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Review Article

Improving building energy performance by addressing today's demand-side challenges: A review of contributions from Latin America

Mejoras al desempeño energético en edificaciones abordando los desafíos actuales del lado de la demanda: Una revisión de contribuciones de Latinoamérica

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Abstract: Due to the current global energy crisis, the United Nations' following measures to overcome related challenges have been established with the participant nations' agreements. Despite the efforts to include underdeveloped and developing countries in such a decision process, most contributions continue to be shifted to the northern hemisphere. This work highlights the efforts made by Latin American (LA) countries, between 2018-2020, in contributing specifically to the improvements regarding building energy performance to address current demand-side challenges. Such challenges are related to the demand-side management: (i) uncontrolled peaks in demand and (ii) insufficient transmission and distribution capacity in the power network. LA contributions are classified as independent (studies with LA affiliations for LA countries), collaboration (studies with LA affiliations but not for LA countries), and application (studies with non-LA affiliations for LA countries). Studies were also classified as theoretical, experimental, the combination of both, and reviews. The two-stage filtering methodology implemented resulted in a total of 176 documents as a starting literature list. By focusing only on occupants' aspects, passive and low-consumption solutions, and forecasting techniques for smart buildings, the processed literature list resulted in 73 studies. Results showed that LA countries' efforts reside mostly in implementing strategies previously developed and proposed by developed countries to carry out case studies either independently or in collaboration. Finally, a strengths, weaknesses, opportunities, and threats (SWOT) analysis is presented to explain the results obtained.

Keywords: Building performance, demand-side, energy efficiency, energy use, Latin America.

Resumen*:* *Debido a la actual crisis energética mundial y como resultado de los acuerdos de las naciones participantes, se han establecido medidas por las Naciones Unidas para superar los desafíos relacionados. A pesar de los esfuerzos para incluir a los países subdesarrollados en dicho proceso de decisión, la mayoría de las contribuciones continúan estando inclinadas al hemisferio norte. Así, este trabajo se enfoca en destacar los esfuerzos realizados por los países Latinoamericanos (LA), entre 2018-2020, para contribuir específicamente en las mejoras en el desempeño energético en edificaciones para abordar los desafíos actuales del lado de la demanda. Dichos desafíos están relacionados con la gestión de la demanda: (i) picos de demanda no controlados y (ii) capacidad de transmisión y distribución insuficiente en la red eléctrica. Las contribuciones de LA se clasifican en independientes, colaboración y aplicación. Los estudios también se clasificaron en teóricos, experimentales, ambos y revisiones. La metodología de filtrado de dos etapas implementada dio como resultado un total de 176 documentos como lista inicial. Al centrarse sólo en los aspectos relacionados con los ocupantes, las soluciones pasivas y de bajo consumo y las técnicas de previsión para edificios inteligentes, la lista procesada resultó en un total de 73 estudios. Los resultados mostraron que los esfuerzos realizados por los países LA residen en su mayoría en la implementación de estrategias previamente desarrolladas y propuestas por países desarrollados, para realizar estudios de caso como independiente o en colaboración. Finalmente, se presenta un análisis de fortalezas, oportunidades, debilidades y amenazas (FODA) para explicar los resultados obtenidos.*

Palabras clave*:* *Desempeño energético de edificios, eficiencia energética, lado de la demanda, Latinoamérica, uso de la energía.*

1 Introduction

The current global energy crisis has encouraged researchers and developers since the United Nations (UN) established the Sustainable Development Goals (SDGs) agreed upon in 2015. Within these SDG, three are directly related to achieving more sustainable strategies in the energy sector. The seventh SDG, affordable and clean energy, was set to increment clean energy access, energy efficiency, and renewable energy usage. The eleventh SDG focuses on the sustainability of cities and communities. The twelfth SDG looks for collective efforts to promote people's sense of responsibility regarding water consumption, energy, and food consumption.

The transition to systems with a more significant share of renewable energy and decarbonization pathways is a global phenomenon. That involves paradigm shifts in energy infrastructure, markets, and innovative business models. Renewable energy sources are dependent on the climate. Their incorporation into a grid system must be necessary and maintain the market's supply and demand conditions. Possible ways of integration and implementation can be considered, such as creating policies, energy efficiency strategies measures and indicators, on-site generation technologies, demand-side management, and storage systems.

Latin America and the Caribbean (LAC) countries have developed different paths by achieving energy efficiency with a diverse degree of implementation and compliance (OLADE, BID, & CEPAL, 2017). The categorization of types of energy efficiency policies and initiatives in LAC has been described on the International Renewable Energy Agency (IRENA) webpage (International Renewable Energy Agency (IRENA), 2020).

LAC region is still trying to find adequate solutions according to the local climate, cultural, social, technical, and economic context. Policies and regulatory measures regarding energy usage have been implemented over the last decade. Some LAC countries as Panama, Costa Rica, Argentina, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, and Uruguay have building energy efficiency regulations.

1.1 Motivation and objective

The three SDG mentioned before can be achieved, to a great degree, by focusing on the demand-side management regarding energy-related challenges. Among these challenges are: (i) uncontrolled peaks in demand, which can increase the operating costs for energy companies and increase the electricity tariffs for consumers; and (ii) insufficient transmission and distribution capacity in the power network. In principle, both challenges can be addressed by controlling the energy demand of the building sector. The control of the power demand at the building sector can be achieved by contributing to improving: (i) occupants' (consumers') behavior, (ii) more efficient passive and semi-passive solutions, (iii) systems' energy efficiency, (iv) power generation systems such as on-site renewable sources, and (v) energy storage methods. Such demand-side management can bring substantial benefits, such as cost reductions, more resilient power networks. While expensive upgrades to the power network can delay or prevent an increase in renewable variable on-site sources.

As shown in figure 1, it is known that most developed (developing) countries have already addressed these demand-side issues (Antonopoulos *et al.*, 2020). They have developed innovative strategies related to consumption and sustainability in the construction sector, thereby closing the gap to meet the UN SDG 2030 with these contributions. Other countries have adopted those contributions to perform case studies or serve as a framework to build strategies adjusted to local conditions. The latter is the case of some Latin American countries, agreeing to the UN SDG, present a more significant gap yet to meet such goals. Regardless of possible cultural or political drawbacks preventing underdeveloped countries from increasing the efforts towards reducing this gap, an increment in collaboration among European and Latin American countries can be spotted.

Therefore, this investigation focuses on performing a comprehensive review of recently reported literature regarding only Latin American countries and their actions in achieving the SDG to assess and classify most of their contributions in the past two years.

1.2 Scope and document structure

This review extends to building applications from the demand-side perspective, only regarding the studies and investigations where LA countries play an essential role through (i) co-authorship (countries as collaboration), (ii) case studies in LA countries (countries as applications), and (iii) individual authorship (countries as independent).

The category "countries as collaboration" refers to developing a particular study where the co-authors' affiliations lie in a LA country. The Latin American contribution is made by collaboration only. However, the main study was made or applied somewhere outside LA countries. The category "countries as applications" refers to studies in which an LA country served as an application, i.e., an LA country used as a case study. Moreover, in which any LA country affiliation does not represent the primary co-authorship. Finally, the category "countries as independents" refers to studies where the primary co-authorship affiliation belongs to a LA country. Such studies are performed in a LA country.

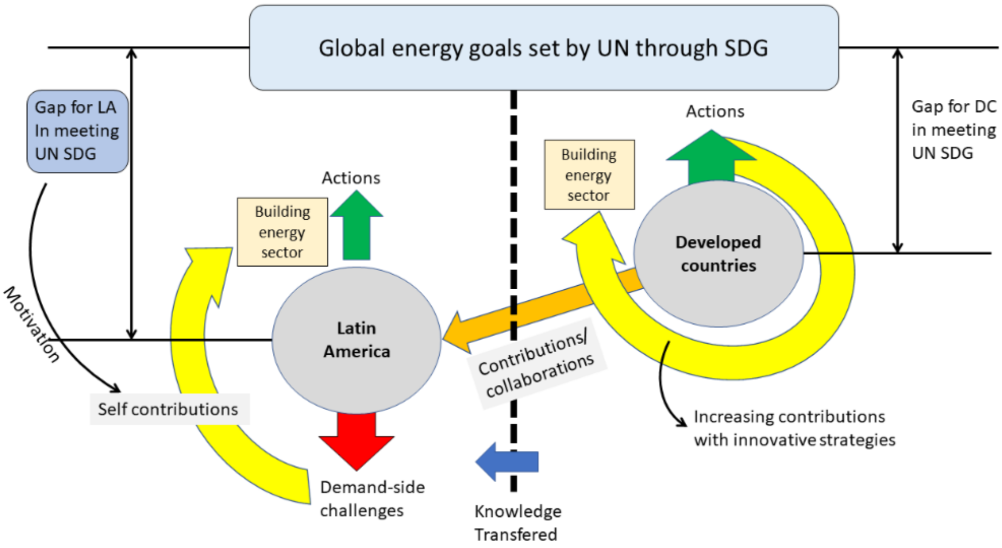

Figure 1: Latin America challenges compared with developed countries.

The research flow adopted here starts by recalling the challenges most countries face in trying to meet the SDG through research regarding energy building performance. The motivation, objective, and scope of conducting this review are established, followed by the methodology for data collection, filtering, and classification. The selected data (mostly research articles) is analyzed by strategies that improve buildings' energy performance, leading to globally assess the role and status of LA countries' contributions.

2 Methodology

The methodology implemented here consists of three stages: data collection, process filtering, and classification to perform further analysis. Figure 2 presents a schematic with the overall procedure implemented to choose the final literature list. Here, three main search engines were employed by distinguishing the indexed quality: Scopus, JCR, and not Scopus nor JCR, i.e., Latindex, choosing publications only from the year 2018 to 2020.

2.1 Literature search strategy

The literature search approach adopted here consisted of applying the Boolean operators in the combination of identified keywords. Three main co-words drive such keyword combination: "building energy performance," "demand-side," and "Latin American countries." These co-words can generate different keywords, as presented in figure 3. To relate the resulting keyword presented in figure 3, building energy performance relates to every aspect of the building envelope and systems and its operation.

The factors influencing total energy use in buildings and the role of occupant behavior in buildings' energy consumption have been identified as causing the discrepancy between the designed and real total energy use in buildings (International energy agency & energy in buildings and communities program, 2016). Wei, Jones, & De Wilde (2014) showed at least 27 factors that influence occupants' behavior in residential buildings.

Different physical and behavioral characteristics regarding buildings (type, year of construction, floor area), weather, appliances and lighting, heating system, Domestic Hot Water (DHW) systems, households (age and number of household members, gender) have a relationship in driving residential electricity demand (Guerra-Santin *et al.*, 2010; Mora, Carpino, & De Simone, 2017; Mora, Carpino, & De Simone, 2015). In this matter, a recent study performed a robust sensitivity analysis to identify the most influential input variables by using a low-income house in Brazil and EnergyPlus-based simulations. The results showed that the most influential input variable for each criterion was: thermal transmittance and solar absorption of the roof and window ventilation area (Silva & Ghisi, 2020). The search for more energy-efficient systems, by passive and semi-passive (or low-consumption) solutions, lead to the conception of greener buildings such as the ones categorized as Passive House, nearly Zero Energy Buildings (nZEB), Net Zero Energy Buildings (NZEB), and the Plus Energy Buildings (PEB). The incorporation of these highly energy-efficient buildings by defining the ZEB concept is associated with the implementation of low-carbon power generation systems such as renewable energies, and consequently, the necessity of energy storage systems automation and domotic approaches to regulating indoor thermal comfort. However, fully automated buildings might not ensure indoor thermal comfort and reduce energy consumption (Energy in Buildings and Communities program, 2019). It has been shown that the more efficient the building systems and equipment, the more the energy consumption is influenced by occupants' behavior.

Furthermore, such energy-efficient systems controlled by occupant-centric-based domotics' aid might need to gather information about the building's current thermal and energy state and demand future weather information to accomplish more significant energy consumption reductions. This need for future weather data has led to the development of conventional forecasting techniques based on energy usage patterns, weather forecasting models, Bayesian-based approaches, and, more recently, the implementation of artificial intelligence.

Finally, the Demand Side Respond (DSR) is about efficient management of demand and energy sources by the customer. DSR strategies can be divided into three categories: time-based programs, incentive-based programs, and energy-saving behaviors (Khan, 2019). The concept of demand-side management has been used since the 1980s and has significantly impacted developing countries. However, technical requirements, such as the smart grid, including smart meters and real-time home energy-monitoring services, have not been widely implemented in developing countries (Khan, 2019). One of the Demand Side's fundamental challenges is the optimal electricity demand forecast in the short, medium, and long term (Hernández & Baeza, 2019). Demand Side addresses commercial, industrial, and residential customers, where buildings are significant players. The short-term forecast issue stands out due to the need for a dynamic response to heterogeneous consumption and an electricity market with flexible rates in which supply and demand must be made promptly and automatically (Javed, Arshad, Wallin, Vassileva, & Dahlquist, 2012).

Moreover, the increasing development of more energy-efficient systems has led to better implementation of Bibliometric analysis

Once the initial database has been gathered by employing the co-word filtering, the metadata (title, abstract, and keywords). Each document is accessed to add a second filtering stage based on the BibTex files drawn from each search engine (figure 2). The same Boolean operators applied in the first filtering stage are employed again to the metadata at the second filtering stage. In this case, the resulting documents will contain only studies where LA countries have the role of "countries as independent" or "countries as application."

After performing the second filtering stage, utilizing a straightforward algorithm implementing the bib2df Package within the R Software, the resulting sample of processed literature list consisted of 176 documents (figure 4a). Most of the documents were published in 2020. Such an algorithm allowed for each document's association to a respective LA country. Brazil presented the most considerable number of publications (figure 4b). However, to further limit this study's analysis, only the literature regarding passive and low-consumption solutions, occupant behavior, and smart buildings was allowed.

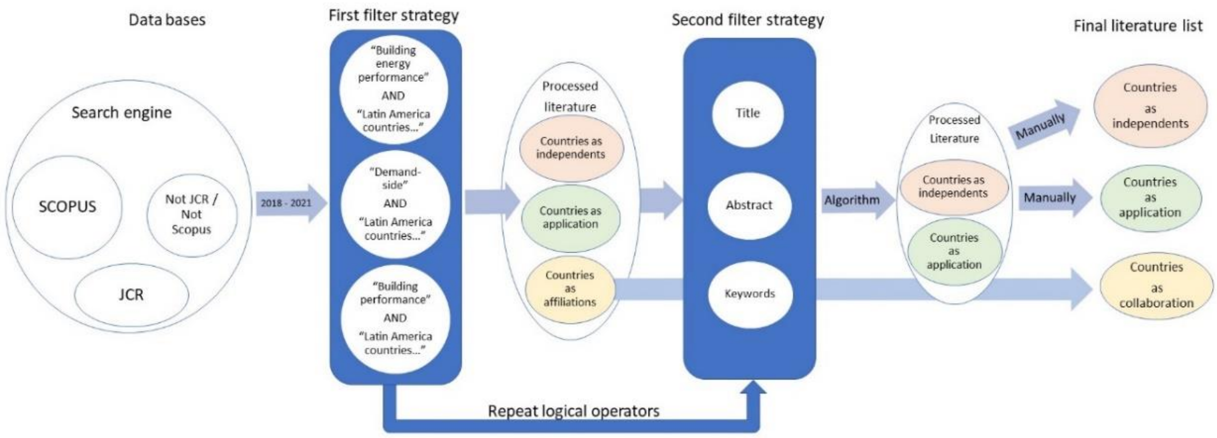

Figure 2: Search methodology to fill the literature database.

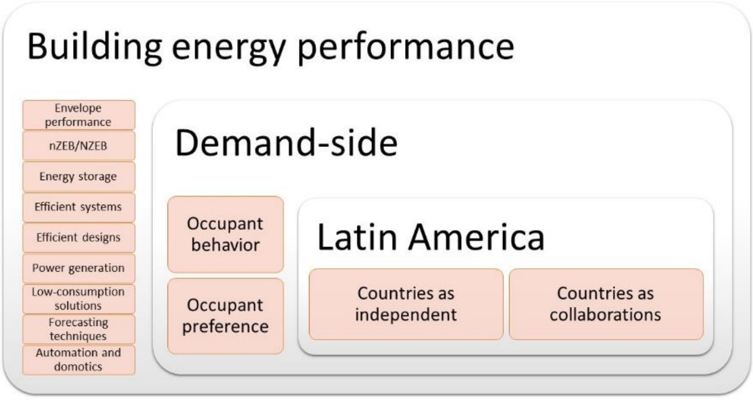

Figure 3: Co-word generation strategy for database search.

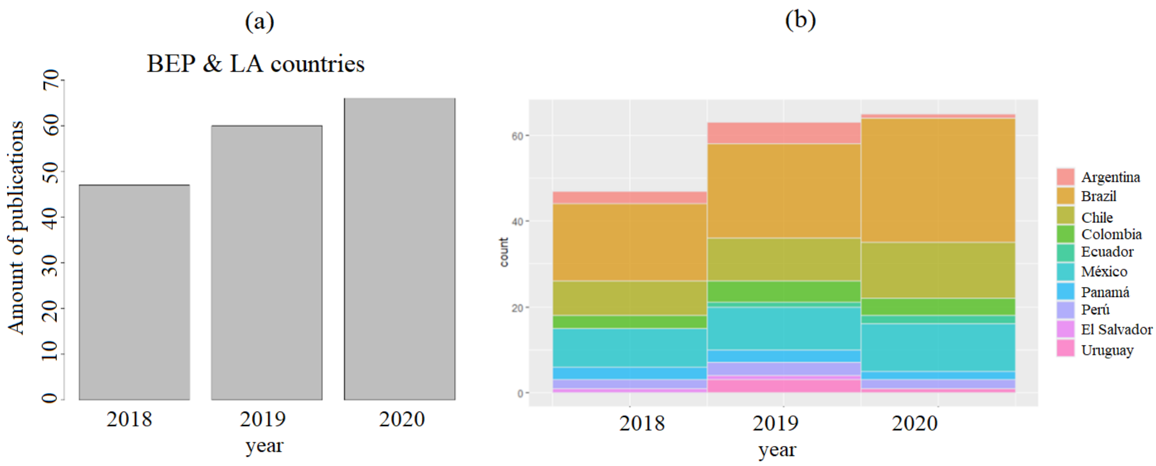

Figure 4: Data regarding countries as independent and as an application. (a) The total amount of publications per year. (b) Amount of publications per LA countries.

3 Results: Controlling the power demand in the building sector

The effective demand-side management design strategy depends on identifying factors responsible for driving electricity demand for each building typology and use (residential, commercial, or others). Hereafter, all the studies encountered are further classified in a type of study as theoretical (T), experimental (E), both (T+E), and review (SoA). This before, only regarding: (i) occupants' behavior, (ii) passive and low-consumption solutions, and (iii) forecasting techniques.

3.1 Occupants' behavior and aspects

Occupants' behavior in buildings include several aspects and greatly influences energy consumption. However, Latin American countries have played a significant role in three main aspects (table 1): Occupancy state and profiling, energy usage, and occupants' comfort.

The energy-saving behaviors can be classified in two ways: investment behavior and curtailment behavior. The literature shows the success of energy-saving behavior strategies, reducing demand between 0.5% and 21.9%, with an average of 10.05% and a median of 8.2% (Khan, 2019).

3.1.1 Occupant's preference

Few LA countries have been found to perform studies regarding occupants' preferences. Bavaresco & Ghisi (2020) proposed a low-cost framework to assess internal blind control patterns (interior window shading). It consisted of a questionnaire-based evaluation to infers self-reported behavioral patterns, and non-physical parameters, and building characteristics that influence internal blind adjustments in Southern Brazil. Results from the questionnaire were analyzed using hierarchical cluster analysis. A field study covering 85 office spaces within 11 buildings in Chile showed that occupants' preferences and behavior might also be influenced by their spatial location within a room or building (Marín-Restrepo, Trebilcock, & Gillott, 2020).

In Brazil, Bavaresco, D'Oca, Ghisi, & Pisello (2020) assessed subjective aspects that drive occupants to control building systems in offices, HVAC, windows, and shades/blinds. These authors implemented a theoretical-driven Structural Equation Modelling approach. Subjective aspects, such as the intention and perceived behavioral control, significantly explained the effects on occupants' choices related to the control of office systems mentioned before.

3.1.2 Occupancy state and profile

Similarly, few LA countries addressed ways to determine the occupancy state and profiles in a space. Chen, Chang, Bruneau, & Sempey (2020) performed an experimental study in an office building in Italy instrumented in terms of indoor environmental parameters. Their results were statistically analyzed by implementing the clustering technique and correlation analysis. A heuristic model was developed to determine the occupancy state based on measured parameters, reaching an error of about 8% compared to the office's actual occupancy. Later, the same experimental results were employed in a theoretical study implementing a frequentist statistical analysis to establish an adequate sensor combination to determine the office's occupancy state (Mora, Fajilla, Chen, De Simone, 2019).

3.1.3 Energy usage

As an important aspect where the occupant behavior and preferences strongly impact buildings' energy consumption, studies focusing on energy usage or energy usage intensity (EUI) have been performed by a few LA countries. In Brazil, as in "countries as independent," Geraldi & Ghisi (2020) performed a statistical building stock model analysis. This model shows the relevance of the EUI with building characteristics, occupancy, and environmental satisfaction on energy usage patterns.

Moreover, occupants' behavior and preferences can be significantly influenced by errors (or failures) in building design and construction and operating and maintenance errors. In this regard, Borgstein, Lamberts, & Hensen (2018) analyzed energy audit results from 33 office buildings, identified 333 failures, and evaluated their impact on occupants. The identified failures concerned building design, construction, operation, and maintenance, where adaptations could mostly amend their impact on performance and occupants' satisfaction in operation and maintenance, i.e., including automated systems, rather than adaptations in the design HVAC system.

3.1.4 Occupants' comfort and indoor environmental quality

The occupants' thermal comfort or thermal satisfaction as an essential aspect that strongly impacts the occupant's behavior and preferences ultimately affects buildings' energy consumption. In fact, with the current dynamics of demographic growth, by 2050, nearly 50% of the world's population will likely reside in tropical countries (Rodríguez & D'Alessandro, 2019). In this matter, contributions have been made by LA countries based on a generalized lack of good ways to consistently evaluate the thermal comfort in cold-humid, hot-humid, tropical climates (Rodríguez & D'Alessandro, 2019; García, Olivieri, Larrumbide, & Ávila, 2019).

García *et al.* (2019) implemented 790 surveys (by applying the same survey to 72 occupants for three months) in eight naturally ventilated offices around Bogota, Colombia. Results showed that 96.58% percent of acceptability is reached for a comfortable operative temperature of 23.47°C. Similarly, in Chile, a field study using surveys and measurements was conducted in 19 buildings. The results showed that occupants adapt themselves to the indoor operative temperatures with a neutral temperature range from 19.5 °C to 24.6 °C, and the preferred temperatures range from 19.9 °C to 24.6 °C amongst all cases studied (Trebilcock, Soto-Muñoz, & Piggot-Navarrete, 2020). The findings of HVAC buildings in summer do not match the steady-state method of ASHRAE 55 (0.5 Clo) since the temperatures are below the range stipulated. However, they do match the TDRe comfort range.

Becerra, Jerez, Valenzuela, Garcés, & Demarco (2018) investigated the relationship between thermal comfort and indoor air quality with occupants' life quality. The Predicted Mean Vote (PMV), along with the Predicted Percentage of Dissatisfied (PPD) and the CO2 concentration, were employed as indicators for measuring thermal comfort and indoor air quality. In this case, 20 households, distributed in five socioeconomically disparate communes. The National Monitoring Network was used as a database. Information about indoor environmental variables was obtained for three winter months. Results indicated that economic inequality is quickly confirmed for thermal comfort aspects. A significant difference was encountered for the cases with the lowest income, which presented the worst conditions.

In contrast, Pérez-Fargallo *et al.* (2018) have previously assessed current thermal comfort regulations and compared them against international regulations. Results showed that users in social houses considered thermal comfort at temperatures below the standards' lower limits. A new model was then proposed to fit best the thermal comfort conditions in social housing in Chile.

Moreover, different studies also focused on determining an adequate comfort temperature in Brazil (Rupp, Kim, de Dear, & Ghisi, 2018; Maykot, Rupp, & Ghisi, 2018; de Abreu-Harbich, Chaves, & Brandstetter, 2018). Maykot *et al.* (2018) aimed to determine a comfortable temperature but separately for women and men within an office building with a mixed-mode operating strategy (air-conditioned and natural ventilation) office building with full air-conditioning. Here, to collect indoor environmental data, microclimate stations were installed. Results showed that the comfort temperature was 24.0 °C for women and 23.2 °C for men. In the mixed-mode operating strategy, comfort temperature was statistically higher for women than for men: 23.7 °C and 23.0 °C, respectively. On the contrary, in the fully air-conditioned building, the comfort temperature was significantly different for women and men: 24.2 °C and 23.4 °C, respectively. Similarly, de Abreu-Harbich *et al.* (2018) performed in situ measurements, recorded users' perceptions by interviewing 200 users, and conducted simulations. Approximately 69.52% of respondents were dissatisfied with natural ventilation, 60.67% with evaporative cooling, and 70.18% with air conditioning. The neutral temperature resulted in 25.90 °C.

Besides addressing the lack of a useful index to evaluate thermal comfort in Brazil, Cóstola, Carreira, Fernandes, & Labaki (2019) conducted field studies on the long-term thermal performance of dwellings with no HVAC system through the introduction of an original performance indicator known as the Seasonal Thermal Sensation Vote (S-TSV). The S-TSV is based on the perceived overall thermal sensation recalled by the user of the building for specific seasons and times of day, specifically for buildings with no HVAC. Results demonstrate the capabilities of S-TSV to describe trends in building performance in this sample. Regarding buildings with or without HVAC systems, Costa, Freire, & Kiperstok (2019) investigated the reasons for installing air conditioning equipment in buildings even under adverse economic conditions and awareness of their negative environmental implications in Brazil. Results of thermal comfort indicated that 53% of the users felt comfortable, despite the poorly maintained building, diminishing the building's thermal regulation capacity.

Furthermore, a related study was performed in Mexico in four different climate zones by Rivera & Ledesma (2019), focusing on enhancing thermal comfort in social housing. Thermal comfort levels showed poor building performance. Overheating was the primary concern for warm semi-humid and sweltering dry climates and overcooling for temperate climates.

In addition to thermal comfort, indoor environmental quality (IEQ) plays a crucial role in determining occupants' productivity. However, analyses interconnecting the building's physical, attitudinal, social, and demographic components in one study are lacking. In this regard, Chen *et al.* (2020) investigated these factors' influence on occupants' IEQ-productivity belief, defined as personal subjective evaluation on the linkage between the impacts of five IEQ aspects (the quality of indoor temperature, air, natural and electric lighting, and acoustics) and productivity. A cross-sectional survey data was collected in university offices from six countries (Brazil was the only LA country). Results indicated that IEQ satisfaction is the strongest positive predictor of the IEQ-productivity belief being more robust in private offices. Men were more likely to perceive the IEQs as having a positive impact on their productivity than women.

On the contrary, women were more likely to consider all IEQs as having positive impacts on productivity than men. A few years earlier, Sant'Anna, Dos Santos, Vianna, & Romero (2018) applied semi-enclosed questionnaires to collect occupants' perceptions about the IEQ in buildings cataloged as green and conventional buildings. Results indicated that both building types of occupants could not differentiate between the green and conventional buildings, but more satisfied occupants with considered green buildings.

3.2 Passive and low-consumption solutions

Regarding passive solutions implemented in buildings, they are used to improve thermal and energy performance. These solutions include vernacular architecture and bioclimatic strategies (orientation, local shading, materials, promotion of weather as natural ventilation). Depending on the type of climate, biomimicry strategies that can be applied directly to building skin and structure, and the innovations regarding building envelope layout configurations (i.e., including phase change materials (PCM) as part of the external walls and windows, or the development of new insulating materials). In this case, table 2 shows that Latin American countries have contributed mostly by investigating both the bioclimatic strategies and new envelope layout configurations.

Table 1:Summary of contributions from LA countries related to occupants' behavior and aspects.

Occupant behavior aspects	Type of contributions with Latin-American countries							
	Independent			Collaboration				Application
	T	E	T+E	T	E	T+E	SoA	T+E
Occupant preference (OP)			(Bavaresco & Ghisi, 2020)		(Marín-Restrepo *et al.*, 2020)	(Bavaresco *et al.*, 2020)		
Occupancy state and profiles (OS)						(Chen et al., 2020; Mora *et al.*, 2019)	(Mora, Simone, Austin, & Austin, 2020)	
Energy usage (EU)		(Geraldi & Ghisi, 2020)			(Borgstein *et al.*, 2018)			(Wong, Krüger, Loper, & Mori, 2019)
Occupants' comfort (OC)	(García *et al.*, 2019; Sant'Anna *et al.*, 2018)	(Maykot *et al.*, 2018; Trebilcock *et al.*, 2020; Becerra *et al.*, 2018)	(de Abreu-Harbich *et al.*, 2018; Costa *et al.*, 2019)	(Cóstola *et al.*, 2019; Rivera & Ledesma, 2019)	(Rupp *et al.*, 2018; Pérez-Fargallo *et al.*, 2018)		(Rodriguez & D'Alessandro, 2019)	*al.*, 2020)

T: Theoretical study and simulations; E: Experimental study; SoA: State of the Art (reviews).

Such low-consumption solutions are generally implemented to aid in reducing the use of conventional air conditioners. As most Latin American countries present hot and humid climates, contributions regarding new semi-passive strategies seemed crucial to lowering energy consumption and the carbon footprint.

3.2.1 Biomimicry approaches

In building applications, the implementation of biomimicry strategies, such as the problem-based and solution-based approaches, was found not to be widely addressed by LA countries in the processed literature list. However, an inspection of various biomimicry strategies to address building climate-related challenges has been performed by Chen, Garzola, Delgado, Jiménez, & Mora (2020). This study analyzed existing organism-based strategies applied in buildings at the envelope-, structure-, shape-, and systems-level. The main idea is identifying organism-based strategies that can help coastal, arid, and humid zones in Panama. The introduction of such nature-concept-based strategies in new buildings design was then discussed and analyzed using a SWOT analysis. A potential biomimicry-based framework for its application was created.

3.2.2 Envelope configurations

From the processed literature list, in 2020, most contributions have been encountered regarding improvements to the buildings' envelope through passive solutions, mostly to reduce cooling needs (table 2). Most research studies considered the assessment of the introduction of phase change materials as part of the envelope layout in different types of climate (Triano-Juárez, Macias-Melo, Hernández-Pérez, Aguilar-Castro, & Xamán, 2020; Xamán *et al.*, 2020; Geraldo, Canaes de Aguiar, & Camarini, 2020; Bimaganbetova, Memon, & Sheriyev, 2020).

Through the implementation of numerical simulations, Triano-Juárez *et al.* (2020) found that when including PCM as an intermediate layer within a concrete roof, a reduction in the temperature of the interior surface (6.4 °C) and the heat gains (22.2 %) was obtained when a 2 cm thickness PCM layer close to the interior surface of a gray coated roof. No significant differences were encountered for a white-coated roof. A typical summer week of warm, humid weather in Mexico was chosen in this study. However, the PCM melting cycles were affected due to the closeness to the roof's interior surface, and its thickness increased. Moreover, incorporating a white reflective coating reduced the maximum interior surface temperature and the cooling load by 14.7–15.4 °C, and 58.1–62.7 %, respectively. A similar numerical study, also in a concrete roof, was performed in a warm-weather zone in Mexico, but including different PCM thickness layer for Paraffin wax - MG29 (R-PCM1), N-Eicosane (R-PCM2), and Salt Hydrates (R-PCM3), and comparing results to a conventional concrete roof (Xamán *et al.*, 2020). The results showed a 57 % reduction in thermal load respecting the conventional R-C, using a 2 cm thickness R-PCM1 layer.

Moreover, a numerical simulation study was performed for eight representative cites of seven different countries with tropical savanna climates, being Brazil the only LA country (Bimaganbetova *et al.*, 2020). Residential buildings' thermal behavior and energy performance were assessed using Design Builder software by integrating eleven different PCMs (PCM21 to PCM31) with different thicknesses, locations within walls, and different surface areas. Results showed that during a summer day, temperature fluctuations dropped by up to 2.76 °C even when the HVAC system was switched off. From energy analysis, for this climate zone, the PCM25 to PCM29 was found to be optimum, obtaining energy consumption reduction up to 68.63 %. Furthermore, superior energy savings were found when considering the thinner PCM layer with greater surface area and constant volume.

On the other hand, another study in Brazil investigated the thermal performance of cross-laminated timber (CLT) construction system as part of a eucalyptus heartwood panel for low-income housing under several different climate conditions (Nunes, de Melo Moura, Güths, Atem, & Giglio, 2020). The simulated envelope combinations showed that different layers and insulation could be adapted depending on the bioclimatic zone.

Furthermore, other passive strategies to reduce cooling needs have been studied recently, such as implementing solar facades (Hernández-López *et al.*, 2020) and the influence of thermal inertia in tropical climates. In a tropical wet zone in southeast Mexico, a room with a solar facade's thermal behavior was numerically assessed for a typical summer and winter day (Avendaño-Vera, Martinez-Soto, & Marincioni, 2020; Hernández-López *et al.*, 2020). By implementing computational fluid dynamic analyses, the effects and impact of vents' size, inlet air location, channel width, wall thickness, and materials were analyzed to optimize solar facade configuration. The study showed promising results when comparing consumption reduction of about 0.7 kWh/d in conventional fan equivalency. Moreover, Avendaño-Vera *et al.* (2020) determine optimum values for thermal conductivity, density, and specific heat capacity, using simulation carried out in Design-Builder for maintaining the indoor operative temperature inside the comfort range for standard dwellings in Chile. In this case, minimum values for thermal conductivity were presented as optimal for all climate zones tested. In contrast, density values depended on the climate zone. The specific heat capacity appeared not to have a significant influence on thermal comfort.

3.2.3 Heating and cooling systems

Few recent studies aimed to develop or assess low-consumption techniques related to the building HVAC systems to reduce the necessary heating and cooling needs (table 2). Most of the studies found performed a theoretical analysis. A numerical assessment based on EnergyPlus was performed and validated to compare the use of green (GR) and conventional roofs under eight cities in Mexico (Ávila-Hernández *et al.*, 2020). Results showed that the GR reduced the indoor temperature up to 4.7 °C in warm weather locations. The GR reduced the cooling demand by up to 99% in temperate weather locations and increased the heating demand by 25%.

On the other hand, Porta-Gándara, Fernández-Zayas, & Chargoy-del-Valle (2020) carried out an experimental study during summertime in a warm and dry zone in Mexico. They assessed the use of natural thermosiphon convective cooling during the night to aid air conditioning systems and reducing energy consumption. Results showed that such a radiative cooling strategy could be of significant help for small dwellings. Since the principle is based on a water-cooling process, it enables coupling with commercial HVAC systems such as chillers.

Moreover, in a related study, an experimental assessment in a real-scale residential building during summertime in southwestern France was undertaken in collaboration with Panamanian researchers (Ortega del Rosario *et al.*, 2020). Here, the thermal performance of coupling of an air-PCM heat exchanger unit with an automated night natural ventilation strategy was evaluated in terms of indoor thermal discomfort hours and operating time. Results suggested that such an air-PCM unit reduces the rising of the indoor air temperature, thus keeping the temperature within thermal comfort levels.

3.2.4 Automation and domotics

Furthermore, concerning studies aiming at introducing strategies involving control systems. Such as automated natural ventilation strategies, i.e., natural ventilation openings activate when the outdoor temperature drops below the indoor temperature, lighting controls to maximize benefits from natural light or adaptive-thermal-comfort-based control systems. In this regard, an experimental study in a merely natural ventilated full-scale building performed during summertime in southwestern France served to evaluate, in collaboration with Panamanian researchers, different control-theory-useful approaches to model the thermal behavior of such building (Chen *et al.*, 2020). The evaluation included the state-space, the process model, and the nonlinear representation and was based on the system identification process approach by considering only the outdoor and indoor air temperature measurements as inputs. Results showed that the nonlinear representation model fitted best with an accuracy of 71%.

Table 2: Summary of contributions from LA countries related to passive and low-consumption solutions.

	Solutions	Type of contributions with Latin-American countries								
		Independent				Collaboration			Application	
		T	E	T+E	SoA	T	E	T+E	T	T+E
Passive	Vernacular and bioclimatic architecture (BA) and Biomimetics approaches (BioA)	(F[lores-Larsen, Filippín, & Barea, 2019; Maciel & Carvalho, 2019; González-Julián *et al.*, 2018; García Kerdan *et al.*, 2019)	(Costa *et al.*, 2019; Soares Gonçalves, Roberta, Mulfarth, Lima, & Ferreira, 2018)	(Hernández-Pérez *et al.*, 2018)	(Chen *et al.*, 2020)	(RChenossi *et al.*, 2019; Dalbem *et al.*, 2019)		(Chen, Bruneau, Sempey, & Mora, 2019)		
	Envelope configurations (EC)	(Arauz, Mora, & Chen, 2019; de la Paz Diulio, Mercader-Moyano, & Gómez, 2019; Mazzocco, Filippín, Sulaiman, & Larsen, 2018; Silveira, Pinto, & Westphal, 2019; Tubelo, Rodrigues, Gillott, & Soarez GonçalvesUriarte, 2018; Nunes et al., 2020; Ramalho de Freitas & Grala da Cunha, 2018; Neves, Melo, & Rodrigues, 2019; Ceballos-Fuentealba, Álvarez-Miranda, Torres-Fuchslocher, del Campo-Hitschfeld, & Díaz-Guerrero, 2019; Venegas, Vasco, García, & Salinas, 2018; Hernández-López *et al.*, 2020; Triano-Juárez *et al.*, 2020; Xamán *et al.*, 2020)	(Canto, Batista, Sanchez, Moreno, & James, 2018; Carvajal, Robles, Solís, Vargas, & Marín, 2018; Boutet, Hernández, & Jacobo, 2020; Carvajal et al., 2018; Rojas *et al.*, 2019; Hernández-Pérez *et al.*, 2019)	(Uriarte-Flores *et al.*, 2019)		(Silvero, Rodrigues, & Montelpare, 2019; Avendaño-Vera *et al.*, 2020)		(Chen, Bruneau, Sempey, & Mora, 2018)	(Bimaganbetova *et al.*, 2020)	(Vicens *et al.*, 2018)
Low-consumption	Heating and cooling (HVAC)	(Flores-Larsen *et al.*, 2019; de Oliveira Veloso, Gonçalves de Souza, & dos Santos, 2020; Rodrigues, Fernandes, Gomes, Gaspar, & Costa, 2019; Dietz, Vera, Bustamante, & Flamant, 2020; Salgado-Conrado & Lopez-Montelongo, 2019)	(Labastid, Bolobosky, Mogollón, & James, 2018; Lugo, Morales, Best, Gómez, García-Valladares, 2019)	(Ávila-Hernández *et al.*, 2020; Lugo *et al.*, 2019; Porta-Gándara *et al.*, 2020)			(Ortega del Rosario *et al.*, 2020)			(Kolokotroni *et al.*, 2018)
	Automation and domotics (AD)		(Bonilla, Samaniego, Ramos, & Campbell, 2018)	(Diaz-Mendez *et al.*, 2018)				(Chen, 2018; Chen *et al.*, 2020)		

T: Theoretical study and simulations; E: Experimental study; SoA: State of the Art.

3.3 Smart buildings forecasting techniques

With the advent and expansion of SmartGrids and a vision of a producer-consumer (prosumer) client, the forecast extends to distributed generation, mainly from photovoltaic and wind sources, in addition to integrating them into the management of energy storage systems. The short-term forecast usually has a day-ahead horizon with the ability to forecast with great accuracy for the next 24 hours, how much generation and demand the prosumer can present. Thus, this forecast integrated to a Demand Side Management can appropriately manage the offers to sell energy blocks, the consumption for an hourly block, and the appropriate energy balances for a building or industry on this horizon. In other words, a good forecast can reduce the uncertainty presented by a complex and dynamic electricity market, as well as the operation of the electricity grid itself (Bunn, 2000).

In recent years, LA countries have contributed novel proposals in Demand Side Management, forecasting models, and theoretical studies for forecasting optimization (Cruz, Alvarez, Al-Sumaiti, & Rivera, 2020; Cruz, Alvarez, Rivera, & Herrera, 2019; Diaz, Vuelvas, Ruiz, & Patino, 2019; García-Guarin *et al.*, 2019; García, Álvarez, & Rivera, 2020; García, Zambrano & Duarte, 2018; Henríquez & Kristjanpoller, 2019; Hernández & Baeza, 2019; Jiménez, Pertuz, Quintero, & Montaña, 2019; Marrero, García-Santander, Carrizo, & Ulloa, 2019; Moret, Babonneau, Bierlaire, & Maréchal, 2020; Paredes, Vargas, & Maldonado, 2020; Ramírez, Cruz, & Gutiérrez, 2019; Rocha, Silvestre, Celeste, Coura, & Rigo, 2018; Romero-Quete & Canizares, 2019; Sanhueza & Freitas, 2018; Zavadzki, Kleina, Drozda, & Marques, 2020; Zuniga-Garcia, Santamaría-Bonfil, Arroyo-Figueroa, & Batres, 2019).

Researchers from Chile proposed a method that seeks to improve the Short-Time Load Forecasting (STLF) using autoregressive integrated moving average (ARIMA) models (Marrero *et al.*, 2019). The work presented three stages to achieve the objective. First, obtain a forecasting model where cyclical patterns are removed, such as seasonal and weekly, daily, and outliers. ARIMA is used to forecast the remaining stochastic component of each hour of the day. As ARIMA is a filter with parameters to be estimated and depends on the data, particle swarm optimization (PSO) is proposed to find the optimal set of parameters. The second step is to forecast the horizon. The last stage is the mechanism of control to get a more automated process. In this work, the proposal is validated with data from two load bars of a distributed generation system in Sancti Spiritus City in Cuba. It is essential to mention that comparison was not made with other forecasting methods in this work, which is critical to validate the methods in this area of study.

Moreover, Hernández & Baeza (2019) from Chile proposed forecasting demand and distributed generation for the operation and planning of electrical systems, based on the Holt-Winters mathematical models in their additive (HWA) and multiplicative (HWM) versions. The possibility of fewer parameters than the ARIMA model, estimated utilizing the Montecarlo Method, was presented. The proposed method was validated using real demand data from a Chilean distribution company and meteorological variables: wind, temperature, and solar irradiation of a central Chile city. The proposed forecast model was used to obtain forecasts in intervals of 2, 4, 8 horizons for demand and photovoltaic generation.

An exciting and straightforward method for short-term demand forecast using the Fourier series was proposed by Garcia *et al.* (2020). In this case, residential and commercial load data from two power transformers in Colombia was used. The forecasting model was based on identifying three parameters of the Fourier series of the historical consumption data related to various harmonic and phase orders. Another group of researchers from Colombia proposed a nonlinear symbolic regression model with differential evolutionary particle swarm optimization to make annual demand forecasts. This algorithm is an assessment with real measurements creating models that conform to 28 weather stations' load forecasting. The learning variables are loads of demand and temperatures grouped by hours for a two-year time interval.

On the other hand, a method to control demand and generation for buildings' distributed energy resources using fuzzy logic was implemented by Ramírez *et al.* (2019). It sought to deal with the problem of uncertainty in consumer behavior and environmental aspects with fuzzy logic. A fuzzy algorithm was developed, employing rules obtained from users' behavior and consumption preferences. This algorithm managed the building's distributed resources, achieved an optimal energy efficiency level, and reduced the electricity rate by up to 30%. The method was validated by a simulator of multiple smart electric managers. The simulator emulated the electrical grid of a building in Mexico City for three types of scenarios with differences differentiated by attitudes regarding energy saving and environmental awareness.

Boya (2019a) analyzed the relationship between ambient temperature and electricity demand in two areas in Panama is carried out. Two analysis tools are used: Wavelet Continuous Transform and Wavelet Coherence Transform, all from the Wavelet Analysis field. This analysis allows us to recognize consumption patterns at various levels of detail, with a scale ranging from years to hours. From the study, it is concluded that ambient temperature is a fading predictor over time. It does not influence demand all the time, a relevant finding for models that use temperature as a dependent variable, i.e., linear Regression or Neural Networks.

On the other hand, a new decomposition method of the electrical demand time series using Independent Component Analysis (ICA) was proposed by Boya (2019b). Here, this method allows for the detection of daily, weekly, seasonal, cyclical patterns, outliers, and stochastic components automatically without the assumption of any previous mathematical model. Data from Panama City was used to validate the proposal.

4 Discussion

It recalls the challenges related to the demand-side management: (i) uncontrolled peaks in demand and (ii) insufficient transmission and distribution capacity in the power network. This investigation's primary motivation is to highlight the contributions made by LA countries, specifically in building energy performance. As seen from the literature review, currently, the efforts made from Latin-American countries to overcome the demand-side challenges mentioned before residing in the implementation of strategies previously developed and proposed by developed countries, to carry out case studies both as independent and as collaboration.

This is the case of occupants' behavior (OB), passive and low-consumption solutions (P&LCS), and forecasting techniques (FT) (figure 5a). However, the aforementioned is not so much the case for the theoretical studies in forecasting techniques (refer to section 3.3).

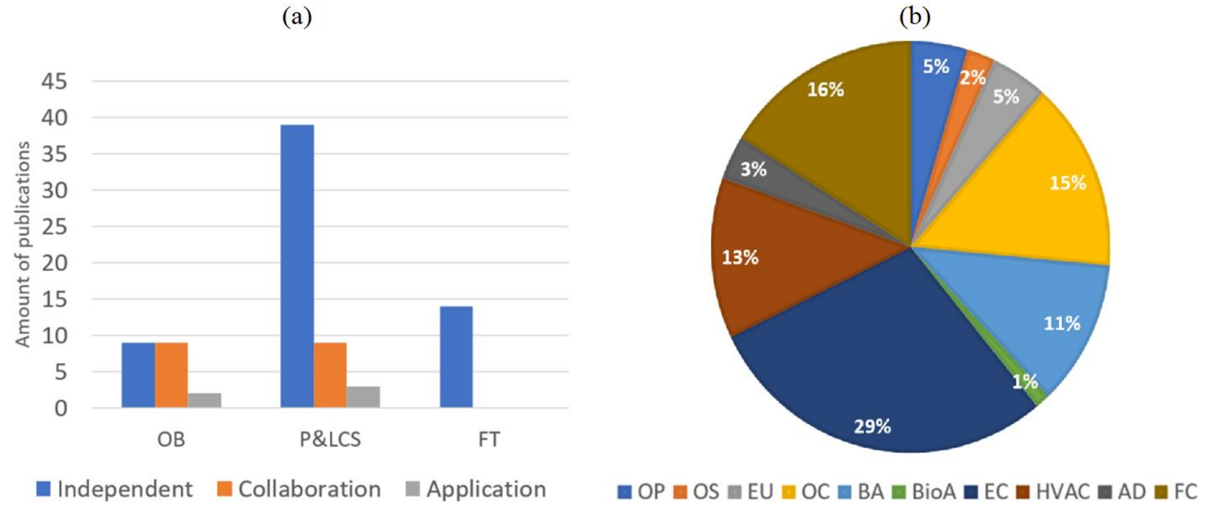

Figure 5: Summary of the research areas most contributed by LA countries. (a) According to the proposed classification. (b) Among the building, energy performance aspects chose for analysis.

Table 3: SWOT analysis.

	Strengths	Weaknesses
Internal	1. Most LA countries present diverse types of climate within the same region. 2. Highly developed human resources educated in developed countries.	1. Short investment in research and development. 2. A not low enough degree of analphabetism. 3. Lack of access to constructive and consumption data makes it challenging to create a system for buildings' energy consumption classification. (de Oliveira Veloso *et al.*, 2020). 4. Lack of incentives and finance as tax incentives, green mortgages, non-financial incentives, tax-lien financing, or others.
	Opportunities	**Threats**
External	1. The need for more field studies involving in situ measurements to contrast theoretical and simulation studies. 2. The current dynamics on the demographic growth, by 2050, it is likely that nearly 50% of the world's population will reside in tropical countries (Rodriguez & D'Alessandro, 2019). 3. The necessity for more suitable ways to consistently evaluate the thermal comfort in cold-humid, hot-humid, tropical climates. 4. Few implementations of biomimicry approach in numerical and experimental studies. 5. Reduced access to constructive and consumption data makes it challenging to create a system for the energy consumption classification of buildings (de Oliveira Veloso *et al.*, 2020). 6. Increment of funding calls promoted by developed-countries organizations to favor collaborations with LA countries.	1. Dependency on the development of new strategies for building applications proposed by developed countries.

The efforts made from LA countries are mainly focused on contributing to the building energy performance through envelope layout configurations (EC) with a 29%, forecasting techniques (FC) with a 16%, occupants' comfort (OC) with a 15%, heating and cooling systems (HVAC) with a 13%, and bioclimatic architecture strategies (BA) with an 11%.

Besides, such studies in building-energy-performance aspects are primarily addressed through theoretical evaluations, including mathematical formulations, numerical simulations, and energy-and-thermal performance-based simulations, followed by experimental studies using questionnaires. This approach addressing the building energy performance aspects might be explained by insufficient funding of research that only allows high-performance simulation software, but not enough to perform full-building-scale experimental studies. It should be noted that starting a research study through simulations might be the safest way.

To further evaluate such results, a SWOT analysis is presented (table 3). This SWOT analysis put forward the strengths that can allow LA countries to increase their contributions to the global energy crisis and recognize the weaknesses that most of them face. Finally, some critical threats that can push back the role of LA countries.

5 Conclusions

This work has focused on the efforts made by LA countries, between 2018-2020, in contributing specifically to the improvements regarding building energy performance to address current demand-side challenges. Such challenges are related to the demand-side management: (i) uncontrolled peaks in demand and (ii) insufficient transmission and distribution capacity in the power network. LA contributions are classified as independent (studies with LA affiliations for LA countries), collaboration (studies with LA affiliations but not for LA countries), and application (studies with non-LA affiliations for LA countries). Studies were also classified as theoretical, experimental, the combination of both, and reviews.

The two-stage filtering methodology implemented resulted in a total of 176 documents as a starting literature list. By focusing only on occupants' aspects, passive and low-consumption solutions, and forecasting techniques for smart buildings, the processed literature list resulted in 73 studies.

Results showed that LA countries' efforts reside mostly in implementing strategies previously developed and proposed by developed countries to carry out case studies either independently or in collaboration. The work highlights can be summarized in the following:

- Recent studies regarding the energy performance building field were mostly focused on improvements to the envelope layout configuration, forecasting techniques, and occupants' comfort.
- Such studies were mostly performed via theoretical analysis, such as the energy and thermal performance simulations and mathematical formulations.
- Most studies were identified as "independent," followed by "collaboration."

The SWOT analysis has shown that LA countries indeed have many opportunities to increase their contributions significantly. However, a crucial concern that can hold back such contribution increment relates to the short investment towards research and development.

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