THERMAL COMFORT IN LOW-COST DWELLINGS: A CASE-STUDY IN CURITIBA, BRAZIL

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ABSTRACT

The main goal of the present study was to determine thermal comfort parameters for dwellers of low-cost houses for a given set of indoor environmental conditions. 112 people living in over 60 dwellings were interviewed, according to a comfort questionnaire where information regarding age, sex, clothing, level of activity, thermal sensation and preference of the subjects was collected. Environmental factors such as air temperature and humidity were simultaneously registered with T/RH data-loggers. Results were then analyzed by comparing subjective and environmental factors. Data consistency was checked out for specific parameter sets and the corresponding neutral, comfort temperatures were obtained by means of regression analysis. For the complete data set, a neutral temperature of 20.42ºC was achieved (indoor temperatures varied from 13.7ºC up to 26ºC – plotting air temperature and humidity in Givoni's Building Bioclimatic Diagram resulted in 29.5% of the hours in a cold situation and 70.5% within the comfort zone). Differences in the neutral temperature were observed between masculine and feminine, young and elderly subjects and for different sets of activity level, clothing and relative humidity. The relatively low neutral temperature obtained by this research showed a good correspondence to the results of a previously conducted pilot-study which generated a neutral temperature of 20.8ºC. It may be concluded that low-income dwellers in Curitiba –regarding its cold climate and the fact that local low-cost houses are usually neither insulated nor heated in winter– accept temperature conditions which are closer to the lower comfort limit, defined for developing countries as 18ºC.

KEYWORDS: Thermal comfort; low-cost houses; neutral temperature.

INTRODUCTION

Man's adaptation to the environment throughout History has always meant a struggle to survive. The capacity to adapt, related not only to the human species, characterizes all living systems. There must be, according to a principle of Cybernetics, self-regulating mechanisms which are responsible for the adaptation process of the system to its surrounding environment. This adaptation occurs basically at three different levels: biologically, through clothing and through the building envelope.

The first kind of human adaptation to the climatic environment was biological and responsible for the emergence of the different human races. Due to a purely biological process, a variety of biotypes, each with its own and unique form of adaptation (body mass, skin colour, body hair and others), spread all around the Earth with slow but steady migrations. The further developing of clothing resulted from the first rational process of seeking artificial control over heat gains and losses between the body and the climatic environment. The so called "third skin", the built environment, is not only a product of the human species. Olgyay (1963) exemplified this by describing the very simple shelter provided by the nest of different kinds of birds, suggesting a highly appropriate manner how to deal with harsh climatic conditions. An interesting approach of the systemic whole formed by man, the built environment and the climate is discussed by Markus and Morris (1980), where the users' response is the main parameter to evaluate the building's performance.

The first studies related to the field of thermal comfort were conducted in the 19th century as part of an effort to improve industrial productivity in the textile industry, in the metallurgy and in the mining industry (Szokolay, 1985). Later, with the development of mechanical systems of indoor climate control, came the first empirical and analytical studies. The studies of P. O. Fanger were mainly related to physiological aspects of thermal comfort and his reference book "Thermal Comfort" (1970) is still one of the most cited. The thermal comfort sensation, according to ASHRAE (1981), reflects "the condition of mind that expresses satisfaction with the thermal environment". This definition implies that the thermal comfort sensation is related not only to physical factors of the environment but also to subjective aspects of a person. Analytically, algorithms have been developed where the main factors influencing thermal exchanges between man and environment are taken into consideration. However, regarding the subjective characteristics of the thermal comfort sensation, the analysis must be of statistical nature.

In the present paper, indoor climatic conditions of air temperature and humidity were compared to people's response in several low-cost houses in Curitiba, Brazil. 112 people living in over 60 dwellings were interviewed, according to a comfort questionnaire where information regarding age, sex, clothing, level of activity, thermal sensation and preference of the subjects was collected. Results were then analyzed by comparing subjective with environmental factors.

METHODOLOGY

The methodology used was in agreement with Nicol's recommendations (*apud* Xavier and Lamberts, 1997), taking also into account Fanger's studies. The development of the present study occurred according to the following steps:

1. Application of thermal comfort sensation questionnaires with low-income dwellers and on site measurements of indoor air temperature and humidity;
2. Conversion of measured air temperatures to a reference relative humidity of 50%;
3. Prediction of neutral temperatures by means of regression analysis;
4. Verification of results' consistency.

The low-income people were interviewed at home within a period of two weeks in July 2001. The interviews took place in the *Vila Tecnológica de Curitiba*, a low-cost housing project consisting of 100 houses for the poor in the outskirts of the city. Information was collected regarding age, sex, clothing, level of activity, thermal sensation and preference of the subjects according to ASHRAE's seven point-scale (-3 cold; +3 hot). Simultaneously, environmental factors such as air temperature and humidity were registered with T/RH HOBO data-loggers. The data-logger was positioned in front of the interviewee with the sensor outside the case (this provides a shorter time constant and allows a quicker stabilization). Only those who were at least one hour at home were interviewed. An average height of 1 m was considered and ventilation rate was kept low.

The conversion of temperature data to a reference relative humidity of 50% was made by a decrease of 1.5K (for people with light clothing) up to 3K (heavy clothing), considering a relative humidity variation of 0 to 100%, according to Fanger (1970).

RESULTS

As a whole, 105 responses were considered reliable to be analysed. Temperature varied between 13.7 and 26ºC and relative humidity from 27.5 up to 79.4%. The conversion of indoor temperatures to a relative humidity of 50% yielded a temperature range of 10.9 to 25.1ºC. Figure 1 shows the measured temperatures versus the thermal sensation votes (the ASHRAE-scale plus 4 points).

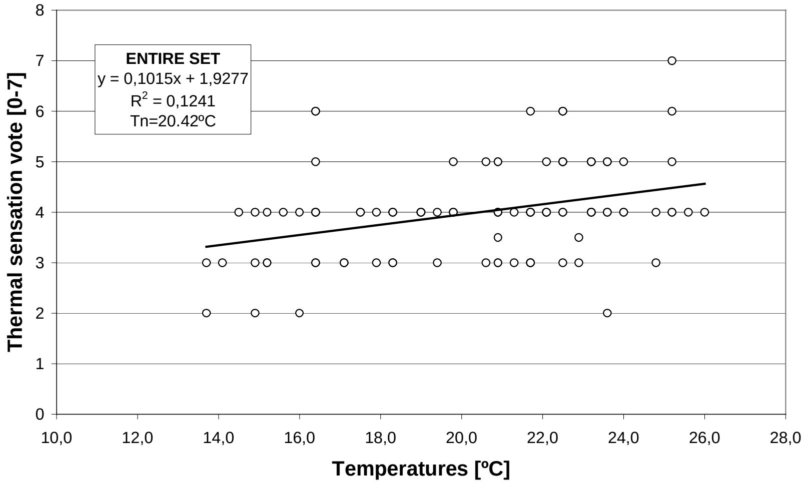

Figure 1: **Measured temperatures versus thermal sensation votes**

The determination coefficient R^2 of 0.1241 was quite low, suggesting that a multiple regression analysis would be more indicated. The regression equation provided a low neutral temperature (where y=4) of 20.42ºC, closer to the lower comfort limit of 18ºC for developing countries, according to Givoni (1992). This indicates a greater tolerance of Curitiba's low-income population concerning colder temperatures. The houses do not have any kind of air-conditioning and very low indoor temperatures were observed in winter (Krüger and Dumke, 2001). The next step was to generate regression equations and the resulting neutral temperatures for specific groups of data, according to: sex, age, activity level, clothing and air humidity. The results are shown in Table I.

Correlations between the generated regression equations and the people's actual, stated sensation was for all sets very low, therefore resulting neutral temperatures should be regarded as rough indicators of comfort preferences. However, the resulting data shows some consistency. Men preferred slightly higher temperatures than women, in agreement with previous studies of Fanger (1970), although Nevins *et al.* (*apud* Fanger, 1970) and later Tanabe *et al.* (1987) came to different results. Older people preferred higher temperatures (due to a decrease of basal metabolic rate with age), higher activity levels (increased muscular activity and heat generation) corresponded to lower comfort temperatures. Nevertheless, regarding clothing and relative humidity levels, the resulting data was unexpected. People with lighter clothes apparently preferred lower temperatures. In this case, it must be noticed that the regression analysis for people wearing up to 0.8 CLO yielded the lowest R^2 (less than 0.01). Also, higher humidity levels should, according to Fanger's studies, be compensated by a temperature drop. Kedhari *et al.* (2000) analyzed the effect of relative humidity in association with air movements on the thermal sensation, observing also a drop of the neutral temperature when humidity was higher. Concerning the presented results, that was not the case.

Table 1: **Regression equations and resulting neutral temperatures for specific groups of data**

Situation	Range	Responses	Regression equation	R^2	Neutral temperature [ºC]
General	0 - 105	105	Y=0.1015T+1.9277	0.1241	20.42
Women		62	Y=0.0614T+2.7504	0.0405	20.35
Men		43	Y=0.1495T+0.9141	0.3074	20.64
Age	06 – 38	75	Y=0.1051T+1.8844	0.123	20.13
	>38 - 70	30	Y=0.0931T+2.0245	0.126	21.22
Activity [W/m^2]	85 – 200	63	Y=0.1241T+1.4073	0.1683	20.89
	>200 - 440	42	Y=0.081T+2.4162	0.0866	19.55
Clothing [CLO]	0.1 – 0.8	47	Y=0.0292T+3.4805	0.0078	17.79
	>0.8 – 1.5	58	Y=0.129T+1.3874	0.2014	20.25
Relative Humidity [%]	27.5 – 53	61	Y=0.0936T+2.1813	0.1146	19.43
	>53 – 79.4	44	Y=0.0924T+1.992	0.0714	21.73

In order to adjust air temperature to its corresponding humidity level, the same procedure was used after converting temperature data to the reference relative humidity of 50%. Table II presents regression equations and resulting neutral temperatures for the same groups of data (except humidity).

Table II: **Regression equations and resulting neutral temperatures for specific groups of data (RH= 50%)**

Situation	Range	Responses	Regression equation	R^2	Neutral temperature [ºC]
General	0 - 105	105	Y=0.0959T+2.148	0.1194	19.31
Women		62	Y=0.0588T+2.8711	0.0399	19.20
Men		43	Y=0.1409T+1.2332	0.2934	19.64
Age	06 – 38	75	Y=0.093T+2.2344	0.1033	19.00
	>38 - 70	30	Y=0.1003T+1.9923	0.1584	20.02
Activity [W/m^2]	85 – 200	63	Y=0.1181T+1.6545	0.1676	19.86
	>200 - 440	42	Y=0.0754T+2.6157	0.0785	18.36
Clothing [CLO]	0.1 – 0.8	47	Y=0.0268T+3.5555	0.0061	16.60
	>0.8 – 1.5	58	Y=0.1209T+1.7013	0.1905	19.01

Similarly to Table I, regression coefficients were quite low. Also, the same group patterns are present in Table II. The inconsistency regarding clothing is also observed and the correlation for people wearing between 0.1 and 0.8 was again the lowest ($R^2=0.0061$).

DISCUSSION

Air temperature, humidity, presumed velocity, clothing and activity level were used as input data to the ANALYSIS software version 1.5 (LMPT/NPC, 1994) to calculate the predicted mean vote (PMV) according to Fanger's equation:

$$PMV=[0.303\exp(-0.036M)+0.028]L \qquad \text{[Eq.1]}$$

where:

M is the metabolic rate

L is the thermal load on the body.

The determination coefficient between calculated and declared thermal sensation was rather low ($R^2=0.04$) for the 63 votes taken into account in this comparison (those whose metabolic activity was lower than 200W/m²). This may suggest: 1) that Fanger's equation does not apply to the collected data and 2) that the collected data presents inconsistencies. The non-accordance between declared sensation votes and calculated PMV's has also been verified in other field surveys (Xavier, 2000; Vergara and Lamberts, 2001). Concerning the data sample, following aspects may have contributed to inconsistencies in its results:

- The great dispersion observed in the regression analysis indicates possible understanding problems on the part of the interviewed people: the substantial difference between regression coefficients for men and women (0.0405 compared to 0.3074), may indicate problems regarding the full understanding of the thermal sensation scale. Women, in the majority housewives, were more numerous in the sample and may have had difficulties to understand the purpose of the questionnaire and the thermal sensation scale.
- Also, one must consider the low educational level of the low-income population, which may have lead to difficulties concerning empirical research and the scientific method.
- Differently to the field surveys of Fanger, Nevins *et al.* and Tanabe, measurements and questionnaires were carried out under non-controlled conditions. Subjects were at their own homes performing everyday activities under different environmental conditions.
- Children votes were also taken into account.

Nevertheless, understanding that the obtained results are mere indicators of the average comfort temperature of low-income dwellers in Curitiba, which must fluctuate between 17.8 and 21.7ºC (Table 1), a comparison was made with the algorithms of Humphreys and Auliciems. Humphreys correlated mean neutral temperatures resulting from over 60 comfort studies around the world, varying between 17 to 31ºC, to local outdoor temperatures (Szokolay, 1985). For non-air-conditioned buildings, the neutral temperature can be calculated according to the formula:

$$T_n=11.9+0.534T_{avg,out} \quad \text{[Eq.2]}$$

Auliciems added more data to Humphreys', having included in his final data 52 studies and 250,000 individual votes. Auliciems' equation is as follows:

$$T_n=17.6+0.31T_{avg,out} \quad \text{[Eq.3]}$$

Three conditions were considered for the average outdoor temperature: the monthly average outdoor temperature, measured by the local meteorological station for July 2001; the average for the days during which interviews took place (between July 12th and 18th); and the average calculated for the periods of hours of interviews. Table III presents the results of both equations regarding these three distinct periods.

Table III: **Using algorithms to predict neutral temperatures**

	Equation	**T_n [ºC], month**	**T_n [ºC], days**	**T_n [ºC], hours**
Humphreys' equation	$T_n=11.9+0.534T_{avg,out}$	19.6	19.3	20.3
Auliciems' equation	$T_n=17.6+0.31T_{avg,out}$	22.1	21.9	22.5

The neutral temperature resulting from the regression analysis of 20.42ºC or the corrected one for RH=50% of 19.31ºC are in accordance with the results of Humphreys' algorithm, calculated for the monitoring period, but lower than those resulting from Auliciems' equation. Auliciems excluded some of Humphreys' initial data, which considered preferred temperatures in colder climates, to establish his equation. The good correspondence between neutral temperatures resulting from the regression analysis and those from Humphreys' equation may relate to the characteristics of local climate (with over 70% of the yearly hours in thermal discomfort due to cold) and to the fact that the houses are non-heated.

CONCLUSIONS

The results have shown that the neutral, comfort temperature of the considered low-income population in Curitiba, Brazil, is situated around 20ºC. This confirms a previous pilot-study with the same population which yielded a neutral temperature of 20.8ºC, based on 34 thermal sensation votes (Krüger *et al.*, 2001). This low temperature reflects the extreme conditions experienced by the low-income population in Curitiba regarding thermal comfort, indicating in an indirect manner the low thermal performance of their houses.

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