Proceedings of 7th Windsor Conference: ***The changing context of comfort in an unpredictable world*** Cumberland Lodge, Windsor, UK, 12-15 April 2012. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Comfort Temperatures for the Low-Income Group in a Hot-Humid Climate

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Abstract

The results presented in this paper are part of the doctoral research that is being done at Delft University of Technology, Netherlands. One of the main objectives is to find the level of thermal comfort accepted by people from the low-income group in Surakarta, Indonesia. Personal aspects (gender and clothing index), characteristics of the dwelling (ventilation, orientation) and surrounding factors (effect of vegetation) were investigated to observe if they significantly influenced the people's responses. Furthermore, these findings will be used to improve the dwellings in the community. A field-survey was conducted in this research involving 426 people from four kampongs in Surakarta. The neutral temperature in this group is found at 32.5°C and the comfort bandwidth ranges from 30 to 35°C, which is shown by four methods of deriving thermal comfort. Various factors were shown to influence the indoor air temperatures and the thermal response of the people.

Keywords: Dwelling, Hot-humid climate, Low-income group, Thermal comfort

1. Introduction

Providing proper dwellings in Surakarta, which has a population of more than 550,000, is still a problem. Statistical data of Surakarta in 2006 showed that the amount of low-income households and improper dwellings is substantial. Approximately 17% of the population belongs to the low-income group, while around 34% of the population still live in the improper dwellings. Having a comfortable living environment is important to increase the productivity of the people as well as their sense of happiness. As a result, it will enhance their quality of life. Unfortunately, there is no adequate building code in Indonesia. This research, therefore, is aimed to finding an acceptable optimum level of thermal comfort for the low-income group of people in Surakarta in order to improve their dwelling conditions.

Previous research in the tropical region has presented some level of indoor air temperature as the comfort temperatures accepted by the people. Office-workers in Thailand who are accustomed to naturally-ventilated buildings accepted temperatures up to 31°C, which is different from those who are accustomed to air conditioned buildings and accepted 28°C as comfortable (Busch, 1992). In Indonesia, university students in Bandung voted 24.7°C as neutral temperature, while neutral temperature in Jakarta slightly higher at 27.2°C (Karyono, 2004). Research by Feriadi (2004) on households in Yogyakarta Indonesia reported slightly higher neutral temperatures of 29.2 or 29.9°C.

Occupants of the dwellings who come from the low-economic level might have a different comfort level than the population of middle to upper economic classes. A previous study in Hyderabad India by Indraganti (2009) found that the occupants/tenants of apartments owned by the low-economic class accepted temperature range 27.3-33.1°C and neutral temperature 30.2°C which are higher than the comfort band standard in India (23-26°C). The neutral temperature found in the low-economic group was about 2K higher than the higher class.

Thermal comfort depends on three different factors: physiological, behavioural, and psychological factors. In a warm climate, physiological adaptation to warm conditions takes places through vaso-dilatation, sweating and heat acclimatisation. Examples of behavioural adaptation are reducing activity, reducing the amount of clothing, finding a cooler place, opening windows and using a fan. Psychological adaptations is not defined definitively yet (Humphreys, 2009), but previous research confirmed that the human response to thermal comfort can be influenced by the following: 1) people will easier accept thermal comfort when they are doing a mild activity 2) people will provide a response to thermal comfort based on their thermal experience (Auliciems, 1981). These two conditions prevailed in the case studies in Surakarta: people perform miscellaneous occupational activities with metabolic rates from 0.7 to 3.4 Met Units; and they have been living in the neighbourhood for a long time span (average 18 years).

Other factors such as personal condition, dwelling characteristics, and the surrounding environment are investigated. The influence of gender has been studied by Ellis (1953) who reported that gender has no influence on thermal acceptance. On the other hand, Indraganti (2009) showed that women accepted higher temperatures compared to men. Research in the tropical regions mostly reported that people preferred to have a higher air velocity in their dwellings (Feriadi, 2004; Nicol, 2004). Evans (1980) recommended a north-south wall orientation to reduce heat gain, while heavy-weight construction is more preferred for protecting dwellings from the hot weather (Rahman, 1995; Sari, 2010).

2. Methodology

Surakarta is a city in Central Java which is located close to Yogyakarta. This research consisted of a case study in Surakarta, Indonesia involving four kampongs where most of the inappropriate dwellings belonging to the low-income groups of people located. These kampongs have bad living conditions and are characterized by a dense occupancy, relatively narrow dwelling areas, limited access to the infra-structure, and prone to frequently flooding, see Fig 1 and 2.

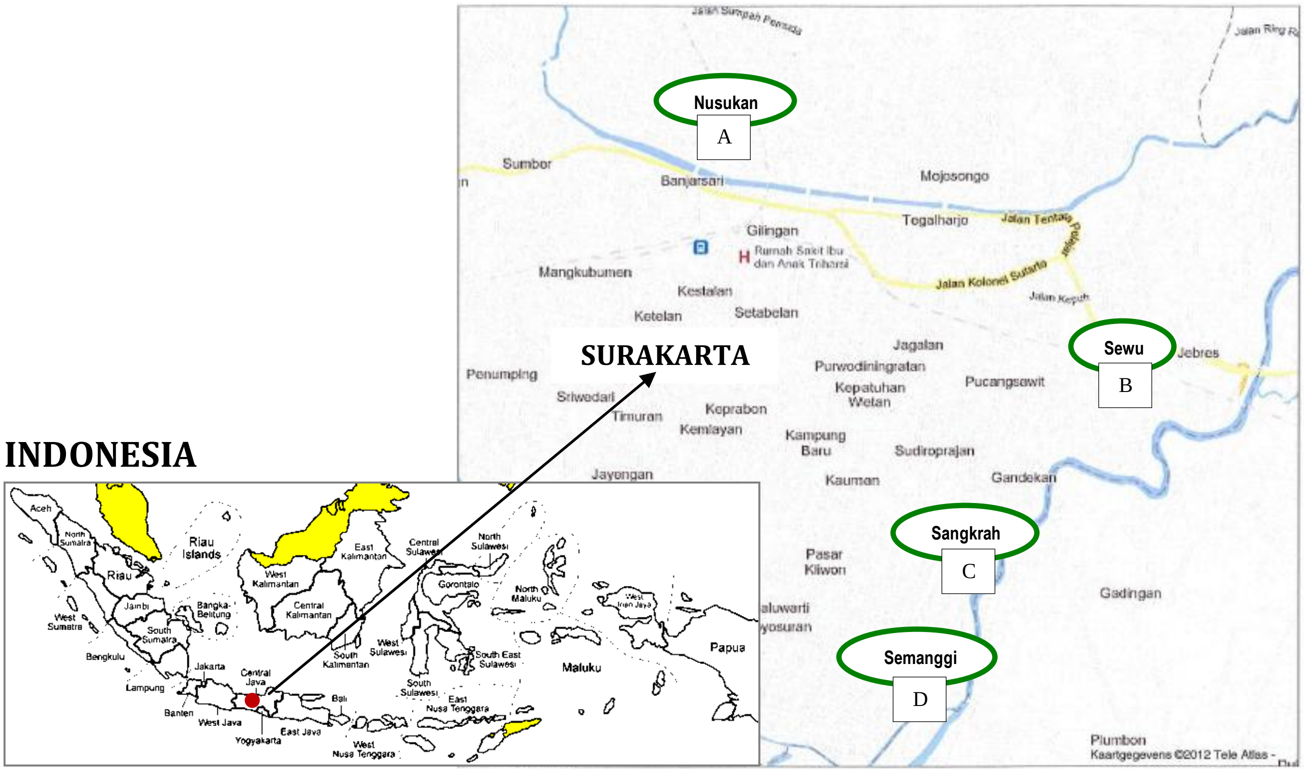

Fig 1. Location of the four kampongs surveyed in Surakarta, Central Java, Indonesia
(A=Kp Nusukan, B=Kp Sewu, C=Kp Sangkrah, D=Kp Semanggi)

Methods used in the survey are measurements of momentary thermal conditions (air temperature, radiant temperature, relative humidity and air velocity), followed by continuous thermal measurements (including indoor air temperature and relative humidity) for 24 hours, interviews/questionnaires about thermal sensation, comfort acceptance, thermal preference and thermal problem, as well as observations of the surrounding environment.

Measurements of momentary thermal conditions were done by using a digital thermometer and humidity meter (humidity and temperature meter CEM DT-615), air velocity meter (TSI Thermal Anemometer Model AVM410) and an additional black globe, put on the digital air thermometer to measure the radiant temperature inside and outside the dwellings.

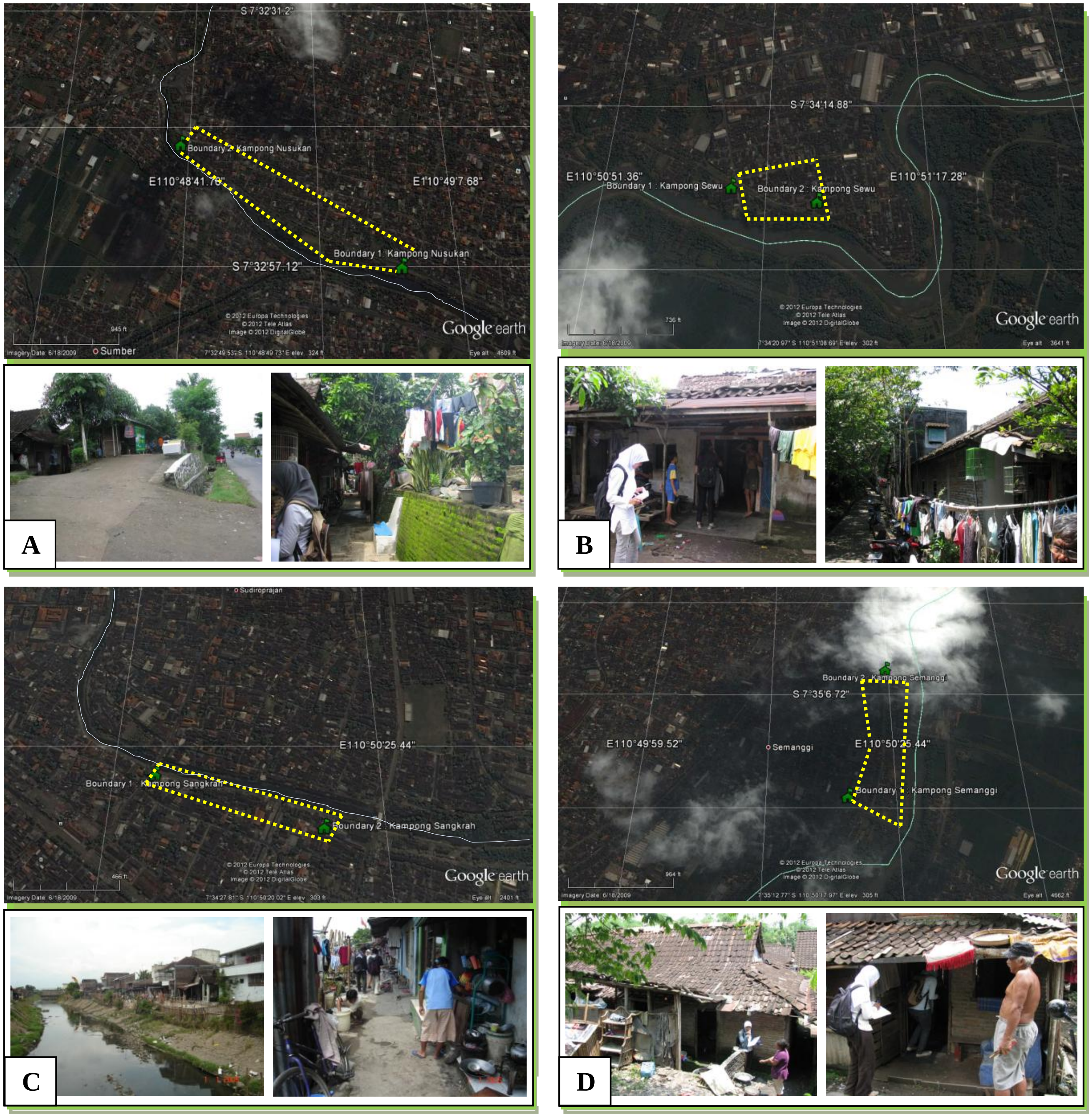

Fig 2. Situation in the four kampongs: Kampong Nusukan (A), Kampong Sewu (B), Kampong Sangkrah (C), Kampong Semanggi (D)

Momentary measurements were taken at relatively the hottest part of the day, between 09.00 to the 14.00 WIB. Residents were, at the same time, questioned about their acceptance of thermal comfort in their dwellings at that time (see Fig 3). While for the continuous measurements, Hobo data loggers (Hobo U12 Temperature / Relative Humidity / Light / External Data Logger - U12-012) were placed in some dwellings with different physical conditions (brick house, wooden house, bamboo houses, or combination material of brick and others) to measure the thermal conditions in the dwellings for 24 hours.

Fig 3. Thermal comfort momentary measurement and interview with the occupants

The questionnaires consisted of four parts:
1) the thermal vote on a seven point scale,
2) thermal acceptance, a direct question asked to people about their thermal feeling at the moment, covering 5 levels ranging from comfortable to intolerable,
3) thermal preference, a question about the momentary thermal environment (whether they want to have a warmer condition, if they want the thermal conditions to be not changed, or do they want to have a cooler thermal condition), and
4) thermal problems, the last question asked to people if the thermal condition at the time of measurement caused any problem in doing activities or not.

The local Javanese language and pictograms (see Fig 4) were used during the interview to help people understanding all these questions.

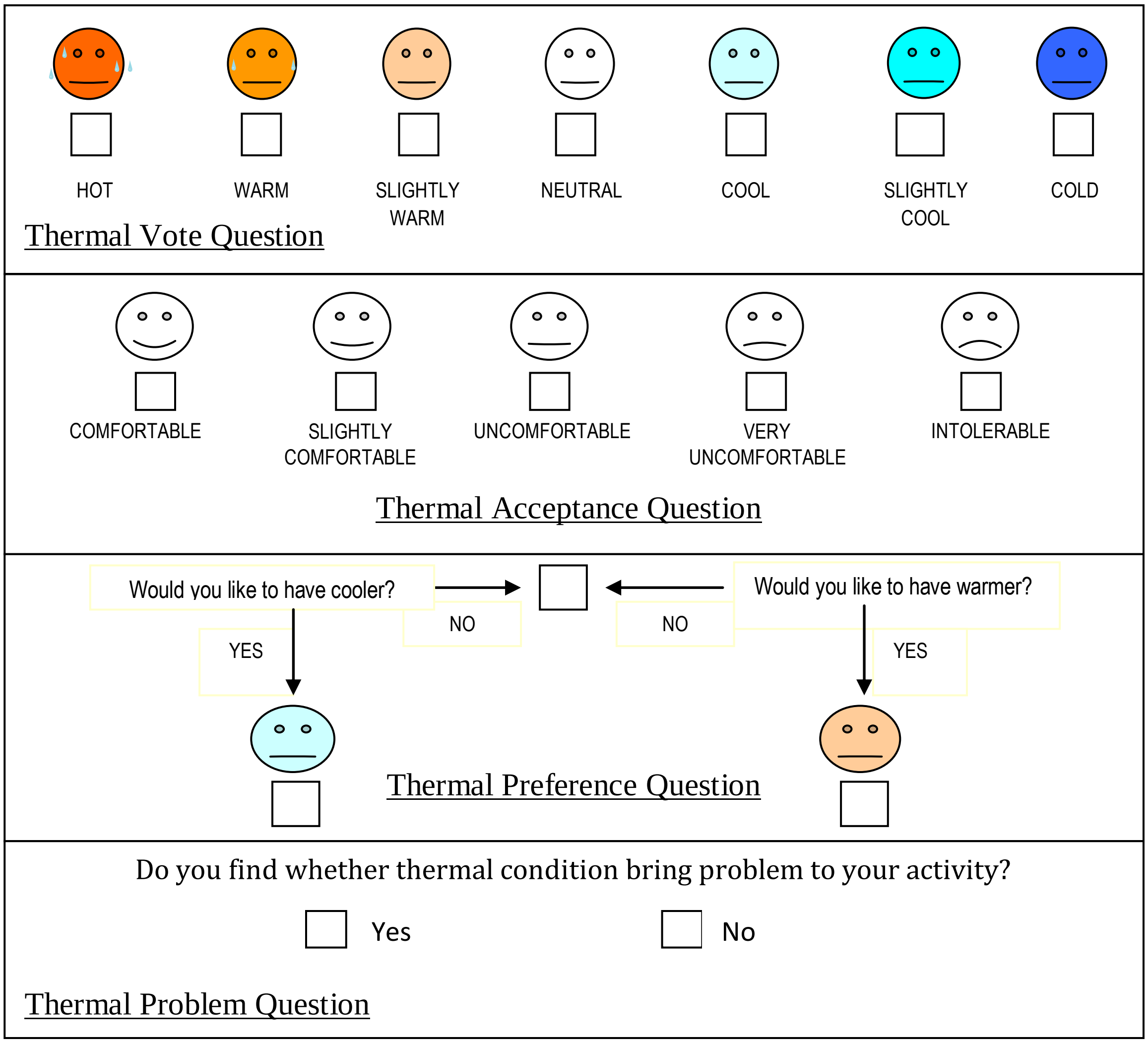

Fig 4. Images of the comfort questions addressed to people during the field-survey

In addition, observations were made of the amount of vegetation, the sufficiency of ventilation in the dwellings, the environment around the house, dwelling characteristics and occupant's personal adaptation to thermal conditions. Vegetation is noted and distinguished based on 5 categories: trees, grass, shrubs, plants in pots, as well as the presence or absence of a garden around the dwellings. The occupants' adaptation to the thermal condition was noted as moving out of the dwellings, dressing in thin clothes, drinking or using a fan. Each dwelling was recorded by a camera and a sketch, mainly to see the building materials, lay-out of the dwelling ventilation sufficiency and dwelling orientation.

3. Results and Discussion

A field-survey was done from 18 November to 29 December 2010. The weather was warm and sunny during the day, but each day it started to rain after 14.00 WIB (Waktu

Indonesia Barat). This survey involved 426 respondents from the four kampongs, 43% (185 respondents) from Kampong Semanggi, 32% (139 respondents) from Kampong Nusukan, 15% (64 respondents) from Kampong Sewu and 7% (38 respondents) from Kampong Sangkrah. Thermal measurement were done for 12 days in Kampong Semanggi (18 November to 04 December 2010), 6 days in Kampong Nusukan (10-21 December 2010), 3 days in Kampong Sewu (22-24 December 2010) and 3 days (01 December and 28-29 December 2010) in Kampong Sangkrah.

Table 1. Thermal environment measured during the field-survey

	Indoor				Outdoor			
	air temp (^{0}C)	rh (%)	radiant temp (^{0}C)	air velocity (m/s)	air temp (^{0}C)	rh (%)	radiant temp (^{0}C)	air velocity (m/s)
Min.	29.6	32.8	29.6	0.0	29.6	35.3	29.6	0.0
Max.	39.7	71.1	39.7	0.9	39.6	70.7	39.7	3.2
Average	33.1	54.6	33.1	0.1	33.1	53.2	33.1	0.6
Std. Deviation	1.6	6.6	1.6	0.1	1.6	6.6	1.6	0.4

It was found from the field-survey (see Table 1) that the measured indoor air temperatures in these naturally ventilated dwellings were always high with 10°C difference of the minimum and maximum. Whereas the outdoor air temperatures were almost the same as the indoor. There are no differences between air temperature and radiant/globe temperature during the measurements. The indoor and outdoor relative humidity measured was varied from approximately 30 to 70% (the relative humidity during the night and early morning can be higher). The air velocity recorded during the field-survey was very low both indoor and outdoor (0.1 m/s in average).

3.1. Comfort Assessments

The comfort assessment consists of four questions about momentary thermal perception. The first question investigated the thermal sensation on a 7 point ASHRAE-scale: -3, -2, -1, 0, +1, +2 and +3 (cold, cool, slightly cool, neutral, slightly warm, warm, and hot).

The thermal sensation in considered to be "comfortable" when people vote -1 (slightly cool), 0 (neutral), or +1 (slightly warm). The -2 and -3 votes were grouped as “cool” while the +2 and +3 votes are grouped as a “hot". From 413 respondents who answered this question, 149 people (35%) voted for a comfortable temperature (120 voted “neutral”, 7 “slightly cool”, and 22 persons voted “slightly warm”, see Table 2). More people voted for "hot" (188 respondents voted “hot” and 24 people voted “warm”), while the rest voted for "cool" (51 people voted “cool” and only one person voted “cold”).

Table 2. Distribution of thermal votes during the field-survey

Thermal Vote Categories			Cases		
			N	Percentage	
-3	cool	Cold	1	0%	13%
-2		Cool	51	12%	
-1	comfortable	Slightly cool	7	2%	36%
0		Neutral	120	29%	
+1		Slightly warm	22	5%	
+2	hot	Warm	24	6%	51%
+3		Hot	188	46%	
		Total	413	100%	100%

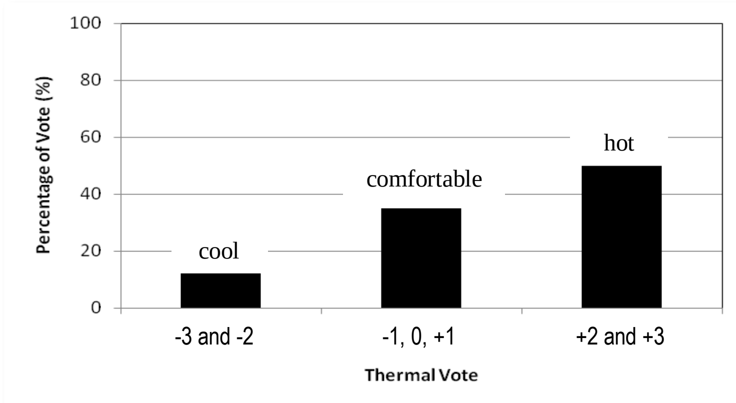

Fig 5. Thermal vote percentage

Fig 5 illustrates the distribution of the votes over the groups. Most of the respondents felt that thermal environment was "hot"; one third of them considered the temperature to be "comfortable", while only a few stated that the thermal condition was "cool". Distribution of these thermal votes over the four kampongs is presented in Table 3 below.

Table 3. Percentage of thermal vote in the four kampongs

kampongs	Seven-point-scales of Thermal Vote							Total
	-3	-2	-1	0	+1	+2	+3	
Semanggi	0 0%	4 2%	3 2%	34 19%	18 10%	12 7%	111 61%	182 100%
Nusukan	1 1%	31 23%	4 3%	45 33%	3 2.2%	11 8%	43 31%	138 100%
Sewu	0 0%	14 22%	0 0%	33 52%	0 0%	1 2%	16 25%	64 100%
Sangkrah	0 0%	5 13%	0 0%	14 37%	1 3%	0 0%	18 47%	38 100%
Total	1 0%	54 13%	7 2%	126 30%	22 5%	24 6%	188 45%	422 100%

Fig 6 shows the distribution of all mean votes over the range of indoor temperatures. It is shown in the graph that respondents voted "comfortable" in the range of slightly below 30 to slightly over 35°C. People voted for warm when the indoor air temperature was from 31.5°C until slightly over 35°C; while beyond this temperature people voted that thermal environment was hot. There are fewer cases of votes for cool and cold.

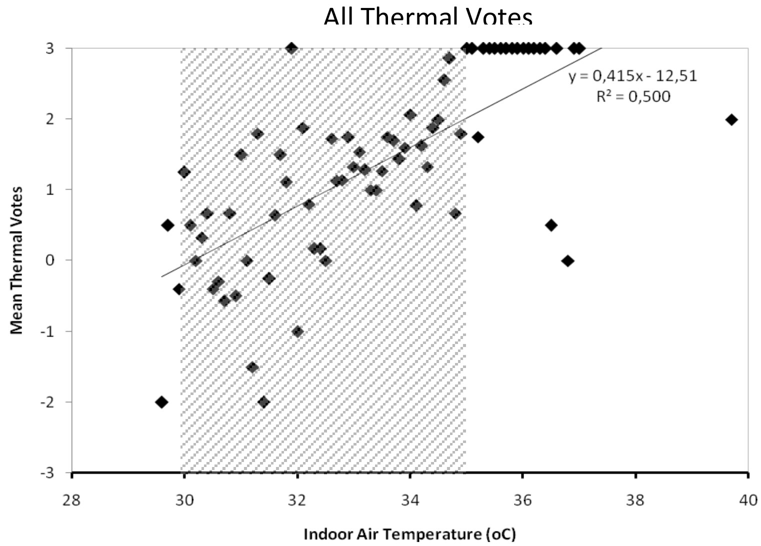

Fig 6. Distribution of the mean votes as a function of the indoor air temperature (the shaded-box includes the majority of the votes for a "comfortable" temperature)

Linear regression of the question about thermal sensation is presented in Fig 7 below. The indoor air temperature is very close to the outdoor air temperature (R square = 0.97). This shows that the building envelope does not sufficiently protect the dwellings from the hot climate. The temperature difference between the indoor and outdoor temperature is very little (maximum 0.7°C). In some dwellings the indoor air temperature is even higher than the outdoor temperature, up to 1.5°C.

The different vote categories shown in Fig 7 and 8 illustrate that at the lower temperatures people voted for “cool”, and as the temperature increased people voted for “comfortable” and then “hot”. These two graphs again show that people vote “comfortable” when the indoor temperature is between 30 and 35°C.

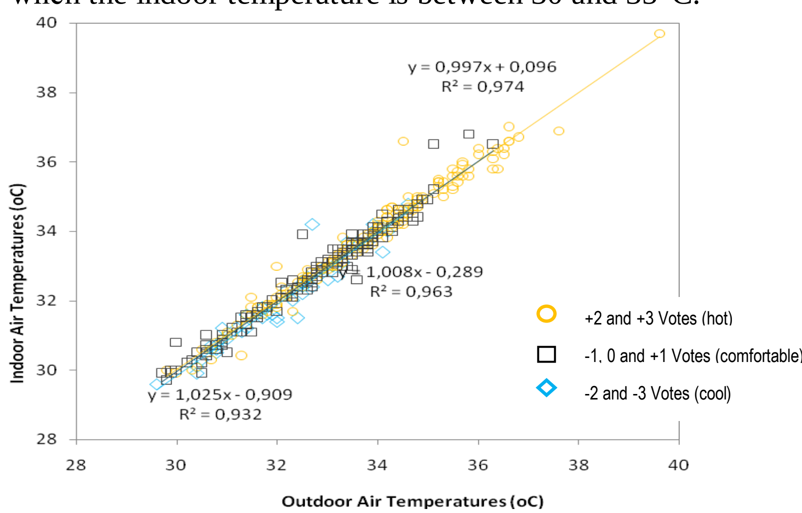

Fig 7. Linear regression of the indoor and outdoor air temperature

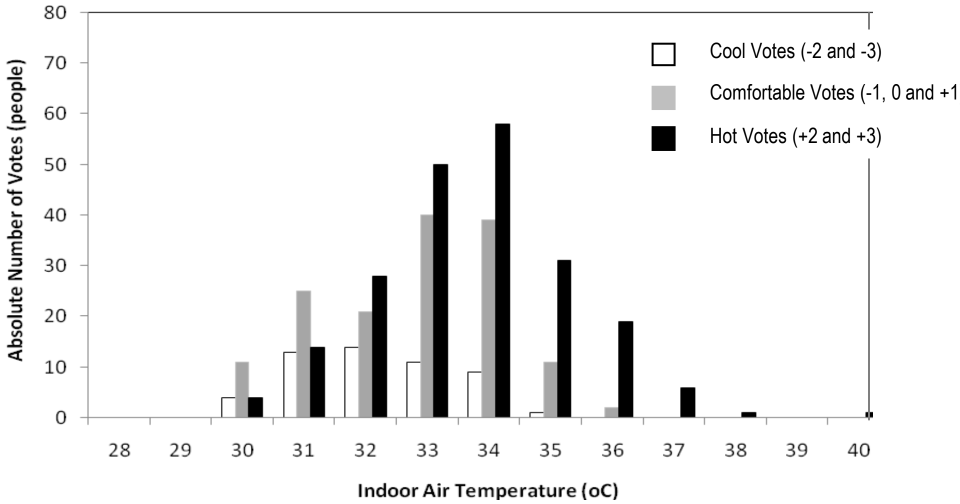

Fig 8. Number of votes for the three categories (cool, comfortable, hot)

Climate Data of Surakarta (coordinate 07° 37' 48" LS and 110º 56' 51" BT, height 170 m from the sea surface) in November - December 2010 is obtained from the Climate Station Office in Semarang, Central Java. The recorded air temperature data is shown in Table 4.

Table 4. Temperature of Surakarta during the field-survey

November 2010	December 2010
Minimum = 23.0°C	Minimum = 24.0°C
Maximum = 31.2°C	Maximum = 32.2°C
Average = 27.1°C	Average = 28.1°C

The neutral temperature (T_{comf}) can be estimated from the people who voted 'neutral' (C=0) and the globe temperature (T_g) measured with the equation as below:

$$T_{comf} = T_g - C/G \qquad \text{(Eq. 1)}$$

Because the globe temperature (T_g) or the radiant temperature are the same in almost all measurement, the equation for this research used the indoor air temperature. Griffiths suggested a single standard value for the linear regression coefficient between comfort vote and the operative temperature (measured temperature). The error in the predictor variable and some adaptation error which may occur is anticipated by assuming that the actual value of the Griffiths constant (=G) greater than 0.4, so that Griffiths constant is chosen at 0.5 (Nicol, 2010).

The mean neutral temperature found in this group is 32.5°C. It is higher than the neutral temperature found in other cities in Asia such as Bandung (24.7°C Ta), Jakarta (27.2°C Ta), Yogyakarta (29.2 or 29.9°C), Hyderabad (30.2°C), and 31°C in Bangkok (Karyono 2004, Feriadi 2004, Indraganti 2009, Busch 1992).

Humphreys previously showed that the neutral temperature related more closely to the monthly mean (the average of the monthly mean maximum and the monthly mean minimum) outdoor temperature than to the minimum or maximum. The running mean outdoor temperature (Trm) for a series of days is calculated by using the mean temperature (*T*od) for the last 7 days ($\alpha = 0.8$) with the following equation (Nicol, 2010):

$$T_{rm} = (T(od\text{-}1)+0.8T(od\text{-}2)+0.6T(od\text{-}3)+0.5T(od\text{-}4)+0.4T(od\text{-}5)+0.3T(od\text{-}6)+0.2T(od\text{-}7))/3.8 \quad \text{(Eq. 2)}$$

T(od-1) etc. are the 24-h daily mean temperatures for yesterday, the day before and so forth.

The linear regression of the running mean outdoor temperature and the indoor air temperature shows a relationship between the increasing running mean outdoor temperature and the comfort temperature in the dwellings (Sig.value = 0.008). It is shown in Fig 9 that the comfort votes of people slightly increase when the running mean outdoor temperature increases. The regression line is much lower compared to Nicol and Humphreys' graph (2010) of the free-running office buildings in France, Greece, Portugal, Sweden, and the UK. The absolute values are somewhat higher, yet accordingly to Nicol's linear regression (see Fig 9). The differences might be caused by the different types of buildings, climate regions, seasons, and adaptation possibility of the respondents.

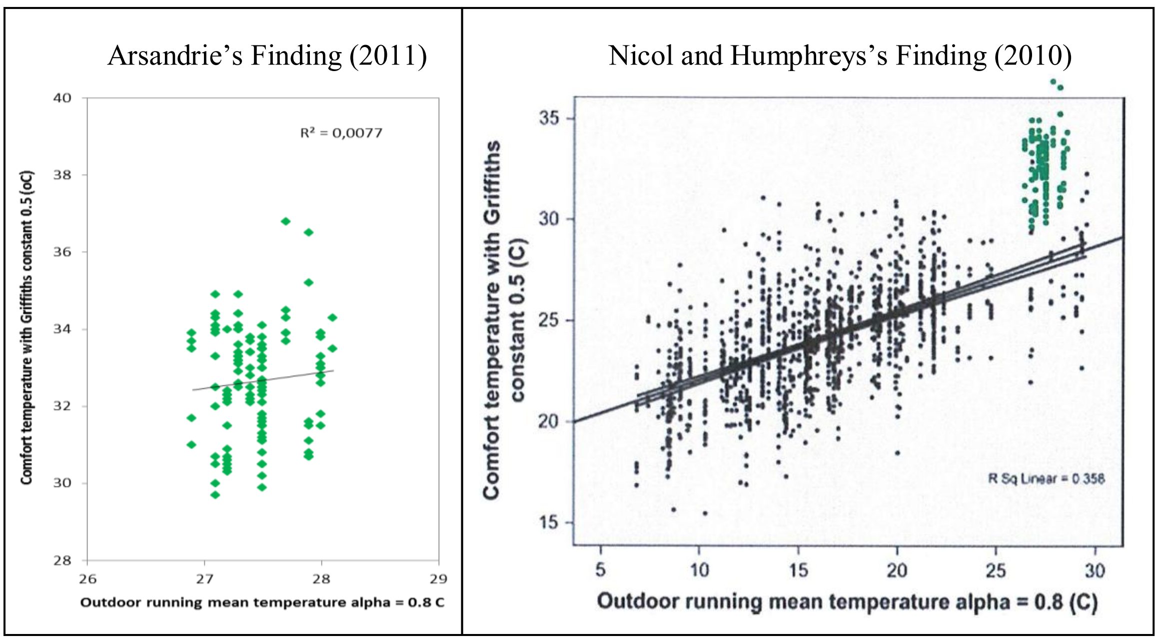

Fig 9. Scattered plot of neutral temperature (G=0.5) against outdoor running mean temperature (alpha=0.8). The green dots are the place of this research among the previous research

The second assessment of thermal comfort is a direct question about the thermal comfort sensation using a 5-point scale: 1-comfortable, 2-slightly comfortable, 3- uncomfortable, 4-very uncomfortable, and 5-intolerable. People were considered to be thermally comfortable when they vote for comfortable (1) or slightly comfortable (2).

Table 5. Percentage of direct question about thermal comfort

Scale		Frequency	Percentage (%)	Total
1	comfortable	183	43	55%
2	slightly comfortable	50	12	
3	uncomfortable	157	37	45%
4	very uncomfortable	31	7	
5	intolerable	1	1	
	Total	422	100	100%

Table 5 shows that more than half (55%) of the respondents accepted their thermal environment (either comfortable or slightly comfortable), while 37% described the momentary thermal environment as uncomfortable and 8% declared the thermal environment as very uncomfortable or intolerable.

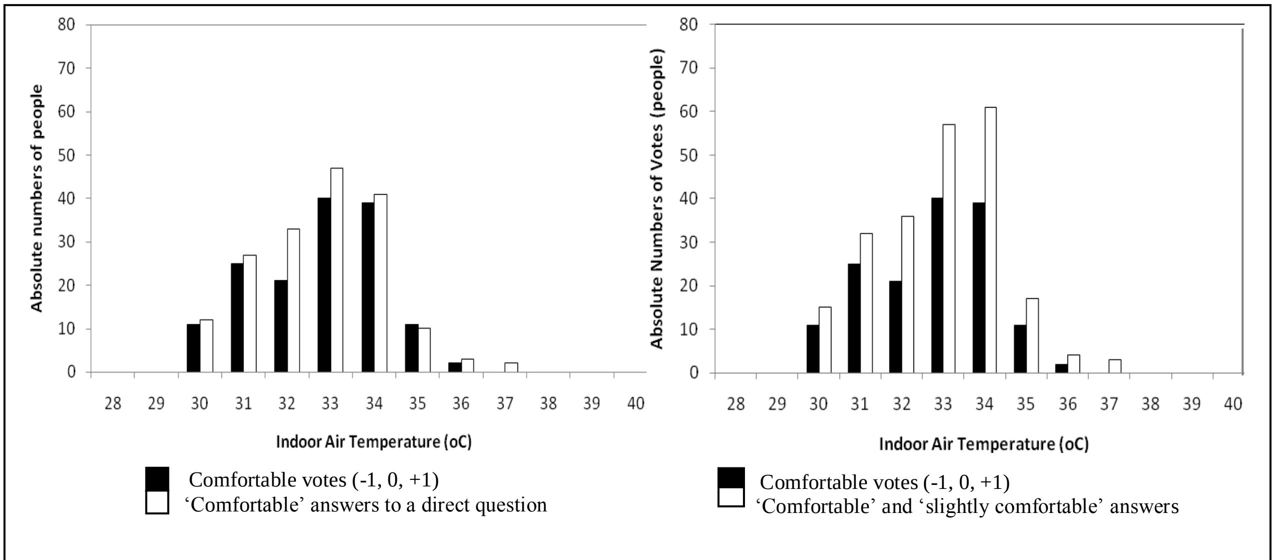

Fig 10. Comparison between thermal comfort inferred from thermal sensation votes (-1, 0, +1) and directly determined comfort (comfortable/slightly comfortable)

Fig 10 shows the directly determined thermal comfort compared to the thermal votes. The graphs above illustrate that slightly more people experience comfort when asked about comfort directly than when the thermal comfort is derived from the thermal sensation votes (left part of Fig 10). If the category "slightly comfortable" is included in the graph (right part of Fig 10) even more people stated for comfortable when they were directly asked about thermal comfort.

The direct answer on thermal comfort between differences kampongs is shown in Table 6. The highest number of people answered the thermal environment as comfortable is in Kampong Nusukan, followed by Sewu, Semanggi, and Sangkrah.

Table 6. Percentage of thermal comfort (direct question) in the four kampongs

	5 categories of direct question on thermal comfort					Total
	1	2	3	4	5	
Semanggi	42 23%	38 21%	79 43%	22 12%	1 1%	182 100%
Nusukan	69 50%	11 8%	49 36%	9 7%	0 0%	138 100%
Sewu	49 77%	0 0%	15 23%	0 0%	0 0%	64 100%
Sangkrah	23 61%	1 3%	14 37%	0 0%	0 0%	38 100%
Total	183 43%	50 12%	157 37%	31 7%	1 0%	422 100%

1=comfortable, 2=slightly comfortable, 3=uncomfortable, 4=very uncomfortable, 5=intolerable

The third question was about thermal preference. Respondents were asked to choose from the three scales of thermal preference: whether they want to have it warmer, cooler, or no change of the momentary thermal environment. The distribution of these answers is presented in Table 7 and 8.

Table 7. Distribution of thermal preference in the field-survey

Thermal Preference	frequencies	percentage
want to have cooler	175	53%
want no change	148	44%
want to have warmer	10	3%
Total	333	100%

Table 8. Distribution of thermal preference in the four kampongs

	thermal preference scale			Total
	want cooler	want no change	want warmer	
Semanggi	123 82%	26 17%	1 1%	150 100%
Nusukan	31 29%	68 64%	7 7%	106 100%
Sewu	9 14%	53 83%	2 3%	64 100%
Sangkrah	12 92%	1 8%	0 0%	13 100%
Total	175 53%	148 44%	10 3%	333 100%

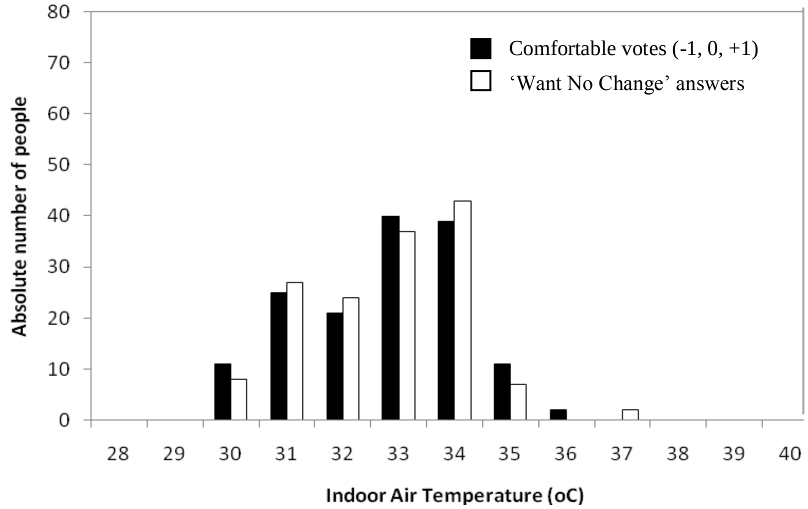

Fig 11. Comparison between comfortable votes (-1, 0, +1) and number of people who stated that they wanted 'no change' of the thermal environment

The number of people who wanted 'no change' to their thermal environment shows a similar range to the number of people who votes a comfortable temperature (see Fig 11). This graph shows a compatibility with the comfort temperatures as a range between 30 and 35°C is also acceptable from this third question on thermal preference. This finding presents the same trend that people want to have cooler temperatures when they experience temperatures over 35°C.

The last question was about the relationship between the thermal environment and experienced problem in activities. Respondents were asked to answer whether the momentary thermal environment caused problems to their activities or not. People had to answer one of two options: 'yes/1' when they experienced difficulties performing their activities due to the thermal condition or 'no/0' when the thermal condition caused no problem to their activities. As many as 260 respondents (63%) answered that the thermal environment caused no problem with their activities; while the rest (153 respondents) experienced difficulties performing their activities due to the momentary thermal condition (see Table 9 and 10).

Table 9. Distribution of all answers to the question about experienced thermal problems

Answer :	Frequency	Percentage
No	266	63%
Yes	156	37%
Total	422	100%

Table 10. Percentage of experienced thermal problems in the four kampongs

	Does the thermal environment cause problem with your activity?		Total
	No	Yes	
Semanggi	99 54%	86 47%	185 100%
Nusukan	91 67%	44 33%	135 100%
Sewu	55 86%	9 14%	64 100%
Sangkrah	21 55%	17 45%	38 100%
Total	266 63%	156 37%	422 100%

Non-parametric SPSS analysis Mann-Whitney Test to two independent variables (thermal problem and indoor air temperature) shows that there is a significant relationship between them (Asymp. sig=0.012). More people experienced problems when the indoor air temperature increased.

Fig 12 shows the comparison between the number of people who voted for a comfortable (-1, 0, +1) temperature and the number of people who said that thermal condition during the measurement caused no problem with their activities. As can be seen in Fig 12, more people have no problem in the range of indoor temperature when they vote "comfortable".

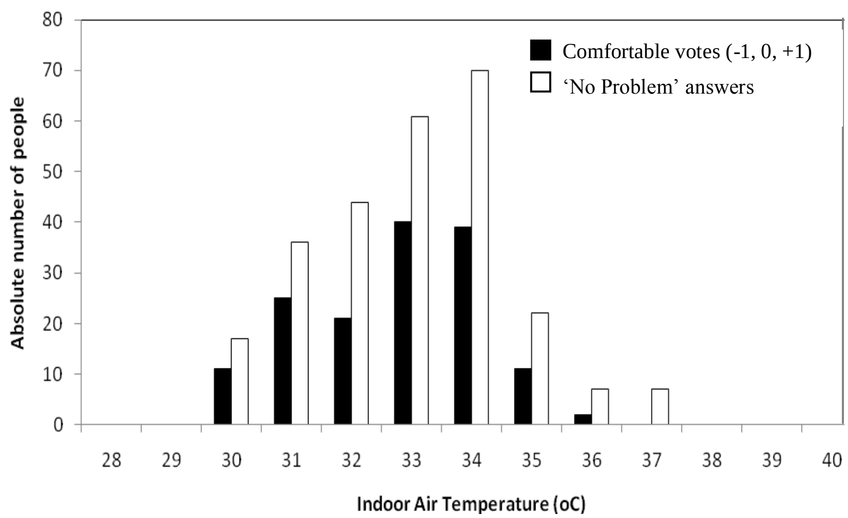

Fig 12. Comparison between comfort votes (-1, 0, and +1) and people who stated that they felt no problem with the momentary indoor air temperature

Results from the subjective thermal comfort questions conducted in this field-survey strongly recommend a bandwidth of indoor air temperatures between 30 and 35°C as acceptable by the people in this community, although 33 - 34°C is more preferred as around 40% of the responses fall in this bandwidth. More people in this community stated that the thermal environment caused no problem to their activities, which is a similar result as the acceptance of people to a 'slightly comfortable' (see Fig 10 and 12). The thermal comfort vote (slightly cool, neutral, slightly warm), 'comfortable' thermal acceptance and 'want no change' preference of the thermal environment have shown the same trends (see Fig 13).

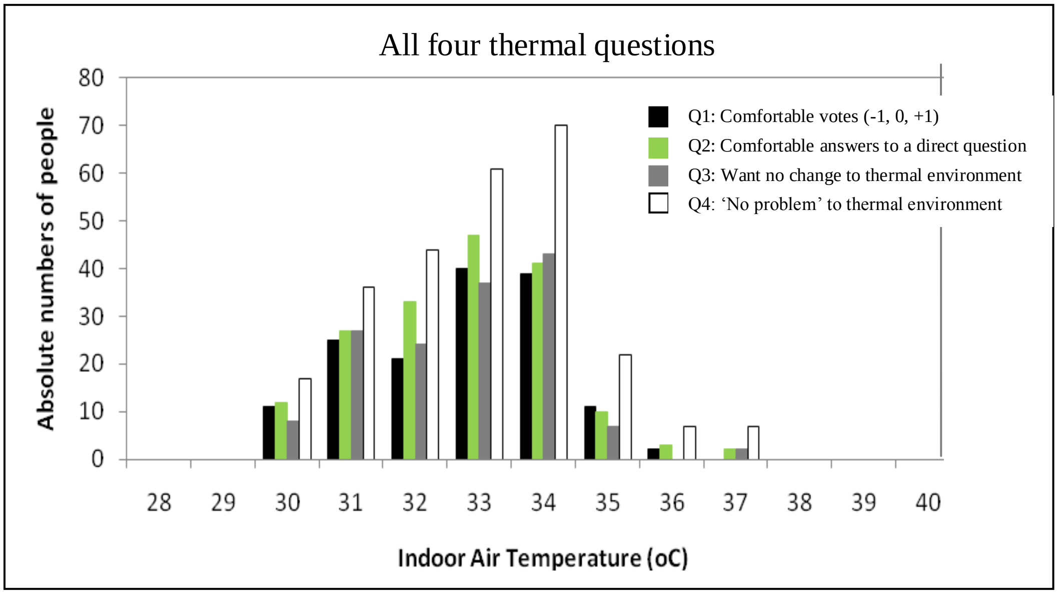

Fig 13. Comparison of the four comfortable answers to thermal comfort

3.2. Influential Factors

Thermal environment and the people sensation of the thermal comfort at the moment are, according to literature (see introduction), shown to be influenced by the following factors: gender, clothing index, orientation of dwelling, ventilation and surrounding vegetation.

Gender

Under the circumstances where women and men have (extremely) different activities and a different time spent in the building, it is presumed that there is a significant influence of the men and women's response to thermal comfort. This field-survey has recorded that 33% (142 people) of the respondents were male and 67% were female. Almost all of the women, mostly housewives, are working at home, while most of the men work outside home (see Table 11).

Table 11. Distribution of male and female respondents in the four kampongs

	Male	Female	Total
Semanggi	55 30%	130 70%	185 100%
Nusukan	61 44%	78 56%	139 100%
Sewu	14 22%	50 78%	64 100%
Sangkrah	12 32%	26 68%	38 100%
Total	142 33%	284 67%	426 100%

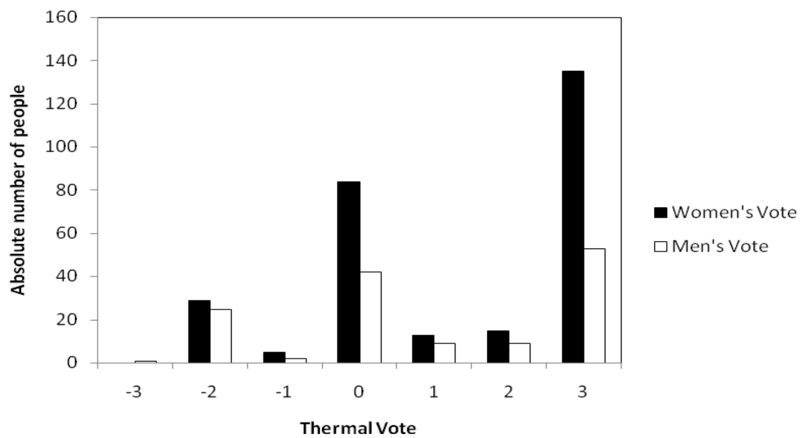

Fig 14. Number of votes between different genders

Nonparametric Test of two unrelated independent samples with Mann-Whitney Test shows the value of Asymp.sig = 0.24 which means that there is a relationship between gender and thermal vote (see Fig 14). However, a significant relationship is not found between gender and the other thermal assessments (thermal acceptance, thermal preference, and thermal problem). It can be concluded that women tend to have more complaints about the thermal environment which is shown by their votes to the thermal comfort.

Clothing Index

The clothing index of the occupants in the four kampongs surveyed varied from 0.18 to 0.81 clo, with the average clothing index being 0.35 clo, see Table 12 and 13 below.

Table 12. Clothing index worn by men and women during the field-survey

	Clothing Index (clo)	
	Male	Female
Min.	0.18	0.21
Max.	0.55	0.81
Average	0.36	0.34
Standard Deviation	0.08	0.10
Numbers of people	137 (32.9%)	279 (67.1%)

Table 13. Clothing index worn by men and women in the four kampongs

	Clothing Index (clo)		
	Min.	Max.	Average
Semanggi	0.18	0.81	0.35
Nusukan	0.20	0.55	0.35
Sewu	0.24	0.55	0.36
Sangkrah	0.24	0.55	0.34

Most women wear a light dress (clothing index of 0.27 clo) to avoid high insulation of their bodies. These dresses are the common daily home dress of nearly all women in the country. Women wear slightly more clothes than men for cultural and religious reasons while men have more flexibility to adapt their clothing (see Fig 15 and 16).

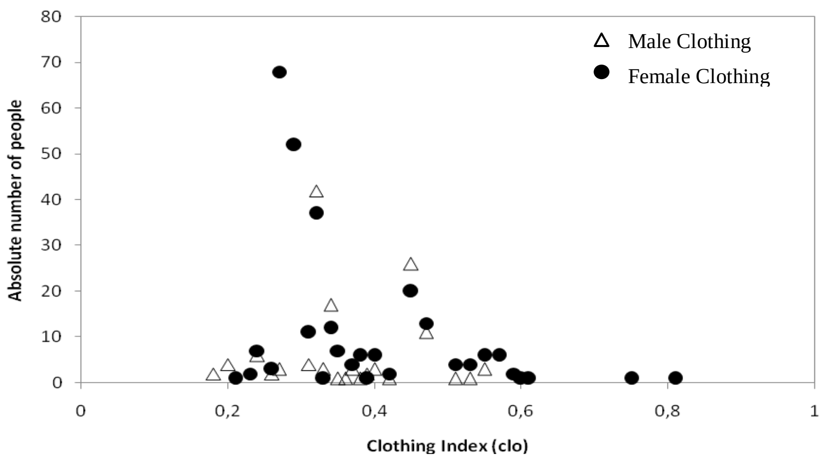

Fig 15. Clothing index (clo) between males and females

Fig 16. Different clothing of men and women worn during the field-survey

Non parametric statistic with Kruskal-Wallis test shows that there is a relationship between clothing index and the response of people to the thermal vote (Asymp. sig=0.018). The graph corresponds well with the findings from the previous research (de Dear, 1997; Humphreys, 2007).

Ventilation

Ventilation in the dwellings is distinguished into two categories based on the sufficiency of the ventilation. The first category, where there is only one door in the dwellings, is called 'less' (ventilation), and the second category is called 'sufficient' and is defined when there is not only one door, but there are two doors or a door and window(s) as well as some other small openings. The differences of ventilation between kampongs are shown in Table 14 below.

Table 14. Percentage of dwellings' ventilation in the four kampongs

	Ventilation		Total
	less	sufficient	
Semanggi	102 55%	83 45%	185 100%
Nusukan	73 53%	66 48%	139 100%
Sewu	9 14%	55 86%	64 100%
Sangkrah	12 32%	26 68%	38 100%
Total	196 46%	230 54%	426 100%

Ventilation seems to have the most important effect on the thermal environment and thermal sensation in the dwellings. The non-parametric statistic Mann-Whitney Test for two independent variables shows that there is a significant relationship between ventilation and the indoor air temperature (Asymp.Sig=0.018). Dwellings which have sufficient ventilation have a lower indoor air temperature compared to the dwellings which have less ventilation (see Fig 17). When there is sufficient ventilation, the mean indoor air temperature will decrease about 0.4°C compared to the condition of less ventilation in the dwellings. There is, however, no significant relationship between the ventilation ratio and indoor relative humidity.

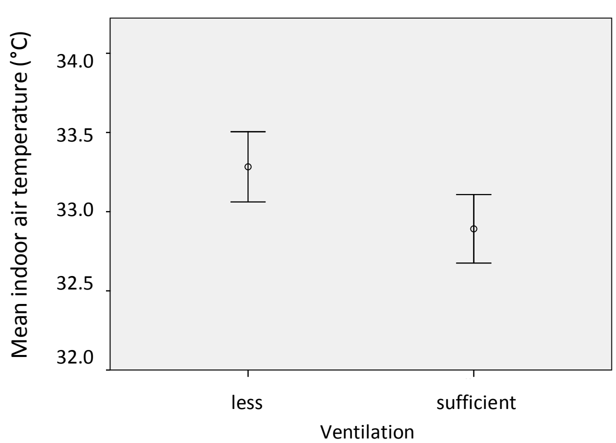

Fig 17. Relationship between ventilation and the indoor air temperature

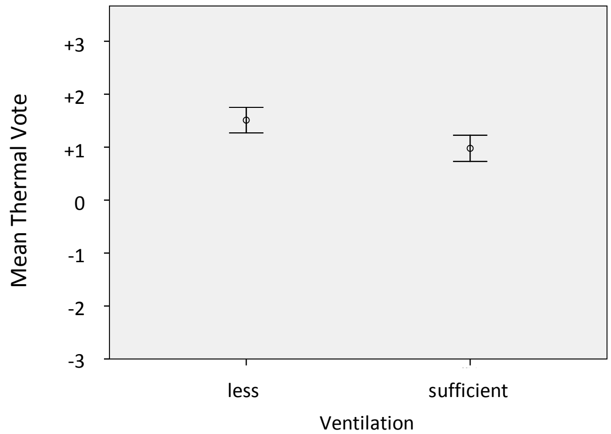

Fig 18. Relationship between ventilation and thermal vote

Mann-Whitney Test to the variables ventilation and thermal sensation show that there is a significant relationship between ventilation and thermal vote (Asymp.Sig=0.004). When dwellings have sufficient ventilation, people voted for slightly cooler thermal sensation (see Fig 18). The Mann-Whitney Test also shows that there is a significance between ventilation and thermal acceptance (Asymp.Sig=0.001) as well as the thermal preference (Asymp.Sig=0.003) and thermal problem (Asymp.Sig=0.013).

Orientation of the dwelling

Orientation is defined by the main entrance of the dwelling. Some dwellings have only one access (for examples in Kampong Nusukan and Sangkrah) because the dwellings are attached to each other. Dwellings in these two kampongs are set in a row which faces the north. Most of the dwellings in Kampong Sangkrah face the Pepe River while the ones in Kampong Nusukan have the view of Pepe River on the backside (see Fig 19). Almost every dwelling in Kampong Nusukan has a wide window in their kitchen which is facing the river. Dwellings in Kampong Semanggi and Sewu have two accesses (on the front and back/side) and they vary in orientation. Table 15 shows the dwelling orientation in the four kampongs.

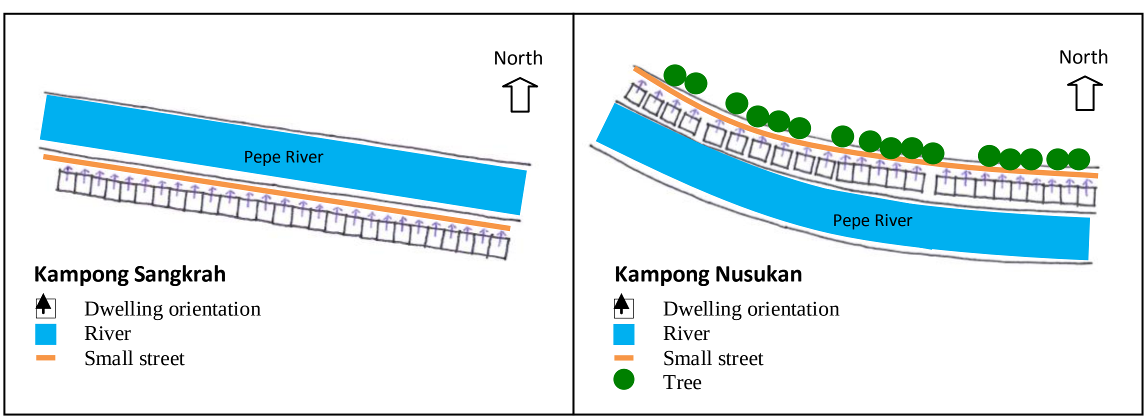

Fig 19. Orientation of dwellings in Kampong Sangkrah and Nusukan

Table 15. Frequencies of the dwellings' orientation in all kampongs

	orientation of dwelling				Total
	North	East	South	West	
Kampong Semanggi	45 24%	24 13%	68 37%	48 26%	185 100%
Kampong Nusukan	109 78%	18 13%	2 1%	10 7%	139 100%
Kampong Sewu	19 30%	4 6%	33 52%	8 13%	64 100%
Kampong Sangkrah	18 47%	10 26%	4 11%	6 16%	38 100%
Total	191 45%	56 13%	107 25%	72 17%	426 100%

The Kruskal-Wallis Test of non-parametric statistic shows that the orientation of dwelling relates significantly with the air temperature (Asymp. Sig=0.00), but not with the relative humidity and the air velocity. A north orientation gives the lowest indoor air temperature, followed by south, east, and west (see Fig 20).

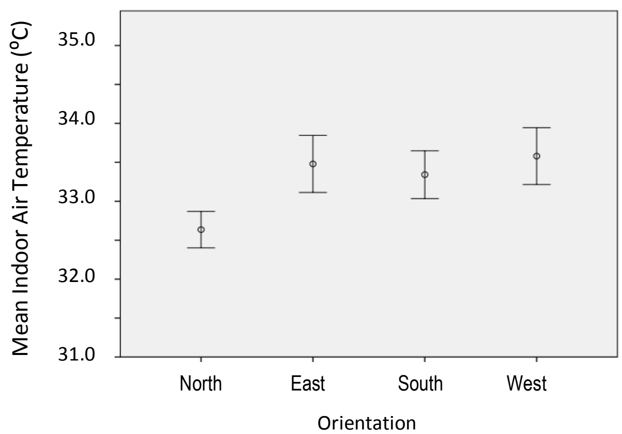

Fig 20. Relationship between dwelling orientation and the mean indoor air temperature

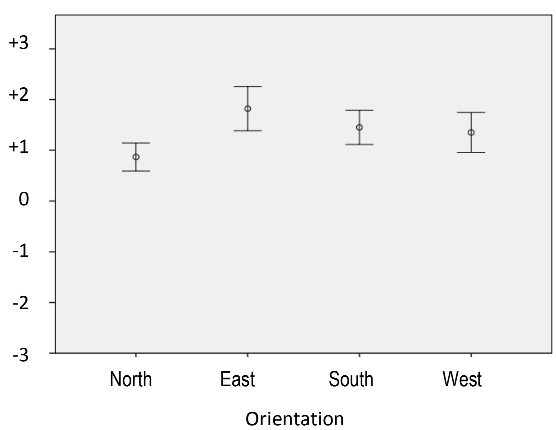

Fig 21. Relationship between dwelling orientation and thermal vote

The same test of the relationship between the orientation of the dwellings and the thermal assessment shows that there is a relationship between the dwelling orientation with thermal vote, thermal acceptance, and thermal problem (Asymp. sig value=0.01), but there is no relationship of orientation with thermal preference.

Respondents voted for neutral and slightly warm when the dwellings are facing north, while for the other orientation they voted a slightly warm to warm. From the statistical tests it can be concluded that the better dwelling orientation in the area is the north-south orientation compare to the east-west orientation. It corresponds to the dwelling orientation recommended for hot-humid climates in previous research (Evans, 1980).

The effect of trees

Green area recorded during the field-survey is categorized based on the type of vegetation and its ability to reduce heat in the nearby dwellings and to influence the air velocity outdoor and indoor (through shading, evaporation, reflecting or windbreaker effects). We made five vegetation categories: trees, shrubs, grass, plant in the pot, and the availability of a garden.

Some initial analysis to the influence of these five categories in combination (percentage of the combination in each dwelling) to the thermal environment and the thermal comfort responses showed no correlation between them. As an alternative, these five types of vegetation are simplified into two categories of “no tree” and “with tree/s” as “tree” is the most significant vegetation category which is applied to more than 50% dwellings in the four kampongs (see Table 16 and 17).

Table 16. Percentage of the five types of vegetation surrounding

	categories of vegetation				
	Tree	Shrubs	Grass	Plant in pot	Garden
Applied	61%	30%	18%	34%	13%
Not Applied	39%	70%	82%	66%	87%
Std. Deviation	0.5	0.5	0.4	0.5	0.3

Table 17. Trees and no tree in all kampongs

Kampong	with or without tree		Total
	tree/s	no tree	
Semanggi	111 60%	74 40%	185 100%
Nusukan	96 69%	43 31%	139 100%
Sewu	49 77%	15 23%	64 100%
Sangkrah	3 8%	35 92%	38 100%
Total	259 61%	167 39%	426 100%

Non-parametric statistics to the two independent variables of “tree” and “indoor air temperature” by using the Mann-Whitney Test shows that there is a significant relationship between these two variables (Asymp. sig=0.019). This test shows that if there are some surrounding trees, the indoor air temperature in the dwelling tends to be slightly lower (0.3°C) than when there are no surrounding trees (see Fig 22). The same test showed that there is no significant relationship between surrounding trees and indoor/outdoor relative humidity and air velocity.

Fig 22. Relationship between trees around a dwelling and the indoor air temperature

Mann-Whitney non-parametric statistics test of the surrounding trees and thermal assessment (thermal comfort vote, thermal acceptance, thermal preference, and thermal problem) shows that there is a significant relationship between the availability of the surrounding trees and the thermal assessment. When there are some surrounding trees, people tend to vote for a slightly cooler thermal sensation compared to when there are no trees (see Fig 23). The significance value is 0.001 (< 0.05).

The same statistic test shows that there is no significant relationship between trees and thermal acceptance but there is one in the relationship of trees and thermal preference (Asymp. sig=0.000) and thermal problem during activities (Asymp. sig=0.006).

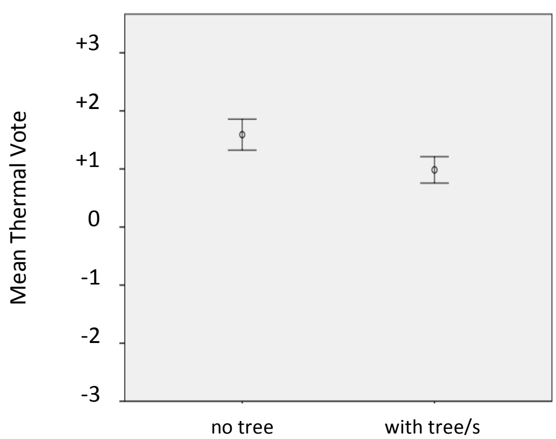

Fig 23. Relationship between trees and thermal vote

4. Conclusion

The mean neutral temperature found in this research is 32.5°C, which is higher than some other cities in Asia. Thermal comfort assessments in this research found a bandwidth of comfort temperatures between 30 and 35°C as acceptable by the people in this community. However, more people prefer to have a smaller range between 33 - 34°C. The distribution of comfortable thermal votes (slightly cool, neutral, slightly warm), 'comfortable' thermal acceptance and 'want no change' preference of the thermal environment has explained this finding. More people of the low-income community in Surakarta stated that the thermal environment caused no problem to their activities which corresponds to the acceptance of people to a "comfortable" and "slightly comfortable" thermal environment.

Research found that there is a significant influence of trees; when there are some surrounding trees the indoor air temperature in the dwellings tends to be slightly lower (0.3°C) than when there are none. The better dwelling orientation is the north-south orientation compared to the east-west orientation as far as the indoor air temperature is concerned. A third influence, the amount of ventilation has a significant influence on the indoor air temperature. When there is sufficient ventilation, the indoor air temperature is shown to decrease about 0.4°C. Ventilation also correlates well with the thermal sensation of the people. From the investigation of personal circumstances, it is found that people who voted "hot" were wearing fewer clothes than those who voted "cool". Women in this community show more complaints against thermal environment compared to men.

Those findings above, in combination with computer simulations, will be used to provide a guideline for dwelling improvement in Surakarta. More in depth investigation will also be conducted on the various factors which influence thermal comfort and thermal response of people.

Acknowledgment

The author is grateful for some alumni of Muhammadiyah University of Surakarta (UMS) Indonesia who helped during the field-surveys in 2009 and 2010. Gratefully acknowledged is the Delft University of Technology (TU Delft) Netherlands and DIKTI (Directorate of Indonesia Higher Education) for support. The people in the four kampongs are thanked for their participation in the field-survey.

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