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Original
A field survey in Calcutta. Architectural issues, thermal comfort and adaptive mechanisms in hot humid climates / Pellegrino, Margot; Simonetti, Marco; Fournier, Laurent. - ELETTRONICO. - (2012). (Intervento presentato al convegno 7th Windsor Conference 2012 "The changing context of comfort in an umpredictable world" tenutosi a Windsor (UK) nel 12-14 Aprile 2012).

Availability:
This version is available at: 11583/2704729 since: 2018-03-30T11:02:32Z

Publisher:
NCEUB

Published
DOI:

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

A field survey in Calcutta. Architectural issues, thermal comfort and adaptive mechanisms in hot humid climates.

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Abstract

This paper presents and discusses results of a small-scale field survey on occupant comfort and related perceptions observed in two university buildings in Calcutta, India, in 2011. These buildings were free running and ventilated by fans. The study was made in two different days, collecting a full set of architectural observations, objective physical measurements and subjective assessments through questionnaires. The study found a neutral temperature of 30.9ºC from the regression of votes on the 7-points ASHRAE scale. These values are much higher than the comfort range of 23 – 26 °C specified by Indian Codes. This finding could have enormous energy implications to building design, HVAC design and practice in India. Results also indicate a higher neutral temperature, compared to previous studies. The role of humidity and air movement were further investigated. Multiple regression analysis helped in understanding the relative influence of each parameter for the comfort perception.

Keywords

Tropical climate, quality of architecture, adaptive comfort, field survey.

1. INTRODUCTION

1.1 Background of the study

Thermal comfort in tropical climates represents a field of investigation that is still open to lively discussion. Among the many issues, one seems to assume a special weight: the determination of the neutral, preferred and acceptable temperature, according to the perception of users. This task can be particularly important if related to an indoor environment such as a school or a university, where the density of people and the social rules of behavior exacerbate the already difficult environmental conditions of hot and humid climates. An understanding of the users' perception of comfort may allow for a more critical approach to ASHRAE Standards 55 [1] and also a deeper analysis of local thermal comfort. The ASHRAE standard 55 is a "national voluntary consensus standard" developed by the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) and recognized by the American National Standards Institute (ANSI). With practical, air-conditioning design-oriented charts and data, this standard is widely and conveniently used the world over by air-conditioning companies for the sizing and design of their installations, and consequently has an enormous influence, going much beyond the geographical area of the USA. Due to its worldwide influence, our study was based on ASHRAE standard 55.

This study presents a field survey carried out in 2011 in Calcutta, in different classrooms belonging to two Universities. The main objectives of this study were the determination of neutral temperature and the investigation of the role played by air movement and humidity in comfort perception.

1.2 Previous studies on thermal comfort in the tropical climate

Scientific literature concerning the perception of thermal comfort is widespread for all the earth's climates. Comfort in tropical climates started to be investigated during the 50s by Webb [48], Ellis [11] and Givoni (who has continued the research up to the present [32;14]). Neutral temperature and related equations are the core of some research during the 70s and 80s [Rao, Ho in Singapore [39]; De Dear and Leow in Singapore [8;9]. Starting from the 90s, the investigations became more in-depth and frequent: Busch in Thailand [6]; Baker et al. [3]; Mallick in Bangladesh [31]; Karyono in Indonesia [26]. Research by Humphreys and Nicol are particularly significant: from the 70s to present day they are carrying out extensive and detailed field studies also in tropical countries [19;33;34;35], investigating the role of occupants' behavior and highlighting the strong correlation between indoor and outdoor conditions in the area of thermal comfort perception.

A further step forward was taken in 2000: more building typologies (offices, private houses, schools; naturally ventilated, free running buildings, A/C buildings) and more countries became involved: Khedari et al. in Thailand [27]; Zainazlan et al. in Malaysia [52]; Jitkhajornwanich in Thailand [25]; Xiaojiang et al. in Shanghai [51]; Huimei et al. in China [18]; Han et al. in China [16]; Hussein et al. in Malaysia [20]; Raja et al. in Nepal [37]; Feriadi et al. in Indonesia [13]; Hwang et al. in Taiwan [21], Wong et al. in Singapore [49;50] and Kwok et al. in Japan [28], the last three also working on schools and classrooms.

India has been the object of some research, but the scenario is still now far from being complete and exhaustive, especially because of the complexity and variety of environments and local microclimates. Among them: Sharma et al. [43]; Indraganti in Hyderabad [22;23]; Rajasekar et al. in Chennai [38]. An interesting and fertile branch of research has been recently carried out in India by some scientists and professionals (architects, engineers) interested in associating comfort and energy, since the two issues, as previously stated, are strongly interconnected. This study aims at following the same path, taking as reference the work of Thomas and al. [46]; Lall et al. [29;30], Pellegrino [36].

1.3 The Indian scenario

The lack of scientific research in India concerning thermal comfort and thermal mechanisms of adaptation is particularly worrying within the context of the growing importance of India's economy.

In India, there are two institutional acts that regulate thermal comfort inside buildings: the National Building Code (NBC) [4] and the *Energy Conservation Building Code* (ECBC) [5]. These two texts, despite representing an important step forward in the definition of energy policies in India, are nevertheless less effective than expected for two reasons. Firstly, they are mandatory only for offices and new buildings which consume a great amount of energy. This means they do not take into account the low-rise high-density private buildings, which represent 80% of the typologies built in the cities. Secondly, they identify a very narrow range of acceptable indoor temperatures for A/C buildings, (with summer design conditions set between 23-26°C with a RH range of 50-60%, and winter conditions between 21-23°C with RH not less than 40%) adopting the USA energy code – ASHRAE Code 90.1 – without any references to the local climates or any field survey techniques concerning the local comfort sensations and perceptions.

India is developing incredibly fast. Today, the energy consumption in Indian residential buildings is the highest among all the Asia Pacific Partnership countries. This makes India the third largest contributor of CO2 emissions in the world (Jain, [24]). Previous studies are starting to highlight the relevance of issues linked to the increasing penetration of A/C in society (Roaf [42]), particularly in the middle income classes of the Asian emerging countries like India (Lall, [29,30]; Pellegrino [36], Steemers et al. [45], Tiwari [47], Singh et al. [44]). Social sciences have to play a more active role in a scenario where delicate environments can be menaced by habitual behavior, i.e. determining that air conditioning is a status symbol more than a real necessity. At the same time, thermal comfort analysis will help governments and institutions in recognizing the importance of local characteristics, in order to improve laws and directives concerning energy use. Resource consumption, but also pollution and CO2 production are the risky consequences of an uncontrolled use of energy: A/C buildings, for example, emit 2–3 times the CO2 compared to mixed mode and naturally ventilated buildings, with no significant improvement of comfort (Steemers [45]).

2. CALCUTTA AS A CASE STUDY

2.1 The Calcutta climate

Calcutta is located in eastern India, at 22°33′N 88°20′E in the Ganges Delta at an elevation ranging between 1.5–9 m. Despite being one of the biggest, most populated and important cities in India, it has never been the object of scientific studies concerning thermal comfort. Calcutta has a typical tropical, warm and humid climate. In order to get an immediate idea of the kind of climate people and buildings experience in Calcutta, it is useful to plot the typical temperature and humidity on Givoni-Milne's bio-climatic chart [32] (Fig 1). Using the conventional psychrometric chart as a background, Givoni and Milne have roughly delimited the comfort zone, and outside this comfort zone, a wide range of common architectural or mechanical solutions which can restore comfort efficiently. If we further extend Givoni-Milne's bio-climatic chart with the help of recent ventilation data from Joseph Khedari's studies [27], we can approximately fit the entire range of typical climatic conditions within the domain of bio-climatic (non-mechanical) comfort.

Another benchmark against which we can possibly plot Calcutta's climate is the conventional "office" comfort zone as defined by ASHRAE-55 [1], Fig. 2. This criterion essentially tells us that during the three winter months from December to January, sedentary activities can take place comfortably outdoor in Calcutta.

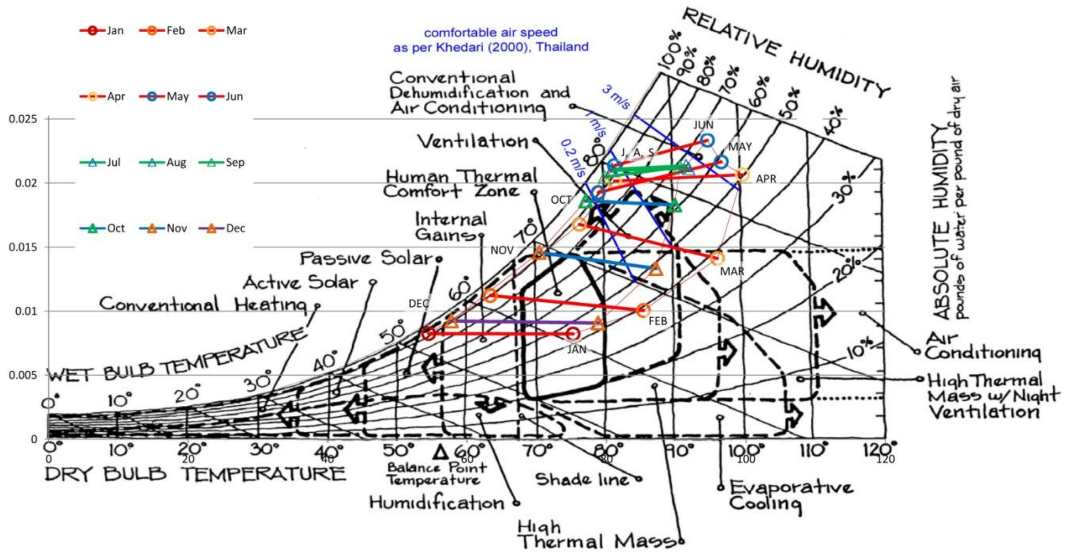


Fig. 1: daily variations of temperature and moisture for each month of a typical year in Calcutta, superimposed to the Givoni-Milne bio-climatic chart (1981). Climatic data from Dumdum airport.

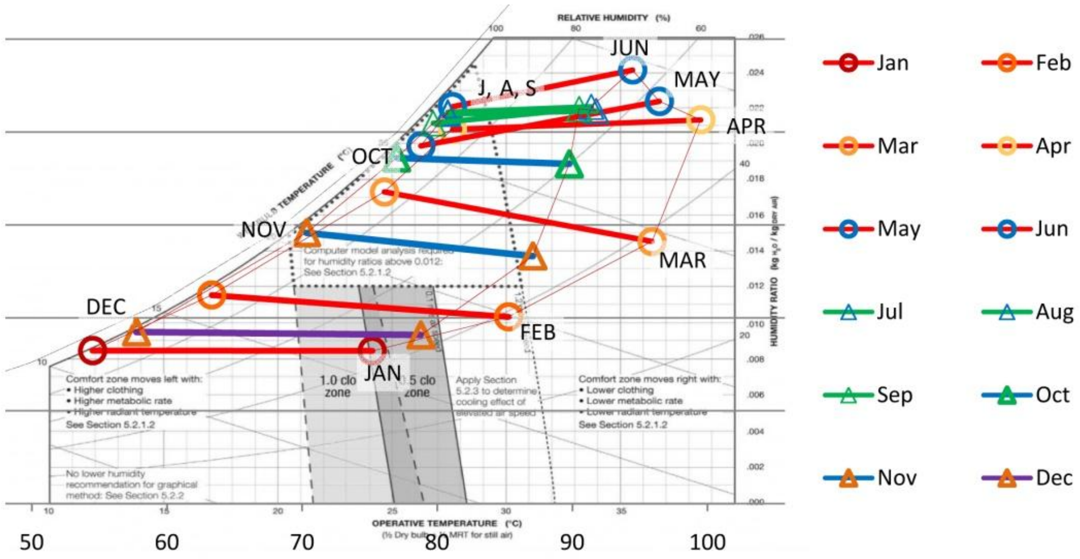


Fig. 2: Calcutta's variations of temperature and moisture superimposed to ASHRAE-55 comfort zone

Fortunately, for the rest of the year the wind pattern in Calcutta is very helpful to bio-climatic comfort. The summer months (March to September) benefit from an almost permanent breeze, always coming from the South. Therefore, traditional architecture has typically the largest facade facing the South, and is very narrow in the North-South direction, often only one room and a verandah, so as to let as much breeze as possible enter.

The solar irradiation on typical building's surfaces for Calcutta is shown in Fig.3. In summer, the sun rises and sets almost vertically and climbs very high, making the

East and West walls much more vulnerable to solar heating than the South wall. Fig.3 shows the resulting hourly radiation exposure on a conventional building envelope in winter and in summer. Even if the solar radiation do not change much for other surfaces, it varies enormously for the South wall, which is very well protected in summer.

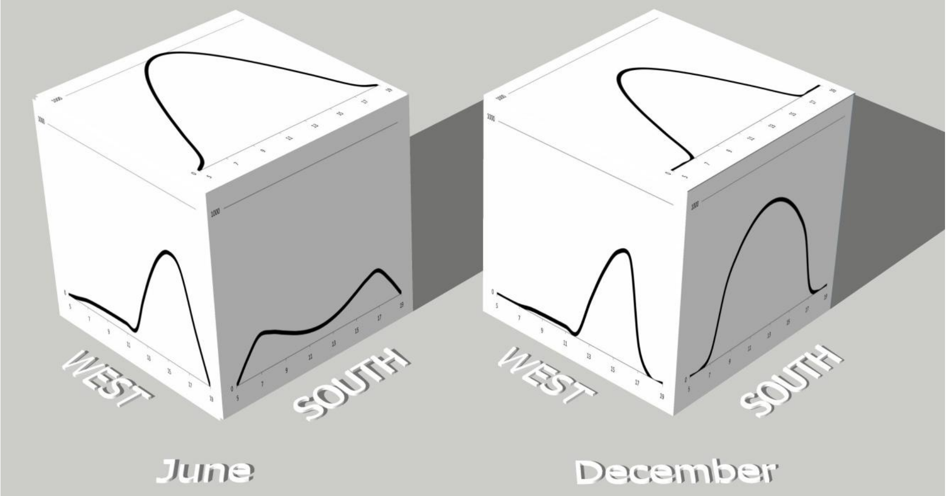


Fig. 3: hourly solar radiation falling on the walls and flat roof of a typical building in Calcutta, in summer and in winter. Direct and diffuse radiation added, ignoring clouds and nebulosity, for 22.5°N latitude. The side of the cube is 1kW/m2. Data calculated with "Solar Radiation On Collector"-www.builditsolar.com/Tools/RadOnCol/radoncol.htm

2.2 Calcutta's buildings and recent developments.

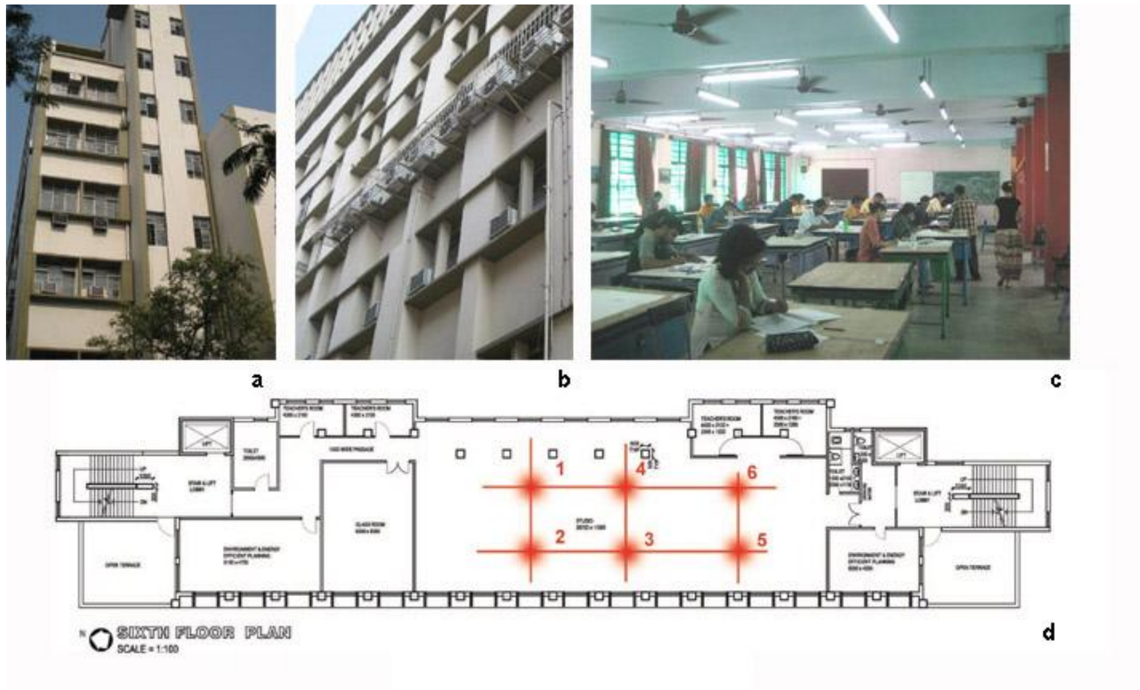
What has happened to the building sector in Calcutta during recent decades is well known, in common with most of the megalopolises in the world. The economical pressure, the incredible development rate, the industrialized cement-based technology, the growing prices of free land, the exploitation of every centimeter of building surface has led to the creation of dense and qualitatively poor architecture, where any attention to the environment has been totally forgotten and any link with nature cut. Poor quality buildings are speeding up the phenomenon of A/C penetration in society. If it is true that in Calcutta the number of private cooled spaces is still relatively low, the baseline scenario of A/C demand from 2009 to 2010 is growing at a rate of 15.54%. Even nowadays it is estimated that about 860.000A/C appliances are owned in Calcutta, which is more than the washing machines and ¼ of refrigerators in homes (Global change program [15]). In terms of energy consumption (and pollution) previous studies (Pellegrino [36]) demonstrated that A/C flats can consume between two and six times more than a flat without A/C, according to the frequency of use.

2.3 Calcutta: the field survey.

A small scale field survey was carried out in May 2011 in two Universities of Calcutta: the Jadavpur University (JU), Architecture Department and the Meghnad Saha Institute of Technology (MSIT). The scope was to collect architectural information about the buildings, environmental data and subjective responses from the students through questionnaires concerning thermal comfort. All the analyses were made during two different days, the 20th and the 25st of May.

(i) *The buildings.* The Architecture Department in JU is on the 6th and 7th floors (the last two ones) of a building dated around the beginning of the 60s. (Fig.

1.a,b,c,d). The block measures 60x12m: its longitudinal axis is oriented almost perfectly E-W. The building has a conventional reinforced concrete structure, with brick infill walls and partitions, organized according to a beam-column system. The columns are 50x50 cm, the brick walls are plastered on both sides, for a total thickness of 27 cm. The survey was done on the 6th floor, in the main classroom, which measures 26.5x12 m. (Fig. n. 1.c). The space is wide, there are no false ceilings and between each beam there are three fans. Windows at both sides are big (1.5x1.2 m). Many of them are without panes and the air can flow continuously. Only a small concrete overhang provides a little shade: otherwise, the windows are totally exposed to the morning and afternoon sun. In an attempt to attenuate this phenomenon, big pieces of green plastic layers have been put on the windows, reducing the light but probably worsening the heat transfer.



Figures 1.a,b,c: north and west side of the building; the classroom. Figure 1.d: the 6th floor plan. Red marks indicate the position where data have been collected.

The MSIT is a modern structure built in 2000 (Fig. 2.a,b,c). Like JU, it has a reinforced concrete structure and a beam-column system. The building is an open block organized around two open courtyards, one in front and one at the back.

Figures 2.a,b,c: the entrance; the balcony; one of the two classrooms

It has been built with more attention to climate: shaded corridors, balconies, overhangs above the windows guarantee better ventilation and shading even if many classrooms, such as the two ones where the survey was carried out, are totally unprotected from solar radiation. They are situated on the ground floor, one exposed

S-W and one N-E, measuring about 67 sqm. They are equipped with ceiling fans and four single-glazed windows (2.5 x 1.2 m), mostly open.

(ii) The environmental data. On the 20th of May the survey was carried out in JU at 2.30 pm. Outdoor temperature was 32.2°C and RH was 61%. With the help of two HTC – Easylog Temperature and Humidity data loggers, indoor temperature and RH were measured in six different points in the classroom, as shows in Fig.1.d. Air speed was recorded with the HTC – AVM 07 Anemometer. All the measurements were taken at about 1.5 meter from the floor. With the help of an HTC- MT4 MT6 InfraRed thermometer, surface temperature was collected on the floor, the ceiling, the walls and the windows, that is all the main surfaces of the classroom. Operative temperature T_{op} was calculated using the formula

$$(1) \qquad T_{op} = (hc*T_a + hr*T_r)/(hc+hr)$$

as prescribed by ASHRAE [1;2].

At the MSIT the methodology was the same. Two classrooms were monitored, but only one station point was selected inside them, because of their smaller dimensions. The same data as JU data was collected. Table 2 shows all the values found.

	day	**time**	**T_{out} (°C)**	**T_{ind} (°C)**	**T_{op} (°C)**	**RH (%)**	**W_{speed} (m/s)**
JU	20_05_11	2.30 pm					
Pt. 1,6			32.2	30.9	31.7	63.4	1.1
Pt. 6			32.2	30.7	31.5	64.9	1
Pt. 2,3,5			32.2	31.2	31.8	62.1	1
MSI	25_05_11	2.30 pm					
room 203			35.8	32.8	33.6	78.9	1.4
room 202			35.8	33.4	34.1	70.6	2.3

Table 2. Data collected during the surveys.

iii) Quality of the building and adaptive behavior. The poor quality of the buildings, especially JU, has to be emphasized. No shading of windows, unfavourable solar and wind orientation and lack of panes in the windows were characteristics that increased the internal building climate’s vulnerability to the external climate. On the other hand, the behaviour of users did not seem to indicate a great attention to the environment, as if the weather did not have any relevance. This attitude can only partly be explained by the results of the analysis, which show that the level of climate adaptation is very high. The use of ceiling fans was the only concrete action carried out. It was also possible to detect some incorrect behaviour, such as the partial covering of the non-glazed windows with an opaque plastic material, which transmits the heat, instead of shielding from the sun's rays. In the absence of wind, it is in fact not always advisable to leave the windows open. In the morning and early afternoon the temperature inside the buildings is usually lower than the outside air temperature, but it increases in the second half of the afternoon, with a time shift due to the inertia of the building materials. During the day, open windows allow the entry of the warmer outside air. So, to generate air movement, it may be preferable to use fans. At night time, on the contrary, the outdoor air enters in the building to cool it.

iv) The questionnaires. 100 questionnaires were distributed to the students (Table 3; two of them have not been filled in). They were all Indian nationals. All of them were assumed to be naturally acclimatized to the climate of Calcutta. Their age lied within 19 and 23 years old; 42 women and 58 men were interviewed. The questionnaire consisted of questions relating to subjective thermal sensation (TSV) and comfort (TCV). Seven point scales concerning the subjective perception of Humidity and Air Movement were also proposed.

For ease of understanding for the respondents who were more comfortable with Bengali, the regional language in the region, a Bengali version of the questionnaire accompanied the one in English, helping comprehension where required.

	SEX	**N.**	**AGE**				
			19	**20**	**21**	**22**	**23**
JU	**total**	**54**	**7**	**8**	**21**	**12**	**6**
	female	27	3	3	12	5	4
	male	27	4	5	9	7	2
MSIT	**total**	**46**		**11**	**25**	**9**	**1**
classroom 202	*total*	*28*		*7*	*15*	*6*	
	female	13		0	10	3	
	male	15		7	5	3	
Classroom 203	*total*	*18*		*4*	*10*	*3*	*1*
	female	2		2	0	0	0
	male	16		2	10	3	1

Table 3 shows the details of the population sample.

2.4 Analysis of votes; data elaboration.

This section presents the results of the questionnaire survey of thermal comfort condition in the two locations.

(i) Comparison of scales and votes.

The results of subjective responses to temperature (Thermal Sensation Vote = TSV) are presented in Figure 3. They show that the majority of the respondents voted neutral, slightly warm and warm sensations. The ASHRAE Standard 55-2005 [1] specified that an acceptable thermal environment should have 80% of occupants who vote for the central three categories (-1, 0, 1; question n. 1). In this study, only 60.2% voted within the central three categories showing that all two locations were outside ASHRAE's thermal acceptable conditions criteria. The results coming from the Bedford scale (TCV) are also shown in Figure 3, to compare them with the TSV. In this study, 70.5% of the total sample voted the central three categories: the percentage is 10.3% higher compared to the TSV.

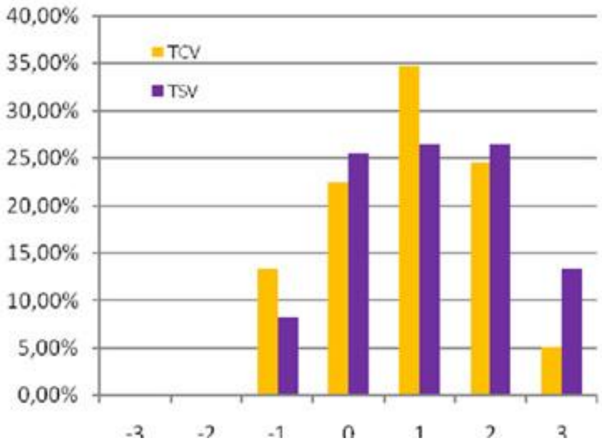


Figure 3: superimposition of TSV and TCV total sample.

(ii) Neutral temperature

The ISO standard 7730 based on Fanger's work [12] gives an equation relating thermal conditions to the ASHRAE seven point thermal sensation scale and it is known as the Predicted Mean Vote (PMV). The Predicted Percentage Dissatisfied (PPD) is calculated from PMV and predicts the percentage of people who are likely to be dissatisfied with a given thermal environment. Table 4 shows the TSV responses, the mean TSV, the PMV and PPD for all the zones surveyed. For JU, the choice was made to separate the analysis according to the differences of temperature recorded in the different zones: points 1 and 4 are taken together; the same for points 2, 3 and 5. Point 6 was analyzed separately (see figure n.1.d to find the position of the points). For MSIT, analysis was carried out separately for classroom n. 202 and 203. PMV and PPD were calculated. The clothing that the occupants wore could be categorized as light summer clothing (tropics), with a clothing insulation value of 0.5 clo. Their metabolic rate was estimated to be 1.2 met, which corresponds to sedentary activities. It is important to note that ISO7730 PMV has been calculated even though in all the surveyed zones the values of air temperature and air speed were beyond the upper limits (30°C and 1m/s) of validity of the equation. The output values are therefore given for information only. Quoting from ISO7730:2005 *"The index should be used only for values of PMV between −2 and +2, and when the six main parameters are within the following intervals: [...] air temperature 10 °C to 30 °C; air speed 0 m/s to 1 m/s"*.

Place	**T_{op} (°C)**	**TSV**							**mean TSV**	**PMV**	**PPD**
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**			
MSIT cl. 202	34,13	0	0	0	3	5	12	8	1.89	3.28	99.8
MSIT cl. 203	33,61	0	0	0	1	3	9	5	2	3,1	99.5
JU pt. 1,4	31,68	0	0	3	7	8	1	0	0.36	1.88	71.3
JU pt. 6	31,45	0	0	2	8	6	2	0	0.44	1.73	63.5
JU pt. 2,3,5	31,79	0	0	3	6	5	3	0	0.47	2	76.9

Table 4: profile of TSV and Calculated PMV and PPD Values for all Locations.

The neutral temperature is the temperature at which most people vote for "neutral" (0) in the seven point ASHRAE scale. Figure 4 shows the regression of mean TSV and operative temperature (T_{op}) respectively. To create this graph, TSV data have been regrouped around the mean vote. As it is possible to see comparing Fig.4 (regression mean TSV/T_{op}) and Fig. 5 (regression TSV/T_{op}), results concerning neutral temperature seem not to change if votes are regrouped, as also previous studies describe [20].

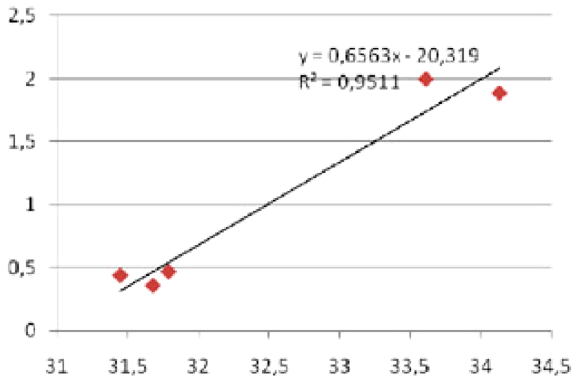


Figure 4. Regression of mean TSV on T_{op}

For every 1.5°C rise in T_{op}, a unit increase in TSV was observed.

The neutral temperature based on TSV regression is 30.9ºC with an acceptable range of 29.4ºC to 32.5ºC.

This range is much higher than the comfort range of 23 – 26 °C, specified in the Indian Codes [4,5]. This finding could have enormous energy implications in building design, HVAC design and architectural practice in India.

The results indicate a higher neutral temperature, compared to previous studies (Wong [50], De Dear [8;9], Busch [6], Hussein [20]). In table 5 it is possible to compare the results obtained from the present study with previous literature.

	Pellegrino et al.	Hussein et al.	Nyuk	De Dear	Busch	Rajasekar	Indraganti	Feriadi et al.	Wong et al.
Neutral T (TSV)	**30.9**	28.4	28.4	28.5	28.5	29	29.2	29.2	28.8

Table 5: a comparison of literature on neutral temperature.

Table 6 shows the mean TCV compared to the mean TSV. Figure 5 shows non-regrouped TSV and TCV. The neutral temperature resulting from TCV/T_{op} regression is 30.9°C, exactly the same obtained by TSV/T_{op} correlation.

	Top	**mean TSV**	**mean TCV**
MSIT 202	34.13	1.89	1.46
MSIT 203	33.61	2	1.17
JU C+B	31.68	0.36	0.37
JU F	31.45	0.44	0.17
JU A+E+D	31.79	0.47	0.44

Table 6: Mean TSV, mean TCV.

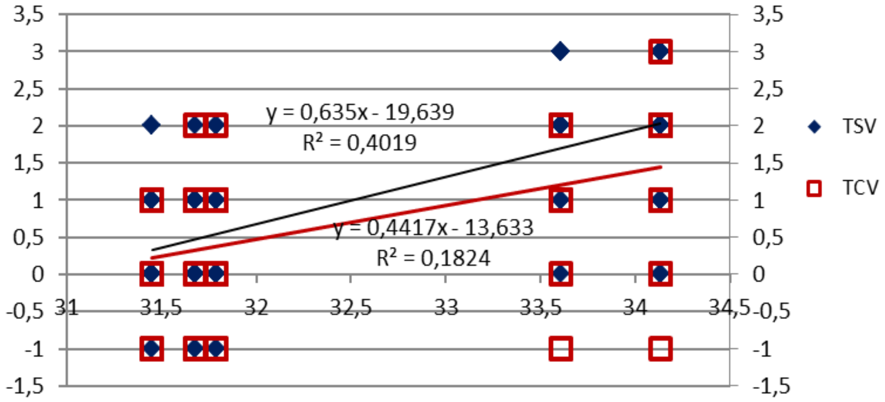


Figure 5: TSV and TCV regression on T_{op}.

(iii) The role played by air speed and humidity.

The results obtained indicate a high value for the neutral temperature. One possible explanation can be found in the analysis of the role played by air movement. In all the classrooms, both in JU and in MSIT, many fans were running continuously. As previously shown in Table 2, the air speed values were very high: from 0.9 to 2.3 m/s. Air movement detected by previous studies was often lower than this (0.5 m/s of mean for Indraganti, 0.3-1 m/s for Hussein, 0.5 of mean for Rajasekar). The current comfort standards such as ASHRAE 55 (1992, 2004) limit indoor air speeds to 0.4

m/s. But our observations are more in agreement with Khedari [27] who has recorded in Thailand comfortable air speeds up to 3m/s. It is also relevant to observe that the mean outdoor air speed in an open field in summer in Calcutta is very stable and generally above 2m/s.
It was very interesting to compare this data with the subjective responses coming from the questionnaires. In table 7 it is possible to see that, in a scale where (-3) means “much too still” and (+3) means “much too breezy”, 58.3% voted (-3,-2,-1); 25% voted (0), and only 16.7 voted (1). Even if the air speed was so high, especially if compared to the standard value, 76.1% of the sample felt quite comfortable with it (-1,0,1), or would have liked it to be even faster. It is also interesting to see the correspondence between Wind Sensation Vote (WSV) and TSV. The data does not correlate well. To understand the links between the values it was necessary to operate a multiple regression, involving Operative temperature ($T_{op)}$ and air speed (V_a).

TSV	**WSV**						
	much too still	too still	sligtly still	just right	slightly breezy	Subtotal	%
-1			2	2	3	7	7.3
0	1	3	9	7	5	25	26
1		5	15	4	4	28	29.2
2	3	6	5	6	4	24	25
3	1	4	2	5		12	12.5
Subtotal	5	18	33	24	16	**96**	
%	5.2	18.7	34.4	25	16.7		100

Table 7: subjective responses to air speed from the questionnaires.

The importance of air speed in comfort perception is fundamental and it has significant influence in the determination of the neutral point. Even before calculating the correlations, we observed that room 202 in MSIT, that had the highest Top, had a lower TSV compared to room 203, this could be possible thanks to the higher air speed (see table 2).

Multiple regression can help in understanding the weight of each parameter for comfort perception. The following equation was found:

$$\textbf{(2)}\quad \mathbf{TSV = 0{,}19\ T_{op} + 0{,}35\ WBT - 1{,}82{*}\sqrt{V_a}\ {-12{,}61}}$$

This equation is similar to the Sharma and Ali [43] one:

$$(3)\quad TSI = 0.745{*}T_{op} + 0.308{*}WBT - 2.06{*}\sqrt{V_a} + 0.841$$

This equation is closely similar to the Rajasekar [38] one:

$$(4)\quad TSV = 0.33{*}T_{op} + 0.04{*}WBT - 1.47{*}\sqrt{V_a} - 9.37$$

TSV = Thermal Sensation Vote, T_{op} = Operative Temperature (Degree C°), WBT = Wet Bulb Temperature (Degree C°), V_a = Air Speed (m/s)

Equation 1 has to be further investigated with the help of a wider database, in order to get a significant R value and better describe the multiple regression mechanisms.

Concerning relative humidity, ranging from 63.5% to 78.9%, 60.2% of the sample answered (-1,0,+1), whereas 38.8% answered that the air was humid or much too humid (Tab. 9, Fig. 6).

	HR					
scale values	TOTAL		MALES		FEMALES	
-3		0.00%		0.00%		0.00%
-2	1	1%	1	1.60%		0.00%
-1	6	6.10%	3	9.50%	3	8.60%
0	20	20.40%	11	17.50%	9	25.80%
1	33	33.70%	20	31.70%	13	37.10%
2	34	34.70%	26	41.30%	8	22.80%
3	4	4.10%	2	3.20%	2	5.70%
total	98		63		35	

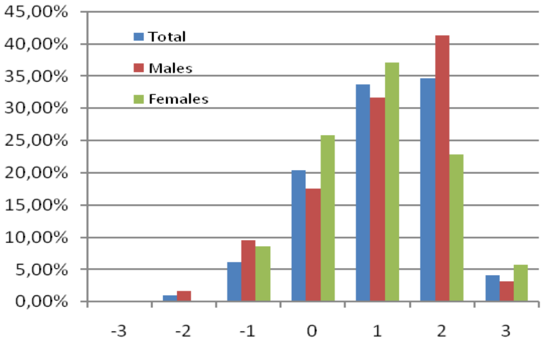


Table 9 and Fig. 6: subjective responses concerning relative humidity.

Conclusions.

The field study we carried out in Calcutta is a small scale study. A quite large number of subjective assessments has been collected (about 100 questionnaires), but it is referred to limited climate conditions. Only one specific period of the year has been monitored: temperatures aren't well distributed and don't cover all the possibilities of Calcutta climate. Further investigations and field surveys planned by the team will increase the number of observations and results will be compared with the present ones. Nevertheless, we think that the sample can represent an important step toward the investigations in Calcutta, being the first field study that has been carried out in the city. The number of data allows the creation of linear regressions and distribution graphs, as well as the proposition of a multi parameter equation.

Based on the subjective studies it is found that occupants in naturally ventilated schools belonging to the hot humid climate of Calcutta show acceptability to a wider range of environmental conditions than specified by ASHRAE and ISO standards, as well as by local codes (Indian Code).

Compared to previous studies, the results indicate a higher neutral temperature of 30.9ºC, with acceptable range of 29.4ºC to 32.5ºC. This latter difference may depend on the high speed of the air: the relative influence of the air speed is high, especially compared with the influence of air humidity, as equation (2) describes. The sample showed a good adaptability to high values of air movement: even if the air speed was high, 76.1% of the sample felt quite comfortable with it (-1,0,1), or would like it to be even faster.

Givoni's bio-climatic chart (fig. 1) shows that the climatic conditions in Calcutta are acceptable in different environments in different seasons. From inside a closed room in winter nights, to full sunlight in winter mornings, to the deep shade of a large tree in summer afternoons, letting the breeze flow freely underneath. The wind pattern is very stable in the hot months, almost always above 2m/s. Interestingly, this is similar to the kind of air speed that people find comfortable in our survey.

Our survey shows that ceiling fans are essentially used as a compensation for buildings which otherwise are amplifying the unfavorable effects like heat intake and reducing the favorable effects like cooling breeze.

These observations show:

1. The wide feasibility and practical acceptance of mechanical fans instead of air-conditioning for improving the comfort of naturally ventilated buildings in Calcutta for a comparatively extremely low energy consumption, even in the case when buildings are not well designed according to the climate.

2. A fortiori, research is urgently required for designing in dense urban environments in warm and humid climates, buildings which will be permeable to and amplify the beneficial aspects of the climate instead of making us more vulnerable to its uncomfortable aspects.

Acknowledgements

Authors would like to thank Prof. F. Nicol and Arch. A. Lall for advice and guidance during the preparation phases of field survey. Many thanks also to Prof. S. Bose (Jadavpur University) and Prof. B. Thakur (Meghnad Saha Institute of Technology) for allowing the development of the survey during their class hours. Finally, we thank the participants of 2012 NCEUB congress who, with their observations, gave to the authors a feedback on data analysis.

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