Thermal performance evaluation method for low cost single-family one-floor housing for Porto Alegre - Brazil

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Abstract

This paper presents a thermal performance evaluation method for low cost single-family one-floor housing considering the climatic conditions of Porto Alegre, city in the south of Brazil. The method aims toward a global evaluation of housing through requirements and criteria that complement the standards approved recently and it considers mathematical procedures that can be easily applied by government agents involved in this task. Thermal parameters such as global flow heat coefficients, thermal inertia, obtained from literature, are proposed. Four low cost houses built in Porto Alegre, considered to be references according to social and economic local reality, were evaluated through the method. Government agents involved in the project, design, financing, building, overseeing and evaluation of low cost housing in Porto Alegre and experts from research institutes in Brazil also gave their opinions of the method. Three degrees of performance for housing, in accordance with availability of government resources, are defined. The method can be used as an evaluation of possible solutions, thereby aiding decision makers.

Keywords: hygrothermal performance; low cost housing; performance evaluation.

1. Introduction

In Brazil the housing presents historically problems of thermal comfort and energetic efficiency. This is mainly verifiy for low cost housing and its low performance has been subject of broad researches. The studies found on the user's perception [1][2][3][4] or computational simulations and measurements in loco [5][6][7]. Studies have been developed with the intention of configuring guidelines for the project of low-income housing and define methods for evaluation for the Brazilian context [8][9][10]. In brief, the evaluations can be divided in three groups: measurements in loco evaluations; physical models evaluations (simulations computacionais or not); users' perception evaluations. The complexity of computational simulation methods is a difficulty for the improvement of low-income housing thermal performance. Because of the complexity, only experts in the thermal comfort are able to use the softwares, with the result that several buildings present inadequate thermal conditions mainly buildings for low and middle income families. The users' perception evaluantin requer that housing have been constructed, that cannot be possible. Therefore, simplified methods could be a form of improving the quality of housing for the poors in Brazil.

ABNT [8] recommends standard methods for thermal parameters, procedures for treatment of climatic data, general weather conditions for different regions, methods of evaluation and guidelines for low-income housing in Brazil. Also, ABNT specifies procedures for calculation of thermal resistance, thermal transmittance, thermal capacity, time-lag and solar factor for roofs and walls. Turik [9] proposes the use of coefficients of volumetric heat loss and heat load. Barbosa [10] proposes the comparison of thermal discomfort hours promoted by the housing with the thermal discomfort hours considered acceptable for a cultural referencial.

All of the mentioned methods were developed for a partial evaluation of the building, considering isolated elements (walls and roof), except the method proposed by Turik [9] that considers the global coefficients.

This paper presents some procedures based on simplified physical models for hygrothermal performance evaluation that intend to take the whole building behaviour into account. Besides the global coefficients, the thermal inertia, the thermal effusivity and the radiant temperaturae asymmetry are considered. The procedures can be used in the design phase. Proposed thermal parameters are aplicable to Brazilian reality and to low cost housing. The parameters were obtained from specialized bibliography and submitted to the appreciation of seven government agents and six experts on thermal comfort field.

Four low cost houses one-floor single-family constructed in Porto Alegre, city in south of Brazil, were evaluated through the procedures. Three thermal performance standard degrees were defined starting from obtained results (figure 1).

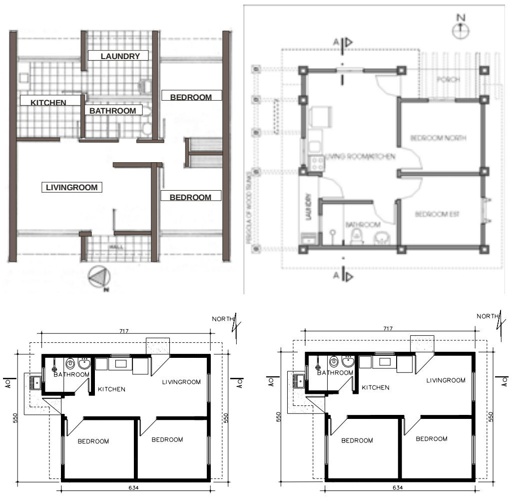

Figure 1. Floor plan for the houses 1, 2, 3 and 4 respectivelly

The houses are characterized by consultants and government agents as excellent (1 and 2), acceptable (3) and non-recomended (4) solutions. The house 1 was designed by a building company specialized in low-cost housing. The house 2 was designed by a research team. Both houses were submited to measurements [11][12][13] and are considered examples of the best local practice.

The houses 3 and 4 are considered traditional and non-recommended solutions respectivelly. They were indicated by government agents involved in the project, design, financing, building, overseeing and evaluation of low cost housing in Porto Alegre.

The performance reached for houses 1 and 2 demonstrates that is possible improve the housing quality without significant additional costs.

2. Thermal parameters

2.1 Climatic and indoor conditions, comfort conditions

For purposes of simulations, outdoor and indoor air temperatures, relative humidity and global solar radiation were obtained from specialized bibliography [14]. They are presented on Table 1. The comfort zone adopted is defined by Givoni [15] that stipulates the comfort minimum air temperature equal 18 °C, the comfort maximum air temperature equal 29 °C and maximum air relative humidity equal 80%. The outdoor and indoor air temperature of simulation is considered equal the comfort limits by Givoni. For summer conditions the outdoor temperature is assumed equal to the sol-air temperatures [16]. For winter conditions the design-day of 10% is assumed [17].

Table 1. Climatic and indoor conditions

Winter conditions
Outdoor air temperature of simulations: t_e = 7,5°C Tipical amplitude outdoor air temperatures: 10,0K Medium relative humidity: UR = 95,0% Indoor air temperature of simulations: t_i = 18,0°C
Summer conditions
Maximum outdoor air temperature of simulations: 33,5°C
Minimum outdoor air temperature of simulations: 23,0°C
Air relative humidity: UR = 72,0%
Indoor air temperature of simulations: t_i = 29,0°C

2.2 Thermal resistance, thermal transmittance, time-lag and solar factor

The parameters thermal resistance, thermal transmittance, time-lag and solar factor were defined in accordance with Brazilian standards [8]. Solar factor is obtained by multiplying abosrtivity, thermal transmittance and inverse surface coefficient.

2.3 Temperature amplitude decrement

The temperature amplitude decrement is calculated according to formula [9]:

$$\mu = e^{-0,1309 \times R_t \times \sqrt{B_1 + B_2}}$$

The coefficients B_1 e B_2 is defined by ABNT [8].

2.4 Coefficient of volumetric heat loss and heat load

The coefficient of volumetric heat loss is computed according to the formula:

$$\mathbf{GV_{loss}} = \frac{\mathbf{Q_T}}{\mathbf{V \times (t_e - t_i)}}$$

where:

GV_{loss} = coefficient of volumetric heat loss, $\frac{\mathbf{W}}{\mathbf{m^3\ \ K}}$

Q_T = heat load, W

V = volume of the interior space, m^3

t_e, t_i = outdoor and indoor air temperatures

The volumetric coefficient of heat loss can be broken down into different contributions of heat loss: air flow through the building, heat loss through the walls and the windows [18].

The volumetric coefficient of heat gain GV_{gain} is given by the same formula, but Q_T is equal maximum heat flow corresponding to maximum $T_{sol\text{-}air}$ for every external surfaces of building.

2.5 Condensation on internal surfaces

The analysis of condensation on internal surfaces is based on flow of heat under steady state conditions across walls and roof at night in the winter. The internal surface temperatures are analysed when indoor air temperature, minimum outdoor air temperature and air relative humidity are respectively 18°C, 7,5°C and 95%.

2.6 Radiant temperature asymmetry

The radiant temperature asymmetry is the difference between the plane radiant temperature of the opposite sides of a small plane element.

This parameter is important in comfort conditions [19]. The plane radiant temperature is given by:

$$T_{rp} = \sum_i t_{si} \times f_i$$

where:
T_{rp} = plane radiant temperature, °C
T_{si} = internal surface temperature, °C
f_i = angle factors, according to [19]

For winter conditions the analysis has to consider the rooms with smallest internal surfaces temperatures or rooms with large surfaces of windows, mainly windows without opaque elements.

For summer conditions the analysis has to consider rooms with west, norhwest and southwest walls, because these walls receive a higher level of radiation in the summer. In addition horizontal surfaces (roofs) must be analysed.

The values of 9°C and 14°C are adopted for maximum radiant temperature asymmetry (corresponding 20% of people expressing discomfort) [19].

2.7 Thermal inertia and thermal effusivity

Thermal inertia is a building's overall capacity to store and release heat and thermal effusivity is associated with the thermal reaction of the firts centimetres of the internal surfaces of a room under internal heat gains [20]. Thermal inertia is classified as very weak, weak, medium and strong and the analysis is made for southern walls, south-southern walls, internal walls and floors [14,21].

Thermal effusivity of homogeneous material is defined as the root of the thermal conductivity multiplied by density and specific heat and characterises how easily heat can be absorbed by a material [20]. Thermal effusivity is around 2,000 and 20 for heavy and light materials respectively [20].

Besides the parameters presented above coefficients that consider the priority solar orientation of roof for summer conditions and the priority northern wall for winter conditions are proposed.

3. Findings

3.1 Calculated parameters

Calculated thermal parameters for the four houses are presented on Table 2. According to findings the radiant temperature asymmetry and the thermal effusivity were not significant to differ the four houses. The time lag and temperature amplitude decrement reproduce the same characteristics of walls and roof, therefore one can be adopted for simulation of thermal inertia of houses.

Thermal resistance, thermal transmittance, time-lag and solar factor were discarded because they are included in the thermal inertia and in the coefficient of volumetric heat loss or gain.

3.2 Local climatic conditions and thermal performance monitoring

Considering results previously published [13] the local climate presents frequently daily temperature amplitudes equal to or higher than 10K. Periods with the mean outdoor air temperature below 18°C preceded by three days or more with maximum outdoor air temperature equal or higher than 29°C are frequent. Periods with maximum outdoor air temperatures equal or higher than 29°C preceded by three days or more with mean outdoor air temperature equal to or under 18°C are also frequent. The climatic behaviour suggests the thermal inertia of building is a important bioclimatic strategy as well as the thermal transmittance of roof. For winter conditions the passive solar heating results in prioritizing northern walls and windows.

Table 2. Calculated parameters

Thermal parameters	Houses			
	1	2	3	4
GV$_{loss}$ $\frac{W}{m^3\,K}$	3.0	2.8	3.8	5.3
Condensation on walls	no	no	no	no
Elements do not satisfy criteria for ΔT_{rp}	roof	roof	roof	roof
GV$_{gain}$ $\frac{W}{m^3\,K}$	16,1	14,7	17,1	18,8
Thermal inertia	med.	med.	med.	med.
Thermal effusivity $\frac{W \times s^{\frac{1}{2}}}{m^2\,K}$	977	1,282	1,235	2,040
Southern roof ratio	0,54	0,88	-	-
Northern wall ratio	0,23	0,37	0,30	0,30

3.3 Opinions of government agents and experts

Interviews with government agents involved in the project, design, financing, building, overseeing and evaluation of low cost housing in Porto Alegre demonstrate thermal performance evaluation methods have not used. The agents have used non-quantitative prescriptions based on their experiential knowledge, such as thickness and amount of layers for walls and roofs, long roof overhangs shading the walls, louvered windows, solar orientation of building, ventilated roof attic, cross-ventilation and deciduous trees, among others. Besides the adoption of accepted standards building designs because of their good thermal performance is also usual. The government agents have indicated the need of methods that consider levels of performance according to necessity of housing and availability of resources.

About the method presented in this paper, the government agents expressed their concordance but they did not intensify the critique. Qualitative guidelines are important according to the agents, such as absortivity (color of surfaces), solar orientation of building, window orientation with respect to the window and shading devices. They also mentioned urban planning guidelines for low cost building plots as a strategy to improve the thermal quality of housing.

Some of parameters suggested by the agents were included in the proposed method.

The main problems verified by the experts are linked to the conditions of indoor air temperature. The building envelope are considered important because it is easy adjustable, such as layers (thickness, amount, thermal properties), size, orientation, location and methods of windows opening.

The experts have considered important overall evaluation parameters and levels of classification that allows comparison results obtained by several researchers.

Starting from the findings, some of the parameters initially proposed were discarded.

4. Hygrothermal performance evaluation

Table 3 presented the selected parameters. The thermal parameters are organized in four groups, referring: overall housing, roof, walls and windows.

Table 3. Criteria for the thermal parameters

Overall housing	weight
$3,1\ \frac{W}{m^3 K} \le GV_{loss} \le 4,0\ \frac{W}{m^3 K}$	3
$2,0\ \frac{W}{m^3 K} \le GV_{loss} \le 3,0\ \frac{W}{m^3 K}$	4
$GV_{loss} < 2,0\ \frac{W}{m^3 K}$	5
$16,5\ \frac{W}{m^3 K} \le GV_{gain} \le 18\ \frac{W}{m^3 K}$	3
$14,5\ \frac{W}{m^3 K} \le GV_{gain} \le 16,4\ \frac{W}{m^3 K}$	4
$GV_{gain} \le 14,5\ \frac{W}{m^3 K}$	5
Medium thermal inertia	5
Northern or northeastern windows	5
Level 1	16
Level 2	18
Level 3	20
Roof	**weight**
$U_{roof} \le 2,80\ \frac{W}{m^2 K}$	2
$\varphi \ge 1,1$ h	5
$\varphi \ge 1,3$ h	2
FCS ≤ 4,0 %	2
total	11
Walls	
$\varphi \ge 4,0$ h	5
FCS ≤ 3,4 %	1
Shaded western and northwestern walls only on the summer	3
total	
Windows	**weight**
$15\ \% \le A_{ventilation} \le 25\ \%$	4
Cross ventilations	4
Windows orientation with respect to the wind	4
Shading devices with 50% of ventilation	4
Windows with shading devices	4
total	20
Level 1	56
Level 2	58
Level 3	60

The three level give rise to classification showed on Table 4.

Table 4. Classification for low cost housing

Classification	Evaluation	Weight interval
A	Optimum	51 – 60
B	Medium	46 – 50
C	Minimum	40 - 45

The values of reference for the thermal parameters are based in literature and values obtained for houses analyzed. The minimum level of performance is equal to the level reached by house 3, representative of local practice according to government agents (level 1). The level 2 is associated to performance of houses 1 and 2. The level 3 is associated to performance better than reached by houses 1 and 2.

The value of criteria weights are based on opinion of experts and the bioclimatic chart of Porto Alegre. The parameters that improve the best comfort for winter conditions have higher weights (thermal inertia and solar heating). The parameters that promote natural ventilation are considered more important. These parameters are followed by shading devices. The overall housing parameters have lower weights.

5. Conclusion

The method allows the comparison between solutions through the proposed criteria. The method can be also used as a decision tool helping designers, consultants and financial agents. The expected results were reproduced by the method, that is, the houses with more favourable configuration (houses 1 and 2) reach the best performance in comparison with houses 3 and 4. The house 4, the non-recommended solution, presented the worst performance.

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