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## Experimental Evaluation of Subjective Thermal Perceptions For Different Local Window Screenings

Rezuana Islam<sup>1</sup>, Sajal Chowdhury<sup>1\*</sup>, Mahbuba Afrin<sup>1</sup>, Amit Kusum Chowdhury<sup>1</sup>, Mahzerin Sultana<sup>1</sup>  
Tahjiba Tarannum<sup>1</sup>, Saadia Jahan Noor<sup>1</sup>, Nafis Ahmed Mahdi<sup>1</sup>

### ABSTRACT

In tropical climate, restricting convective gain while allowing cross ventilation creates paradoxical difficulty regarding indoor thermal comfort. Changing global climate gives new dimensions to the scenario results in subsequent pressure on increasing energy demand towards thermal comfort. Passive techniques can be a good way to deal with the problem. However, occupants' thermal perception may vary from person to person for a definite indoor environmental setup. Perception of subjective thermal comfort is crucial for human health and wellbeing which in turns effects performance. In the current study evaluation of subjective thermal performance regarding improved indoor thermal comfort has been studied for three different local window screening: i) plastic bottle with its wider face towards wind direction, ii) plastic bottle with its narrower face towards wind direction and iii) perforated bamboo screen. Six subjects: four female and two male (ages between 22-24), have been investigated for 30mins. in an experimental simulation chamber for three consecutive days. Questionnaire regarding thermal sensation and perception has been prepared to collect subjective response at 10mins. interval. From the experiment it is seen that subjective responses varies for different window screenings as well as for a specific indoor thermal condition created with definite screening. Subjects find the indoor environment comfortable for screening with plastic bottle with its wider face towards wind direction compared to other two. Bamboo screening has comparatively better performance than the screening plastic bottle with its narrower face towards wind direction. The current analysis only considers the thermal sensation of the subject and further extension of study considering factors like the subject's site-specific thermal sensation and other psychological effects can contribute towards improving indoor thermal comfort in tropics towards human health and wellbeing.

**Keywords:** Thermal Comfort, Subjective Perception, Window Screening, Thermal Performance, Tropics

### INTRODUCTION

People spend more than 80–90% of their lives indoors today (ASHRAE, 2010). Among other things, a healthy indoor environment needs to have a comfortable temperature (Wang and Pan, 2014; Jamaluddin *et al.*, 2014). It ensures that the people who live there are healthy and happy, directly impacting their mental peace and indirectly impacting their productivity (Horr *et al.*, 2016; Clements-Croome, 2017). So, when passive ways of keeping a room comfortable do not work, people use mechanical ways, a solution that focuses on energy. Studies show that the building sector, with its heating, ventilation, and air conditioning (HVAC) systems, is one of the largest consumers of energy in the world, using about 40% of all energy (Pérez-Lombard *et al.*, 2008). In tropical and subtropical areas, cooling buildings have become necessary for comfort. A typical building in a tropical country uses about 56% of its energy for heating, ventilation, and air conditioning (Boukhanouf *et al.*, 2013; Katili *et al.*, 2015). Energy use in buildings is increasing in developing countries like South East Asia, which is expected to be higher than in developed countries (Katili *et al.*, 2015). Bangladesh is a deltaic country in South Asia. It has a tropical monsoon climate with many different weather changes all year. The summer is hot and humid from March to June, the monsoon rains from July to October, and the winter is cool and dry from early November to late February. Here, most buildings are made, so the temperature inside is comfortable without extra work. The window is the central part that lets air from outside come in and helps heat escape through evaporation and convection. This helps keep the temperature inside comfortable. However, recently,

<sup>1</sup> Department of Architecture, Chittagong University of Engineering & Technology, Chattogram 4349, Bangladesh

\*Corresponding author: [sajal\\_c@cuet.ac.bd](mailto:sajal_c@cuet.ac.bd)

Bangladesh has been named one of the most climate-vulnerable countries. Studies on the trend of climate change in Bangladesh have shown a significant rise in temperature (Chowdhury and Debsharma, 1992; Chowdhury and Ahmed, 2015; Mia, 2003) with widespread warming during both the hot (March–May) and cool (December–February) seasons (Alexander and Zhang, 2006; Huq and Ayers, 2007). So, since there are regular hot spells throughout the year, buildings getting too hot is still a big problem in the modern world. The problem is serious for hot, humid, climate-vulnerable countries like Bangladesh, where the outdoor air temperature (AT) is usually much higher than the standard comfort temperature for more than half the year. This situation makes it hard to keep a building comfortable with passive methods, leading to health risks related to comfort and higher energy demand for heating and cooling. So, this study aimed to find out how different local window screens affect the temperature inside and how people feel about the temperature inside.

## METHODOLOGY

Ventilation helps convective and evaporative heat loss only when the air temperature (AT) and relative humidity (RH) outside are lower than the skin temperature (AT) and RH inside. In tropical climatic zones cross ventilation plays a vital role towards passive cooling strategies. Hence window and window-screening design becomes crucial. In this research different types of local window screening have been tested to evaluate subjective thermal perceptions. Three different types of screenings have been prepared with locally available materials i.e. plastic bottle and bamboo. A questionnaire has been developed to collect subjective response regarding thermal comfort using ASHRAE 7-points thermal sensation scale. Subjective thermal perception has been collected in a thermal perception simulation chamber for three consecutive days. Six subjects have been investigated for 30mins. and a total of twenty-four thermal responses have been collected for each screen types at a 10 mins. regular interval. Performance of the three screening has been compared and evaluated based on the subjective thermal perception of indoor environment.

### Experimental Setup

The experiment is conducted in a thermal perception simulation chamber shown in Fig. 1. A chamber has been prepared with an area of 1.2 x 2.1sqm chambers having a height of 2.13m. The three sides of the chamber has been made with hardboard whereas the front side has been accommodated a wood frame to facilitate changing of screening whenever necessary as shown in Fig.1. The wooden frame is then put on a tripod of 0.8m tall - the height of a window sill. At the outside of the chamber, a desk fan has been set up on a table nearly about a distance of 1m from the screen. The desk fan can generate three different wind speeds: 0.8 m/s, 1.4 m/s, and 2 m/s, which correspond to low, medium, and high speed respectively.

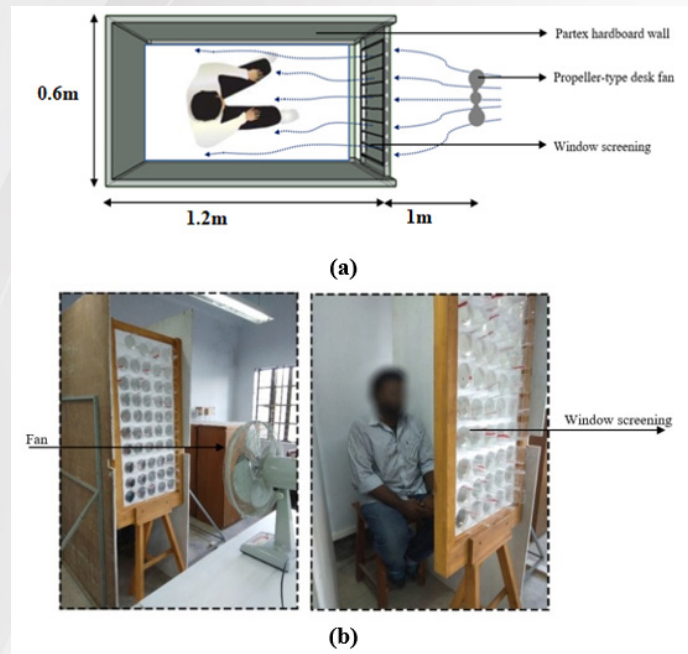
### Window Screening

First window screening has been made with sorted plastic bottle waste. A 75mm (3 inch.) dia bottle is selected and dissected for plastic bottle screening. The narrower face has a dia. of 18mm ( $\frac{3}{4}$ -inch.). Then they are installed side by side to form a porous screen which requires 60-65 plastic bottles (Fig.2). On the other hand, locally available bamboo species have been used for bamboo screening. Bamboo is chosen for its popularity and availability in local market. The bamboo is dissected longitudinally, and a 25mm x 18mm (1-inch x  $\frac{3}{4}$  inch) perforation is made @100-125mm (4-5 inch) c/c gap. For the length of 1.1m (3ft 7-inch), an average of 22 nos. perforation has been made on both sides of the single strip of bamboo (Fig.2).

### Subjects Details

For this experiment, six subjects, four females and two males ages 22 to 24 (Table 1), participated voluntarily and who are students, which makes it easier to make an accurate comparison of their comfort perception. The subject's blood pressure, height, and body weight were measured for the research purpose using lab-oriented digital instruments.

The subjects were seated on a wooden stool where they were only allowed to read. However, no electronic device was allowed during the experiment, and the metabolic rate (M) was approximately 1.0 met according to ISO-EN 7730. All subjects were healthy, non-obese, non-smokers, not taking any medication, and abstained from alcoholic beverages at least 24hrs before experiments. The subject wore a typical summer suit. The male sample consisted of regular full pants, T-shirts, underpants, socks, and shoes (sandals), and the female sample wore cotton salwar-kameez, undergarments, and shoes (sandals). Clo-value was determined to be 0.53–0.6 clo. according to ISO-EN 9920 for both samples.

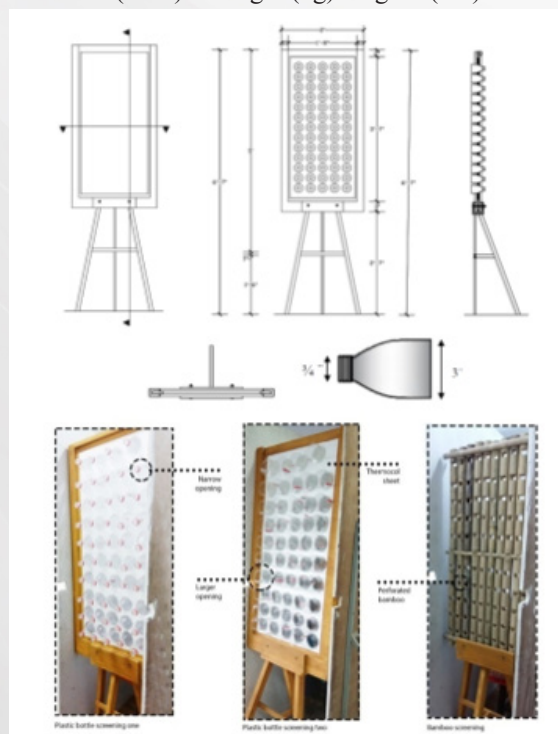


**Figure 1:** (a) Experimental chamber and (b) experimental setup with the subject (bottom right)

**Table 1:** Anthropometric data of the subjects

Subject	Gender	Age (years)	Height (cm)	Weight (kg)	BMI (kg/cm <sup>2</sup> )
S-1	M	24	165	72	26.45
S-2	M	22	171	78	26.67
S-3	F	22	162.5	51	19.31
S-4	F	23	157.5	58	23.38
S-5	F	23	157.5	58	23.38
S-6	F	23	150	62	27.56

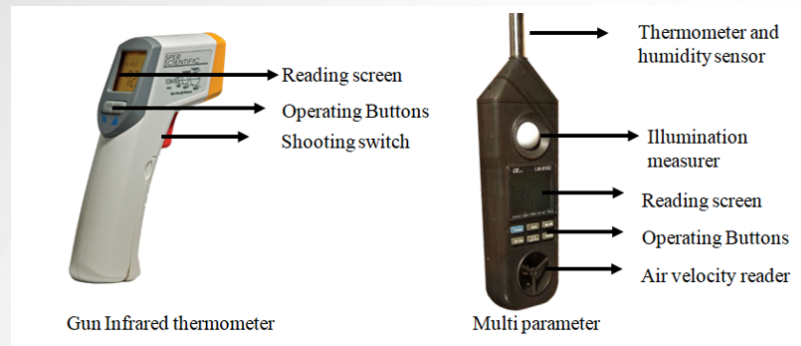
Where, M = Male, F= Female, Body Mass Index (BMI) = weight (kg)/height<sup>2</sup> (m<sup>2</sup>).



**Figure 2:** Window screening frame details

### Physical Measurement

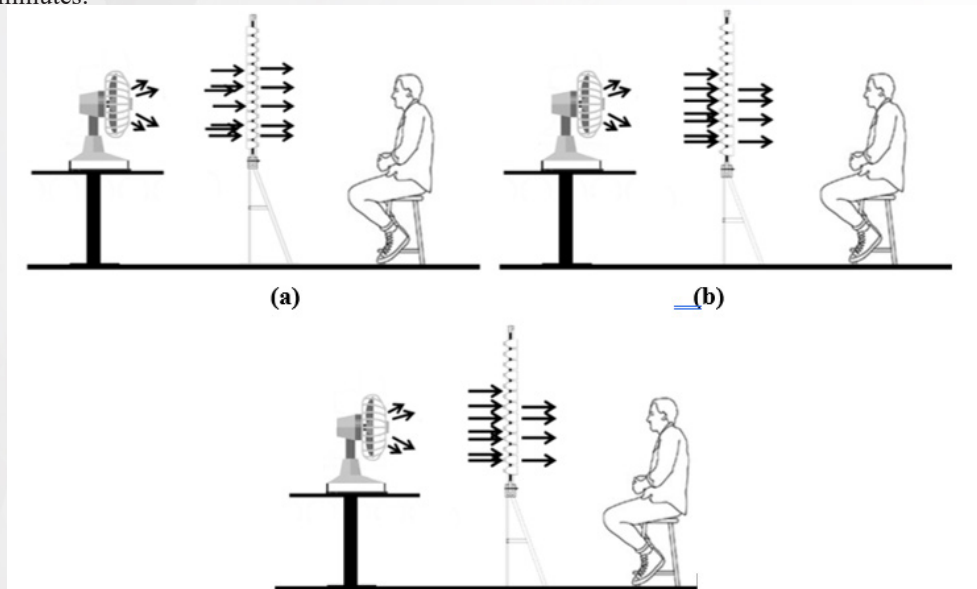
AT and RH were taken using a specialized thermometer and gun shooter (fig. 3) at 0.6–1.1 m height from the floor level. However, during the experiment, the subjects were not informed about the AT and RH for avoiding any kind of bias. For the research purpose, the subject's Blood Pressure (BP) (mmHg), height,  $h$  (cm), and body weight,  $m$  (kg), were measured (table 1) just before entering the chamber.



**Figure 3:** Equipment for temperature measurement

### Experimental Procedure

The subjective thermal perception was performed for each subject individually for each of the three window screenings (Fig. 4). Most of the experimental sessions are performed between 11 am to 2 pm. Each experiment requests the subject to sit in the chamber for 30 minutes.



**Figure 4:** Experimental process: (a) Plastic bottles with wider face towards wind direction, (b) Plastic bottles with narrower face towards wind direction and (c) Local bamboo screening

During the experiments, subjects needed to answer questionnaires according to the ASHRAE comfort scale. As an initial step, the subjects were allowed to rest for a minimum 15min for adaptation and preparation. Then before entering the experiment chamber, the subject's BP, height, and weight were measured. Then just after entering the chamber, each subject was asked to answer the questionnaire (fig. 5) supplied to them. Then the fan speed was gradually increased from low (0.8 m/s), middle (1.4 m/s), and then high (2.0 m/s) after each of the 10 min intervals, and the subject was asked to fill out the questionnaire supplied. The whole session lasted for 3 hours and the thermal sensation of the subject was noted. Meanwhile, the temperature data AT and RH were recorded for each experiment.

### RESULT AND DISCUSSION

The experiment was conducted for three consecutive days. Outcome of the experiments has been presented from Table-2-4. From the perception of the thermal environment within the chamber subjects expressed their subsequent thermal sensation. A comparative thermal sensation of the subjects for the screenings in question has been illustrated in Fig. 6.

The first-day experiment was conducted for the plastic bottle window screening with its wider face towards the wind direction. Average AT of 27.3°C and RH of 64.23% (Table-2) were recorded inside the chamber. From the table it is seen that at the starting of the experiment the respondents were feeling warm or slightly warm and after 10mins they started feeling better with a perception of slightly cool environment. It is seen that within the stable AT and RH condition, increasing wind speed improves

### Survey Form

Experiment date: \_\_\_\_\_ Experiment No.: \_\_\_\_\_  
 Subject name: \_\_\_\_\_ Age: \_\_\_\_\_ Gender: \_\_\_\_\_  
 Height: \_\_\_\_\_ Weight: \_\_\_\_\_ Body Mass Index (BMI): \_\_\_\_\_  
 Clothing: \_\_\_\_\_ Clo. value: \_\_\_\_\_  
 Start time: \_\_\_\_\_ End time: \_\_\_\_\_

<u>0 min.</u>	<u>10 min.</u>	<u>20 min.</u>	<u>30 min.</u>
Outdoor AT: _____°C RH : _____% Wind speed: _____ms <sup>-1</sup>	Outdoor AT: _____°C RH : _____% Wind speed: _____ms <sup>-1</sup>	Outdoor AT: _____°C RH : _____% Wind speed: _____ms <sup>-1</sup>	Outdoor AT: _____°C RH : _____% Wind speed: _____ms <sup>-1</sup>
<b>Thermal Perception:</b> <input type="checkbox"/> Cold <input type="checkbox"/> Cool <input type="checkbox"/> Slightly cool <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly warm <input type="checkbox"/> Warm <input type="checkbox"/> Hot	<b>Thermal Perception:</b> <input type="checkbox"/> Cold <input type="checkbox"/> Cool <input type="checkbox"/> Slightly cool <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly warm <input type="checkbox"/> Warm <input type="checkbox"/> Hot	<b>Thermal Perception:</b> <input type="checkbox"/> Cold <input type="checkbox"/> Cool <input type="checkbox"/> Slightly cool <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly warm <input type="checkbox"/> Warm <input type="checkbox"/> Hot	<b>Thermal Perception:</b> <input type="checkbox"/> Cold <input type="checkbox"/> Cool <input type="checkbox"/> Slightly cool <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly warm <input type="checkbox"/> Warm <input type="checkbox"/> Hot
<b>Thermal Sensation:</b> <input type="checkbox"/> Very uncomfortable <input type="checkbox"/> Uncomfortable <input type="checkbox"/> Slightly uncomfortable <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly comfortable <input type="checkbox"/> Comfortable <input type="checkbox"/> Very comfortable	<b>Thermal Sensation:</b> <input type="checkbox"/> Very uncomfortable <input type="checkbox"/> Uncomfortable <input type="checkbox"/> Slightly uncomfortable <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly comfortable <input type="checkbox"/> Comfortable <input type="checkbox"/> Very comfortable	<b>Thermal Sensation:</b> <input type="checkbox"/> Very uncomfortable <input type="checkbox"/> Uncomfortable <input type="checkbox"/> Slightly uncomfortable <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly comfortable <input type="checkbox"/> Comfortable <input type="checkbox"/> Very comfortable	<b>Thermal Sensation:</b> <input type="checkbox"/> Very uncomfortable <input type="checkbox"/> Uncomfortable <input type="checkbox"/> Slightly uncomfortable <input type="checkbox"/> Neutral <input type="checkbox"/> Slightly comfortable <input type="checkbox"/> Comfortable <input type="checkbox"/> Very comfortable

**Figure 5:** Questionnaire about comfort feeling with following air movements

subject's perception of environment from slightly warm to cool over time. At that beginning of the session it is observed that out of six subjects, four expressed that they were feeling neutral and rest of the two were uncomfortable (Fig. 6). But when over time wind speed had been increased they started feeling better but after 30mins when wind speed became 2.0ms<sup>-1</sup>, subjects perceived the environment cool and started to feel comfortable.

Second session was done with a set-up where the screen is placed in reverse way towards wind direction. Table-3 presents the overall findings of second day experiment. During the experiment average AT and RH were 27.4°C and 63.5% respectively. Respondents find the environment warm to slightly warm with a wind speed of 0.2ms<sup>-1</sup>. Increasing wind speed 0.2ms<sup>-1</sup> to

**Table 2:** Experiment with plastic-bottle screening wide face towards wind side: Subjects perception

Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms <sup>-1</sup> )	Perception	Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms <sup>-1</sup> )	Perception
S-1	0	27.6	69.2	0.2	Warm	S-4	0	27.0	63.8	0.2	Neutral
	10	27.5	67	0.8	Slightly warm		10	27.0	63.2	0.8	Slightly cool
	20	27.5	64.2	1.4	Slightly cool		20	27.1	61.8	1.4	Cool
	30	27.3	63.6	2.0	Cold		30	27.3	65.3	2.0	Cool

S-2	0	27.3	62.0	0.2	Slightly warm	S-5	0	27.1	63.8	0.2	Slightly warm
	10	27.4	62.5	0.8	Slightly cool		10	27.0	63.2	0.8	Cool
	20	27.3	60.8	1.4	Cool		20	27.1	61.8	1.4	Cool
	30	27.2	62.3	2.0	Cool		30	27.3	65.3	2.0	Slightly cool
S-3	0	27.4	66.7	0.2	Slightly warm	S-6	0	27.2	67.0	0.2	Neutral
	10	27.4	67	0.8	Slightly cool		10	27.4	67.3	0.8	Slightly cool
	20	27.6	60.8	1.4	Slightly cool		20	27.6	67.8	1.4	Slightly cool
	30	27.5	65.3	2.0	Cool		30	27.5	67.0	2.0	Cool

0.8ms<sup>-1</sup> respondent perceive the environment warm to become cool. During this experiment at the starting point subjects were feeling slightly uncomfortable to neutral. Over time with the increasing wind speed they found it neutral to uncomfortable. Final experiment was done with local bamboo screening made from locally available bamboo. Unlike the other two sessions six respondents were participated for 3hrs where each subject was investigated for 30mins. The average AT was 21.17°C, and the average RH was 49.46% (Table 3). Summary of the findings has been presented in Table-3. It is observed that at the beginning of the session respondents finds the environment within the test chamber slightly warm to neutral. But after 10-20mins later of the session when wind speed was increased from 0.2 ms<sup>-1</sup> to 2.0 ms<sup>-1</sup> most of the subjects finds the condition of the chamber slightly cool to cool. Three subjects expressed that they were feeling neutral while three were feeling uncomfortable. But at the end of the session all the subjects found the environment neutral to comfortable.

Above discussion reveals that subjects find the chamber comfortable when screening made up of plastic bottle with its wide

**Table 3:** Experiment with plastic-bottle screening narrowface towards wind side: Subjects perception

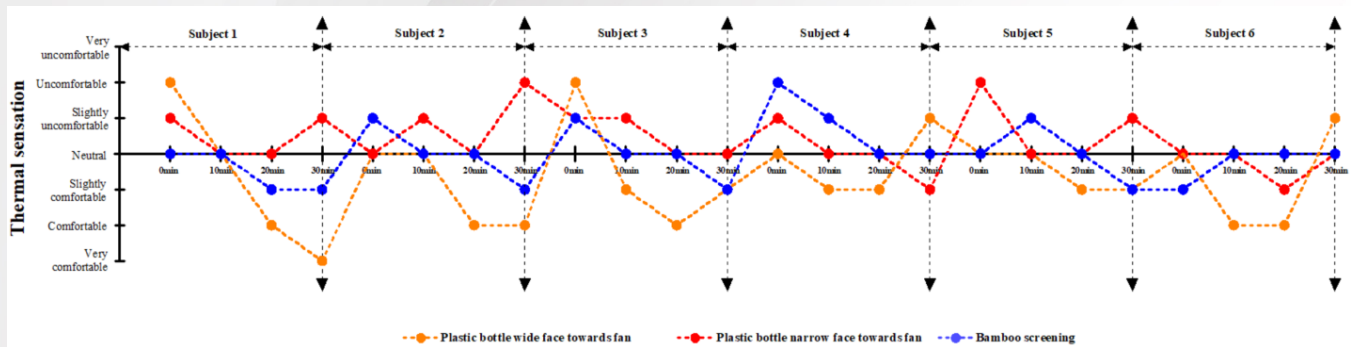
Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms <sup>-1</sup> )	Perception	Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms <sup>-1</sup> )	Perception
S-1	0	27.2	60.7	0.2	Warm	S-4	0	27.1	62.5	0.2	Slightly warm
	10	27.3	61.5	0.8	Slightly warm		10	27.3	62.5	0.8	Cool
	20	27.2	67.6	1.4	Cool		20	27.1	60.6	1.4	Neutral
	30	27.4	63.3	2.0	Neutral		30	27.7	63.3	2.0	Cool
S-2	0	27.8	61.3	0.2	Slightly warm	S-5	0	27.3	61.2	0.2	Warm
	10	27.7	61.0	0.8	Warm		10	27.3	61.5	0.8	Neutral
	20	27.6	60.6	1.4	Neutral		20	27.2	63.6	1.4	Cool
	30	27.0	62.0	2.0	Slightly cool		30	27.8	61.3	2.0	Slightly cool

S-3	0	27.4	62.4	0.2	Slightly warm	S-4	0	27.3	67.4	0.2	Neutral
	10	27.3	61.5	0.8	Slightly cool		10	27.9	67.5	0.8	Cool
	20	27.2	67.6	1.4	Slightly warm		20	27.2	67.6	1.4	Neutral
	30	27.4	63.3	2.0	Cool		30	27.5	67.3	2.0	Cool

**Table 4:** Experiment with bamboo screening: Subjects perception

Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms-1)	Perception	Name	Time (min.)	AT (°C)	RH (%)	Wind speed (ms-1)	Perception
S-1	0	22.0	42.8	0.2	Slightly warm	S-4	0	22.5	44.7	0.2	Slightly warm
	10	22.1	47.8	0.8	Neutral		10	22.8	42.3	0.8	Neutral
	20	22.1	44.2	1.4	Slightly cool		20	22.5	54.2	1.4	Slightly cool
	30	22.5	55.4	2.0	Slightly cool		30	22.5	44.1	2.0	Cool
S-2	0	22.1	45.9	0.2	Neutral	S-5	0	22.4	50.4	0.2	Slightly warm
	10	22.1	47.8	0.8	Neutral		10	22.3	50.8	0.8	Slightly cool
	20	22.1	46.7	1.4	Slightly cool		20	22.7	56.8	1.4	Slightly cool
	30	22.2	49.2	2.0	Slightly cool		30	22.1	50.2	2.0	Cool
S-3	0	22.0	47.2	0.2	Slightly warm	S-6	0	22.4	53.2	0.2	Neutral
	10	22.2	49.2	0.8	Neutral		10	22.8	53.7	0.8	Slightly cool
	20	22.1	44.2	1.4	Neutral		20	22.8	55.4	1.4	Slightly cool
	30	22.1	47.8	2.0	Cool		30	22.5	50.5	2.0	Cool

face is installed towards wind direction is set as window screening than other two. This happens as when wind passes through a wide to narrow valve AT decrease as a result of Joule Thomson effect. Again, previous studies show that air flow has notable impact on subjects' thermal comfort. People feel comfortable in higher temperature when air flow is introduced in a space (Mallick, F. H. 1996; Mallick, F. H. 1994). In case of screening with plastic bottle having its narrow face towards wind less wind passes through the bottles and due to decreased wind flow subjects responded little to the fan's increasing air velocity and found the environment slightly uncomfortable. Compared to two others bamboo screening performs better than screening with plastic bottle having its narrow face towards wind. In this case the opening in the frame is equal on both sides, which made most of the air pressure pass more effectively toward the subject sitting in the chamber. Less wastage of air pressure made the procedure more acceptable. The relative air movement in the chamber with the thermal sensation of the subject was found to be more effectually linked during the session.



**Figure 6:** Comparison of subjective thermal perception of different window screening

## LIMITATIONS

The current analysis only considers the thermal sensation of the subject. However, other factors like the subject's site-specific thermal sensation and other psychological effects were out of the scope of this research. This research can be further extended by integrating the above factors to find their effect.

## CONCLUSIONS

The experiment represents the thermal sensation of the subjects towards other window screenings made of locally available and waste materials. From the experiments, it has been identified that the framing of plastic bottles with their wider surface facing toward the fan indicated relatively better indoor comfort conditions than the framing of plastic bottles with their narrower surface facing toward the fan during the hot summertime. The last session was conducted with a bamboo perforated screening system subjects find the performance of bamboo screening comparatively better than the screening plastic bottle with its narrower face towards wind direction. As the current analysis only considers the thermal sensation of the subject, hence, further extension of study considering factors like the subject's site-specific thermal sensation and other psychological effects can contribute towards improving indoor thermal comfort in tropics towards human health and wellbeing.

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