

RESEARCH PAPER

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

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The Brazilian Federal Government has been recently promoting energy-conservation initiatives, most notably the 'Thermal Performance in Buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Housing' and the 'Federal Regulation for Voluntary Labelling of Energy Efficiency Levels in Commercial, Public and Service Buildings'. These new regulations provide information for designers based on Brazil's climate requirements, with specific advice related to lighting systems, HVAC and the thermal envelope of buildings. Nevertheless, requirements for naturally ventilated indoor environments appear as an open category without clear criteria. To address this, the paper proposes guidelines for naturally ventilated environments in which specific thermal and air movement acceptability goals must be achieved. The guidelines are based on results from field experiments in non-residential naturally ventilated buildings in different climatic zones as well as drawing on other studies. The proposed guidelines consider occupants' adaptive potential as well as thermal and air movement acceptability. Combining thermal acceptability with air movement acceptability is a key design challenge. Permissible operative temperature ranges are based on the ASHRAE 55 adaptive comfort standard, and minimum air velocity requirements within the occupied zone are specified. Considerations also included 'active' occupants and specific control over openings and fans.

Keywords: adaptive comfort, air movement acceptability, design guidelines, natural ventilation, occupants, satisfying, thermal acceptability, thermal comfort

Le Gouvernement fédéral brésilien encourage depuis peu les initiatives en faveur des économies d'énergie, et tout particulièrement les initiatives « Performances Thermiques des Immeubles – Zones Bioclimatiques Brésiliennes et Directives de Construction pour les Logements à Faible Coût » et « Réglementation Fédérale pour l'Étiquetage Volontaire des Niveaux de Rendement Énergétique des Immeubles Commerciaux, Publics et de Services ». Ces réglementations nouvelles fournissent aux concepteurs des informations basées sur les exigences climatiques du Brésil, et s'accompagnent de conseils spécifiques relatifs aux systèmes d'éclairage, aux systèmes CVCA et à l'enveloppe thermique des immeubles. Néanmoins, les exigences relatives aux environnements intérieurs à ventilation naturelle apparaissent comme une catégorie ouverte sans critères clairs. Pour traiter ce problème, le présent article propose des directives pour les environnements à ventilation naturelle dans lesquels des objectifs spécifiques d'acceptabilité thermique et en matière de circulation d'air doivent être atteints. Ces directives sont basées sur les résultats d'expériences de terrain menées dans des immeubles non résidentiels à ventilation naturelle dans différentes zones climatiques, mais s'appuient également sur d'autres études. Les directives proposées prennent en considération le potentiel adaptatif des occupants aussi bien que l'acceptabilité thermique et en matière de circulation d'air. Réussir à

combiner l'acceptabilité thermique et l'acceptabilité en matière de circulation d'air pose un problème de conception essentiel. Les plages de température de service admissibles sont basées sur la norme de confort adaptatif ASHRAE 55, et les exigences minimales quant à la vitesse de l'air dans la zone occupée sont précisées. Ont également été pris en considération les occupants « actifs » et les commandes spécifiques des ouvertures et des ventilateurs.

Mots clés: confort adaptatif, acceptabilité de la circulation d'air, directives de conception, ventilation naturelle, occupants, satisficing [stratégie de prise de décision], acceptabilité thermique, confort thermique

Introduction

The potential for energy conservation and greenhouse gas mitigation from the building sector has been well documented (Intergovernmental Panel on Climate Change (IPCC), 2007). In order to achieve this, technical solutions such as insulation, cooling and heating systems, efficiency in appliances, etc. are often heralded as the main mitigation path. The ultimate success or failure, in terms of a building's long-term viability, energy use and occupant satisfaction, depends heavily upon the indoor environmental quality delivered to building occupants. With this concept in mind, designers are beginning to explore how they may widen the range of opportunities for occupant comfort, both in new-build and retrofit contexts. This has reawakened interest in natural ventilation for the provision of comfort, particularly in terms of regulations and standards worldwide (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2004; International Organization for Standardization (ISO), 2006; van der Linden *et al.*, 2006; Comité Européen de Normalisation (CEN), 2007).

In Brazil where there is a broad range of climates, the idea of a unified standard that takes into consideration both technical and behavioural issues is not an obvious choice. Much of Brazil's territory is classified as a hot, humid climate. In such regions, natural ventilation combined with solar protection are the most effective bioclimatic design strategies to improve thermal comfort passively. Despite these passive options, the number of buildings relying on active systems as the main cooling strategy continues to increase inexorably.

In 2001 Brazil experienced a major electricity crisis as a result of extreme climatic events (a lack of rain to drive hydroelectricity generation) and inadequate infrastructural investments (transmission lines and back-up generation plans). As a consequence, the consumption reduction imposed was 20% for the entire country, with some of this reduction becoming permanent as a result of government actions and population engagement (Lamberts, 2008). The Brazilian Government has been promoting energy-conservation initiatives including the 'Thermal Performance in Buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Housing' (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 efforts to provide information for designers based on Brazil's climate requirements, with specific items related to lighting systems, heating, mechanical ventilation and air-conditioning (HVAC) and the thermal envelope of buildings, but design requirements for naturally ventilated indoor environments are yet to be defined.

Revisiting Brazilian energy-efficiency initiatives

In Brazil, power generation is largely from hydroelectricity, accounting for approximately 91% of the total. Brazil's total hydroelectric power potential is 260 GW, of which approximately 22% has already been implemented (Brazil Ministério do Desenvolvimento, 2009). Of this, 40% is in the Amazon region where demand is low, while most of the potential for large developments in the southeast have already been exploited (Brazil Ministério do Desenvolvimento, 2009). Due to the lack of investments in the supply side and constant growth of demand, energy efficiency improvements have become essential.

Energy used in buildings accounts for about 48.3% of the total electrical energy consumption in Brazil (Brazil Ministério do Desenvolvimento, 2009): with 23% of this dedicated to commercial and public buildings and approximately 22% to the residential sector (Ministério das Minas e Energia, 2007). Based upon this, the Federal Government released a 'National Policy of Conservation and Rational Use of Energy' focusing on energy efficiency in buildings and equipment. Among the Brazilian Government actions on energy efficiency are two that should be highlighted: design guidelines for the residential sector and a rating system for commercial buildings.

For the residential sector, the 'Thermal Performance in Buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Housing' (ABNT, NBR 15220-3, 2005) is the main reference. The requirements concern the thermal envelope, lighting and acoustics, along with minimum requirements for ventilation and openable areas. One important contribution made by this document was the definition of bioclimatic zones (Figure 1). Eight zones were defined

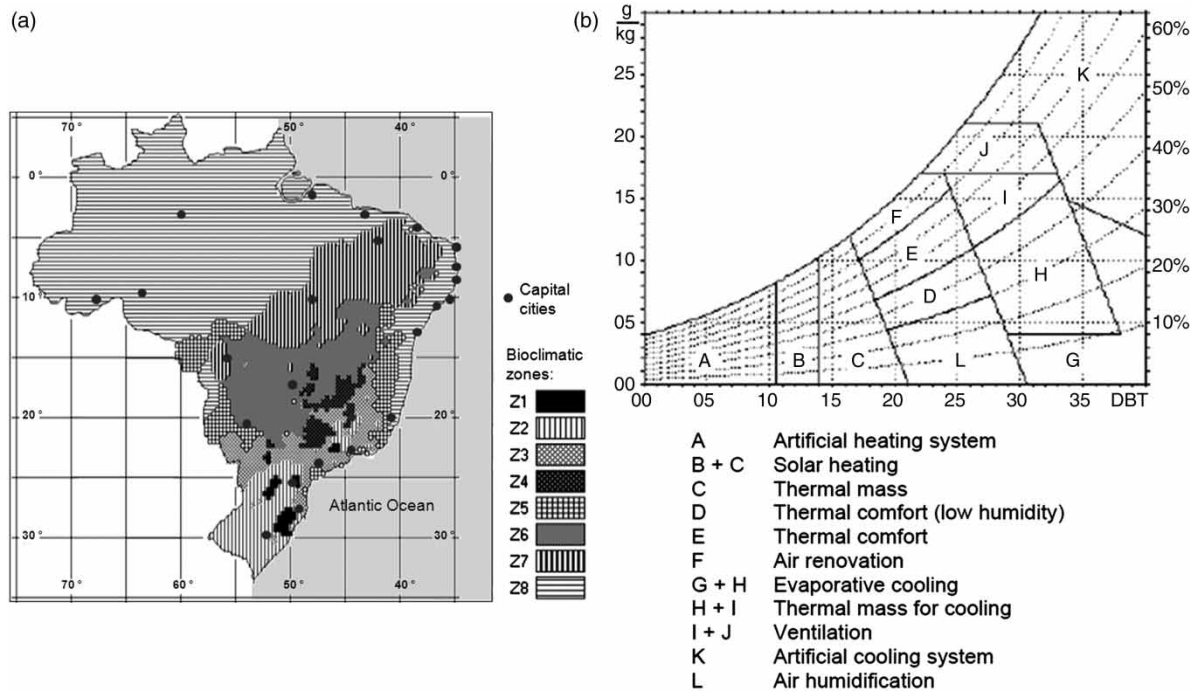


Figure 1 (a) Bioclimatic zoning in Brazil and (b) bioclimatic chart (ABNT, NBR 15220-3, 2005)

based on detailed climate data from 330 sites across Brazil. Based upon this division, a set of specific bioclimatic design strategies was developed, with particular emphasis on the early design stage.

The ‘Federal Regulation for Voluntary Labeling of Energy Efficiency Levels in Commercial, Public and Service Buildings’ addresses commercial and public buildings. This new regulation is based on a study focusing on Brazil’s climate requirements with specific items related to lighting system, HVAC and the 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 (Carlo and Lamberts, 2008).

Figure 2 shows different bioclimatic strategies and recommended ventilation patterns for Zones 1–8. The first is ‘cross-ventilation’, indicating necessity of airflow through the indoor environments for Zones 2, 3 and 5. The second is ‘selective ventilation’, applicable during warmer seasons and/or when the indoor temperature is higher than the outdoor temperature for Zones 4, 6 and 7. The final pattern is ‘permanent ventilation’, which is designed for 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 Zone 1, corresponding to the coldest region in Brazil.

These regulations established a consistent amount of technical information about building’s thermal

envelope, but left a gap for naturally ventilated environments that needs to be addressed. Natural ventilation is frequently associated with a strong concern about airflow distribution in indoor environments, hence the recommendations related to openable areas and ventilation patterns (ABNT, NBR 15220-3, 2005). This is also the traditional reference of regional building codes across Brazil, with requirements dealing exclusively with minimum openable area without much consideration of thermal comfort criteria. These are undoubtedly a contribution to improving an occupant’s thermal comfort through natural conditioning, but a more accurate comfort specification for thermal indoor environments is desirable.

Adapting a model for Brazilian occupants: evidence from previous field experiments

Given the wide range of climate conditions found in Brazil, differences in thermal acceptability are not surprising. For instance, thermal acceptability in the south of Brazil has been observed from 14 to 24°C (Xavier, 2000; Lazarotto and Santos, 2007), while in the north-east acceptability limits extend from 24.5 to 32°C without compromising occupants’ thermal comfort (Araújo, 1996). Despite minor differences, the observed range of acceptable temperatures in Brazil is consistent with the ASHRAE 55 (2004) adaptive model. As identified by the Brazilian researchers, field evidence indicates adaptive opportunities to be a decisive factor in these thermal environments, particularly clothing adjustments (Lazarotto and Santos,

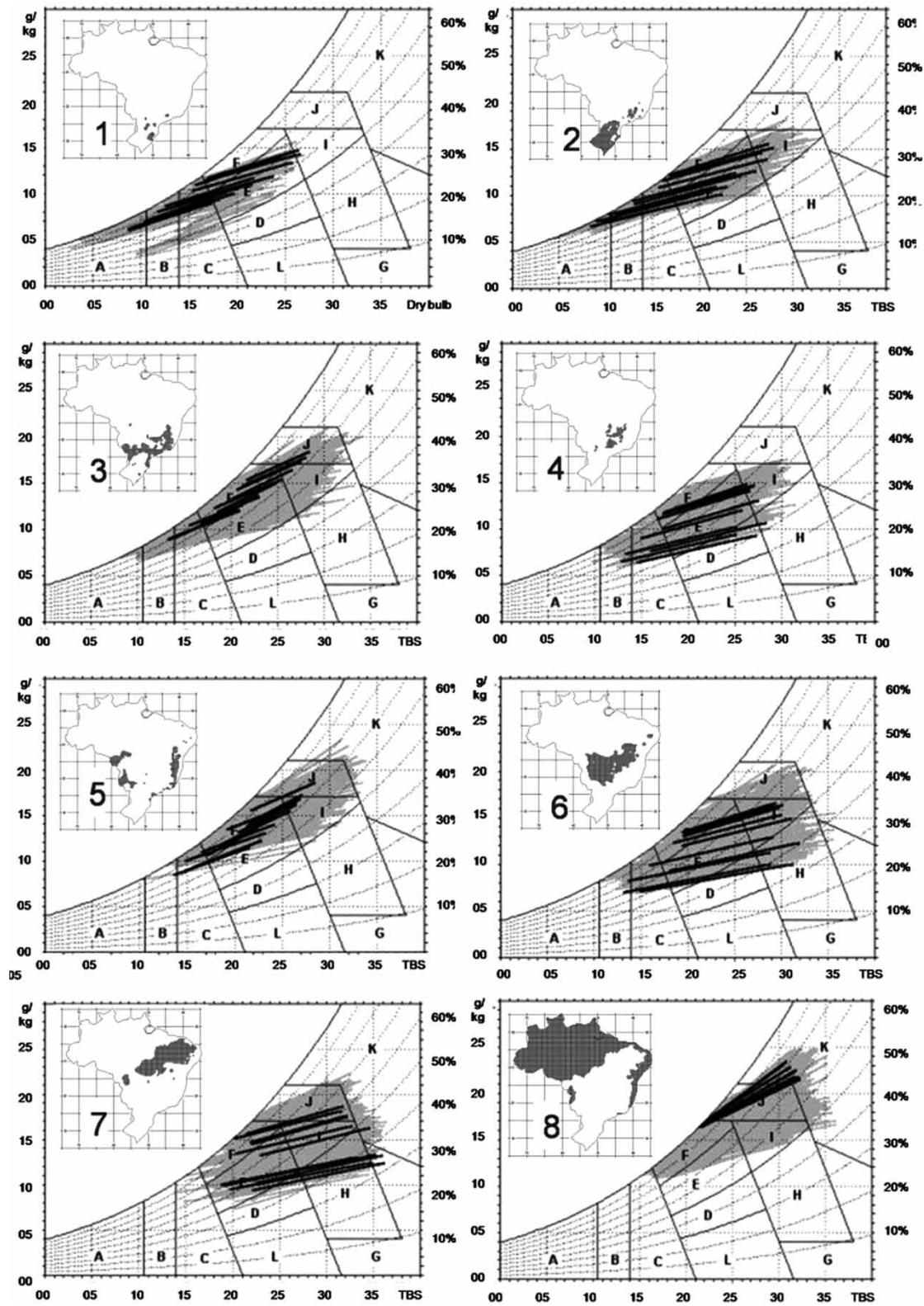


Figure 2 Bioclimatic design strategies and ventilation pattern for different zones (ABNT, NBR 15220-3, 2005).
Ventilation pattern: Zone 1: Not recommended; Zone 2: Cross-ventilation; Zone 3: Cross-ventilation; Zone 4: Selective ventilation;
Zone 5: Cross-ventilation; Zone 6: Selective ventilation; Zone 7: Selective ventilation; Zone 8: Permanent ventilation.

2007; Andreasi *et al.*, 2010) and air movement enhancement by use of fans (Gonçalves *et al.*, 2001).

Discrepancies into occupants' adaptive opportunities, particularly in terms of clothing insulation (Ruas, 1999; Andreasi, 2001) and air movement (Araújo, 1996; Cândido *et al.*, 2010) were found. In the first case, the main complaints related to restricted degrees of freedom within the dress code (Andreasi, 2001), with occupant satisfaction being maximized by a flexible dress code (Lazarotto and Santos, 2007). In the second case, occupants' complaints stemmed from their preference for 'more air movement' (Cândido *et al.*, 2010), especially in the hot-humid zone which attracted strongest demand for higher air velocities. This demand was more pronounced at operative temperatures above 26°C (Araújo, 1996; Andreasi *et al.*, 2010; Gonçalves *et al.*, 2001). In addition to higher air velocities, occupants also appreciated having control over fans as a complementary source of ventilation, especially during weather without breeze.

Field experiments performed in Brazil's hot-humid climate zone showed almost 90% thermal acceptability within the operative temperature ranges prescribed in the ASHRAE Standard 55 on adaptive comfort (Cândido *et al.*, 2011). However, occupants required air velocities values higher than the average 0.3 m/s found within the ASHRAE RP 884 database in order to achieve air movement acceptability. In this hot, humid context, occupants' overall thermal environmental satisfaction cannot be defined simply in terms of an operative temperature range. Air movement is the main determinant of whether or not operative temperature in the high 20°Cs will be acceptable or not. Based on these results, it is clear that Brazilian occupants in naturally ventilated buildings (1) accept temperature swings during the day and year, (2) prefer higher air velocities *if* (3) control and fans are provided. These generalizations can be easily related to the three categories of responses that occupants undertake in order to re-establish thermal comfort as summarized by de Dear *et al.* (1997): behavioural, physiological and psychological adaptation.

The weight of research done so far focuses on thermal sensation, preference and acceptability in buildings where occupants wear uniforms or relatively strict dress codes prevail, and adaptive opportunities are limited (high school classrooms, army headquarters, etc.). Despite natural ventilation being one of the main bioclimatic design strategies in Brazil, more detailed field studies combining thermal comfort and air movement questionnaires with accurate indoor climatic instrumental observations are therefore necessary.

This paper summarizes a first attempt at defining guidelines for non-residential naturally ventilated

environments in which thermal and air movement acceptability criteria must be achieved in addition to specific requirements for occupants' control.

Method

Results presented and discussed here are based on original field experiments performed in non-residential naturally ventilated buildings located in various different climatic zones in Brazil (9°31'S and 27°35'S). The fundamental feature of this field research design is the proximity, in time and space, of indoor climate observations with corresponding comfort questionnaire responses from the occupants. Field experiments resulted in approximately 5000 questionnaires collected during both summer and winter seasons.

When buildings were selected for inclusion in this study the following criteria were applied: (1) windows had to be easy to access and operate; (2) rooms could not have a mechanical cooling system (refrigerated air-conditioning); (3) rooms could have complementary mechanical ventilation with unconditioned air (fans); (4) the opening and closing of windows had to be the primary means of regulating thermal conditions; and (5) occupants had to be engaged in near sedentary activity (1.0–1.3 met), and permitted to adapt their clothing freely to the indoor and/or outdoor climatic conditions.

The questionnaires comprised four different and complementary parts. The first part focused on thermal sensation, preference and acceptability. The second part consisted of questions related to air movement acceptability and preference. The third part focused on exposure to air-conditioning and thermal history. The fourth and last part recorded occupants' activities and clothing.

The subjects started answering the questionnaire at least 30 minutes after they arrived in the room in order to minimize any influence from their previous activities. Each subject answered the questionnaire on five separate occasions during the same experiment period (approximately 140 minutes). Simultaneous indoor climatic observations were taken with a microclimatic station (Babuc A and SENSU), including air temperature, globe temperature, air velocity and humidity. These were recorded by a data logger with a 5-minute interval throughout the entire 140-minute period.

The field experiments were purposely designed to register air velocity values at exactly the same time and location as the occupants answered their questionnaires. This was because the project's focus was on the occupant's perception of air movement, and the tendency for this parameter to vary in space and time more than the other comfort parameters. The

instrument used for these observations was a portable hot-wire anemometer (Airflow Developments, model TA35 sensor) within a 1 metre radius around each occupant. Smoke sticks were used to visualize the airflow direction during each anemometer measurement. A sample of 30 instantaneous air speeds were registered for each subject each time they completed a questionnaire, yielding a total of 150 air-speed values for each occupant. This procedure enabled a mean air velocity to be associated with each subject for each of their five comfort questionnaires.

Results and discussion

Adaptive capacity potential

Buildings can be assessed in terms of their 'adaptive capacity potential' (Kwok and Rajkovich, 2010, p. 20), which 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 daylight natural ventilation, shading, insulation, and envelope strategies.

A building's design must comply with bioclimatic strategies for its specific zone. The following information must be provided as minimal design requirements:

- orientation and site planning
- design strategies applied according to its specific bioclimatic zone
- opening design: location, dimension and detailed information of apertures' operability
- complementary devices for ventilation (if applicable) such as wind catchers, ventilated sills, pergolas, verandas, etc.;
- complementary mechanical devices (if applicable), *i.e.* ceiling and/or desk fans, their distribution in the indoor environment and occupants' control availability (individual or group)

There will be no grading of adaptive capacity potential and all buildings must provide design evidences of *at least* the aforementioned strategies. In this regard, buildings will be assessed in a *qualitative* sense. Buildings complying with this item will be then considered for subsequent analysis.

Acceptable thermal conditions

A combination of thermal and air movement acceptability criteria will be considered in order to evaluate

thermal indoor environmental conditions. The following items will provide more details about these requirements.

Indoor operative temperatures

The Brazilian acceptable thermal conditions were derived from the ASHRAE 55 adaptive model (de Dear and Brager, 2002). Thermal acceptability goals will be set at 80% and 90%. Extensions from the neutral temperature will be $\pm 2.5^{\circ}\text{C}$ for 90% of thermal acceptability and $\pm 3.5^{\circ}\text{C}$ for 80% of thermal acceptability.

Air movement

Air velocity is recognized as a key parameter in an occupant's thermal comfort and has been considered in comfort standards worldwide. Typically, *maximum* limits are established in order to avoid draft. While draft might be a relevant concern in cold climates, it is largely irrelevant in warm environments (Arens *et al.*, 2002; Khedari *et al.*, 2000; Tanabe and Kimura, 1989; Zhang *et al.*, 2007). Field studies suggest that there may be a zone of temperatures and air velocities in which devices and designs that move air across large areas can do so without creating an 'appreciable' draft risk for the occupants. Previous work has focused on air movement in field studies, including the maximum air velocity range that could be regarded as 'acceptable' for occupants during their activities. In this case, the considerations were constantly related to the concept of avoiding any disturbing or undesirable air movement (draft). This discussion has been revived due to occupant's complaints, which are often related to preferences for 'more air movement' (Toftum, 2004; Zhang *et al.*, 2007). Revisions to air speed limits have been proposed along with more specific requirements for occupant's control (Arens *et al.*, 2009).

For these guidelines, air movement acceptability must be considered and the target values will be an 80% and 90% limit. In order to achieve these targets, indoor environments must meet *minimum* air velocity requirements according to Figure 3.

The air velocity requirements must be achieved during a building's occupied hours.

Supplementary air movement can be achieved by the use of fans, which are encouraged in order to supply airflow for occupants, especially during periods when exterior wind is absent or/and areas with low porosity (city centres, for example). Nocturnal ventilation techniques are also encouraged, but limits will not be established in terms of air velocities. Table 1 summarizes an occupant's control requirements over openings and complementary mechanical

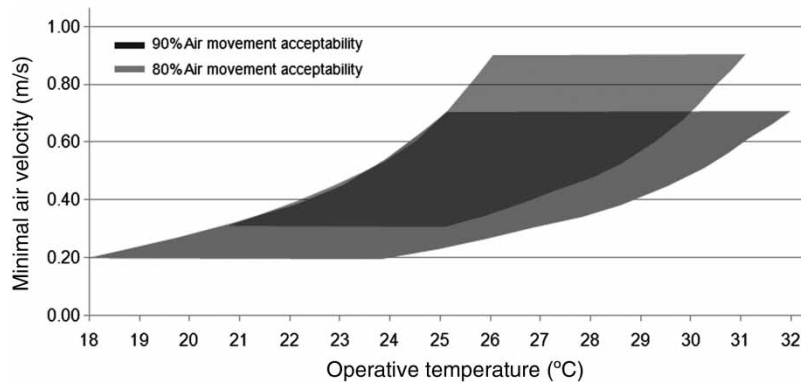


Figure 3 Minimal air velocity values required within the occupied zone, corresponding to 80% and 90% air movement acceptability

devices. Three different categories were defined for application *in combination with* the air velocities detailed above.

Labelling categories

Naturally ventilated buildings applying for a thermal comfort and energy efficiency label will be graded into three different categories. Table 2 summarizes the suggested requirements for natural ventilation. Buildings must conform to the adaptive capacity potential, and both thermal and air movement acceptability percentages must be met in order to be classified into one of the three categories. Category 1 comprises indoor environments where air movement acceptability met or exceeded 90% and received three stars for occupant control. Category 2 corresponds to buildings where air movement acceptability was 80% and received two stars for occupant control. The last category (3) applies to indoor environments with 80% air movement acceptability but received only one star for occupant control.

In order to conform to the existing Federal Regulation for Voluntary Labelling of Energy Efficiency Levels in Commercial, Public and Service Buildings presented in detail in Carlo and Lamberts (2008), the following classification is suggested. The NatVent category will be combined with the percentage of hours in the comfort zone (PHC). The results for the suggested label are summarized in Table 3.

Conformity

Buildings applying for this labelling must provide proof of conformity according to the above criteria. Adaptive capacity must be demonstrated with detailed information related to the building's design strategies and their relevance to its bioclimatic zone.

Thermal and air movement acceptability must be shown by means of calculation and/or simulation

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

Category	Available occupant's control within the occupied zone	
	Openings	Fans
☆☆☆	Individual access – operable and airflow directional design	Individual
☆☆	Group access – operable and airflow directional design	Every four occupants
☆	Group access – operable	Every six occupants

Table 2 Suggested design requirements for naturally ventilated buildings

Natural ventilation category	Adaptive capacity potential	Thermal and air movement acceptability	
		Acceptability (%)	Occupant's control
1	Yes	90	☆☆☆ and ☆☆
2	Yes	80	☆☆
3	Yes	80	☆
4	Yes	–	☆

and/or wind tunnel experiments for buildings in the 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

Table 3 Suggested labelling categories for naturally ventilated buildings

Label category	Percentage hours in the comfort zone (PHC)	Natural ventilation category
A	$\text{PHC} \geq 80$	1
B	$70 \leq \text{PHC} < 80$	2
C	$60 \leq \text{PHC} < 80$	3
D	$60 \leq \text{PHC} < 80$	4

- air velocity provided by the complementary mechanical devices and occupant's control pattern applied; within the occupied zone
- 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 control

Field experiments must be in compliance with minimal requirements specified in the measurement protocol. 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

The overwhelming weight of evidence from a large number of studies indicates that increased air movement in warm environments is essential for improving occupant thermal comfort, and therefore higher air velocities are suggested for these contexts. Air movement has major significance in terms of preference and acceptance of the indoor thermal environment, and thermal (*i.e.* temperature) acceptability alone was necessary but insufficient to satisfy occupants. Combining thermal acceptability and air movement acceptability is the key challenge design in these indoor environments. Brazil's climatic context should move it towards this linkage, incorporating these separate but connected dimensions of environment, as well as specific requirements for an occupant's control into a comprehensive standard for naturally ventilated buildings.

This study proposed a set of guidelines for a future Brazilian standard focusing on naturally ventilated indoor environments, and taking into consideration thermal

comfort, air movement acceptability and their interactions. The main criteria of indoor environmental quality considered in these guidelines were a combination of thermal and air movement acceptability. Based upon this, operative temperature ranges drawn from the ASHRAE adaptive model, overlain with minimum air velocity requirements.

This is a first attempt at combining design 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 active behaviour will be a successful path towards more healthy, stimulating and sustainable buildings in Brazil. In other words, moving away from 'thermal boredom' towards 'thermal delight' (Heschong, 1979), architects might have the opportunity of not only satisfying occupants, but also applying a more holistic design approach, more culturally relevant and environmentally *responsible* design. The recent revival of natural ventilation might help architects in (re)discovering such potential and in returning back to basics, considering again buildings as the third skin, a response to the climate and culture. After all, buildings are built for their occupants. It can be a sculpture, but not only that.

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