PARAMETRIC ANALYSIS APPLIED TO THE THERMAL PERFORMANCE EVALUATION OF LOW-COST HOUSES: A CASE-STUDY IN CURITIBA, BRAZIL

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ABSTRACT

The construction of dwellings for people with low incomes in developing countries encompasses a broad range of issues starting from the choice of the building site, to the construction phase and finally to the evaluation of the building itself. For tropical climates, the thermal evaluation of low-cost dwellings should be primarily related to the optimization of internal comfort conditions. Usually low-cost housing projects are implemented throughout Brazil equally, with no concern to the climatic region where houses are to be built. In this way, the same building system is applied in cities with very distinct characteristics. To correct these distortions, projects such as the research project *Normalização em Conforto Ambiental* (Standards Development for Comfort in the Built Environment) are being developed in Brazil, with the aim of: helping to develop standards which promote buildings that are adequate for the climate. The Technological Village of Curitiba, the first to be implemented in Brazil, consists of 100 houses that are being inhabited, and 20 houses in the Street of Technologies which are displayed for public visitation, built with different materials and building systems. The first step of the present research consisted of a thorough evaluation of the thermal performance of the Village's 18 different building systems. The houses were occupied during the monitoring of air temperature and relative humidity (with data-loggers of the kind HOBO), which were carried out in winter and in summer. Measured data was then compared to specific parameters based on the recommendations of the Brazilian Comfort Norm. The last step of the research was to perform a parametric analysis of wall and roof thermal transmittance and time-lag and, by doing so, subsidize the development of the referred Norm. In this analysis, an statistical evaluation and thermal simulations were performed in order to verify the influence of the mentioned parameters in the thermal performance of low-cost houses.

KEYWORDS: Thermal performance; low-cost houses; thermal simulations

INTRODUCTION

Curitiba (latitude = 25^{o} S, altitude = 910m) is characterized by a humid subtropical climate. The high humidity of the air, associated to the high daily and yearly amplitudes of air temperature (negative values are frequent in winter) cause thermal discomfort to its population. Furthermore, local architecture, by following imported standards, shows a great inadequacy regarding climate response, specially in the case of low-cost housing. Having as a goal the development of patterns that favor adequate houses regarding local climate, projects such as the development of a Thermal Performance Norm [1] have been taking place in Brazil. The purpose of the present paper is to assist the development of this Norm by on site monitoring of different low-cost houses, adjusting or confirming the limits proposed by the Thermal Performance Norm. For that purpose, the technological village of Curitiba was used as research object. The building parameters which were taken into account were: wall transmittance and time-lag; roof transmittance and time-lag. Data resulting from the monitoring was compared to calculated data regarding these parameters and an statistical analysis was performed, with the aim of assessing correlations between the thermal performance and the thermophysical properties of the set of houses which were monitored. Thermal simulations were then used to test the effect of the variation of the referred parameters on indoor comfort in order to confirm statistical correlations.

METHODOLOGY

In the development of the research, the following procedure was chosen:

1. Choice of the building systems to be evaluated;
2. Definition of the monitoring periods;
3. Monitoring with HOBO data-loggers;
4. Bioclimatic evaluation of the results;
5. Comparison of the results with the recommended parameters of the Comfort Norm;
6. Parametric analysis of wall and roof transmittance, inertia and solar factor (statistical);
7. Testing the influence of thermophysical properties on the thermal performance of low-cost houses (thermal simulations).

THE TECHNOLOGICAL VILLAGE OF CURITIBA

The Technological Village of Curitiba was opened in May 1994 and consists of 100 houses destined for the low-income population. The houses are built with different materials and according to 18 different building systems. In this research, 18 occupied houses made with different building materials and according to each building system were evaluated. Their description and the thermophysical properties of wall and roof constructions are shown in Table I.

MONITORING

The thermal evaluation was performed with indoor temperature measurements in the chosen houses. In order to have more precise information about the thermal environment, occupation schedules and patterns were also observed. Measurements were taken with HOBO data-loggers and carried out in two different periods: in winter, from July 9th to August 3rd, 2000 and in summer, from December 12th, 2000 to January 10th. The data-loggers were set to record air temperature and humidity with a sampling time of 15 minutes.

LOCAL CLIMATE

The coldest capital of Brazil has an average height of 910 m above sea level, latitude 25°31'S and longitude 49°11'W. Of the 8 bioclimatic zones defined in the Brazilian Thermal Comfort Norm, Curitiba belongs to the first one, which corresponds to only 0.8% of the national territory. According to the Norm, the main strategies with regard to passive building design are solar heating and thermal inertia. The recommended thermal characteristics are the following [1]:

- Wall transmittance should be equal or less than 3.00W/m²K;
- Roof transmittance should be equal or less than 2.00W/m²K;
- Wall time-lag should be equal or less than 4.3h;
- Roof time-lag should be equal or less than 3.3h.

Table I: **Thermal characteristics of the building systems**

Building System	Uwall [W/m²K]	Uroof, winter [W/m²K]	Uroof, summer [W/m²K]	ϕwall [h]	ϕroof, winter [h]	ϕroof, summer [h]
1. Concrete panels	2,76	2,50	1,80	3,60	3,90	3,90
2. Wood panels	3,70	3,75	2,02	0,90	0,50	0,50
3. Wood panels	3,16	2,80	2,01	1,10	0,80	0,80
4. Mineralized wood boards	1,59	2,45	1,57	4,40	1,40	1,40
5. Polystyrene plastered boards	0,39	0,80	0,74	5,80	7,00	7,00
6. Earth cement bricks	2,88	2,80	2,01	2,80	0,80	0,80
7. Hardwood boards	3,44	2,80	2,01	1,80	0,80	0,80
8. Masonry, insulated	0,53	2,48	1,84	5,40	0,80	0,80
9. Lightweight concrete panels	1,84	3,75	2,01	2,40	0,60	0,60
10. Fiber cement panels	2,53	3,75	2,02	1,70	0,50	0,50
11. Concrete panels with air cavity	2,74	4,61	2,25	2,50	0,80	0,80
12. Concrete boards	5,22	2,80	2,01	1,00	0,80	0,80
13. Concrete panels with air cavity	2,55	4,61	2,25	4,00	0,80	0,80
14. Concrete panels with polystyrene inner layer	1,35	2,80	2,01	3,20	0,80	0,80
15. Ceramic hollow blocks	2,48	3,75	2,01	2,40	0,60	0,60
16. Concrete hollow blocks	3,30	2,82	2,02	3,40	0,80	0,80
17. Concrete boards	5,22	2,80	2,01	1,00	0,80	0,80
18. Concrete panels	4,64	4,73	2,26	2,16	0,30	0,30

PARAMETRIC ANALYSIS: STATISTICAL

Monitoring results in terms of air temperature and humidity were plotted in Givoni's Building Bioclimatic Chart and the percentage of hours of thermal comfort or discomfort assessed, considering the temperature limits of 18ºC and 29ºC [2]. Figures 1-4 present these results versus both mentioned thermophysical properties of the 18 dwellings (thermal transmittances and inertias, Table I). For the winter period, regarding thermal transmittance (Fig. 1) and thermal inertia (Fig. 2), no correlation can be identified in the graphs between the thermal properties of the building envelope and its thermal performance, suggesting that other parameters may be far more determinant of thermal comfort.

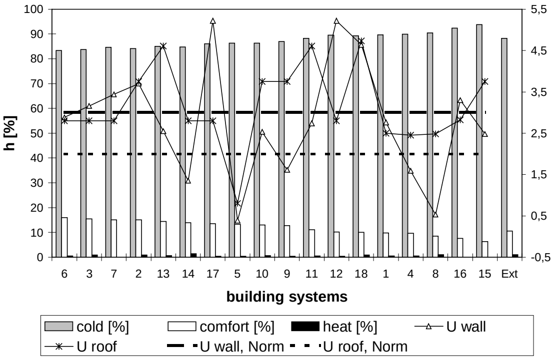

Figure 1: **Comfort levels and transmittances in winter**

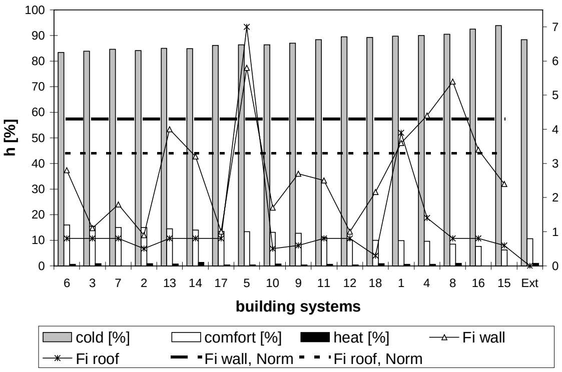

Figure 2: **Comfort levels and inertias in winter**

As for the summer period, analyzing both graphs regarding their tendency, one verifies clearly that while in the transmittance graph (Fig. 3) thermal performance worsens for higher transmittance values, the thermal inertia graph (Fig. 4) shows the opposite, which could mean that the recommended thermal inertia limits should be regarded as minimal and not as maximal.

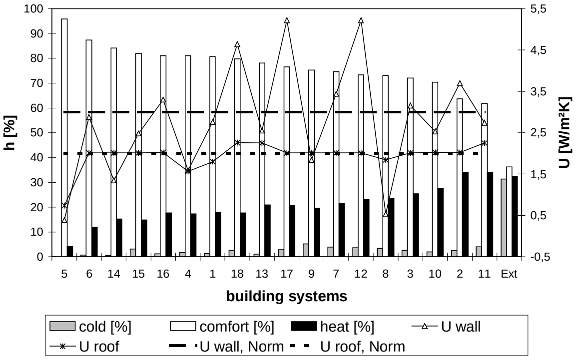

Figure 3: **Comfort levels and transmittances in summer**

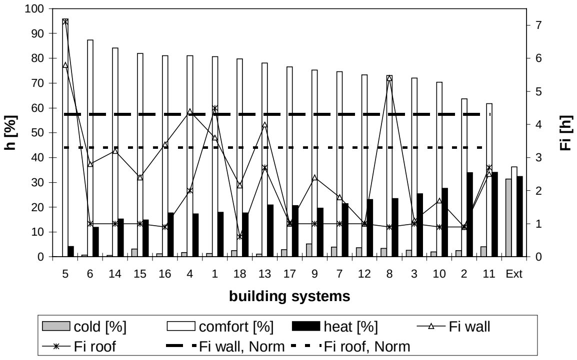

Figure 4: **Comfort levels and inertias in summer**

Thus, by comparing both winter and summer situations, while in summer the thermal properties of the building envelope seem to excert an influence over the thermal performance of the houses, in winter, other factors will affect thermal performance, independently or not.

In order to quantify the degree of influence of both parameters (thermal transmittance and inertia) in the thermal performance of the monitored low-cost houses, regression analysis was performed for three different kinds of analysis: percentage of hours of comfort; degree-hours of cold and heat for the winter and summer periods, considering a Tbase of 18ºC and 29ºC; and minimum and maximum temperatures for winter and summer, respectively.

Table II: **Correlation coefficients (R) between thermal properties and: a) percentage of hours of comfort; b) degree-hours of cold and heat; and c) minimum and maximum indoor temperatures**

Thermophysical Properties	**Correlation coefficients (R)**					
	Winter (hours of comfort)	**Summer (hours of comfort)**	**Winter (Tbase <18ºC)**	**Summer (Tbase >29ºC)**	**Winter (average of the minima)**	**Summer (average of the maxima)**
Uwall	0,08	0,35	0,31	0,27	0,48	0,29
φwall	0,29	0,58	0,27	0,41	0,66	0,35
Uroof	0,04	0,60	0,51	0,33	0,61	0,32
φroof	0,01	0,46	0,50	0,10	0,67	0,07

From Table II, it can be noticed that the highest R-value is related to the thermal inertia of the roof in winter (sixth column). As for the summer period, the highest correlation had also the roof, with its thermal transmittance (third column). The importance of the roof in the thermal performance of single, one-storyed houses is related to its heat gains in summer due to a greater surface area and to the heat storage capacity of the attic in winter, specially for the latitude of Curitiba, close to the Tropic of Capricorn, where the Sun is not that low in winter.

Regarding walls, correlation sets indicate the thermal inertia as the main parameter related to the thermal performance of the houses, for the three sorts of analysis performed, both for summer and winter. Differences between the three types of analysis, particularly between the first and the last two, are due to the fact that the latter express the intensity of thermal discomfort, whereas the plain analysis of the percentage of comfort and discomfort hours is strongly related to the data sample. In summer there was a broader range of comfort hours than in winter, where thermal discomfort due to cold was rather high, thus the very low R-values for that period.

PARAMETRIC ANALYSIS: THERMAL SIMULATIONS

The French software COMFIE (*Calcul d'Ouvrages Multizones Fixé à une Interface Experte)* was used for thermal simulations of the monitored houses. The software is a simplified simulation tool using modal analysis, requiring information regarding global characteristics of the building, wall materials, compositions and building finishes, glazing, occupancy schedules, shading features as well as basic climatic data concerning the building site (local hourly air temperatures and humidities and solar radiation data). Outputs are hourly minimum, mean and maximum temperatures for each zone considered with the corresponding heating load [3].

For both monitoring periods (winter and summer), 12 days were used as climatic input data to the COMFIE software in order to perform simulations with 3 of the 18 monitored houses: building systems 3, 8 and 16. The choice of the houses for thermal simulations took into consideration the difference between the thermal properties of the building envelope. For that purpose, a weather file was generated, based on measured outdoor air temperature and humidity and radiation data. The results of these simulations were then compared statistically with those of the measurements. R-values were quite good, varying between 0,85 to 0,97. Simulations were then performed with the local test reference year (TRY).

Parameter testing was performed by considering different ranges of the four mentioned parameters in the three houses. In this case, an equivalent material was calculated for all external walls and roofs, so that for all three houses an unique material layer could be used for simulating those building elements. Variations of transmittance and inertia of walls and roofs were then applied to the simulation models, taking into account following ranges:

- $0{,}5 \le U_{wall} \le 4{,}0$ W/m²K
- $1{,}0 \le \varphi_{wall} \le 10$ hours
- $0{,}5 \le U_{roof} \le 4{,}0$ W/m²K
- $1{,}0 \le \varphi_{roof} \le 10$ hours

The results are shown here in terms of degree-hours of cold and heat for winter and summer, considering a Tbase of 18ºC and 27ºC (Tbase of 29ºC did not generate results for some parameter ranges).

Due to space limitations, only the variation of the transmittance of external walls for the three houses[1] will be discussed in this section. As one can notice from Fig. 5 and 6, the same variation of thermal transmittance of walls yielded a different capacity of the houses to reduce indoor comfort levels (here in terms of degree-hours). Building system 16, for instance, had a drop of only 8 degree-hours in winter and of about 260 degree-hours in summer, although the transmittance range remained exactly the same.

These results may be related to the different correlations between thermal transmittance of external walls and the thermal performance of the monitored buildings, according to the monitoring period (winter or summer) (Table III), and specifically to the stronger correlations of the degree-hours and minimum and maximum indoor temperatures analysis regarding the winter period. Furthermore, the simulations varying external wall transmittance for both periods indicated the importance of keeping that parameter at low levels. The summer graph (Fig. 6) suggests that wall transmittances close to 1,25 W/m²K and 1,5 W/m²K would be optimal (under these limits, heat gains would be trapped inside the built environment).

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[1] Note: discontinuities in the graph are due to limitations of the simulation tool.

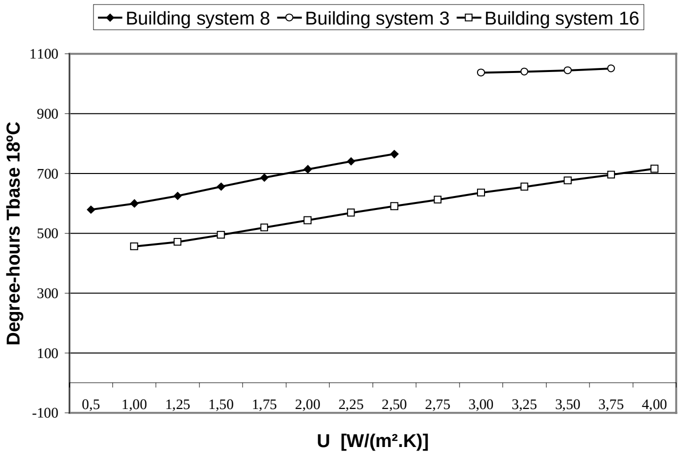

Figure 5: **Simulations results considering a transmittance range of 0,5-4,0 W/m²K (winter)**

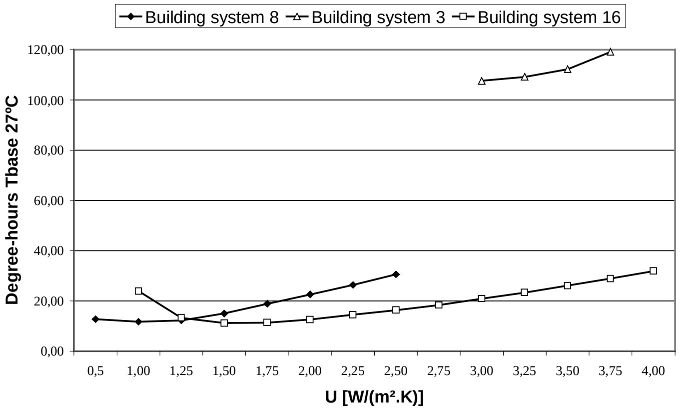

Figure 6: **Simulations results considering a transmittance range of 0,5-4,0 W/m²K (summer)**

FINAL REMARKS

The methodology used in the research comprised four different steps: the simultaneous monitoring of occupied houses, built with different materials; the thermal performance evaluation of the monitoring results in terms of comfort levels; an statistical analysis between thermophysical properties of the evaluated houses and their thermal performance; and simulations concerning variations of specific thermophysical parameters, related to the Brazilian Thermal Performance Norm. The results of the parametric analysis indicated certain levels of influence of the analyzed parameters on the thermal performance of low-cost houses in Curitiba, which could help architects and planners choose general strategies concerning those parameters.

REFERENCES

[1] RORIZ, M.; GHISI, E.; LAMBERTS, R. (1999). Uma proposta de norma técnica sobre desempenho térmico de habitações populares. *In:* V ENCONTRO NACIONAL DE CONFORTO NO AMBIENTE CONSTRUÍDO, Fortaleza, Brasil. (Proceedings in CD-ROM)
[2] GIVONI, B. (1992). Comfort, Climate Analysis and Building Design Guidelines. *In*: Energy and Buildings, Vol. 18.
[3] PEUPORTIER, B.; SOMMEREUX, I.B. (1994). *COMFIE: passive solar design tool for multizone buildings – User's manual.* Centre d'énergétique, École des Mines de Paris.