Proceedings of Conference: ***Adapting to Change: New Thinking on Comfort*** Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Towards a Brazilian standard for naturally ventilated buildings: guidelines for thermal and air movement acceptability.

Christhina Cândido[1, 2], Roberto Lamberts[1], Richard de Dear[3] and Leonardo Bittencourt[4]

[1] Federal University of Santa Catarina, Florianópolis – Brazil
[2] Macquarie University of Sydney, Sydney – Australia
[3] The University of Sydney, Sydney – Australia
[4] Federal University of Alagoas, Maceió/AL – Brazil

[*]*Corresponding author's email: ccandido@els.mq.edu.au*

Abstract

In 2001, Brazil suffered an electricity energy crisis as a result of meteorological conditions and poor strategic investments. One of the most important outcomes was the establishment of the energy efficiency law by the Federal Government, after long ten years of politic process. After this landmark event, the Brazilian Government has been promoting energy conservation initiatives including the Thermal Performance in Buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses (ABNT, NBR 15220-3, 2005) and the Federal Regulation for Voluntary Labelling of Energy Efficiency Levels in Commercial, Public and Service Buildings (Carlo and Lamberts, 2008). These new regulations summarize an immense effort in order to provide guidelines based on Brazil's climate requirements for designers with specific items related to lighting systems, HVAC and building's thermal envelope. Yet requirements for naturally ventilated indoor environments appear as an open category. This paper summarizes a first attempt in order to define guidelines for naturally ventilated environments in which specifications for thermal and air movement acceptability goals must be achieved.

Keywords: thermal acceptability, air movement acceptability, standard, natural ventilation, thermal comfort, energy conservation.

Introduction

The building sector potential in terms of energy conservation is a fact (IPCC, 2007). In order to achieve this, technical solutions are commonly indicated as the main mitigation path, such as insulation, cooling and heating systems, efficiency in appliances, etc. Behavioral change, however can deliver faster and long-lasting results. Baring this concept, designers are beginning to shift their attention to how they widen the range of the opportunities available in a building to provide comfort for occupants, both in new-build and retrofit contexts. This in turn has re-awakened an interest in the role of natural ventilation in the provision of comfort also in terms of regulations and standards worldwide (ASHRAE, 2004, van der Liden, 2006).

In Brazil, where there is a broad range of climatic differences, the idea of a unified standard that takes into consideration both technical and behavioral issues is a challenge. Much of Brazil's territory is classified as having a hot humid climate. In such regions, natural ventilation combined with solar protection are the most effective building bioclimatic design strategy in order to improve thermal comfort by passive means. Despite these favourable conditions, the number of buildings relaying in active systems as the main cooling design strategy continues increasing inexorably.

In 2001, Brazil suffered an electricity energy crises as a result of meteorological conditions (lack of rain for the hydroelectricity based system) and poor strategic investments (transmission lines and backup generation plans). As consequence, the imposed consumption reduction was 20% for all country and some of this reduction became permanent as a result of government actions and population engagement (Lamberts, 2008). One of the most important outcomes was the establishment of the energy efficiency law by the Federal Government, after long ten years of politic process.

After this landmark event, the Brazilian Government has been promoting energy conservation initiatives including the Thermal Performance in Buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses (ABNT, NBR 15220-3, 2005) and the Federal Regulation for Voluntary Labelling of Energy Efficiency Levels in Commercial, Public and Service Buildings (Carlo and Lamberts, 2008). These new regulations summarize an immense effort in order to provide guidelines based on Brazil's climate requirements for designers with specific items related to lighting systems, HVAC and building's thermal envelope. Yet requirements for naturally ventilated indoor environments appear as an open category. This paper summarizes a first attempt in order to define guidelines for naturally ventilated environments in which specifications for thermal and air movement acceptability goals must be achieved.

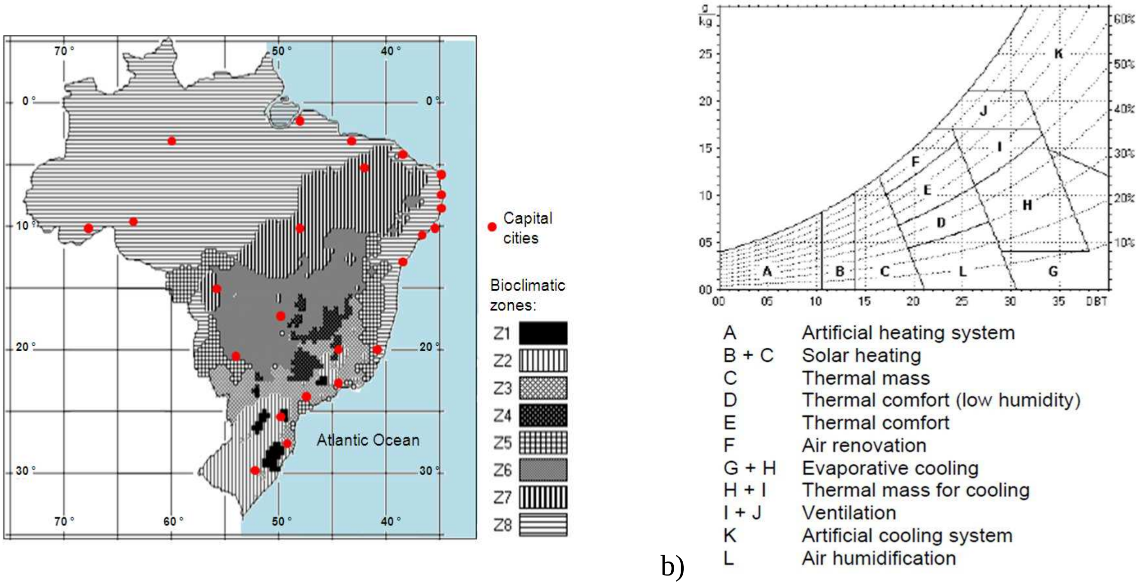
Revisiting Brazilian energy efficiency initiatives

The energy matrix in Brazil is based manly on hydroelectricity but there was a considerable increase in coal usage during the recent years (Ministério das Minas e Energia, 2007). Investments in a more sustainable energy matrix are essential for a developing country like Brazil, however it is important to bear in mind that there are other areas needing scarce financial resources such as educational and health programs. Therefore investments cannot be wasted and there ample opportunities for energy conservation.

Based upon this, the Federal Government released a *National Policy of Conversation and Rational Use of Energy* focusing on energy efficient buildings and equipment. Despite de fact that these actions were mainly focused on electricity use, its impact was undoubtedly significant considering that 23% of the hydroelectricity is dedicated to commercial and public buildings and approximately 22% to residential sector (Ministério das Minas e Energia, 2007). Among the several actions on energy efficiency promoted by the Brazilian government there are two that might be highlighted: design guidelines for residential sector and the labeling system for commercial buildings.

For the residential sector the "Thermal performance in buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses" (ABNT, NBR 15220-3, 2005) is the main reference. The requirements were related to thermal envelope, lighting and acoustics, along with minimum requirements for ventilation and opening areas. Currently the energy efficiency labeling for residential buildings is in progress and it will be made public later in 2010. One important contribution of this document was the definition of bioclimatic zones and Figure 1 shows their definitions. Eight zones were defined according to its climate characteristics from 330 cities across Brazil. Based upon this division, a set of specific bioclimatic design strategies was indicated focusing its application during the early design stage.

For commercial and public buildings, there is a newly released "Federal Regulation for Voluntary Labeling of Energy Efficiency Levels in Commercial, Public and Service Buildings". This new regulation is based on a study focusing on Brazil's climate requirements for designers in general with specific items related to lighting system, HVAC and building envelope. In similar fashion to the residential sector, the eight bioclimatic zones and design strategies are intended as a reference for designers and architects. Currently it is voluntary but it will become mandatory in 2013 with scheduled reviews every 5 five years (Carlo and Lamberts, 2008).



a) b)

Figure 1. (a) Bioclimatic zoning and (b) bioclimatic chart (ABNT, NBR 15220-3, 2005)

Figure 2 shows different bioclimatic strategies and recommended ventilation pattern for zones 1 to 8. Three different patterns for natural ventilation are provided. The first is "cross-ventilation" which is self-explanatory, indicating necessity of airflow through the indoor environments for Zones 2, 3 and 5. The second one is called "selective ventilation" and its application is specific during warmer seasons and/or when the indoor temperature is superior to the outdoor temperature for Zones 4, 6 and 7. The third and last pattern is "permanent" ventilation and it is suggested to Zone 8 where there is the strongest dependence on natural ventilation for occupants' thermal comfort. The only bioclimatic zone where ventilation is not indicated is the number 1, corresponding to the coldest regions.

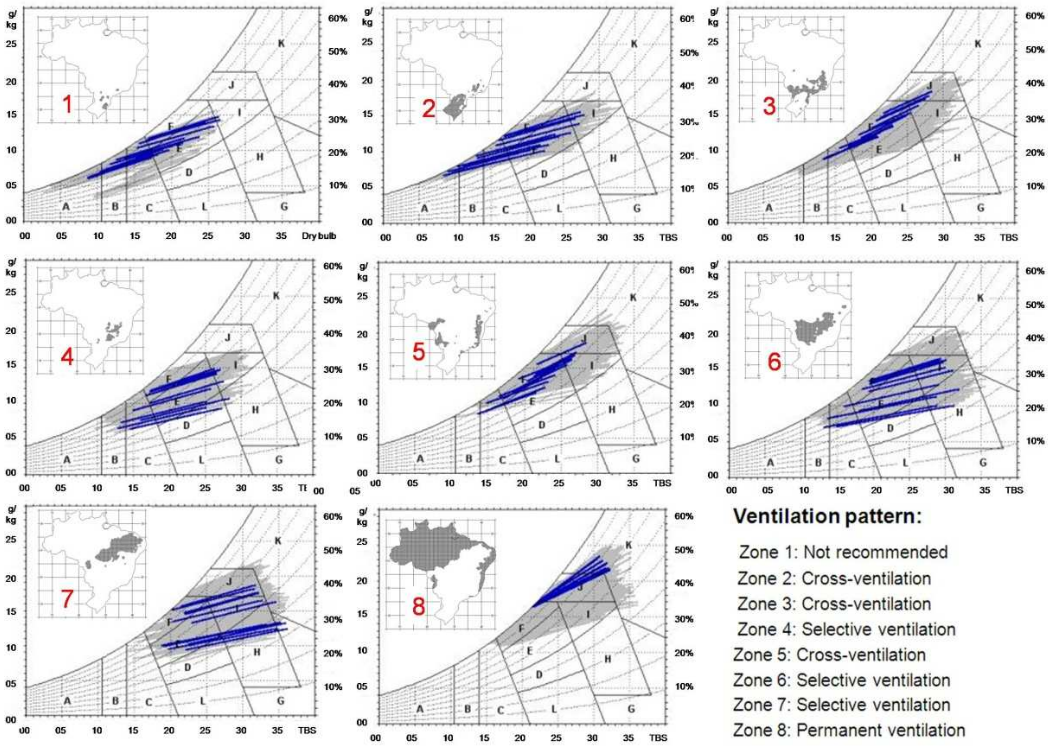


Figure 2. Bioclimatic design strategies and ventilation pattern for different zones (ABNT, NBR 15220-3, 2005).

These two regulations were an important contribution for energy efficiency in buildings and it will be possible to quantify this within the next years. These regulations established a consistent amount of technical information about building's thermal envelope. In terms of naturally ventilated environments, however, there is a gap willing to be fulfilled. Naturally ventilated buildings receive high incentives as far as it is proved that they provide thermal comfort to the occupants. Natural ventilation is frequently associated with a strong concern about airflow distribution in indoor environments, hence the recommendations related to opening areas and ventilation pattern (ABNT, NBR 15220-3, 2005). This is also the traditional reference for regional buildings' codes all over Brazil. These requirements are undoubtedly a contribution to occupant's thermal comfort but a more accurate relationship with thermal indoor environments is necessary. Thermal acceptance in general is not completely fulfilled in existing regulations. Field experiments developed in Brazil offer more insight into this necessity and will be presented in the next section of this paper. Considering that natural ventilation is indicated in seven of the eight bioclimatic zones in Brazil, a set of standards that focuses on air movement enhancement in combination to thermal comfort is therefore necessary.

Adapting a model for Brazilian occupants

1. Field experiments' evidence

Based on the wide range of climate conditions found in Brazil, differences in terms of thermal acceptance is not surprising. Previous studies attempted to understand the limits for temperature in which occupants would consider as acceptable in naturally ventilated buildings. As expected, there is a significant variation in terms of acceptable temperatures. For instance, in the South of Brazil, acceptability can be found in a range from 14 to 24°C (Xavier, 2000; Lazarotto et al, 2007) while in the Northeast these values can be easily extended from 24.5 to 32°C without however compromising occupants' thermal comfort (Araújo,1996).

Figure 3 shows results from different field experiments. The red dots represent results from the experiments and it is possible to see minor discrepancies in relation to the model. Adaptive opportunities played a major role in these thermal environments particularly by means of clothing adjustments (Lazarotto et al, 2007; Andreasi et al, 2010) and air movement enhancement, especially by use of fans (Gonçalves, 2001). It is noticeable that the range of temperatures that were found as acceptable for occupants felt in similar range predicted by the adaptive model (de Dear and Brager, 1998).

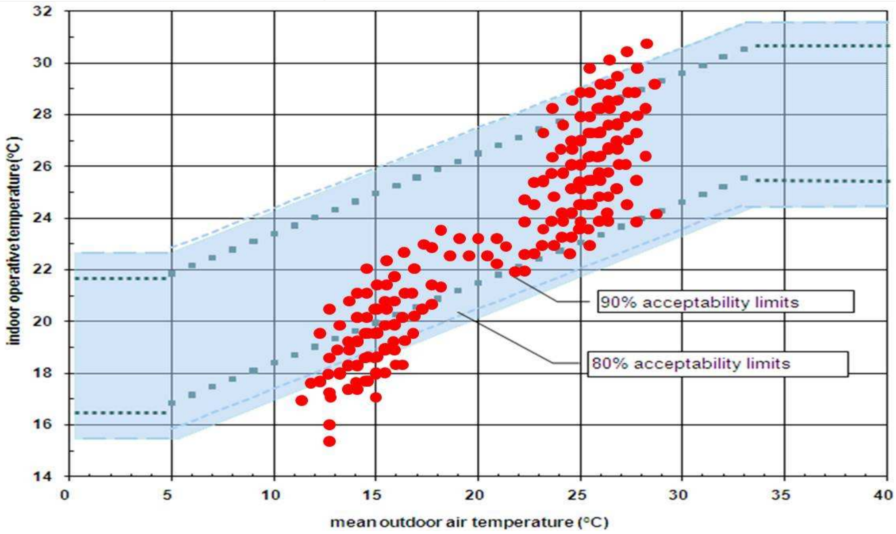


Figure 3. Thermal acceptability for naturally ventilated buildings (after de Dear and Brager, 1998).

Interestingly, discrepancies were found also related to occupant's adaptive opportunities, again here in terms of clothing insulation (Ruas, 1999; Andreasi, 2001) and air movement (Araújo, 1996, Cândido et al, 2010). In the first case, the main complains are derived from the degree of freedom within the dress code (Andreasi, 2009) and, conversely, occupants were satisfied with a flexible one (Lazarotto et al, 2007). The second case, occupant's complains were related to the preference for more air movement (Cândido et al, 2010), especially for the hot humid zone, where there is the strongest demand for higher air velocities.. This demand was more noticeable for operative temperatures above 26°C (Araújo, 1996; Andreasi et al, 2010; Gonçalves, 2001). In addition to higher air velocities values, occupants also appreciated having control over fans as complementary source of ventilation, especially for periods without breeze. Ceiling fans tend to be a useful device in order to increase air movement for these occupants (Gonçalves, 2010).

Based upon these results, occupants in naturally ventilated buildings (i) accept temperature swings during the day and year, (ii) prefer higher air velocities *if* (iii) control and fans are provided. These results can be easily related to the three categories of responses that occupants undertake in order to reestablish thermal comfort summarized by de Dear et al (1997): behavioral, physiological and psychological adaptation.

2. General requirements

The general guidelines suggested in this paper are related to naturally ventilated environments and it comprises two main items: adaptive capacity opportunities and acceptable indoor conditions, including specific requirements for thermal and air movement acceptability. This is a first attempt in order to provide indicators and start a discussion about future standard for naturally ventilated buildings in Brazil.

General requirements are related to occupant's activities and adaptive opportunities regarding specifically openings and control over fans. Occupants must be developing sedentary activity (1.0 to 1.3 *met*) for at least thirty minutes and they must be able to actively modify their thermal indoor environment at least in terms of garments and openings.

Windows must be accessible and controllable primarily by the occupants and they might be combined fans in order enhance air velocity. In addition, specific requirements will be determined in terms of number of occupants and their access to control of fans.

i. Adaptive capacity potential

Into this section, buildings will be assessed in terms of their "adaptive capacity potential" (Kwog and Rajkovich, 2010). The adaptive potential can be defined as " a design approach that relies on an implicit understanding of the ecological and physical context of the site, orientation, site planning, passive heating and cooling design strategies, openings in the envelope for optimal daylighting; natural ventilation, shading, insulation, and envelope strategies" (Kwog and Rajkovich, 2010). Buildings' design must be in compliance with bioclimatic strategies for its specific zone. The following items will be assessed as minimal design requirements in order to be in accordance to the adaptive capacity potential:

- Orientation;
- Site planning;
- Bioclimatic design strategies applied according to specific zone;
- Openings design: location, dimension and detailed information of its operability
- Complementary devices for ventilation enhancement: wind catchers, ventilated sills, pergolas, verandahs, etc) *in combination* with daylighting and shading systems;
- Complementary mechanical devices i.e. ceiling and/or desk fans and its distribution inside indoor environment and occupants control (individual or group).

There will be no grading of adaptive capacity potential and all buildings must provide design evidences of *at least* the above-mentioned strategies. In this level, buildings will be assessed in a *qualitative* way, in order to offer the highest adaptive opportunities potential for occupants of these thermal environments. Buildings complying with this item will be considered for subsequent analysis regarding acceptable indoor conditions.

ii. Acceptable thermal conditions

A combination of thermal and air movement acceptability will be considered in order to evaluate thermal indoor environmental conditions. The following items will provide more details about these requirements.

a. Indoor operative temperatures

The acceptable thermal conditions applied will be established according to the adaptive model (de Dear and Brager, 1998). Allowable indoor operative temperatures will be presented as a variation of mean monthly outdoor temperatures and it was based on field experiments carried out in different regions in Brazil presented before in Figure 2. Thermal acceptability goals will be 80 and 90%. Extensions of the neutral temperature will be of ±2.5°C for 90% of thermal acceptability and ±3.5°C for 80% of thermal acceptability.

Specific air movement requirements will be necessary for operative temperatures higher than 26°C. Minimal air velocity values will be required and complementary mechanical cooling devices will be requested. These complementary requirements aim to enhance adaptive opportunities for the occupants into these environments.

b. Air movement

Air velocity values are recognized as one of the essential variables to improve occupant's thermal comfort and it has been considered in comfort standards worldwide. Typically, *maximum* limits are established in order to avoid dissatisfaction, especially due draft. This might be true in cold climates, but questionable for warm environments (Arens et al, 1998, Khedari et al, 2000, Tanabe and Kimura, 1989, Zhang et al, 2007). This discussion has been revived due to occupant's complaints, often related to preferences for "more air movement" (Toftum, 2004, Zhang et al, 2007). Revisions to limits have been proposed considering also more specific requirements for occupant's control (Arens et al, 2009).

For this Brazilian standard, air movement acceptability must be considered and the target values will be for 80 and 90%. In order achieve these targets indoor environments must fulfil *minimal* air velocity requirements according to Figure 4. The air velocity requirements must be achieved during the occupied period. For operative temperatures higher than 26°C, complementary ventilation will be required.

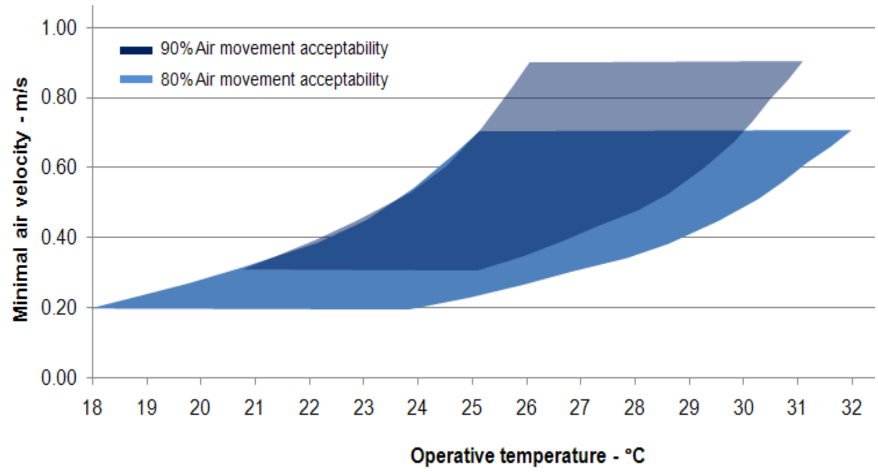


Figure 4. Minimal values for air velocity corresponding to 80 and 90% air movement acceptability.

Complementary ventilation can be achieved by use of fans and are encouraged in order to supply airflow for occupants especially during periods of absence of exterior wind or/and areas with low porosity (city centres, for example). Nocturnal ventilation techniques also are encouraged but limits will not be established in terms of air velocity values. Table 1 summarizes occupant's control requirements over openings and complementary mechanical devices. Three different categories were defined. This classification can be applied *in conjunction* with air velocity values above detailed.

Table 1. Categories related to occupants' control over openings and fans.

Categories	Available occupant's control	
	Openings	Fans
☆☆☆	Individual access - Operable and airflow directional design	Individual
☆☆	Group access - operable and airflow direction design	Every four occupants
☆	Group access - Operable	Every six occupants

3. Labeling categories

Naturally ventilated buildings willing to receive a thermal comfort and energy efficiency label will be graded into three different categories. Table 2 summarizes the suggested requirements for natural ventilation. Building must be in conformity to the adaptive capacity potential and thermal and air movement acceptability percentages must be accomplished in order to be classified into one of the three categories. Category *1* comprises indoor environments where air movement acceptability achieved 90% and received three stars for occupant's control. Category *1* corresponds to buildings where air movement acceptability was 80% and two stars for occupants control. The last category, *3*, considers indoor environments where 80% of air movement acceptability was achieved but only one star for complementary occupants' control.

Table 2. Suggested requirements for natural ventilation.

NatVent Category	Adaptive capacity potential	Thermal and air movement acceptability	
		Acceptability	Occupant's control
1	Yes	90%	☆☆☆ and ☆☆
2	Yes	80%	☆☆
3	Yes	80%	☆

In order to be in conformity to the existing Federal Regulation for Voluntary Labelling of Energy Efficiency Levels in Commercial, Public and Service Buildings, the following classification is suggested. The NatVent category that the building was classified will be combined to the percentage of hours into the comfort zone (PHC). The results for the suggested label were summarized into Table 3. The EqNumV column corresponds to the numerical values that are necessary for the complete building's energy evaluation presented in more detail in Carlo and Lamberts (2009) and it comprises lighting and cooling systems and thermal envelope.

Table 3. Suggested labelling categories for naturally ventilated buildings.

Label Category	% Hours into the comfort zone (PHC)	NatVent Category	EqNumV
A	PHC ≥ 80%	1	5
B	70% ≤ PHC < 80%	2	4
C	60% ≤ PHC < 80%	2	3
D	50% ≤ PHC < 70%	3	2
E	PHC < 50%	-	1

4. Conformity

Buildings willing to receive this labelling must provide proof of conformity according to the above requirements. Adaptive capacity must be showed by detailed information related to building's design strategies, according to its specific bioclimatic zone. Qualitative analysis are acceptable but quantitative area preferable in order to provide detailed information about this components/strategies and its performance.

Thermal and air movement acceptability must be shown by means of calculation and/or simulation and/or wind tunnel experiments for buildings in design stage. For existing buildings, comprehensive indoor climatic measurements must take place. Simulations/experiments must represent:

- Indoor operative temperature ranges within the thermal comfort zone;
- Air velocity values *and* airflow distribution within the occupied zones.
- Air velocity provided by the complementary mechanical devices and occupant's control pattern applied;
- Complete plans, descriptions, detailed information for maintenance and operation must be provided and kept during building's life occupancy.

- Identification and distribution of all mechanical cooling devices must be indicated and detailed, especially in terms of occupant's control.

Field experiments must be in compliance with the minimal requirements specified into the measurement protocol detailed in this guideline. In this document, the method will be described including step-by-step measurement procedures, instrumentation and questionnaires. Indoor environmental data must consider, but not be limited to air temperature, mean radiant temperature, humidity, air speed, outdoor temperature, occupants' clothing and activity. More detailed information will be provided in the guidelines.

Conclusions

This paper presented guidelines for a Brazilian standard for naturally ventilated buildings. The main variables of indoor environmental quality considered in these guidelines were a combination of thermal and air movement acceptability. Based upon this, operative temperature ranges were based on the adaptive model and minimal air velocity requirements were also determined. Specific occupant's control over openings and fans were also considered. Finally, an energy conservation labelling system was proposed.

This is a first attempt to combine guidelines for naturally ventilated buildings in Brazil and more detailed information is therefore necessary. Future comfort field experiments will be undoubtedly a crucial source of information for further refinements of these guidelines. However, there are enough indications that providing occupants with control and requiring an active behaviour over passive design techniques will be a successful path towards more healthy, stimulating and sustainable buildings in Brazil.

References

ABNT, NBR 15220-3 – Desempenho térmico de edificações – Parte 3: Zoneamento bioclimático brasileiro e diretrizes construtivas para habitações unifamiliares de interesse social, 2005, 23 pp.

Andreasi, W. (2001). Avaliação do impacto de estratégias bioclimáticas na temperatura interna no Passo do Lontra, Pantanal do estado de Mato-Grosso do Sul. MPhil thesis. Federal University of Santa Catarina, Florianópolis, 2001. 134pp.

Andreasi, W. Lamberts, R. Cândido, C. (2010) Thermal acceptability assessment in buildings located in hot humid regions in Brazil. Building and Environment, V.45, 1225-1232.

Araújo, V. M. D. de (1996) Parâmetros de conforto térmico para usuários de edificações escolares no litoral nordestino brasileiro. PhD thesis. University of São Paulo, São Paulo, 1996. 179pp.

Arens E. A., Xu T, Miura K, Zhang H., Fountain M.E., Bauman F. (1998) A study of occupant cooling by personally controlled air movement. Build Energy 27:45–59.

Arens, E., Turner, S., Zhang, H., Paliaga, G. (2009) Moving air for comfort. ASHRAE Journal, 2009, pp. 18-29.

ASHRAE (2004). Standard 55: Thermal environmental conditions for human occupancy. ASHRAE: Atlanta.

Cândido, C., de Dear, R., Lamberts, R., Bittencourt, L. S. (2010) Air movement acceptability limits and thermal comfort in Brazil's hot humid climate zone. Building and Environment, V.45, pp. 222-229.

Cândido, C., de Dear, R., Lamberts, R., Bittencourt, L. S. (2010) Cooling exposure in hot humid climates: are occupants “addicted”? Architectural Science Review, V.53, pp 1-6.

Carlo, J., Lamberts, R. (2008) Development of energy efficiency labels for commercial buildings: Effects of different variables on electricity consumption. Energy and Buildings 40: p 2002-2008.

de Dear, R.J. and Brager, G.S. (2002).Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55, Energy and Buildings 34 (2002) (6), pp. 549–561.

de Dear, R., Brager, G., Cooper, D. (1997). Developing an Adaptive Model of Thermal Comfort and Preference: Final Report ASHRAE RP-884 Project. Available online: http://sydney.edu.au/architecture/documents/staff/richard_de_dear/RP884_Final_Report.pdf.

Gomes, C. H. de G. (2003) Análise dos níveis de conforto térmico em um edifício de escritórios na cidade de Maringá. MPhil thesis. Federal University of Santa Catarina, Florianópolis, 2003. 129pp.

Gonçalves, W., Valle, R. M. Garcia, E. S., O papel de mecanismos adaptativos no conforto térmico de estudantes universitários em Belo Horizonte – MG. ENCAC 2001, São Pedro – SP, Brazil. pp. 1 – 8.

Goulart, S, Lamberts, R., Firmino, S. (1997) Dados climáticos para projeto e avaliação energética em edificações para 14 cidades brasileiras, Florianópolis, 1997, 345 pp.

Ho, S.H., Rosario, L., Rahman, M.M. (2009) Thermal comfort enhancement by using ceiling fan. Aplied Thermal Engineering, V 29, pp. 1648-1656.

IPCC. Summary for policymakers. In: Metz B, Davidson O, Bosch P, Dave R, Meyer L, editors. Climate change 2007: mitigation of climate change. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007.

Khedari, J., Yamtraipt, N., Prantintong, N., Hirunlabh, J. (2000) Thailand ventilation comfort chart. Energy and Buildings, V.32, pp 245-249.

Kwok, A. Rajkovich, N. B. (2010). Adressing climate change in comfort standards. Building and Environment V.45, pp. 18-22.

Lamberts, R. (2008). Trends in Brazilian building ventilation market and drives for change. Ventilation Information Paper V23, pp. 1-4.

Lazarotto, N. Santos, J. C. P. (2007) Avaliação do conforto térmico de estudantes do ensino fundamental na região noroeste do RS. ENCAC 2007, Ouro Preto – MG, Brazil. pp.1038 – 1046.

Lei n. 10295, de 17 de outubro de 2001: Dispõe sobre a Política Nacional de Conservação e Uso Racional de Energia, Diário Oficial da União, Brasília, 2001, available at www.inmetro.gov.br/qualidade/lei10295.pdf, access on: March 17, 2003.

Ministério das Minas e Energia, Balanço Energético Nacional, 2007, available at http://www.mme.gov.br, access on: 25 January, 2010.

PROCEL, Plano de ação para eficiência energética em edificações, Eletrobrás, Rio de Janeiro, 2003, 39 pp.

Roriz, M., Ghisi, E., Lamberts, R. (1999) Bioclimatic zoning of Brazil: A proposal based in Givoni and Mahoney methods. Sustaining the Future: Energy, Ecology, Architecture: Plea '99 - the 16th International Conference Plea (Passive & Low Energy Architecture). pp. 211 – 217, PLEA International, Brisbane, Australia.

Ruas, A. C. (1999) Avaliação de conforto térmico: Contribuição à prática das normas internacionais. MPhil thesis. State University of Campinas, Campinas, 1999.78pp.

Tanabe S, Kimura K (1989) Thermal comfort requirements under hot and humid conditions. Proceedings of the First ASHRAE Far East Conference on Air Conditioning in Hot Climates, Singapore, ASHRAE, 3–21.

Toftum, J. (2004). Air movement – good or bad? Indoor Air: 14, pp. 40-45.
Xavier, A. A. de P. (1999) Condições de conforto térmico para estudantes de 2° grau na região de Florianópolis. MPhil thesis. Federal University of Santa Catarina, Florianópolis, 1999. 197pp.

van der Linden, A.C., Boerstra, A.C., Raue, A.K., Kurvers, S.R., de Dear, R.J. (2006) Adaptive temperature limits: A new guideline in The Netherlands. A new approach for the assessment of building performance with respect to thermal indoor climate. Energy and building, v38 pp 8-17.

Xavier, A.A. de P. (2000) Predição de conforto térmico em ambientes internos com atividades sedentárias – teoria física aliada a estudos de campo. PhD thesis. Federal University of Santa Catarina, Florianópolis, 2000. 251pp.

Zhang, H., Arens, E., Fard, S. A., Huizenga, C., Paliaga, G., Brager, G., Zagreus, L. (2007) Air movement preferences observed in office buildings. Int J Biometeorol: 51, 349 – 360.