ESTIMATION OF RELATIVE HUMIDITY FOR THERMAL COMFORT ASSESSMENT

Eduardo L. Krüger
Programa de Pós-Graduação em Tecnologia
Centro Federal de Educação Tecnológica do Paraná
Av. Sete de Setembro, 3165
Curitiba/PR - 80.230-901 - Brazil
tel: [41]310-4711, fax: [41]310-4712
e-mail: krueger@ppgte.cefetpr.br

ABSTRACT

Estimating relative humidity from outdoor air temperature and humidity, and indoor air temperature is a means to assess thermal comfort conditions when indoor relative humidity is not available. Buildings in tropical countries are usually well ventilated in the summer and show a large infiltration area. Considering that sources of moisture are minimal in such cases, indoor absolute humidity can be assumed to be the same as the outdoor value. However, if the indoor relative humidity is not available, it can be estimated from measured outdoor air temperature and humidity by converting these to absolute humidity, which would be assumed to be the same in- and outside. Provided that indoor air temperature is known, it is then possible to calculate relative humidity. In this paper, relative humidity estimates were compared with measured relative humidity values in four different low-cost houses in Curitiba-Brazil (latitude = 25^{o}, altitude = 914m). This comparison comprises: a) a statistical analysis and b) the evaluation of comfort levels on the Building Bioclimatic Chart. In the statistical analysis, correlation coefficients were analyzed and in the evaluation of comfort, measured and estimated values were plotted in the chart and the percentage of hours within each zone was compared. The four different construction systems were: a wood board house, plastered on both sides; a reinforced concrete-panel house; a reinforced polystyrene plastered board houses; and, a house made of pre-molded pillars spaced with concrete prefabricated plates. These four houses were occupied during the monitoring period. Measurements (with HOBO data-loggers) were carried out in 15 days with a sampling time of 15 minutes.

INTRODUCTION

When indoor relative humidity is not available, an estimate can be obtained from external (outdoors) air temperature and humidity and internal (indoors) air temperature. This correlation between relative humidity estimates and actual values can be quite substantial, especially in buildings where the tropical weather predominates. In such places, ventilation is a necessity in the summer period when leakage area in windows and in the building envelope is considerably high.

The importance of obtaining relative humidity data of a specific environment is particularly related to the possibility of plotting these values in the psycrometric chart or in the so called Building Bioclimatic Chart (GIVONI, 1969; WATSON & LABS, 1981), simplifying, then, the thermal evaluation of the building.

In this paper, a statistical comparison as well as a bioclimatic evaluation was proceeded for four different low-cost houses, taking measured relative humidity values as reference. The procedure of plotting both, temperature and humidity data in the psycrometric chart, was conducted with the ANALYSIS software (developed at the Laboratório de Eficiência Energética em Edificações of the Universidade Federal de Santa Catarina - LabEEE/NPC/UFSC), used in similar researches (KRÜGER & LAMBERTS, 1999; 2000).

ESTIMATING RELATIVE HUMIDITY

The estimation was made considering the following assumptions: a) ventilation rates between in- and outdoors are not to be despised, due to building shape and volume (small volume and insufficient control of leakage areas), and b) generation of internal moisture is minimal.

Therefore, the procedure consisted in obtaining outdoor absolute humidity, calculated from measured temperature and relative humidity data, assuming it to be the same indoors, and converting it to relative humidity with indoor temperature data.

The equation 1 (ASHRAE, 1981), which follows, was used in order to convert outdoor temperature and relative humidity in absolute humidity (and vice versa for the interior):

$$w = 0.62198 \times \left[\frac{\phi}{100} \times p_{ws} \right] \times \left[p - \frac{\phi}{100} \times p_{ws} \right]^{-1}$$

(Eq. 1)

where:

w	=	absolute humidity [Pa/Pa]
p	=	atmospheric pressure [Pa]
ϕ	=	relative humidity [%]
p_{ws}	=	saturation pressure [Pa], function of temperature T [K]

Atmospheric pressure was kept constant for the corresponding altitude of 917m above sea level.

Saturation pressure for the temperature range of -100ºC to 0ºC was calculated as follows (ASHRAE, 1981):

$$\ln(p_{ws}) = C_1/T + C_2 + C_3 \times T + C_4 \times T^2 + C_5 \times T^3 + C_6 \times T^4 + C_7 \times \ln(T)$$

(Eq. 2)

and for the temperature range of 0ºC to 200ºC (ASHRAE, 1981):

$$\ln(p_{ws}) = C_8/T + C_9 + C_{10} \times T + C_{11} \times T^2 + C_{12} \times T^3 + C_{13} \times \ln(T)$$

(Eq. 3)

where:

p_{ws}	=	saturation pressure [Pa]
T	=	absolute temperature [K]
C_1-C_{13}	=	non-dimensional constants

MONITORING

Measurements were carried out in two different periods (from July 5th to July 18th and from July 18th to July 31st, 2000) by using HOBO data-loggers (Table 1). Sampling time was 15 minutes and samples were converted into hourly values.

The low-cost houses, with an average area of 38 m², were being occupied by the families during the monitoring period. The four evaluated building systems are the following:

- Building system A: a reinforced concrete-panel house;
- Building system B: a wood board house, plastered on both sides;
- Building system C: a reinforced, polystyrene plastered board house; and,
- Building system D: a house made of pre-molded pillars spaced with concrete prefabricated plates.

RESULTS

The comparison of the thermal performance of the building systems should be made in pairs and preferably in relation to outside conditions (Table 2, last column). In the first monitoring period, the building systems A and B presented similar temperature profiles and percentages in the comfort zone (Fig. 1 and 2), which were higher than the outside figures. In the second monitoring period, both building systems C and D presented lower percentages in the comfort zone than the outside ones. Nevertheless the massive use of insulation in the building system C prevented higher temperature amplitudes, which were observed in the building system D. It can be beneficial in cooler periods, but may result in thermal discomfort in hotter periods (compare Fig. 3 and 4).

In the major comparison between measured and estimated data (Table 2), correlation (R) and determination (R^2) coefficients were substantial for the four analyzed building systems. As for the results of the data plotted in the building bioclimatic chart, the greatest difference of hourly percentages in the comfort zone was noticed in the building system B. In Fig. 2 substantial differences between measured and estimated relative humidity can be clearly observed. They occur mainly in the coldest hours, specifically from the night of 07/12 to the end of the monitoring period.

The coldest day (Table 3) was the one when the lowest internal air temperature took place in each building system. In that day, a good correspondence between measured and estimated values was observed at the psycrometric chart. This could be explained by the very low temperature profile inside the houses. Considering that below 18°C (lower limit of Givoni's comfort zone), relative humidity (even if caused by different agents) is not relevant to the definition of a *bioclimatic zone,* it does not affect the results, which invariably correspond to thermal discomfort due to cold. Nevertheless, in the statistical analysis, correlation and determination coefficients were mostly low, with the exception of building system D (Fig. 4), which pointed out a good correlation between measured and estimated data in every analyzed case (global, coldest day, comfort situation, and hottest day).

The comfort situation (Table 4) comprehends the time period when air temperature varies within the temperature limits of 18°C and 29°C. In this situation, correlation coefficients rose substantially, compared with the coldest day ones. This rise could be explained by the existence of increased ventilation rates. The exception was the building system C, in which hours within this temperature limits were non-existent. Percentile differences in the building system B psycrometric chart become clear when the points that characterize them can be observed in the comfort borderline. In this case, the distribution of the hours in adjacent zones is related to the fact that the estimate values are higher than the measurements.

The hottest day (Table 5) was the one when the hottest internal air temperature took place in each building system. In that day, both correlation and determination coefficients were high in almost all building systems, presenting a prefect correspondence between values in the comfort zone. The exception was building system C, in which indoor temperatures are lower than outside ones and thermal performance is inferior than the one pointed out in building system D, which was monitored at the same period. The most common complaint about this particular building system refers to condensation and mould formation in its walls.

CONCLUSIONS

The analysis of the test reference year (TRY) of Curitiba (Fig.5) indicates that only 20% of the yearly hours are situated in the comfort zone whereas 73.2% correspond to thermal discomfort due to cold. Most of these hours are situated in the zone 7 (Thermal Mass/Solar Heating), where humidity is relevant only between 18°C and 20°C. Thermal discomfort due to excessive heat is not significant. Thus, errors in the estimation of relative humidity, considering the TRY of Curitiba, should not have a significant influence on the zones and strategies definition.

In summer, the percentage of hours in the thermal comfort is low and there is thermal discomfort due to cold (zone 7: Thermal Mass/Solar Heating) and due to heat (zones 2 and 3: Ventilation and Evaporative Cooling). Considering that warmer temperatures usually require the use of ventilation, the approximation of temperature and moisture patterns in and outside should favor the estimation of relative humidity. In winter, most of the hours are situated in the zones 8 and 9 (Passive Solar Heating and Artificial Heating) where errors in the estimates have no influence on the zones and climate control strategies definition.

REFERENCES

American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE). **Handbook of Fundamentals**. Atlanta : ASHRAE, 1981.

GIVONI, Baruch. **Man, Climate and Architecture.** Amsterdam : Elsevier,1969.

GOULART, Solange; LAMBERTS, Roberto & FIRMINO, Samanta. **Dados Climáticos para Projeto e Avaliação Energética de Edificações para 14 Cidades Brasileiras.** Florianópolis, Núcleo de Pesquisa em Construção / UFSC, 1997.

KRÜGER, Eduardo; LAMBERTS, Roberto. Avaliação do desempenho térmico de casas populares. In: VIII ENCONTRO NACIONAL DE TECNOLOGIA NO AMBIENTE CONSTRUÍDO. (2000 : Salvador). **Proceedings...** Salvador : ANTAC/UFBA, 2000.

KRÜGER, Eduardo; LAMBERTS, Roberto. Evaluation of the thermal performance of low-cost houses under tropical climatic conditions. In: PLEA CONFERENCE ON PASSIVE AND LOW-ENERGY ARCHITECTURE, 17., 1999, Brisbane, Australia. **Proceedings...** Brisbane : University of Brisbane, 1999.

WATSON, Donald; LABS, Kenneth. **Climatic Building Design.** New York : McGraw-Hill, 1981.

ACKNOWLEDGEMENTS

To the M.Sc. Students of the Programa de Pós-Graduação em Tecnologia from the Centro Federal de Educação Tecnológica do Paraná, especially to the Architect Eliane Müller Seraphim Dumke and to the Civil Engineer Ariel Orlei Michaloski. I would also like to thank the staff of the Laboratório de Eficiência Energética of the Universidade Federal de Santa Catarina (LabEEE/NPC/UFSC) for the loan of the data-loggers.

TABLES

Table 1: Monitoring period

Building Systems	Monitoring		Text [ºC]			Tint [ºC]		
	Start	End	Min	Max	Aver	Min	Max	Aver
A	07/05//2000 7 PM	07/18/2000 9 AM	-3.3	27.7	11.7	4.6	24.6	14.6
B	07/05/2000 7 PM	07/18/2000 9 AM	-3.3	27.7	11.7	4.1	24.0	14.3
C	07/18/2000 11 AM	07/31/2000 1 AM	-1.4	25.9	10.3	10.4	18.5	13.9
D	07/18/2000 5 PM	07/31/2000 7 AM	-1.4	25.9	10.2	5.9	20.2	12.8

Table 2: Major comparison between measured and estimated data

	R	R^2	Hours Percentages [%]								
			Measured			Estimated			External		
			Cold	Comf.	Heat	Cold	Comf.	Heat	Cold	Comf.	Heat
A	0.84	0.71	68.0	31.0	1.0	68.3	30.4	1.3	80.9	18.5	0.7
B	0.93	0.86	69.6	30.4	0	73.9	25.1	1.0	80.9	18.5	0.7
C	0.82	0.67	100	0	0	99.3	0.7	0	89.8	8.9	1.3
D	0.90	0.81	94.4	5.6	0	94.1	5.9	0	90.1	8.6	1.3

Table 3: Comparisons for the coldest day

	R	R^2	Hours Percentages [%]					
			Measured			Estimated		
			Cold	Comf.	Heat	Cold	Comf.	Heat
A	0.49	0.24	100	0	0	100	0	0
B	0.47	0.22	100	0	0	100	0	0
C	0.46	0.21	100	0	0	100	0	0
D	0.90	0.82	100	0	0	100	0	0

Table 4: Comparisons for the comfort interval (18ºC ≤DBT≤29ºC)

	R	R^2	Hours Percentages [%]					
			Measured			Estimated		
			Cold	Comf.	Heat	Cold	Comf.	Heat
A	0.87	0.76	7.6	89.5	2.9	12.4	83.8	3.8
B	0.89	0.79	7.1	92.9	0	20.4	76.5	3.1
C	-	-	-	-	-	-	-	-
D	0.84	0.71	5.6	94.4	0	0	100	0

Table 5: Comparisons for the hottest day

	R	R^2	Hours Percentages [%]					
			Measured			Estimated		
			Cold	Comf.	Heat	Cold	Comf.	Heat
A	0.94	0.89	20.8	79.2	0	20.8	79.2	0
B	0.94	0.88	29.2	70.8	0	29.2	70.8	0
C	0.49	0.24	100	0	0	91.7	8.3	0
D	0.92	0.84	62.5	37.5	0	62.5	37.5	0

FIGURES

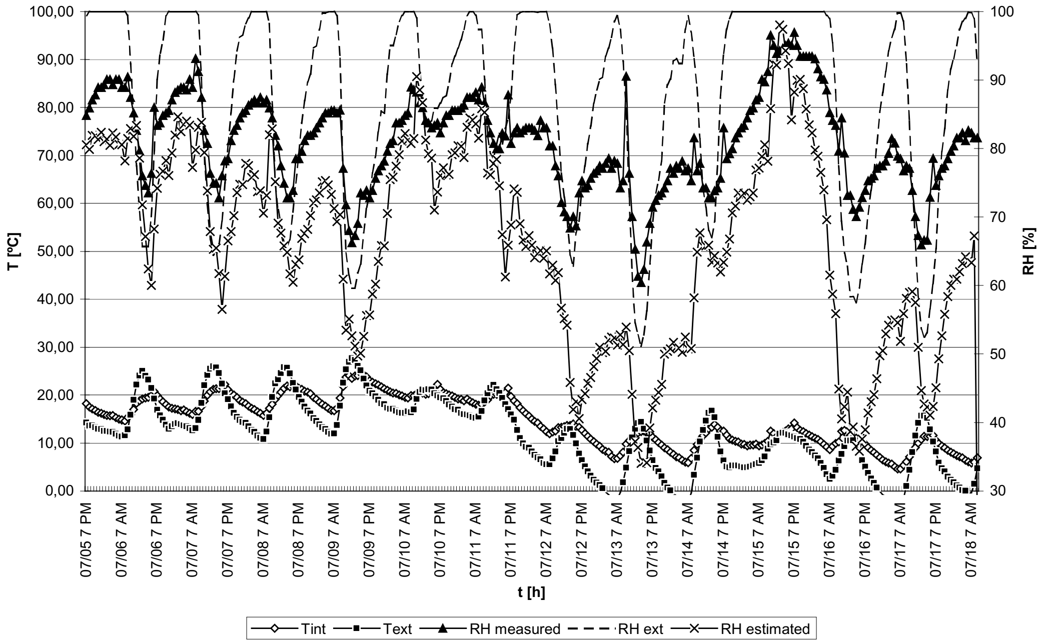

Figure 1: Temperatures and relative humidities for Building System A

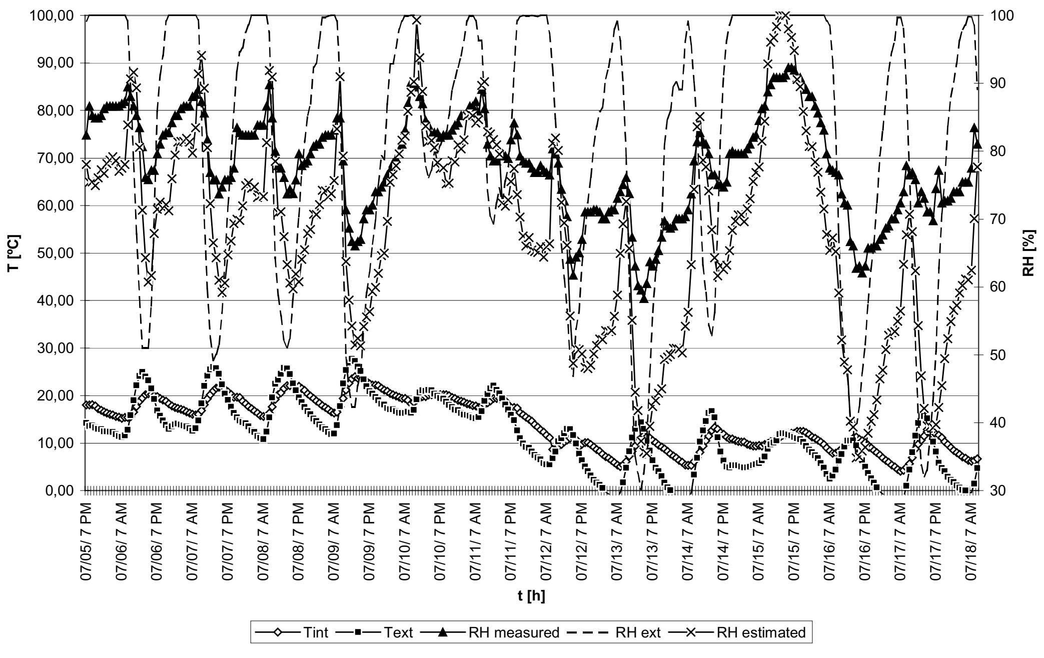

Figure 2: Temperatures and relative humidities for Building System B

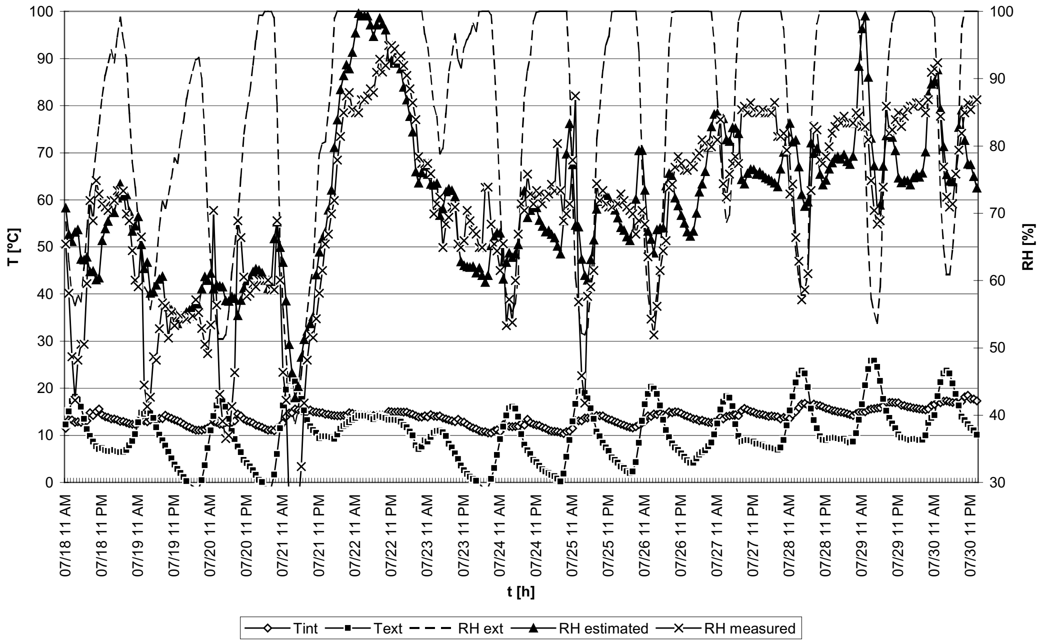

Figure 3: Temperatures and relative humidities for Building System C

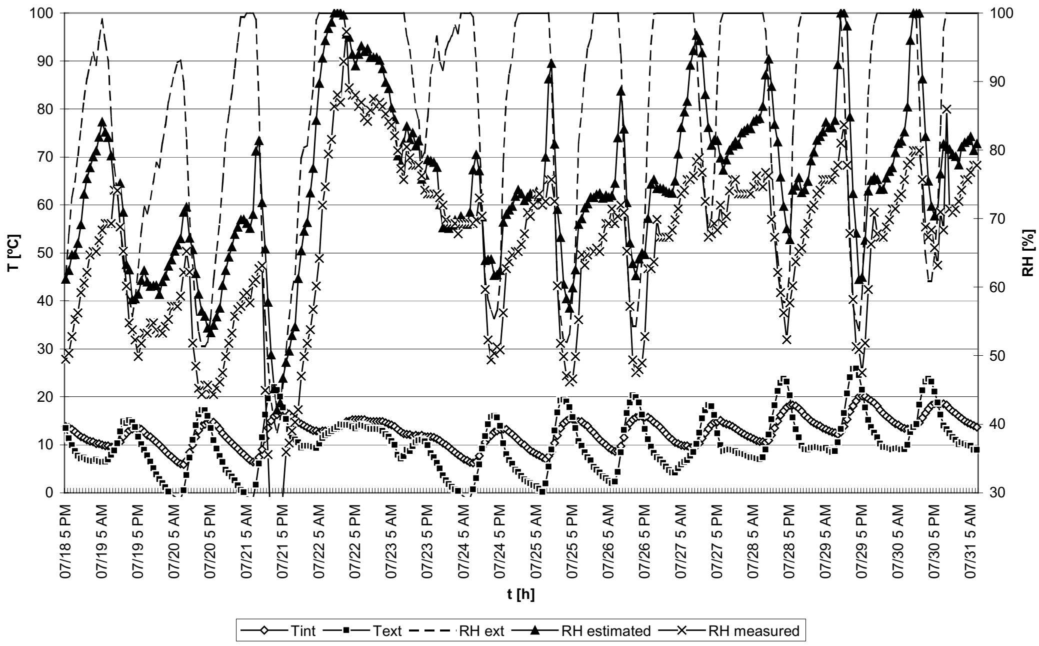

Figure 4: Temperatures and relative humidities for Building System D

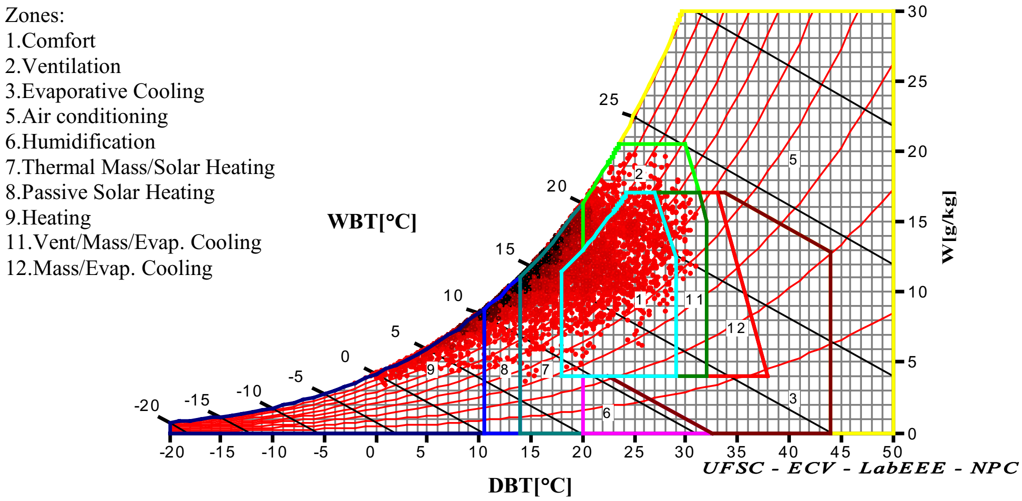

Figure 5: Bioclimatic evaluation for Curitiba, i.e., air temperature and humidity throughout the year for the test reference year (TRY)