Measurement items	Temperature, humidity, and air velocity
Measuring instruments	Data logger-4HC for temperature and humidity Extech AN100 for air velocity
Calculate of wet bulb temperature	Psychometric charts
Calculate of effective temperature	Diagrams effective temperature
Field measurement	11th - 27th September 2016 Time: 6:00 am to 05:00 am (every hour/24 hours)
High measuring instruments from the ground/floor	150 cm
Number of measuring points	2040 points

Figure 5.Sample place condition of measuring instruments (a) Siring Tendean, (b) Sasirangan Village, and (c) Bilu Village

3. RESULT

3.1. THERMAL CONDITION

Indoor mean temperature in Village of Sasirangan highest maximum of 34.8°C, and the mean minimum temperature is low also in this village, 25.4°C.Higher temperature conditions occur in a floating house. Indoor mean temperature in floating houses highest maximum of 36.2°C, and the mean minimum temperature is low also in this houses, 24.2°C. Similarly, indoor air humidity the highest and the lowest occurred in the Village of Sasirangan. The indoor mean temperature in Siring Tendean lower than other places. The average indoor temperature between 27.6°C-32.9°C.And, the lower humidity, between 59.5% - 77.9% (Table 4).

The average maximum outdoor temperature was lowest in Siring Tendean. Open space is the best in outdoor conditions. Open space temperatures lower than other places, but the air humidity is relatively high 85.3%. Maximum temperatures of open space 32.4°C and a minimum temperature of 25.4°C. The open space around the floating markets, the temperature is relatively high compared to other places in Siring Tendean. This place maximum temperature of 34°C or higher 1°C - 2°C from elsewhere. This is due to a lack of vegetation (Table 4). The average air velocity ranges from 1.56 m/s - 1.78 m/s. During the day the air velocity can reach 2 m/s - 3 m/s but at night tends to be low.

Table 4. Thermal conditions in the surveyed places

	Indoor Condition					*Outdoor Condition*				
	Maximum		Minimum		Mean	Maximum		Minimum		Mean
	T (□)	RH (%)	T (□)	RH (%)	V (m/s)	T (□)	RH (%)	T (□)	RH (%)	V (m/s)
Siring Tendean										
Mean	32,9	59,5	27,6	77,9	0,1	33,3	63,7	25,3	82,4	1,7
Menara	31,7	60,1	27,2	75,0	0,1	33,8	61,3	25,6	79,5	1,8
Anno	34,0	58,8	28,0	80,7	0,1	33,2	61,5	25,5	79,5	1,7
Open Space						32,4	65,8	25,4	85,3	1,7
Around Floating Market						34,0	66,1	24,7	85,4	1,7
Sasirangan Village										
Mean	34,8	55,4	25,4	83,8	0,1	34,9	54,4	25,2	84,7	1,6
Floating Houses	36,2	51,0	24,2	87,7	0,1	35,9	50,9	23,8	87,9	1,6
Houses in Settelment	33,4	59,8	26,6	79,9	0,1	34,0	58,0	26,7	81,4	1,7
Bilu Village										
Mean	33,5	59,9	25,9	82,9	0,1	34,8	55,7	24,3	85,4	1,6
Houses aside Pedestrian Ways	36,1	48,6	24,8	85,6	0,1	36,5	43,7	24,0	87,7	1,6
Houses in Settelment	30,8	71,2	27,0	80,2	0,1	33,1	67,8	24,6	83,1	1,6

T = Temperature, RH = Humidity and V = Velocity

3.2. THERMAL COMFORT CONDITION

3.2.1. SIRING TENDEAN

Thermal comfort indoor and outdoor in Siring Tendean can be seen in Figure 6. The outdoor thermal comfort is relatively more comfortable than indoor.Theeffective temperature outdoor is not out of the comfort zone at maximum conditions, but the minimum conditions this occurs. The condition can be concluded cold outdoor conditions. Conditions of open space is relatively cooler than other places in the area Siring Tendean. The effective temperature difference between indoor and outdoor is 2°C-4°C. The minimum effective temperature of indoor is 24.2^{o}C and outdoor 19.8^{o}C, in the morning. Meanwhile, the maximum effective temperature is in the daytime, the indoor temperature is 28.8^{o}C and outdoor 27.2^{o}C. Comfort conditions trend to warm indoors, while outdoors trend to be cool. This shows that the insulation of buildings against external environmental conditions is high. Thermal comfort in buildings can be maximized if the ventilation system of the building is better.

The regression equation in Siring Tendean are: y=1.5207x - 17.303 and R^2=0.6618 (significant) for indoor and outdoor buildings, and y=1.0978x - 6.8165 and R^2=0.6618 (significant) for indoor buildings and open space.

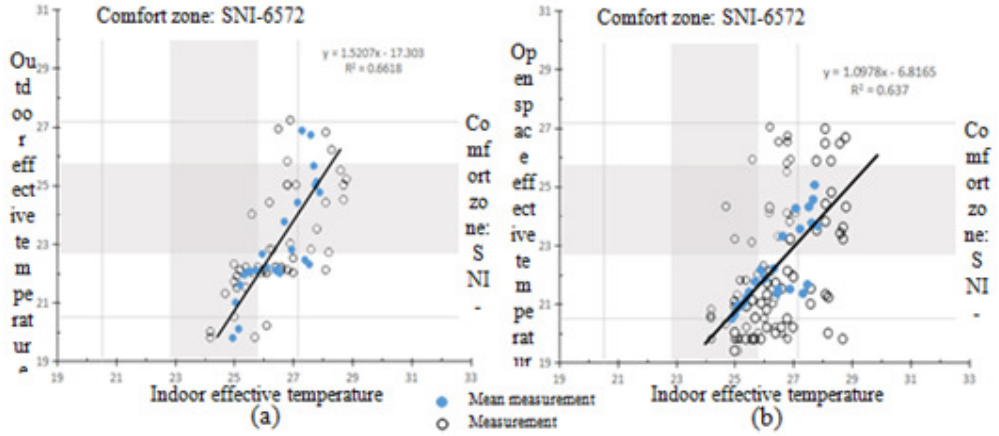

Figure 6. Thermal Comfort Conditions in Siring Tendean (a) regression indoor and outdoor in menara and anno building (b) regression indoor Menara-Anno building and outdoor open space.

3.2.2. SASIRANGAN VILLAGE

Outdoor thermal comfort is more comfortable than the indoor. Indoor thermal conditions of a floating house is quite high. Effective temperature is high enough indoor for floating house with 31^{o}C, occurred at noon. This causes the floating house uncomfortable, especially during the day. The outdoor effective temperature is not comfortable at the minimum effective temperature. The condition can be concluded cold outdoor conditions and relatively comfortable. Effective temperature indoor thermal of comfort conditions is higher in Sasirangan village between 3-4^{o}C than outdoor. The highest difference occurred in the floating house at the maximum effective temperature conditions. The indoor minimum effective temperature is 23.2^{o}C while the outdoor 19.2^{o}C, this occurred in the morning. And, the indoor maximum effective temperature is 31.2^{o}C while the outdoor 27.2^{o}C, this occurred at noon in the floating house, as shown in the figure 7. This suggests that the indoor in the floating house is hotter than outdoor. The indoor effective temperature is high because the air ventilation and building materials.Indoor thermal comfort settlement house more comfortable than floating house.

The regression equation in Sasirangan Village are: y=0.7441x + 2.4395 and R^2=0.807 (significant) for indoor and outdoor floating house, and y=1.4853x - 16.656 and R^2=0.7863 (significant) for indoor buildings and open space.

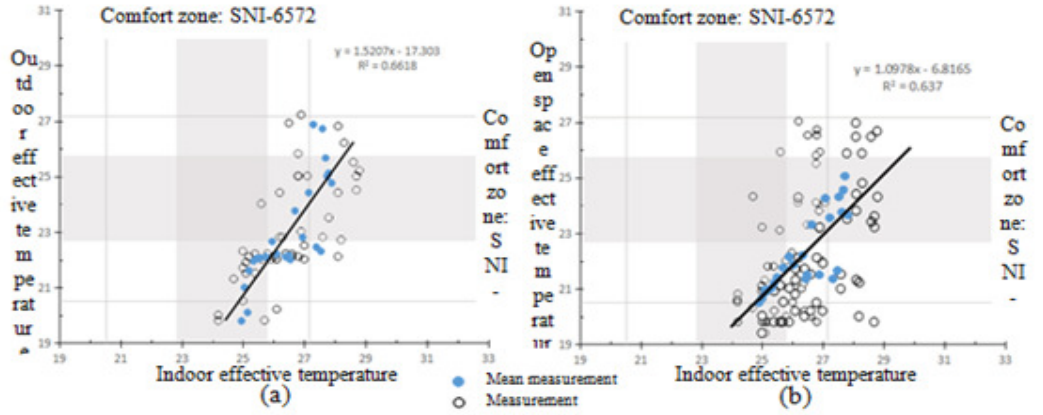

Figure 7. Thermal Comfort Conditions in Sasirangam Village (a) regression indoor and outdoor in floating houses (b) regression indoor and outdoor in Settlement houses.

2.2. BILU VILLAGE

Thermal comfort conditions in the village can be seen in Figure 8. The outdoor thermal comfort is relatively more comfortable than indoor. The outdoor maximum effective temperature is not out of the comfort zone, unless the minimum conditions. It can be concluded colder outdoor conditions. Effective temperature indoor thermal of comfort conditions is higher in Sasirangan village between 3-4^{o}C than outdoor. The indoor minimum effective temperature is 23^{o}C while the outdoor 19.4^{o}C, this occurred in the morning. And, the indoor maximum effective temperature is 30,1^{o}C while the outdoor 27.6^{o}C, this occurred at noon in the houses aside pedestrian ways. This shows the house beside pedestrian ways is hotter than the outside environmental conditions. The indoor thermal comfort in settlement house more comfortable than the houses aside pedestrian ways.

The regression equation in Bilu Village are: y=0.9052x - 1.9281 and R^2=0.7487 (significant) for indoor and outdoor houses aside pedestrian ways, and y=1.1249x - 7.8158 and R^2=0.5345 (significant) for indoor buildings and open space.

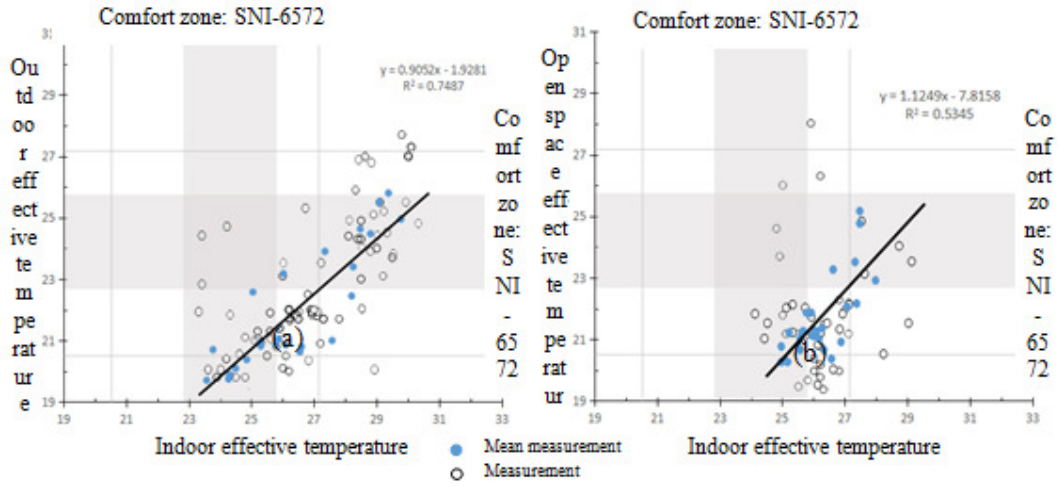

Figure 8. Thermal Comfort Conditions in Bilu Village (a) regression indoor and outdoor houses aside pedestrian ways (b) regression indoor and outdoor settlement houses.

4. DISCUSSION

Indoor effective temperatures always exceeded the threshold of thermal comfort SNI 6572. The value of the effective temperature was highest in floating houses at Sasirangan village and houses aside pedestrian ways at Bilu village. The highest effective temperature in both places this happened during the day, about 30^{o}C. Outdoor effective temperature down just past the threshold of thermal comfort SNI 6572, as shown Figure 9. Almost all places have a minimum effective temperatures outdoor around 20^{o}C and occurred in the morning.

These conditions indicate that the environmental conditions outdoor the relatively comfortable to move. Green open space is the best condition. Effective temperature is always in the comfort zone. This proves, the more open green space, the better micro-climatic conditions. Effective temperature around the river is lower than the mainland region. It can be seen from the effective temperature difference in floating houses-houses aside pedestrian ways and settlement in Sasirangan-Bilu village, the difference between 0.5^{o}C-0.8^{o}C (Table 5).

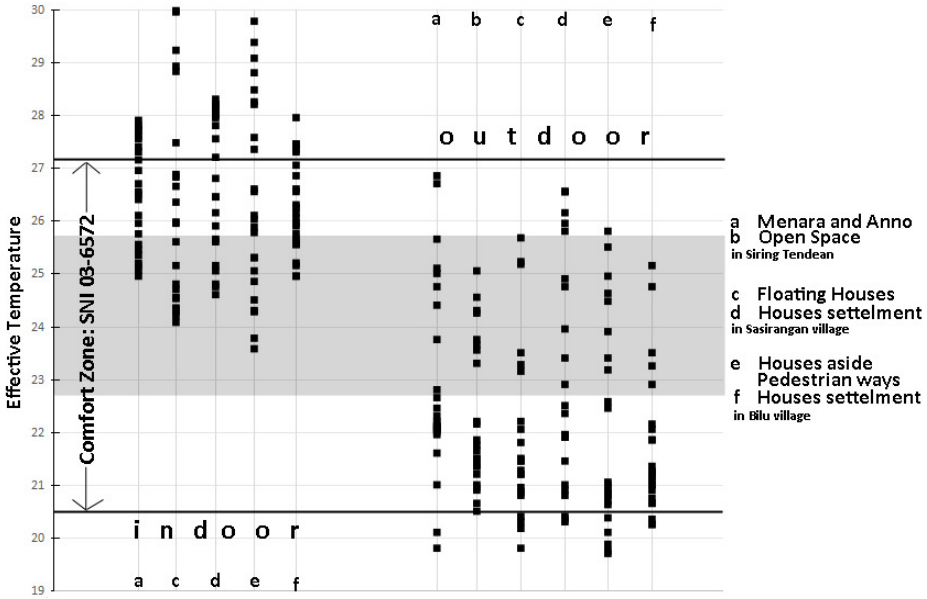

Figure 9.Range of effective temperature

Indoor and outdoor effective temperature differences highest on minimum conditions, between 3.88°C to 5.15°C. While the maximum condition is quite varied, as shown in Table 5. The highest difference between the mean effective temperature indoor and outdoor occur in a floating house, with the difference value 4.30°C

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Table 5. Difference mean effective temperature in the surveyed

	Minimum Mean Effective Temperature						*Maximum Mean Effective Temperature*					
	a	**b**	**c**	**d**	**e**	**f**	**a**	**b**	**c**	**d**	**e**	**f**
Indoor	24.95		24.08	24.60	23.58	24.95	27.90		29.98	28.15	29.78	27.95
Outdoor	19.80	20.50	19.80	20.30	19.70	20.25	26.85	25.05	25.68	26.55	25.80	25.15
Difference	**5.15**	**4.45**	**4.28**	**4.3**	**3.88**	**4.7**	**1.05**	**2.85**	**4.30**	**1.6**	**3.98**	**2.8**

a Menara and Anno
b Indoor Menara-Anno and Open Space
c Floating houses
d Houses in settlement (Sasirangan Village)
e Houses aside pedestrian ways
f Houses in settlement (Bilu Village)

Time and duration of thermal comfort in indoor and outdoor, are also important elaborated. It may be more detail describing the micro-climatic, environmental and building conditions. As described above, the open space is the most comfortable all the day. The duration of thermal comfort in open spaces is 16 hours in cool comfort zone and 8 hours in the optimal comfort zone, as shown Figure 10. While the outdoor thermal condition around the building is comfort, it is slightly lower than the open space. Comparison of indoor thermal comfort conditions in buildings Menara and Anno, it can be better building Menara. These buildings began uncomfortable from 11 AM - 7 PM. Optimal comfort conditions occur at midnight (Figure 10). Although the interval indoor effective temperature is relatively low, but this condition is long enough to survive in the room.

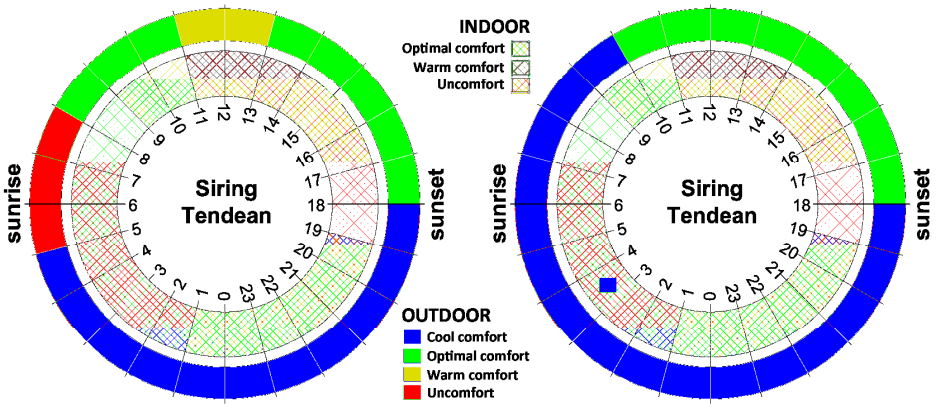

Figure 10.Time and duration thermal comfort conditions in Siring Tendean (a) indoor and outdoor in Menara and Anno (b) indoor Menara-Anno and open space/floating market

Outdoor thermal comfort in Sasirangan village, is shown in Figure11. At daytime, the outdoor thermal comfort at floating houses and settlement houses there is a difference, the conditions in around the floating house, more comfortable. Effective temperature out of comfort zone in the morning is average from 5 AM-8AM.After the morning, the effective temperature is optimal comfort, warm comfort and cold comfort.As described earlier, the indoor effective temperature in floating housesis very high at noon.

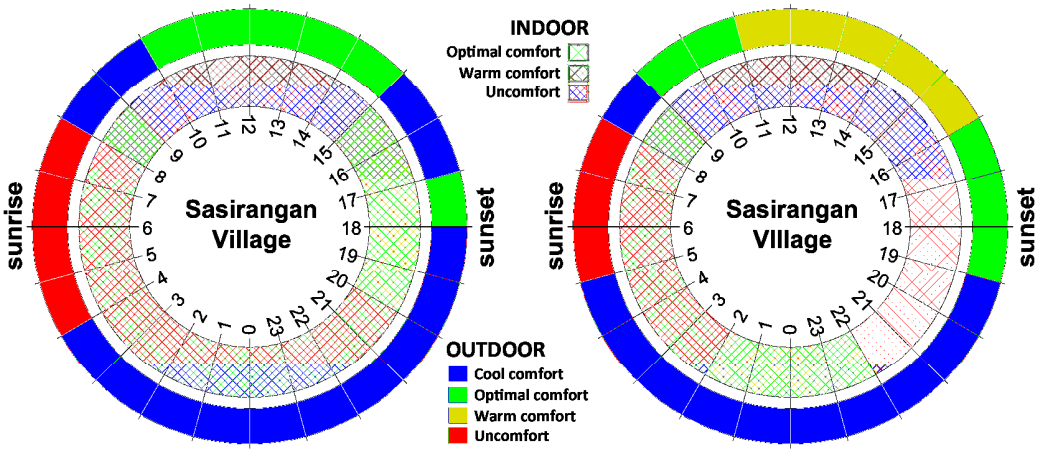

Figure 11.Time and duration thermal comfort conditions in Sasirangan village (a) indoor and outdoor in Floating Houses (b) indoor in settlement houses

Durationuncomfort conditions of hours 10 AM – 3 PM or 6 hours and the indoorsettlement housesin Sasirangan village from 9 AM - 10PM or 13 hours. In comparison, floating houses shorter duration in uncomfort.Despite the extremely high temperatures during the day, floating houses quicker off the heat. It is also caused by environmental factors around the river which has a lower effective temperature.

The thermal condition in Bilu village, is shown in Figure12. At daytime, the outdoor thermal comfortin the settlement houses more comfortable than houses aside pedestrian ways. Outdoor

effective temperature in house aside pedestrian ways, very low in the morning. This is indicated by the length outside the comfort zone, from 2AM - 7 AM or 5 hours.The indoor conditions, uncomfort duration in houses aside pedestrian ways isfrom10 AM – 19 PM or 9 hours,and the house in the settlementis from 12 AM – 17 PM or 5 hours.

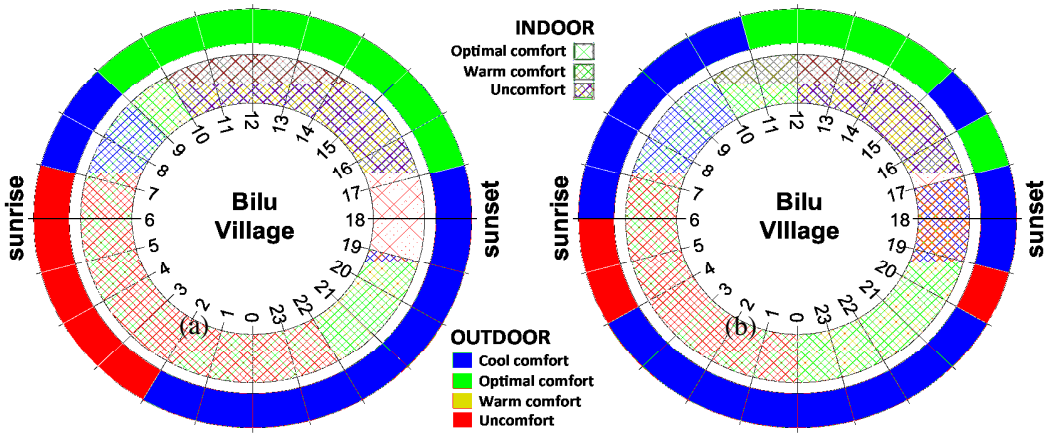

Figure 12.Time and duration thermal comfort conditions in Bilu village (a) indoor and outdoor in Houses aside pedestrian ways (b) indoor in settlement houses

5. CONCLUSIONS

Thermal condition in floating house very high at the noon, especially indoor. But this condition is not a long time, and affect thermal comfort in floating houses.Inoutdoor conditions were good during the day occurred in the area open space in Siring Tendean.The area around the river has a relatively low temperature and high relative humidity. It happened in the morning. The wind speed is higher during the day than at night.The average air velocity ranges from 1.56 m/s - 1.78 m/s. Effect of open space in Siring Tendean cause higher wind speeds than the other place.

Regression of thermal comfort of indoor and outdoor shows significant value, with coefficient of determination (R^2) between 0.5345-0.807. Range effective temperature of outdoor is greater than the range effective temperature indoor. The average effective temperature of outdoor is always in the comfort zoneof SNI 03-6572.Meanwhile, effective temperature of indoor has been always out of the comfort zone of the upper threshold.The average effective temperature ofindoor range shorter, except in floating houses and houses aside pedestrian ways.Most comfortable conditionsof outdoor environment is open space in Siring. More comfortable indoor conditions in floating houses, although the temperature is high enough during the day, but the inconvenience duration shorter than the other place.This could be due to the high humidity and the wind flow was pretty good, because the open area around the river.

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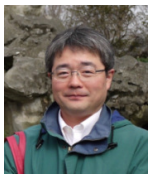
AUTHORS

Akbar Rahman : He is graduated of Architecture at the University of Lambung Mangkurat, Master of Architecture at the University of Diponegoro, with specialization Urban Design in the Tropics. Is currently completing a doctoral course in Department of Civil Engineering and Architecture at Saga University, Japan. And he is a member of Indonesian ArchitectsAssociation (IAI)



ShoichiKojima : He is a Professor, Department of Civil Engineering and Architecture at Saga University, Japan. He received PhD at Kyushu University, Japan. He is a member of the Architectural Institute of Japan (AIJ), and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). His research interests include indoor thermal environment and heating, ventilating and Air-Conditioning (HVAC).