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Assessments of Thermal Comfort and Indoor Air Quality in the Low-Income Dwellings

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Abstract: This study is a part of research about improvement of the dwellings which belong to the low-income people in Surakarta Indonesia. It focuses on the discussion about the proper method used to assess thermal comfort of the dwellings and the comfort feeling accepted by the occupants. Consideration is also emphasized on the indoor air quality and health of the people who live in the dwellings. This research is expected to provide a guidance of how to conduct a field-survey of thermal comfort and indoor air quality which can be used by the local government, stakeholders and other researchers in the development process. For this purpose, a pilot survey was conducted, including three steps, i.e., momentary measurements of the indoor/outdoor thermal environment, questionnaires/interviews about thermal sensation, indoor air quality, health and observations and checklist. The results of the pilot survey method were evaluated to be implemented in the final field survey which highlighted on the improvement of the measurement procedures (time planning, equipments, surveyors), interviews/questionnaires and the observation. As conclusions, the method of conducting field survey in the dwellings of the low-income groups must consider the efficiency of the procedures and accuracy of the measurement equipments. The background of the dwelling's occupants has to be considered as well. Meanwhile, communication with the low-income community must be facilitated using simple local language and supported by pictograms.

Key words: Dwellings, health, indoor air quality, low-income, thermal comfort

INTRODUCTION

Research conducted in the developing or poor countries should emphasize the most severe community as its priority. The development of a country sometimes cannot be enjoyed by the people who are living in poverty. When this situation remains, a gap between the poor and the rich groups will be larger which a potential to create problems. As in some other countries which have high population, this problem also occurs in Indonesia. Many people are still living in poor conditions, with a quality of life below standard, for example having a low-income, low education, limited access to the public facilities and infrastructure. This study describes the field-survey methods used to investigate the thermal comfort of the dwellings belong to the low-income people and the comfort feeling accepted by the occupants. Consideration is also emphasized on the indoor air quality and health of the people who live in the dwellings. The pilot survey method used in this research was conducted to find a proper method of the field survey including the measurement procedures (evaluation of the time planning, type of measurements, equipments used), the questionnaires/interview and the observation.

Information from the related departments and organizations (Local Government of Surakarta, Health Department, Environmental Department, WHO in Jakarta) was obtained to provide data of the people condition in the community. Population demography in Surakarta shows that the most low-income people (30%) are living in Kecamatan Pasar Kliwon, where also the most improper dwellings exist (40%) (Fig. 1). The Local Government of Surakarta informed that a financial support program is provided by the government to help the low-income people to improve their improper dwellings. This research is expected to provide a guidance of how to conduct a field-survey of thermal comfort and indoor air quality which can be used by the local government, stakeholders and other researchers in the development process.

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Table 1: Comparison of indoor environment in regulations and guidelines for environment

	Concentration level			Non-enforceable guidelines and reference levels			
Variables	NAAQS/EPA	OSHA	Max.	Canadian	WHO/Europe	NIOSH	ACGIH
CO_2		5000 ppm	5000 ppm 10,000 ppm (1 h)	3500 ppm (L)		5000 ppm 30,000 ppm (15 min)	5000 ppm 30000 ppm (15 min)
CO	9 ppm 35 ppm (1 h)	50 ppm	30 ppm 60 ppm (30 min)	11 ppm (8 h) 25 ppm (1 h)	90 ppm (15 min) 50 ppm (30 min) 25 ppm (1 h) 10 ppm (8 h)	35 ppm 200 ppm (C)	25 ppm
NO_2	0.05 ppm (1 year)	5 ppm (C)	5 ppm 10 ppm (5 min)	0.05 ppm 0.25 ppm (1 h)	0.1 ppm (1h) 0.02 ppm (1year)	1 ppm (15 min)	3 ppm 5 ppm (15 min)

Min = Minutes; h = Hours; Y = Year; C = Ceiling; L = Long-term; ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality

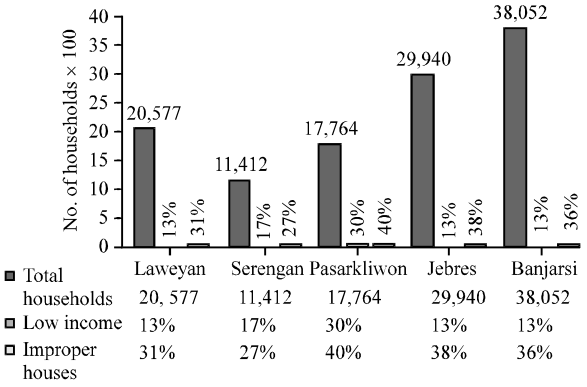

Fig. 1: Data of households and dwellings in Surakarta; households and low-income in Surakarta in 2006

Literature review: Thermal comfort research has been conducted since 1930s, either in a climate chamber or in real buildings, to investigate the level of acceptable thermal comfort of the people who are living under certain conditions. Recently, the field surveys to investigate the thermal comfort sensation without controlling the thermal circumstances developed into a lot of research. The ASHRAE scale of warmth sensation ranging from -3 (cold) to +3 (hot) is widely used, as well as a direct question of the thermal acceptance and thermal preference (Ellis, 1953; McIntyre, 1976; Nicol and Roaf, 2005; Humphreys *et al*., 2007). Assessments of the relationship between thermal condition and productivity of the people is observed as well. The dependency of these subjective assessments on the physiological, behavioral and psychological factors may cause the responses to these specific questions to be influenced by socio-economic, cultural and climatic experience expectations of the participants (Auliciems, 1981; Indraganti and Rao, 2010). Field surveys of thermal comfort which were conducted in different countries using different languages might create a discrepancy in meaning. Therefore, the translation has to be adjusted to the participant's language as good as possible to obtain the closest response as expected in the original language (Humphreys *et al*., 2007).

The low-income groups of people which are identical with slum, may have indoor air problems as well. For this reason, the investigation of the indoor air quality and health of the people who live in the investigated dwellings was conducted in this research. Unfortunately, previous research about this issue has not much been done in Indonesia where the number o f people who have low-income is significant. The literature demonstrate some examples from hot-humid countries such as in Kenya, Pakistan (Siddiqui *et al*., 2009), Hong Kong (Lee *et al*., 2002) and Guatemala (Naeher *et al*., 2000). Those examples in general agree that in tropical environments dampness in the dwellings, cooking activities and tobacco smokes are the main sources of indoor air problems which influence the health of the occupants. However, they found in the surveys that different locations may have different culture and cooking habits. In other words, the indoor air environment differs from place to place. The local context and environment plays important role on this.

The types of people activities in the low-income groups may trigger the indoor air pollutants/gaseous such as Nitrogen dioxides (NO_2), Carbon monoxide (CO) and Carbon dioxides (CO_2) from the cooking fuels and smoking. By referring to the data from PLEA (Passive and Low Energy Architecture) Table of Major Indoor Air Pollutants in the Dwellings (Table 1), possibly pollutants in Indonesia can be:

- Smoke from cooking and smoking activities
- Biological agents, from the wet or moisture of the walls

Carbon monoxide (CO) from kerosene fuels, leakage combustion, wood fuels, gas stoves, or tobacco smoke. The average concentration of CO indoor without gas stoves varies from 0.5-5 parts per mln. (ppm). The level of CO indoor closes to the gas stoves often reaches 5-15 ppm and it could reach 30 ppm or more if it is close to the stoves which are not well-set.

- Nitrogen dioxides (NO_2) from kerosene stoves, unprotected gas stoves or from tobacco smokes

- Respiration particles from kerosene stoves or tobacco smokes. WHO has concluded that even a very low level of particles in the air (10-20 μ gm^{-3} PM_{10}) is related to an increasing risk of public health
- Carbon dioxides (CO_2) from fossil-fuels, burning forest, human activities, volcanic ash, residue from respiration, dead plant/animals

MATERIALS AND METHODS

A pilot survey method: A pilot survey was conducted in the area where people live in a bad condition in Surakarta, a city located in Central Java Province, Indonesia (Fig. 2). The survey was done in April 2009 which involved as many as 64 people from two kampongs in Kecamatan Pasar Kliwon, i.e., Kampong Semanggi and Kampong Sangkrah. Most dwellers are poor and living in improper dwellings. They have average incomes <5000 rupiah (±50$) per month. As much as 75% participants gave these answers to the question about income. In the dwellings of the low-income people, there live the extended families as grandparents and relatives. Most of the men work as rough workers and women are housewives or working at home to get more income. These low-income dwellings are normally located in the area where the surrounding environment is bad, mostly close to the river where it often gets flooded, or in the area where they sometimes are subject to landslide. These kampongs had ever been attacked by big flood in December, 2007 and 2009 (BSDON., 2007). In the pilot survey, three steps are conducted as follows:

- Momentary measurements of the indoor/outdoor thermal environment
- Questionnaires/interviews of the thermal sensation, indoor air quality and health,
- Observations of the surrounding environment and checklist

Momentary measurements of the indoor/outdoor thermal environment: Thermal measurements were conducted to collect data related to indoor and outdoor thermal conditions at the moment. The survey was done for 7 day in April, 2009, mostly during the day time from 09.00 am to 02.00 pm WIB (West Indonesian Time), this being the most severe condition. Four measurements were taken at the evening to obtain the data at night. The weather conditions were varied from hot, sunny, or cloudy, without any rain.

Data of the air temperature and relative humidity were measured using a Lutron LM-81 HT humidity meter ranging from 10-95% Relative Humidity (RH) and 0-50°C air temperature. The air temperature, relative humidity and air velocity were measured using a 4 in 1 environment anemometer lutron LM-8000 which range from 0 to 50°C air temperature with 0.1°C resolution, 80% maximal RH and air velocity from 0.4-30.0 m sec^{-1} with 0.1 m sec^{-1} resolution (Fig. 3).

Fig. 2: Location of Surakarta, Central Java, Indonesia

Fig. 3: Equipments to measure thermal environment

OUTDOOR			WEATHER	INDOOR		
Ta (°C)	RH (%)	V (m/s)	Heavy rain Raining, Dark cloud, Sunny, Extremely hot, ……	Ta (°C)	RH (%)	V (m/s)

Fig. 4: Datasheet for measurement data

Respondent no: _____ Name: _____ Address: _____

Day/Date/Time	M / F	Age	Clothing	Footwear	Healthy/Unhealthy	How long have you living here

COMFORT VOTE							COMFORT SENSATION					PREFERENCE		
Hot (+3)	Warm (+2)	Slightly Warm (+1)	Neutral (0)	Slightly Cool (-1)	Cool (-2)	Cold (-3)	Intolerable	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Comfortable	Colder	No change	Warmer

Fig. 5: Questionnaires of the thermal sensation vote

Momentary measurements were taken both indoors and outdoors and the weather conditions were noted. All measurements results were written down in the form by the surveyors (Fig. 4). The pilot survey was assisted by 4 surveyors: 2 surveyors conducted the momentary measurements and interview; meanwhile 2 other surveyors documented the observations and checklist.

Questionnaires/interviews of the thermal sensation, indoor air quality and health: Beside measurements, the pilot-survey assessed the feeling of thermal sensation, the health status and the sanitary facilities people have in their dwellings. These were done by giving questionnaires and interviewing the people at the same time as the momentary measurements of the thermal environment. The questionnaires include some questions about thermal vote, thermal sensation and thermal preference using the 7-scale comfort vote, the 5-scale comfort sensation and the 3-McIntyre-Scale of thermal preference (Fig. 5).

The forms have to be translated into the national language to be understandable by the people. Surveyors have to understand the traditional/local language in case people do not understand the national language which is more formally used in Indonesia. It is because of the educational background of the people and their lack of experiences in filling the questionnaires. However, the friendly character of the people was obvious when the pilot survey was conducted. They looked enthusiast and willing to cooperate.

Observations and checklist: Observation and checklist were done to support the case study. Two surveyors filled the form of checklist and documented the

observation by sketches and pictures. Observation to the building's performance and the surrounding environment were done to identify the amount of vegetation surrounding, sufficiency of ventilation in the dwellings, types of building materials, layout of the dwellings and height of the ceilings.

Kampong Sangkrah and Semanggi obviously have lack of green infrastructures (open spaces, playing fields, private garden, green areas). Some dwellings still depend on public toilets. Cooking activities mostly depend on kerosene and wood, or combination on both. Dwellings that belong to low-income people mostly have half construction of brick materials in combination with other materials, such as board, triplex, or bamboo.

RESULTS AND DISCUSSION

From the pilot survey, it is known that the measurement procedures need to be improved for the final survey as well as the questionnaires used and the observation. The final survey was conducted in November-December 2010 included a larger scope, involving 426 participants from four kampongs: Kampong Semanggi, Kampong Sangkrah, Kampong Nusukan and Kampong Sewu (Fig. 6). These four kampongs are characterized by a dense occupancy with relatively narrow living spaces and limited access to the infrastructure. The location of dwellings which are next to the rivers (Bengawan Solo and Pepe Rivers) are prone to frequent flooding, thus decreasing the indoor air quality and causing problem to the people's health.

Time planning: The pilot survey found that a good time management is needed to prepare the field survey. It is because the method used in this research needs the participation of the people. The surveyors have to ask for permission and explain in a very simple language about the necessity of the research and the expected results. Therefore, preparation has to be planned carefully to obtain the optimal contribution of the people to the research.

The pilot survey showed that the time for conducting measurements and interviews were too long (±30 min). It caused the different time of measuring one dwelling to the next were too large and potentially disturbed the participant's activities. Therefore, the measurements of thermal comfort and indoor air quality, questionnaires/interview, observation and checklist were planned to be done for a maximum of 20 min per participant (per dwelling). Interview and measurement were done from 09.00 am to 03.00 pm. The pilot survey proved that measurements and interviews were not effective to be done at the evening considering the privacy of the family members.

Equipments: In the final field survey, the different equipments which have more accuracy were used to measure indoor/outdoor thermal environment. It is especially needed for measuring the indoor air velocity because the level of indoor air velocity in the tropics sometimes is very low (<0.1 m sec^{-1}). The equipments used for the momentary thermal environment were a digital temperature (accuracy 0.1°C) and humidity meter (accuracy 0.1% RH) CEM DT-615 and air velocity meter from TSI-AVM410 (accuracy 0.025 m sec^{-1}). In addition, the radiant/globe temperature was measured using a digital thermometer with a black globe.

The indoor air pollutants were considered to be measured because the interview and observation results of the pilot survey showed the existence of severe illnesses in the community. However, the information available from the related departments was not sufficient to identify the real conditions of the community, for example: data of the air pollutants only provided the measurement results of the main streets, while there are more severe conditions in the low-income community.

Furthermore, data from the Health Department and the local clinic (namely Puskesmas) recorded the same cases of severe illnesses, such as tuberculosis and asthma. Indoor air quality measurements investigated the occurrence of pollutants in the dwellings including the level of Carbon monoxide (CO), Nitrogen dioxides (NO_2) and Carbon dioxides (CO_2). These pollutants were selected because of the cooking activities and the presence of smoking people were relatively high. Indoor air pollutants were measured using the nitrogen dioxides Dräger Tube and Safeair Badges Carbon Monoxide for one-hour monitoring (Fig. 7). The threshold limit value for CO is 25-35 ppm h^{-1}; for NO_2 it is 0.1-0.25 ppm h^{-1}. After an hour of measurement, passive badges were collected and kept in a closed place so that the monitoring results will not be contaminated by sunshine. Meanwhile, the level of carbon dioxide was measured using a Carbon Dioxide Meter (CompuFlow TSI Alnor CF910) range from 0-5000 ppm, resolution 1 ppm and monitor for 15 min (Fig. 8).

The continuous measurement of indoor thermal environment (air temperature and relative humidity) was conducted to support the data of the thermal momentary measurements. Continuous measurement of the indoor thermal environment was done for 24 h using 5 Hobo data loggers (Hobo U12 Temperature/Relative

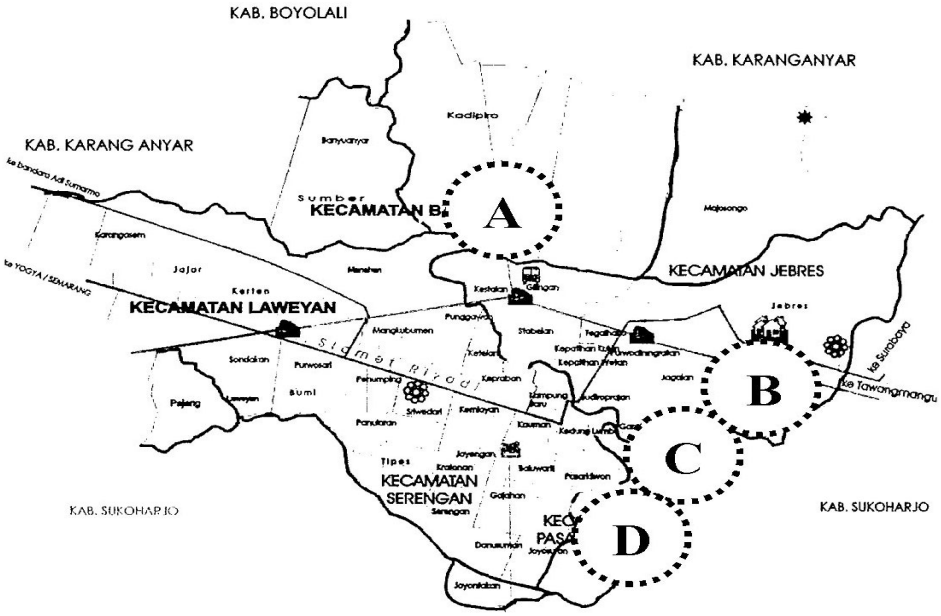

Fig. 6: Location of the four kampongs where the field-survey was done in Surakarta (A = Kampong Nusukan, B = Kampong Sewu, C = Kampong Sangkrah, D = Kampong Semanggi)

Fig. 7: Nitrogen dioxide (NO_2) tubes with the drager accuro pump (left) and the Carbon monoxide (CO) safe air badges (right)

Fig. 8: Carbon dioxide (CO_2) measurement

Humidity/Light/External Data Logger-U12-012). The data loggers measured the indoor air temperature and relative humidity ranging from 10- 50°C with an accuracy of 0.1°C (air temperature) and measured from 40-95% RH with 1% accuracy (relative humidity).

The Hobo's were placed in the dwellings which have different materials (brick, wood, bamboo, or a combination material) to record the fluctuation of indoor thermal environment in the dwellings for 24 h. Also, the data loggers were placed in the dwellings which have the most severe condition, i.e., those dwellings which used wood for cooking but having minimum ventilation. There will be 5 measurements using data loggers every day. For the next day, those 5 data loggers will be collected and data will be transferred into the computer. The final field-survey conducted in Surakarta, therefore consisted of more steps than the pilot survey as follows:

- Momentary measurements of the indoor/outdoor thermal environment
- Momentary measurements of the indoor air quality,
- Continuously measurement of the thermal environment
- Questionnaires and interview
- Observation and checklist of the surrounding environment

Surveyors: The pilot survey showed that the number of 4 surveyors were not sufficient to do all the assessments. Besides, the job descriptions of each surveyor have to be clear. Therefore, the final field-survey was managed to be done by at least 5 surveyors which have the jobs and responsibilities as follows:

- Surveyor 1: Indoor measurements (indoor thermal and pollutants)
- Surveyor 2: Outdoor thermal measurements and observations
- Surveyor 3: Questionnaires and interview
- Surveyor 4: Measurement of the dwellings
- Surveyor 5: Documentation and checklist

Questionnaires and interview: A thermal comfort field-study was conducted to investigate the relationship between people, climate and the dwelling. People were asked to answer questions about thermal sensation. The field-survey conducted in this research which assessed the low-income groups was done by using the national language (Bahasa Indonesia) and the traditional language (Javanese) to be more understandable by the people in the community. As an evaluation to the pilot survey, the questionnaires were converted to the pictograms (Fig. 9). The translation from the original language to pictograms was used to help people in understanding the questions of thermal comfort sensation.

The personal information, thermal comfort sensation, indoor air problems and health status of the participants were asked during the interview. People were asked to answer some personal questions (name, age, job, length of stay in the dwelling), the indoor air problems if they occur (do they have problem with odor in/or nearby), their health problems (do they have a toilet and bathroom at home, do they use a public toilet, do they have a severe illness, do they often have a common illness). A number of questions from the pilot survey which are not closely related to the aims of the field-survey were skipped in the final field-survey. In a field-survey which involved the participation of the people, it is important to conduct a survey which is as simple as possible so the participants will not get tired and lost focused when answering the questions.

The three questions about thermal sensation from the pilot survey were added with one more question about thermal problem so it became four questions. The questions were asked using the specific scales as follow: 7-point ASHRAE thermal sensation scale, from -3 to +3 (-3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, +1 = slightly warm, +2 = warm, +3 = hot) 5-point thermal acceptance scale (1 = comfortable, 2 = slightly uncomfortable, 3 = uncomfortable, 4 = very uncomfortable and 5 = intolerable). Total 3-point thermal preference scale (want to have warmer, want no change, want to have colder) Yes/No questions to assess whether the thermal environment causes a problem to their activities or not.

The pictograms were used during the interview to help the participants understand the questions. People may choose one of the most appropriate symbols which best represented their sensation at the moment. Those four questions were addressed to people at the same time as the momentary thermal measurement was take, (Fig. 10).

Observation and checklist: In the final field survey, the participant's behavior adaptation to the thermal condition was observed. This additional subject of observation was not done in the pilot survey, but found to be important. The behavior adaptation showed the direct responses of the people to the uncomfortable thermal condition. During the field surveys, people in the kampongs mostly spent their day-time sitting outside or walking around their dwellings. The outdoor environment seemed to be more comfortable for people than the indoor environment. Most of the men were doing activities wearing no shirt. In some dwellings, people were sleeping on their terrace. Those showed the typical adaptation to the thermal

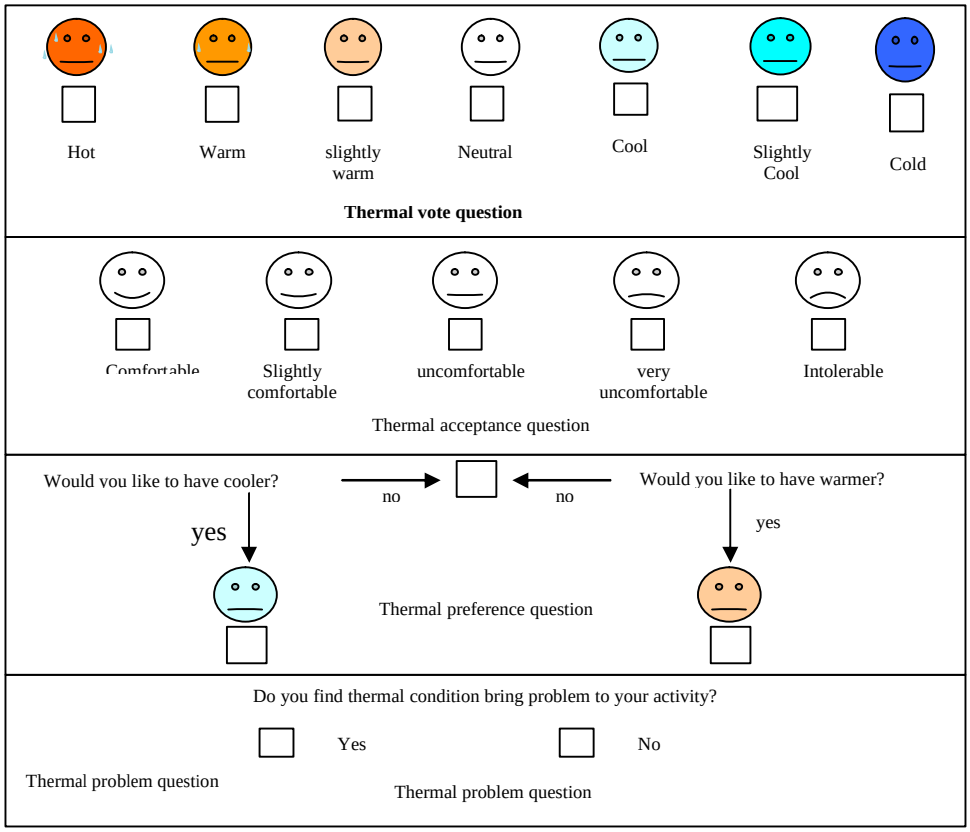

Fig. 9: Pictograms of thermal vote, thermal acceptance, thermal preference and thermal problem questions in the final field study

Fig. 10: Thermal comfort momentary measurement and interview with participants

environment. The behavioral adaptation included moving out of the of the dwellings, dressing in thin clothes, drinking or using a fan.

Observation to the greenery of the surrounding environment was distinguished based on 5 categories: trees, grass, shrubs, plants in the pots and the presence or absence of a garden. All information was written on the checklist and each dwelling was documented by a camera and sketches.

CONCLUSION

From the discussion above, it can be concluded that the proper method of conducting a field survey of thermal comfort and indoor air quality which involve the low-income community should consider the measurement procedures and the communication used as follows:

Measurement procedures: At the beginning, some time has to be spent to get the permissions and to approach the local people. The interview and momentary measurements have to be conducted in a short time so that it will not disturb the occupant's privacy. In addition, the 24 h continuous measurement of the indoor environment is important to be conducted to support data of the momentary measurements.

- The indoor air quality has to be measured since the occurrence of severe illnesses in the dwellings of the low-income community was significant
- The equipments which have a good accuracy are needed, especially to measure the air velocity which is mostly very low in the tropics
- The number of surveyors has to be sufficient to conduct comprehensive field survey of thermal comfort and indoor air quality. It is because the momentary measurement of thermal comfort and the questionnaires/interview of the thermal sensation have to be done simultaneously
- The observation and checklist have to include all aspects of the dwellings and the surrounding environment. It is also important to observe the people behavior adaptation and the health condition of the dwelling's occupants

Communication: Communication with the low-income community must be facilitated using simple local language and supported by pictograms. The pilot study showed how the questionnaires should be so that people better understand how to answer, especially questions about the thermal comfort sensation. Some people hardly understand the national language (Bahasa Indonesia), especially those of an elderly age. Therefore the ability of the surveyors to speak the traditional (Javanese) language is important, besides the national language.

The higher level of socio-economic people may respond differently to the similar field-survey. People from medium and higher economic level usually have higher educational background, more experience and knowledge to understand the questions address to them. However, these people normally require more privacy than the people from lower economic level. Therefore, conducting a field-survey of thermal comfort and indoor air quality has to consider the background of the participants.

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