

Review

Indoor Environmental Quality in Latin American Buildings: A Systematic Literature Review

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Abstract: The amount of time people spend inside buildings is significant. Indoor environment quality deficiencies in some of these buildings may affect the health of its users. Therefore, a systematic literature review has been conducted to assess the quality of indoor environments in existing buildings in Latin America. The objectives of this review are (1) identifying countries and building types whose indoor environment quality has been analyzed the most, (2) identifying most used evaluation strategies, (3) identifying comfort types and most evaluated variables, and (4) determining whether or not Latin American buildings are comfortable and what local factors contribute to that effect. From the 100 selected papers for this analysis, it was noted that Brazil and Argentina led the studies on residences and schools. It was also noted that hygrothermal comfort was the most analyzed comfort type, with temperature and humidity leading the number of studies. Finally, this review shows a lack of studies including buildings whose users are sensitive to indoor environmental quality, such as nurseries, senior homes, or health facilities. Additionally, there is a sustained discrepancy between objective measuring methods and user perception. Furthermore, a detailed analysis of 88 buildings shows that in Latin America, 67.5% of buildings are uncomfortable; thus, it is necessary to improve the designs and regulatory standards, to educate users, and to improve building monitoring management at the operational stage.

Keywords: hygrothermal comfort; indoor air quality; acoustic comfort; visual comfort

1. Introduction

The increase in the number of time people spend inside buildings is significant. Both architects and engineers must think of ways to improve environmental comfort for users and, at the same time, improve energy performance in buildings. Comfort is, in fact, important since people spend around 80% to 90% of their days inside buildings [1]. Hence, it is relevant to study indoor environment quality in different building types.

Buildings affect people's health. There have been reports of diseases related to building use, the most relevant of which is sick building syndrome. Sick building syndrome is a term applied to buildings whose occupants experience physical discomfort just by being in them. It also describes the symptoms that show up after spending a certain number of hours in an enclosed space. These symptoms include eye, nose, and throat irritation, headaches, skin rashes, and respiratory problems. This term was born in the early 1980s when the first energy problems began worldwide. As a result, buildings became more hermetic, ventilation was reduced and, therefore, diseases started to spread [2].

Moreover, low-quality lighting can cause eye irritation and headaches; noise levels over 50 dBA can increase headaches and reduce concentration on tasks [3]. Inappropriate or excessive use of air conditioning (changing comfort temperature or humidity levels) can cause, on low levels, irritation, pain, and an increase of infections. On high levels, it can foster the growth of fungi in the air [4]. If this environment is dry, respiratory diseases will increase. Health consequences have been quantified in terms of deaths. Annually, 4.3 million people die prematurely due to diseases attributable to indoor air contamination caused by using inefficient solid fuels for cooking (data for 2012). Main causes of death are 12% pneumonia, 34% strokes, 26% ischemic cardiopathology, 22% chronic obstructive pulmonary disease, and 6% are due to lung cancer [5].

Finally, besides having significant effects on people's health, it is important to mention that indoor environment quality also affects people's productivity at work. When assessing instruments to measure the loss of productivity at work, Meerding et al. [6] found that reduced productivity due to health problems was predominant in 5–12% of workers, with a mean productivity loss of 12–28%. For example, ventilation and temperature-humidity are associated with absenteeism rates. Furthermore, as Collins et al. [7] point out, it is possible to estimate that by doubling the ventilation rate, absenteeism at work would decrease from 2% (5 d per year) to 1.5% (an average of 3.8 d per year). Regarding temperature, Seppänen et al. [8] showed that for every Celsius degree increase in temperature (on a 25 °C to 32 °C range), there was a 2% reduction of employee performance. No differences were found in the 21–25 °C range.

Several studies show the direct connection between indoor environmental quality (IEQ) and energy performance in buildings. Providing and maintaining acceptable energy cost levels and low carbon emissions require building designers, clients, and users to find the right balance between energy savings and comfort [9,10]. However, good IEQ is fundamental for the wellbeing and good performance of its occupants [11]. Some of the studies from the last decade such as those of [12,13] or [14] deal with thermal comfort and its adaptive models, or ventilation rates and its relation to health [15]. Furthermore, there is interesting research on energy use and the wellbeing of its occupants [16].

There are also article reviews on building evaluations in actual use conditions (post-occupancy evaluation, POE) and the performance of one of the variables of indoor environment quality [17], or as a supplement to management systems for buildings in use to improve any variable of indoor environment quality, thus enhancing energy efficiency [18]. Additionally, some reviews focus on specific building types, such as schools [19,20], and how student health is affected by factors related to indoor environment quality [21], or the connection between IEQ and energy performance [22]. It is also possible to find literature reviews on historic buildings [23] and office buildings [24].

Previous reviews have dealt with the topic of our current review. However, as we will point out below, they have not focused on Latin America and have not considered all the factors or indexes for indoor environment quality that the present review has included.

Traditionally, comfort has been studied from the perspective of the physical environment and the physiology of its occupant, mainly in terms of four factors: hygrothermal comfort, acoustic comfort, indoor air quality (IAQ), and visual comfort [25]. These factors are studied through different interconnected elements that are difficult to estimate, mainly because of the absence of set protocols for measurement recollection (both objective and subjective) and the number of variables to be considered [26]. Thus, comfort is understood as a set of environmental conditions accepted by individuals for carrying out their regular activities [27]. Consequently, hygrothermal comfort must ensure that an individual does not experience too much cold or heat. Therefore, temperature, humidity, and airflow must be kept within the acceptable range. Visual comfort must guarantee enough light for individuals and their activities through appropriate quality and balance. Also, it must provide good outside views. Acoustic comfort entails having an adequate noise level and quality to use the space as it was intended [26]. Finally, IAQ is necessary to improve sensory perception. In turn, it propitiates a clean environment in terms of pollutant emissions such as carbon dioxide (CO₂), particulate matter (PM), or other pollutants.

Therefore, it is of utmost importance to measure and grade indoor environment quality on buildings in use. Such analysis would allow to rectify building management in their operational stage and apply to future designs what previous experiences have taught us. On the other hand, since the wellbeing of users in existing buildings depends on the quality of the construction and local regulation standards, this study undertakes a systematic review of current literature to identify what types of comfort are measured in Latin America, their parameters, building type, and evaluation strategy. With this data, we will try to conclude whether or not Latin American buildings are comfortable. These results will provide updated information to researchers on indoor environment quality in Latin America, thus allowing new research efforts in the field.

2. Materials and Methods

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist 2009 methodology [28]. Indexed 2018 publications found on Google Scholar, Scopus, Scielo, and Latindex were consulted. Additionally, other publications of interest found on Researchgate were included.

In total, 256 results were obtained from each database as follows: Scopus 113, Scielo 15, and Latindex 38. There were over 213,000 results on Google Scholar. Therefore, we only reviewed the first 20 result pages. Thus, we reached a total of 72 additional ones, the majority of which were peer-reviewed conference papers. Finally, Researchgate provided 18 results.

The articles were reviewed by the authors, taking into consideration studies complying with the criteria defined by the authors (Table 1). The inclusion criteria were (1) objective or subjective collection of information, (2) presence of quantitative and qualitative studies, (3) measurements done to buildings in Latin America, (4) analyzed building typology—housing, School, office buildings, university buildings, and government buildings, (5) papers published between 2008 and 2017, (6) papers written in English, Spanish, and Portuguese, (7) papers published in peer-reviewed journals, and (8) peer-reviewed conference papers.

Table 1. Keywords used in the search. Source: Authors.

Term	Comfort Type	Building Type	Country
Confort	Visual	Housing	Argentina
Conforto	Hygrothermal	School	Bolivia
Comfort	Acoustic	Office building	Brazil
	Interior air quality	University building	Chile
		Government building	Colombia
and	and/or	and	Ecuador
			Paraguay
			Peru
			Uruguay
			Venezuela
			Mexico

The exclusion criteria were (1) papers including just simulations (these papers were considered if they had some objective or subjective measurements), and (2) the case study building must exist, or at least a prototype, allowing for the simulation of use conditions. Figure 1 shows a PRISMA flowchart. After the identification, screening, and eligibility stages, 100 papers were included in the qualitative analysis and 88 in the quantitative analysis.

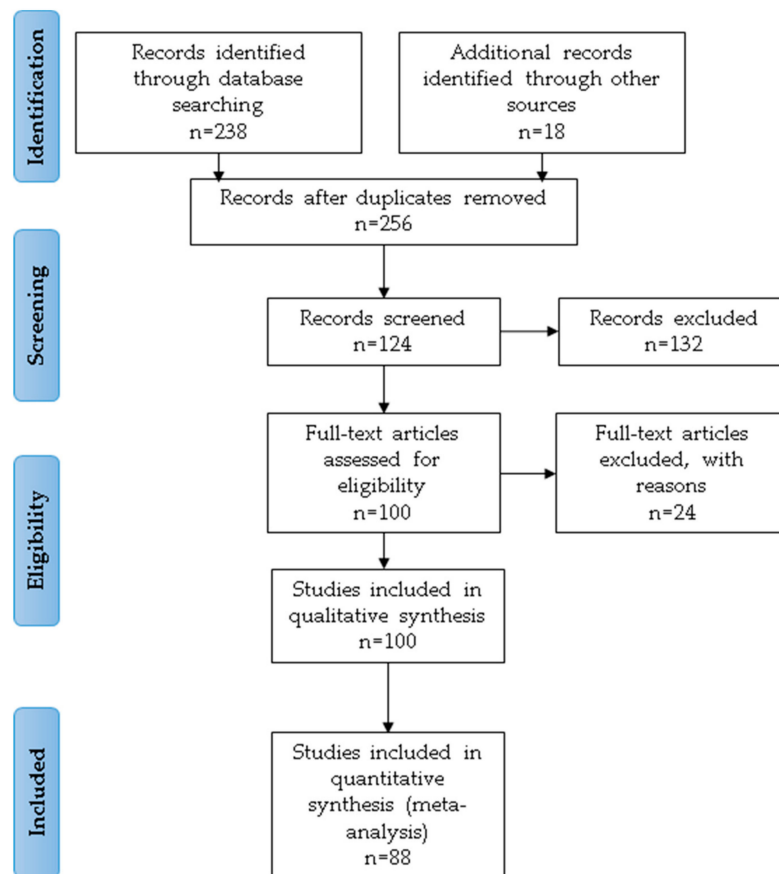


Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of literature search and review. Source: By Authors based on PRISMA 2009 [28].

2.1. Paper Selection and Classification

For this study, we compiled information from papers focusing on indoor environment quality variables affecting the relationship between human beings and the building interiors they use or inhabit. We reduced the span of papers to those concerning the Latin America region. We took into consideration information regarding real data from tools that measured the variables that affect IEQ. Surveys evaluating the same variables were considered as well. All data comparing wellbeing inside existing buildings by means of computer tools or statistical calculations were disregarded as they do not provide an approximation on how buildings behave in real-time.

2.2. Analysis by Variable Type

After classification, a variable comparison was performed. To this end, graphs were used to contrast results and to try and determine whether there were distribution trends in countries carrying out this type of research. Specifically, what building types, which in situ evaluation strategies were used when studying this phenomenon, and what comfort type and variables were most researched were investigated.

Thus, for hygrothermal comfort, we looked for variables such as relative humidity, dry bulb temperature, indoor and outdoor temperature, and air velocity. For visual comfort, natural and artificial lighting of spaces were determined. Likewise, for acoustic comfort, reverberation and ambient noise were considered. For IAQ, ventilation rates and emission of polluting gases such as CO₂, PM, or other were identified.

2.3. Paper Selection Based on IEQ Most Recurrent Variables

From the most recurrent variables for comfort evaluation in existing buildings, conclusions were drawn on whether or not buildings in Latin America were comfortable, what the reasons were behind it, and which variables affected or contributed to the wellbeing of Latin Americans. The analyses, results, and discussions of the 100 papers considered for this review are shown in Table 2.

Table 2. Included literature in the systematic review ($n = 100$). Source: By Authors.

Reference	Year	Country	Building Type	Comfort Type ¹				Assessment Strategies ²				
				H	V	I	Ac	R	O	S	C	Au
Adiane-Borges et al. [29]	2016	Brazil	University buildings	x		x		x		x		
Akustsu et al. [30]	2013	Brazil	School	x						x		
Alias et al. [31]	2010	Argentina	Housing	x				x		x		
Alonso-Frank, Kuchen, Toranzo [32]	2012	Argentina	University buildings	x						x		
Alonso-Frank et al. [33]	2015	Argentina/Brazil	Government buildings		x				x	x		
Alves et al. [34]	2017	Brazil	University buildings		x	x						x
Alves, Duarte, Gonçalves [35]	2016	Brazil	Housing		x				x		x	
Armijo, Whitman, Casals [36]	2010	Chile	School	x				x				
Barbosa-Teixeira, Chebel-Labaki [37]	2012	Brazil	Housing	x				x				
Becerra-Santacruz, Lawrence [38]	2016	Mexico	Housing	x	x			x				x
Betancourt-Velasco, García-Alvarado [39]	2012	Colombia	Housing	x				x			x	
Biondi, Martini, Lima-Neto [40]	2015	Brazil	University buildings	x	x			x			x	x
Boutet et al. [41]	2011	Argentina	School			x			x			
Boutet, Hernández, Jacobo [42]	2013	Argentina	School	x		x			x	x		
Bravo, González [43]	2013	Venezuela	Housing		x				x			
Bressane et al. [44]	2009	Brazil	University buildings	x	x				x			
Bustamante et al. [45]	2012	Chile	Office buildings	x	x			x				
Cisterna et al. [46]	2015	Argentina/Brazil	School	x	x			x	x	x		
Corallo, Kuchen, Gonzalo [47]	2012	Argentina	University buildings	x					x	x		x
Corvalán et al. [48]	2015	Argentina	University buildings	x	x			x			x	
Dalbem et al. [49]	2016	Brazil	Housing	x		x			x	x	x	x
De Vecchi et al. [50]	2017	Brazil	Office buildings	x					x			
De Vecchi, Cândido, Lamberts [51]	2016	Brazil	University buildings				x	x				
Delbene, Evans [52]	2010	Argentina	University buildings	x					x			
Esparza-López et al. [53]	2012	Mexico	Housing				x		x			
Esparza-López et al. [54]	2012	Mexico	Housing	x	x		x			x		
Espinosa-Cancino, Cortés-Fuentes [55]	2015	Chile	Housing	x	x				x			
Fastofski, González, Kern [56]	2017	Brazil	Housing	x	x				x	x		
Felippe, Kuhnen, Silveira [57]	2016	Brazil	School		x					x		
Ferrón, Pattini, Lara [58]	2010	Argentina	Office buildings			x				x		
Ferrón, Pattini, Lara [59]	2011	Argentina/Brazil	Office buildings	x				x			x	
Filippin, Flores- Larsen, Marek [60]	2015	Argentina	Office buildings		x				x	x		
Filippin, Flores-Larsen [61]	2012	Argentina/Brazil	Housing	x				x				
Filippin, Flores-Larsen, Mercado [62]	2011	Argentina/Brazil	Housing	x				x		x		
Filippin, Sipowicz, Flores-Larsen [63]	2013	Argentina	Housing	x				x				
Follari, Filippin [64]	2011	Argentina	Housing			x			x			

Table 2. Cont.

Reference	Year	Country	Building Type	Comfort Type ¹				Assessment Strategies ²				
				H	V	I	Ac	R	O	S	C	Au
Forero-Cortés, Devia-Castillo [65]	2011	Colombia	Housing	x						x		
Forgiarini-Rupp et al. [66]	2015	Brazil	Office buildings	x				x		x		
Fortes-Goulart, Almeida-Dornelles, Caram [67]	2013	Brazil	School	x					x			
Gallegos-Ortega et al. [68]	2017	Mexico	School	x						x		
Gallipoliti et al. [69]	2012	Argentina/ Brazil	University buildings	x				x				
García-Alvarado et al. [70]	2014	Chile	Housing				x		x			
García-Chávez, Díaz-Báez [71]	2012	Mexico	Office buildings	x				x		x		
García-López, Heard [72]	2015	Mexico	Housing	x					x			
Garganta, Murace, Gomez [73]	2016	Argentina/ Brazil	Housing	x					x	x		
Godoi et al. [74]	2009	Brazil	School	x		x			x	x		
Gómez-Amador et al. [75]	2012	Mexico	Housing		x			x		x	x	
Gómez-Azpeitia, Martínez-Torres [76]	2012	Mexico	Office buildings			x		x				
Henrique dos Santos et al. [77]	2015	Brazil	University buildings	x	x	x	x	x		x		
Herrera, Gómez-Azpeitia [78]	2012	Mexico	Housing							x		
Krüger, Laroca [79]	2010	Brazil	Housing				x		x	x		
Leite-Frandoloso, Londero-Brandli, Pedroso-Dias [80]	2012	Brazil	University buildings	x				x			x	
Lelis-Rabelo, Pujadas-Tafrá, Durán-Palma [81]	2012	Chile	Housing		x				x			
Lukiantchuki, Caram [82]	2014	Brazil	Others	x				x				
Manzano et al. [83]	2012	Argentina	Government buildings	x				x				
Marcon-Passero, Trombetta-Zannin [84]	2009	Brazil	Office buildings	x	x					x		
Marincic, Ochoa, Del Río [85]	2012	Mexico	Housing	x						x		
Martines-Torres, Gómez-Azpeitia, Bojorquez-Morales [86]	2012	Mexico	Office buildings	x					x			
Matheus et al. [87]	2012	Brazil	Housing	x				x				
Matoski, Scoczynski-Ribeiro [88]	2016	Brazil	Housing	x				x				x
Mercado, Esteves, Filippín [89]	2010	Argentina	Housing	x				x				x
Molina, Veas [90]	2012	Chile	School, Office buildings	x				x				
Molina, Veas, Ossio [91]	2012	Chile	School	x				x				
Morales-Soler, Mallen, Moreno-Cruz [92]	2012	Colombia	Office buildings	x	x				x	x		
Mundo-Hernández, Sosa-Oliver, Valerdi-Nochebuena [93]	2008	Mexico	University buildings		x				x			
Mundo-Hernández, Valerdi-Nochebuena, Sosa-Oliver [94]	2015	Mexico	Others	x					x			
Muñoz-Vásquez, Marino, Thomas [95]	2014	Argentina	University buildings	x				x		x	x	
Ninaquispe-Romero, Weeks, Huelman [96]	2012	Perú	Housing	x	x	x		x		x	x	
Do Couto Nince et al. [97]	2013	Brazil	University buildings	x				x			x	
Orce-Schwarz, Flores-Larsen, Filippín [98]	2012	Argentina	School	x						x		
Oropeza-Pérez, Petzold-Rodriguez, Bonilla-Lopez [99]	2017	Mexico	Housing	x				x				
Padilha-Montanheiro, Gomes de Faria [100]	2016	Brazil	Others	x					x			
Palme, Saldías-Moreno, Segovia-Ramos [101]	2013	Chile	University buildings	x					x			
Pattini et al. [102]	2009	Argentina/ Brazil	University buildings	x	x			x	x			
Santos Pereira, Souza Silva, Silva Sales [103]	2011	Brazil	School		x							
Piccion et al. [104]	2012	Uruguay	Government buildings	x		x		x			x	
Picción et al. [105]	2010	Uruguay	University buildings	x					x			
Raysoni et al. [106]	2013	Mexico/ USA	School	x				x			x	
Ré, Blasco-Lucas [107]	2014	Argentina	Housing	x				x		x		

Table 2. Cont.

Reference	Year	Country	Building Type	Comfort Type ¹				Assessment Strategies ²				
				H	V	I	Ac	R	O	S	C	Au
Ré, Blasco-Lucas [108]	2012	Argentina	Housing	x				x				x
Ré, Blasco-Lucas, Filippín [109]	2015	Argentina	School	x				x				
Ré, Blasco-Lucas, Filippín [110]	2016	Argentina	School	x				x		x		
Ré, Blasco-Lucas, Filippín [111]	2016	Argentina	School	x				x		x		
Rodriguez, Pattini [112]	2010	Argentina	Office buildings	x	x					x		
Soto-Muñoz, Trebilcock, Pérez-Fargallo [113]	2015	Chile	School	x				x				
Toranzo, Kuchen, Alonso [114]	2012	Argentina	University buildings	x				x		x		
Trebilcock et al. [115]	2012	Chile	School	x				x		x		
Trebilcock et al. [116]	2016	Chile	School	x					x			
Trebilcock et al. [117]	2017	Chile	School	x				x		x	x	x
Trebilcock et al. [118]	2015	Chile	School	x				x		x		
Trebilcock, Soto-Muñoz, Figueroa-San Martin [119]	2014	Chile	School	x				x				
Vargas, Saelzer [120]	2016	Costa Rica	School	x				x				
Vásquez, Prieto, Aguirre [121]	2012	Chile	Office buildings				x		x			
Vasquez et al. [122]	2013	Chile	Office buildings				x		x			
Viloria et al. [123]	2016	Colombia	School	x					x			
Wegertseder, Trebilcock [124]	2012	Chile	Housing	x					x			
Wrobel-Straub et al. [125]	2017	Brazil	University buildings				x		x			
Zannin et al. [126]	2013	Brazil	University buildings	x					x			
Zannin, Zwirtes [127]	2009	Brazil	School	x					x	x		
Zapata-González, Quiceno-Hoyos, Zeng-Huang [128]	2016	Colombia	University buildings	x					x	x	x	

¹ Comfort type: H: hygrothermal, V: visual, I: Indoor Air Quality (IAQ), Ac: acoustic. ² Assessment strategies: R: real-time measurement, O: one-time measurement, S: survey, C: computer simulation, Au: audit.

3. Results

Analysis of selected papers has been divided into three parts: the first one shows the geographic distribution of IEQ research in Latin America and the building type considered. The second one analyzes the used in situ evaluation strategies to assess comfort levels in the case study. The third and final part analyzes the main variables for evaluating comfort levels inside the building. Likewise, we identified the main evaluation objectives of each study.

3.1. Geographic Distribution and Studied Typologies

As shown in Figure 2a, Argentina and Brazil were the Latin American countries who had done more research on IEQ, adding up to 59% (22% Argentina, 28% Brazil, 9% research done by both countries). Next was Chile, with 17% of the studies, and Mexico with 15%. Colombia (5%), Uruguay (2%), and Peru and Venezuela (1%) were the countries with the least amount of research on the subject.

Regarding building typology, housing was the most studied with 31% (see Figure 2b), followed by schools with 26% [30,68,90,98,115,116,123] or example, Felipe et al. [57] surveyed their students to identify the most important factors that they would like to have in their schools. IAQ (clean and ventilated) and lighting comfort were some of the highlighted categories. For university buildings (23%), the study of Alves et al. [34] analyzed how thermal mass and natural ventilation affected thermal performance in old buildings and provided solutions for improving thermal performance in buildings with thermal inertia. In another study, Borges et al. [29] analyzed thermal performance using predictive mean vote (PMV) and predicted percentage of dissatisfaction (PPD) indexes. In the case of office buildings (15%), a study conducted by Vasquez et al. [121] examined the performance of a group of offices built in Chile in the 1960s. Art galleries and hospitals were also analyzed (2%).

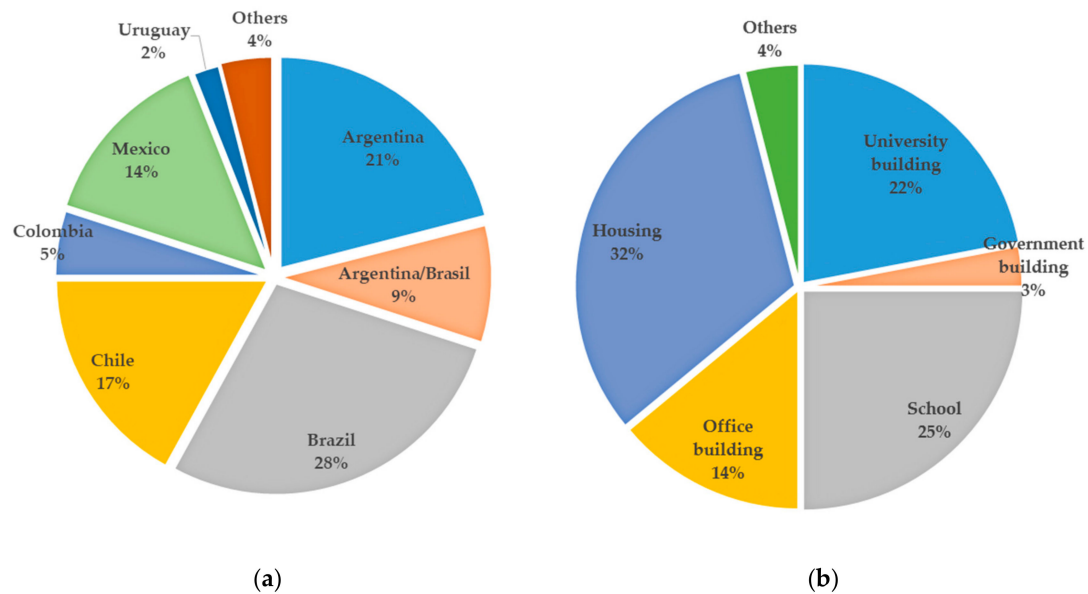


Figure 2. Publication distribution by (a) country and (b) building type. Source: By Authors.

Building typology distribution lacks certain categories whose users are sensitive to IEQ, such as nurseries, senior residences, or health buildings. The only study dealing with hospitals evaluated hygrothermal comfort in facilities in Brazil [82].

3.2. Measuring Strategies

On the subject of strategies used for the data collection on building indoor environment, researchers used different measuring tools, both individually and additively. For example, specific or constant objective measurements of one or more IEQ parameters, surveys, simulations, or audits were observed.

Some of the specific or constant objective measurements were air temperature, air velocity, humidity for hygrothermal comfort, illuminance for visual comfort, CO₂ concentration, CO and total Particulate Matter (PM_{tot}) for IAQ, and equivalent noise level for acoustic comfort, among others.

Surveys, as a subjective measuring tool, were mainly based on questionnaires in which the evaluation of different factors and general satisfaction levels were collected directly from the respondents' opinions. In the selected corpus, it was possible to find thermal satisfaction surveys [38,43,44,47,51,54,55,66,72,80,85,86,90,100,114,117–119,122,123,125] or [104], visual satisfaction [46,102,105,122] or [119], acoustic satisfaction, [44,103,122] humidity sensation [72,78], and air quality [32,33,91]. In general, there were five set satisfaction levels as well as preference levels. For example, in thermal satisfaction [38,43,51,114,119], respondents were asked if they preferred a colder or warmer environment.

Some studies supplemented subjective–objective IEQ measurements with energy consumption measurements [33], energy simulations [69], or an audit consisting of thermal performance evaluation of the building's thermal envelope [56,109], or architectural design [114].

Figure 3 shows the paper distribution by the number of strategies combined to assess IEQ and provides a breakdown of evaluation strategies used. As shown in Figure 3, the majority of articles combined one or two strategies, the main of which were one-time measurements (39), real-time measurements (50), and surveys (40). Only two articles [47,80] included four of the five identified strategies.



Figure 3. IEQ evaluation strategies distribution by the number of methods combined in the same paper.

Source: By Authors.

3.3. IEQ Factors Studied

Some of the factors analyzed by several studies were physical parameters and survey results on the users' perceptions or preferences (Figure 4). Temperature (66 papers), relative humidity (31 papers), and illuminance (28 papers) were the parameters generally measured by sensors like the hobo U-12. In conditioned buildings, it is possible to consolidate temperature measurements, relative humidity, and air velocity via indexes like the predicted mean vote (PMV) or predicted percentage of dissatisfaction (PPD). These indexes are comparable to user survey results. Biondi et al. [40] suggest using the physiological equivalent temperature (PET) as a thermal comfort indicator, which unifies the temperature scale. It takes into consideration air temperature, radiative temperature, air velocity, and humidity equal to the PMV.

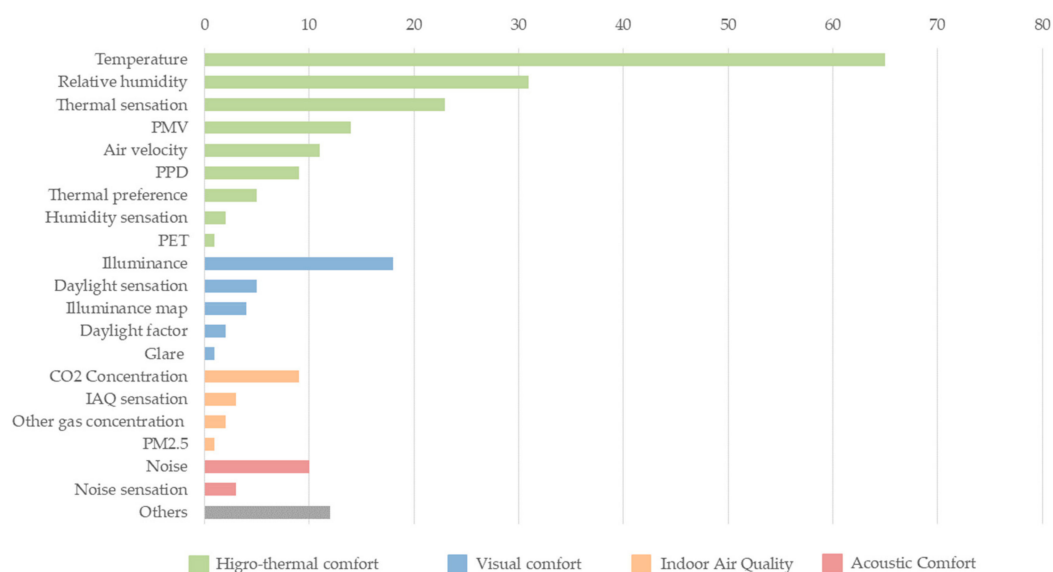


Figure 4. The occurrence of analyzed variables for each comfort type in selected papers. Source: By Authors. PMV: predicted mean vote; PPD: predicted percentage of dissatisfaction; PET: physiological equivalent temperature; PM2.5: particulate matter 2.5 μm .

Concerning hygrothermal comfort, 37 articles measured the indoor environment in free-running conditions, whereas in 41 articles, a mechanical system was used (16 with a heating system, 9 with a cooling system, and 16 with both systems). Twelve articles did not specify the thermal conditions of the building. Some authors combined both situations of free running and conditioned indoor environment because (1) they studied buildings in different climatic zones [116,118], (2) they compared two indoor environments with different conditions [108], or (3) they measured the same environment over various periods with different conditions [64,73,89], and [99].

In 24 of 100 articles included in this study, the most evaluated IEQ variable was temperature as the sole parameter, mostly in residential buildings. The variable was measured through monitoring, sporadic measurements, and perception surveys.

Temperature measuring aims to quantify the impact of (1) different building envelope solutions [38,79], roofing [37] or windows [49]; (2) climate variations of adaptive comfort [35,129]; (3) architectural [54] or bioclimatic [81] design; and (4) comfort perception and hygrothermal comfort local regulations [55,63].

Studies analyzing only one IEQ factor were related to lighting [46,58,59,71,83,101,102,112], and ambient noise [44,77,84,88,93,103,126–128], consisting of 8% for each.

Regarding lighting comfort, illuminance measurements or monitoring in specific environment areas were analyzed, such as workspaces or from a set distance from the window. Few papers took into account the daylight factor, which considers available exterior illuminance. The main topics considered when analyzing this factor were assessment of the potential of innovative [71] or low-cost [58,59] systems; school study cases [46,101]; glare issues [102] or [108]; or effects of lighting designs on comfort levels [83,112].

In terms of acoustic comfort, nine of the ten analyzed articles measured the environment of educational spaces, and one of them measured residential space. These articles registered decibel levels in localized environment spots for a short period. In certain cases, measurements were contrasted with user surveys. The main studied topics were acoustic performance of new building systems [88] or innovative designs [93]; the influence of designs or spaces on schools [103,127]; and noise perception or discomfort in university buildings [77,126,128] or in open office spaces [84]. In [44], the acoustic comfort of a university building was analyzed, highlighting the importance of incorporating acoustic criteria in designs to foster memory, reasoning, interpreting, as well as civic engagement.

There was 38% of articles that analyzed a combination of comfort types. The most common were hygrothermal and IAQ y or hygrothermal and visual comfort.

The main analysis objectives included effects of air conditioning on the general health [76] and comfort feel [50,51]; analysis of building materials [67,75]; implementation or handling of installed equipment [47,130]; energy consumption and comfort [60]; and social context implications on hygrothermal comfort [113,119].

On the subject of IAQ, studies mainly focused on schools and university buildings. The main assessed indicator was CO₂ emissions, although in most cases it was related to other variables. For example, its connection was analyzed with local regulations on air changes [91] or concentration measurements of PM, NO₂, black carbon (BC), and isomer xylenes (BTEX) to determine the effects on asthmatic conditions [74]. On the other hand, only one study [106] measured the concentration of particulate matter PM_{2.5} and other pollutants in schools. In the case of offices in university buildings, the main assessment referred to the applicability of norm DIN EN 13779 [131] and detecting reasons for a bad response on IAQ [47].

4. Discussion

Out of the 100 analyzed articles, 88 focused on hygrothermal comfort according to the variables that have been identified as prominent. Their variables are temperature, relative humidity, lighting, PMV, and air velocity.

In 67.5% of the case studies, results showed uncomfortable situations for users, where the most analyzed types of comfort were thermal and hygrothermal. As for the former, discomfort was due

to indoor temperatures well under the accepted ranges for its occupants. However, it is important to mention that the accepted range will depend not only on the geographical location and climate zone but also on the effect of different factors such as outdoor temperature, the occupant's sex and age range, local and individual culture, socio-economic status, and the reality it entails [117]. Type of residence and its usual temperature, lifestyle, clothing layers and their insulation level, and activities and conducts carried out inside the residence (including the metabolic rate of its occupants) must also be considered.

Furthermore, even if regulations can set acceptable temperature ranges, these may not agree with the users' perception. Therefore, in many cases, measurements and survey results may not reach the same conclusions. ASHRAE 55 [132] and ISO 7730 [133] are the most used regulations in case studies. These regulations determine ranges and fixed parameters for their application. It could be troublesome because, as has been mentioned, there will be factors linked to individuals that have greater influence in comfort perception.

Regarding hygrothermal comfort, variations depend on the region in Latin America under consideration, specifically the climate of each location. In warmer and more humid places, a decrease in relative humidity could be perceived as increased heat. For this reason, the combination of temperature and relative humidity is more relevant. On the other hand, in drier and colder climates, relative humidity does not have a significant role, as it does not affect people's perception of temperature. Nonetheless, as individuals would be accustomed to dry environments, an increase in relative humidity could create a heat perception without, and increase in, temperature [78].

As for CO₂ concentrations, parts per million (ppm) quantity in the air is usually measured. The results of those measurements showed high concentration levels in closed spaces that did not have enough ventilation. These cases are mostly schools and universities, where the study of this factor is more relevant than cases in which thermal comfort is favored over ventilation. For this reason, air currents are impeded by how the indoor space is used (e.g., windows are not opened or ventilation ducts are closed to avoid temperature fluctuations). Additionally, solar coverage and eaves whose main purpose is to avoid direct solar radiation are mentioned. However, these hinder the airflow or interrupt outdoor currents. In these cases, the combination is not right as the two factors cancel each other.

Furthermore, regarding ventilation, it is worthwhile to consider air velocity and its effects on temperature perception. Speeds lower than 0.25 m/s do not affect thermal perception, but above 0.25 m/s there will be a cooling feeling that will alter thermal perception without an actual temperature change.

Thus, it is noticeable that none of the three public buildings complied with comfort standards. On the other hand, the 17 studies (57%) dealing with residential buildings concluded that respondents were not comfortable. This demonstrates a precariousness in the housing sector in Latin America.

Only 5 out of the 20 papers analyzing comfort in schools found that the respondents were comfortable. European studies show a direct link between student academic performance and classroom environment conditions. Good ventilation could impact students' performance up to 14.5% [134], which is the equivalent of 2 academic years' worth of studying. Likewise, good thermal conditions could improve student performance by up to 3.5% [134].

Finally, only 25 out of 88 articles (28%) found that buildings were comfortable. This finding demonstrates a gap existing in Latin America when it comes to providing comfortable indoor environments (Figure 5).

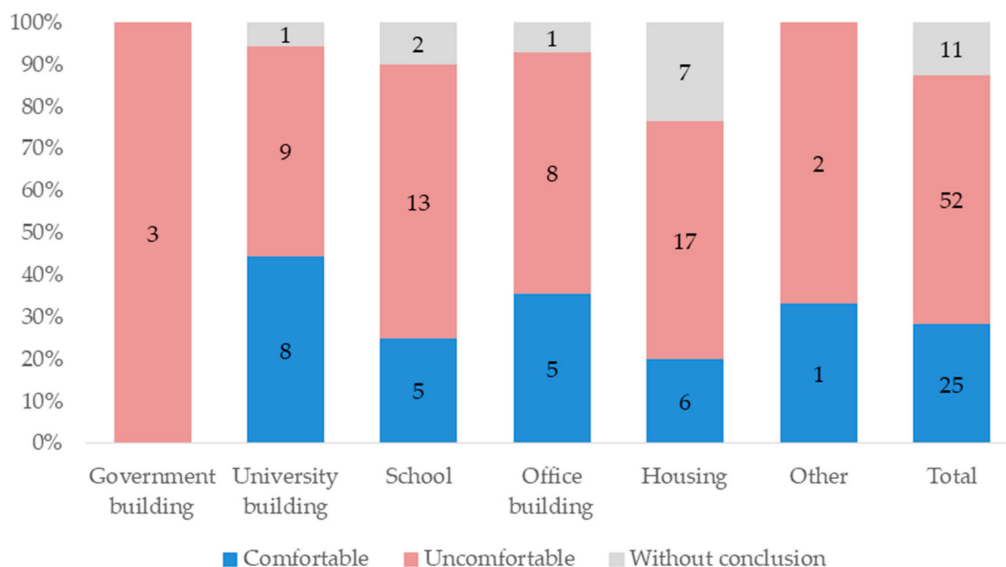


Figure 5. Distribution of building comfort by typology and the total number of studies considered.
Source: By Authors.

5. Conclusions

The current systematic literature review on indoor environment quality in existing buildings in Latin America demonstrated that Brazil and Argentina led these types of studies in schools and housing buildings. It was also noted that hygrothermal comfort was the most analyzed comfort type, with temperature and humidity leading the number of studies. Most studies evaluated comfort along with one or more variables, as well as more than one type of comfort. Regarding evaluation strategies, it was noted that most studies used a combination of one or two strategies. The main implemented strategies were specific and constant measurements and surveys.

The result of the analysis shows a lack of studies concerned with building users sensitive to indoor environment quality (e.g., nurseries, senior residences, or health buildings). There was also a discrepancy between objective measuring methods and user perception. Additionally, the result showed the importance of continuing the analysis of less-studied variables such as ambient noise, lighting, and air quality (CO₂, CO, PM).

Detailed analysis of predominant variables of indoor environment quality showed that local factors such as socioeconomic status, education level, and the precariousness of building solutions in residences and schools affected IEQ in Latin American buildings. Furthermore, most Latin American buildings are not completely comfortable; thus, it is necessary to improve architectural designs, regulatory standards, educate users, or improve building monitoring management at the operational stage.

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