THERMAL INERTIA MASS OF BUILDING ENVELOPES DESIGN TO BE ADAPTED TO A LOCAL CLIMATE

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ABSTRACT

This work is based on an extended research from a doctorate thesis developed in a partnership between Federal University of Rio de Janeiro (UFRJ) in Brazil and INSA of Lyon, Thermal Centre of Lyon, Building Physics Team (CETHIL/ETB) in France. The purpose is to examine the envelope building design considering the outside microclimate to achieve a comfortable indoor climate. The context of exterior climatic features and site location are considered, taking in account an indoor discomfort sequence over a typical warm season. In order to the complexity of architectural design, when we must evaluate a large number of parameters and indoor requirements, the focus of this work is the thermal inertia mass in building envelopes. We take into account that the mass of envelopes can characterize a monitoring approach to achieve a thermal comfort. The method includes an evaluation of a re-use referential design of traditional existing buildings, taking the individual parameters such as activity levels and clothing isolation, and indoor environmental variables, such as: ambient air temperature, mean radiant temperature, relative air humidity and indoor airflow. In order to obtain the thermal performance data, we have carried out dynamical simulations, regrouping several variations of the inertia mass of envelopes, from architectural choices. The obtained results can generate a simplified method dedicated to the actors of the building design team (architects, engineers, technical designers) to orient the use of envelopes to achieve a good indoor thermal comfort for occupants, integrating local climatic characteristics.

KEYWORDS

Building envelopes, thermal inertia, climate, simplified method.

PROPOSAL

Taking in account the thermal design, the building envelope characterizes a monitoring approach to achieve the indoor thermal comfort. The building envelope can control thermal changes between external environmental climate and inside building. For example, the envelope can includes an insulation to make protection as a filter which provides the control of building's thermal loads. The building envelopes should not adversely affect indoor thermal comfort, considering the occupancy requirements in the internal space (Rivard et al, 1995).

A building internal space can be characterized by environmental parameters such as ambient air temperature, mean radiant temperature, air humidity and airflow. Considering a large number of studies comprising laboratory experiments involving the influences of one or more environmental variables on thermal comfort sensation, our approach is based upon a referential method (Fanger, 1970), considering a combination of psycho and physiological parameters (activity level and clothing isolation) and the environmental parameters above. We have adopted a referential index related with thermal comfort sensation such as the operative temperature referred by ASHRAE (1997).

METHOD PROCEDURES

Category of Re-Used Buildings

Due to investigate the thermal inertia of building envelopes, our approach focuses a significant architectural quality, which is characterized by large surfaces of single glazing, poorly insulated and often leaky envelope. Most of this category of buildings were typically old industrial and tertiary constructions in the last century, in Europe (with particularity in France) and in southern of Brazil. Several buildings were failed to demolition or to re-build.

Futhermore, a large number of investigations and studies have shown that the re-use of these existing buildings can provide low energy consumption and a better thermal performance of buildings, from the point of view of environmental impact and economical costs (Queiroz et al, 2002). The re-use of buildings can make improvements to the urban planning and it often gives an opportunity to the most actors involved in the design production such as: architects, engineers and designers. (Queiroz et al, 2001-a).

Climatic Context

We have chosen two types of climates: under a base of a tempering climate, in Lyon (latitude: 45°42' North) in France and in a tropical climate, in Rio de Janeiro (latitude: 22° 55' South) in Brazil. The procedure was adopted a dinamical computer code (Brau et al, 1992, Duta et al, 2000) to obtain the weather climatic database by simulations. Data from two types of climates (tempering and tropical) were required with careful to take in account the climatic sensitive contexte (ASHRAE, 1993). The data were input to hour-by-hour and have included the parameters as: solar flow radiation (diffus and direct); solar angle; solar azimuth; exterior air temperature; sky temperature and exterior air humidity. We have established a discomfort sequence over a typical day in warm season for each climate as: 12:00 to 22:00 p.m.. Table 1 shows the weather climatic database.

Architectural and Thermal Design Parameters

The adopted protoype of a re-used building design

The re-use of building often involves a re-cladding of the envelope. It should be required to make improvements to the thermal performance, based upon a new occupancy in the internal space of the building. We have established a basic prototype as simple as possible. It was served as a typical building being designed to keep a referential case study. The prototype design looks a rectangle plan (12 x 20m = 240m^2), with a large-hightly prismatic volume (1440m^3). It is composed with: single-glazed metal-casement in façades; external walls with concrete block (80 mm) and with variable insulation (40mm); roof in ceramic tile (10mm) and floor with concrete (50mm) (see Figure 1).

TABLE 1
Climate Database

Tempering Climate (Typical day, in July, in Lyon, France)								Tropical Climate (Typical day, in Mars, in Rio de Janeiro, Brazil)							
Solar hour	Flow dir (W)	Flow diff (W)	Solar angl (°)	Solar azim (°)	Air temp (°C)	Sky temp (°C)	Air hum (%)	Solar hour	Flow dir (W)	Flow diff (W)	Solar angl (°)	Solar azim (°)	Air temp (°C)	Sky temp (°C)	Air hum (%)
12:0	705	121	66	0	31,4	24,6	38,4	12:0	708	121	67,1	180	31,2	25,0	69,7
13:0	678	119	63	32	32,3	25,7	36,5	13:0	671	119	63,0	146	31,9	26,0	66,7
14:0	601	116	56	56	32,8	26,4	35,4	14:0	562	114	53,1	125	32,4	26,6	64,9
15:0	480	110	46	72	33,0	26,6	35,1	15:0	395	105	40,3	112	32,6	26,8	64,3
16:0	331	101	36	85	32,8	26,4	35,4	16:0	200	91	27,3	104	32,4	26,6	64,9
17:0	175	89	25	95	32,3	25,7	36,5	17:0	36	70	13,4	97	31,9	26,0	66,7
18:0	49	73	15	105	31,4	24,6	38,4	18:0	0	0	0	91	31,2	25,0	69,7
19:0	1	47	5	115	30,3	23,2	41,0	19:0	0	0	0	86	30,1	23,8	73,9
20:0	0	0	0	126	28,9	21,5	44,2	20:0	0	0	0	80	29,0	22,3	79,1
21:0	0	0	0	136	27,5	19,7	48,0	21:0	0	0	0	76	27,7	20,7	85,1
22:0	0	0	0	146	26,1	17,9	52,2	22:0	0	0	0	72	26,4	19,2	91,7

Operating and Ocuppancy Building

The occupancy building (10 persons) and service system operate on 5 day-week, on: 7:00-to-11:00 and 12:00-to-17:00 p.m.). At night, the building is closed. The activity level requires a medium load (met = 175W) and a clothing isolation with (1 clo). It was required a passive system of heating, cooling and ventilating. The natural air exchange rate (m^3/h) is (1volper/hour = 1440m^3) and the required ambient air velocity is (v = 0,2m/s).

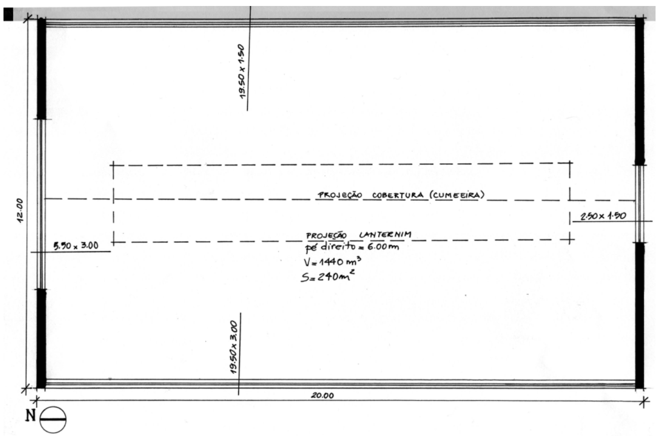

Figure 1: Prototype plan of the re-used building design

Envelope Evaluation

Due to the most important function of building envelopes to provide a protection of inside environment from outside disturbing, we investigate the influences of the glazing envelopes and the opaque envelopes on thermal performance, focusing the variations upon the thermal inertia mass of external walls.

Global coefficient of glazing envelope (C_v)

The prototype building is composed with large surfaces of single glazing (windows). In each façade (solar orientation) the glazing surface has a percentage area per opaque envelope (external walls) as: 24 % (east); 24 % (north); 50 % (west); 5 % (south). Our aim was to established a global coefficient of glazing envelope area, related with solar parameters, such as: solar angle and orientation, solar azimuth, surface azimuth, direct and diffus solar flow, solar transmittance and glazing solar factor. Due to the significant influence on solar heat gains, we adopted a global coefficient. It defines the glazing envelope surfaces, expressing as:

$$C_v = A_v . f_s . \sigma_v . p_s . \tau_v \qquad (1)$$

C_v = global coefficient related with the glazing envelope;
A_v = glazing area, m^2;
f_s = glazing solar factor, %;
σ_v = net effective glazing area, m^2;
p_s = glazing solar position (related with surface azimuth; surface inclination; global solar flow on horizontal plan and global incident solar flow);
τ_v = glazing solar transmittance, %.

In our approach, the factors above were calculated for each climate by a numerical code, based in the A.I.C.V.F. method (Pallier, 2000).The coefficient was applied to each simulation.

Thermal Inertia Variation (Low, Medium, High)

In regard of the thermal inertia mass of building envelopes, it requires a considerable attention in relation with the indoor thermal comfort sensation (Queiroz et al, 2001-b). The surface mass of external envelopes is defined as the average poid per surface area (Kg/m^2). C.S.T.B. (1991) defines a thermal inertia index which is determined by the surface mass of one or more external walls. Considering the basic prototype building, we have modelled three types of building design for opaque walls and covering, with inside, outside or not-insulation, applying the inertia thermal index characterized in table 2.

TABLE 2
Thermal inertia index (C.S.T.B., 1991)

Surface mass (Kg/m^2)	Thermal inertia index
≤149	low
From 150 to 399	medium
≥400	high

Thermal Comfort Quality Criterion (q_1)

Due to proceed a simplified method to evaluate the building thermal behaviour, we adopted a quality criterion for the indoor environment, which is referred to as (q_1). It stresses the importance of a thermal ambient overload to occupants. It is characterized by the variance of the mean resultant temperature during an established discomfort sequence (12:00-to-22:00). The mean resultant temperature (T_i) is based upon the operative temperature (FANGER, 1970, ASHRAE, 1997). We have adopted a referential index of indoor thermal comfort sensation, referred to as (T_i = 27, °C). Our aim is to calculate upon data simulations, the variances concerning the values of mean resultant temperature and the referential index of indoor thermal comfort sensation $(T_i - 27)^2$ over an established discomfort sequence in a warm season for both types of climates (tempering and tropical). The thermal comfort quality criterion can be characterized as a mathematical expression:

$$q1=\sum_{i=12}^{22}(\sigma Ti)? \qquad (2)$$

q_1 = thermal comfort quality criterion, °C;
$(\sigma T_i)^2$ = variance between the mean resultant temperature (T_i) and the referential index of indoor thermal comfort (T_i = 27, °C);
Σ = addition of variances, hour-by-hour, during a discomfort sequence (12:00-to-22:00).

SIMULATIONS

In order to proceed a numerical calculation of the indoor thermal performance, we applied a zone dynamical code (Brau et al, 1992), developed by the Building Physics Team in Thermal Centre of Lyon (ETB/CETHIL). The thermal simulations were carried out, regrouping the prototype building design, with the indoor requirements, and considering the characteristics of each type of climate (tempering and tropical), over a discomfort sequence during a typical day in summer season. Taking in account the thermal inertia index (low, medium, high), considering the prototype building, we applied the variations, such as: (i) building rotation to solar orientation (0°, 90°, 180°, 270°); (ii) glazing-to-wall profoundness ratio (0,0m; 0,4m); (iii) glazing transmittance (0,3; 0,5; 0,7; 0,9). 32 simulations were carried out for three types of inertia, taking in account the variations above. For each climate, there were accounted 96 simulations. Our aim was to calculate the addition of mean resultant temperature variances and to calculate the global glazing coefficient for each simulation. In order to correlate the variances additions (q_1) and the global glazing coefficient (C_v), database simulations were input in graphic configuration (see figures 2 and 3).

CONCLUSION

Considering the numerical results (input in graphics), comparing the climates, it was demonstrated these points: (i) in both climate, considering the three inertia index (low, medium, high) there was a proportional tendency between (q_1) and (C_v), expressing as: [(q_1) = f (C_v)]; (ii) in both climates, high thermal inertia design have made better indoor thermal comfort quality (q_1) than low inertia design; (iii) correlating the climates, the thermal comfort quality (q_1) was better in the tropical climate, adopting both low and high inertia index; (iv) using outside insulation, the thermal comfort quality was better than using inside insulation in tempering climate.

In an approach of this nature, the tendency curves could obviously provide appropriate expert rules and criteria related with a thermal inertia index of envelope design to be adapted to each climate, during a discomfort sequence over a warm season, with relatively improvements in the indoor thermal comfort quality. Finally, in our proposal the intention is to establish a good interactive communication between the actors of the design team (focusing the thermal design), such as architects, engineers and technical designers.

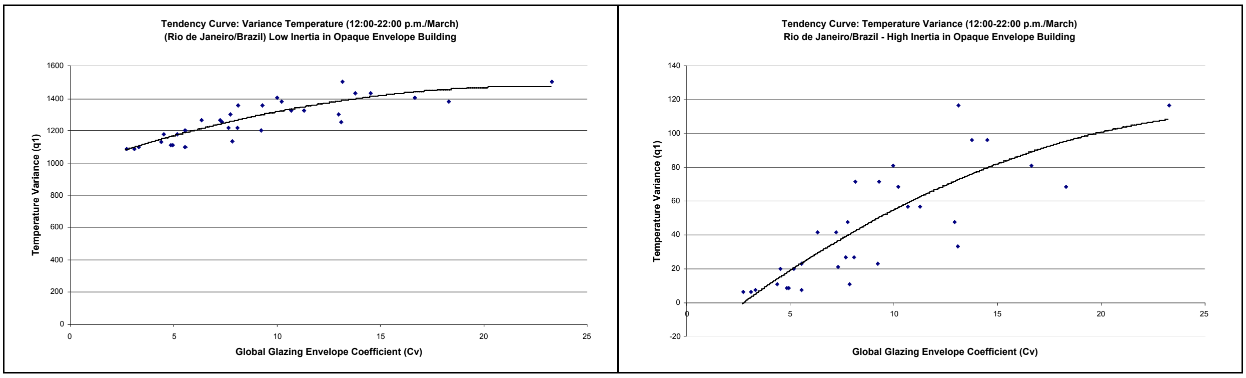

Figure 2: Low and High Inertia, Tropical Climate (Rio de Janeiro, March, 12:00-22:00 p.m.)
Tendency curve: $q_1 = f(C_v)$

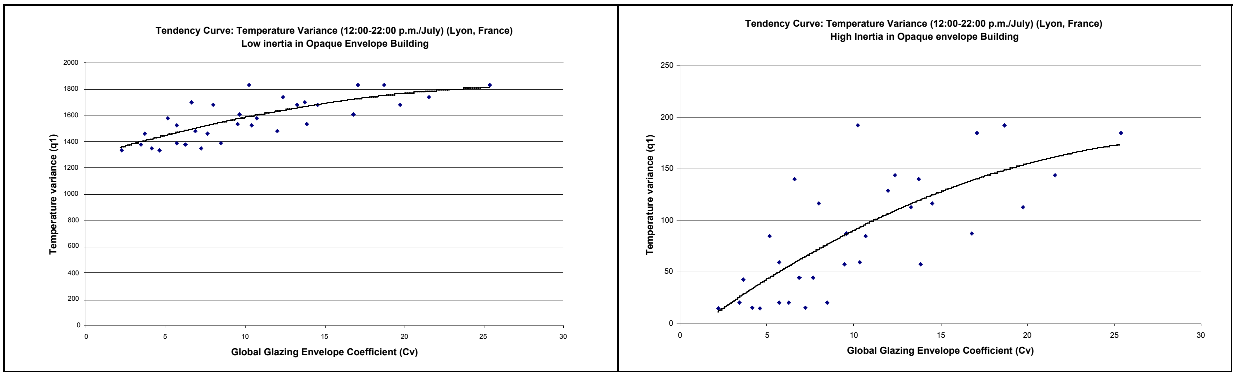

Figure 3: Low and High Inertia, Tempering Climate (Lyon, July, 12:00-22:00 p.m.)
Tendency curve: $q_1 = f(C_v)$

REFERENCES

ASHRAE Handbook Fundamentals (1993), chapiter 24, 24.18-24.23, S. I. Edition, Atlanta, Georgia, U.S.A.

ASHRAE Handbook Fundamentals (1997), *Thermal Comfort*, chapiter 8, S. I. Edition, Atlanta, Georgia, U.S.A.

Brau, J., Krauss, G. and Roux, J. J. (1992). *CODYBA, Cahier des Algorithmes*, INSA de Lyon, Centre Thermique de l'INSA de Lyon-CETHIL, Laboratoire Equipement de l'Habitat, Edition de Agence de l'Environnement et de la Maîtrise de l'Energie-ADEME, France.

C.S.T.B. (1991). *Classe d'inertie thermique d'un bâtiment autre que d'habitation*. Cahiers du Centre Scientifique et Technique du Bâtiment, Référence AFNOR DTU, P-50-704, Annexe 2, France.

Duta, A., Noël, J. And Roux, J. J. (2000). CODYBA-V. 6.0: New version of software for building dynamical behaviour simulation. *Proceedings of the 17th International Conference on Passive and Low Energy Architecture-PLEA 2000,* James & James Edition, Cambridge, England, 746-751.

Fanger, P. O. (1970). *Thermal Comfort, analysis and applications in environmental engineering*, Danish Technical Press, Copenhagen, Denmark.

Pallier, J. M. (2000). *Thermique du Bâtiment, Méthode de l'Association des Ingénieurs en Chauffage et Ventilation de France-A.I.C.V.*F., I.U.T.-Lyon I, Villeurbanne, France.

Queiroz, T. C. F., Bastos, L. E. G. and Depecker, P. (2001-a). Retrofitting building design with conscious of a passive thermal comfort. *Proceedings of the 18th International Conference on Passive and Low Energy Architecture-PLEA 2001*, Florianópolis, Brazil, vol **I**, 121-125.

Queiroz, T. C. F., Bastos, L. E. G. and Depecker, P. (2002). Função termo-regulante do envelope em reconversão de edifícios. Revista do Frio e Ar Condicionado N°. 143, abril, ano XI, 38-48.

Queiroz, T. C. F., Bastos, L. E. G., Depecker, P. and Gaudillière, C. (2001-b). Integral criteria on building envelopes assessment taking in account na approach of thermal comfort in architectural design. *Proceedings of the 4th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings-IAQVEC 2001*, Hunan University, City University of Hong Kong, Changsha, Hunan, China, vol **III,** 1967-1974.

Rivard, H., Bédard, C., Fazio, P.and Ha, K. (1995). Functional analysis of the preliminary building envelopes design process. *Building and Environment* vol **30: 3**, 391-401.