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Selection and Evaluation of Indicators for a Building Energy Labeling System for Colombia

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Abstract.

Buildings are a key player in the fight against climate change. For this reason, the governments of the world advance in the establishment of regulations and tools that promote energy efficiency in buildings. Colombia presents a legal and regulatory framework that favors the sustainable construction market. However, the country still lacks tools to stimulate supply and demand for buildings with greater energy efficiency. Taking into account the above, this article seeks to select and evaluate the relevance of a group of indicators for a Building Energy Labeling System for Colombia. A literature review and an energy characterization exercise based on energy simulations allowed the identification of three indicators: energy for comfort, energy for equipment, and energy for lighting. The results of the energy characterization validated the relevance of the indicators. In the short term, the authors propose to carry out a more detailed analysis of the indicators to establish the necessary considerations for their estimation.

Keywords. Energy labeling system for buildings, energy simulation of buildings, tropical climate.

1. Introduction

Buildings are responsible for 37% and 39% of total energy consumption and related polluting emissions. This situation has led governments to focus a large part of their efforts on improving the energy efficiency of this sector. [1]–[4]. In recent years, buildings with energy-efficient and environmentally friendly designs have become the world trend to reduce energy consumption [5]. Colombia has been making progress in establishing a regulatory framework that promotes energy-efficient buildings. The Resolution 0549 of 2015, the Indicative Action Plan (PROURE 2017-2022), the National Policy for Sustainable Buildings (CONPES 3919), and Law 1715 of 2014 stand out [6]–[8].

On the other hand, the country has a dynamic construction sector. According to figures from the National Administrative Department of Statistics (DANE), in the last year, 20,172,264 m2 were built in the country for different categories of buildings [9]. According to the Colombian Chamber of Construction - CAMACOL, the building activity could present an annual increase of close to 3.1% [10].

In terms of certification and sustainable construction seals, the Colombian Council for Sustainable Construction (CCCS) reported in 2021 about 700 registered projects to obtain any of the certifications that are available in Colombia (LEED, EDGE, CASA, HQE, WELL among others) [11].

Despite these advances, the volume of the market for this type of project is still incipient to the conventional market. This can be attributed to the absence of surveillance and control instruments that verify compliance with current regulations, and the lack of incentives and programs aimed at financing the purchase and construction of this type of building [12]–[14].

Given such a scenario, the revitalization of the sustainable construction market requires the strengthening of control and surveillance of current regulations, new incentives, and tools that make visible the benefits of efficient projects and stimulate their supply and demand, among others. In this sense, the definition of a Building Energy Labeling System - BELS is considered a priority tool.

Among the main attributes of a BELS, the energy evaluation indicators stand out. The correct selection of these defines the quality of the energy evaluation and the success of the labeling system. For this reason, this work seeks to select a group of indicators of potential application in the BELS for Colombia.

To this end, this article presents the results of a literature review focused on identifying indicators for the energy evaluation of buildings. Subsequently, and with the help of energy simulation tools, the most relevant parameters of the energy behavior of a group of residential and office buildings are established. The foregoing will allow validating the capacity of the indicators to evaluate the aspects that most influence energy consumption.

2. Methodology

The methodology of this research consists of three phases: identification of indicators, pre-selection of indicators, and analysis of the relevance of the indicators, as shown in Figure 1.

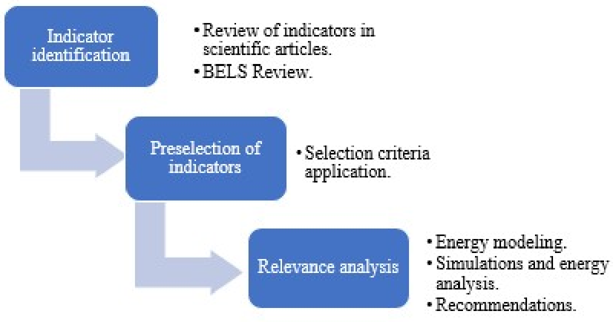

Figure 1. Research methodology.

The identification of energy evaluation indicators for buildings is based on a literature review focused on tropical climates, residential and office buildings, and considering the evaluation of energy performance, thermal comfort, and the interior environment.

The evaluation of the indicators requires the use of energy simulation tools. This is due to the absence of a simplified evaluation tool. For this reason, the possibility of evaluating the indicators through energy simulation results constitutes a criterion for their selection. Additionally, another aspect taken into account corresponds to the capacity of the indicators to assess savings achieved from passive-type strategies.

The researchers carried out a relevance analysis through energy simulations. This had the objective of validating the indicators for their ability to adequately evaluate those aspects that affect the energy consumption of a building. The analysis considered the categories of low-income multi-family housing, middle-income multi-family housing, and high-income multi-family housing and offices.

3. Results

This section presents the results of the selection and analysis of the relevance of the indicators for the energy evaluation of buildings within the framework of a BELS for Colombia.

A. Identification of indicators

The energy evaluation of a building concerning a BELS requires the estimation of indicators [15]. The most used indicator for this purpose is defined as the ratio between energy consumption and the area of the building, for which it is expressed in kW/m^2 [16], [17].

Other indicators take into account the different uses of energy and the comfort conditions inside buildings, in this sense, there are indicators such as annual cooling energy, annual lighting energy, and annual hours of thermal discomfort [16].

Several investigations propose new indicators for the evaluation of the energy performance of buildings. For example, [18] proposes the climatic energy index and the building energy index to quantify the impact of climate on energy performance, while [19] proposes indicators to evaluate the energy performance of the building envelope considering the solar factor of exterior walls and openings. Table 1 presents a summary of the indicators found for the evaluation of energy performance, thermal comfort, and polluting emissions.

Table 1. Indicators for the energy and environmental evaluation of buildings.

Assessed aspect	Indicators	Ref.
Energy performance	Total annual energy consumption [kW/m^2]	[20]–[22]
	Annual energy consumption in refrigeration [kW/m^2]	[16], [20]
	Annual energy consumption in lighting [kW/m^2]	[16], [20]
	Energy savings by generation on-site [kW/m^2]	[22]
	Energy savings through high energy efficiency strategies [kW/m^2]	
	Energy sustainability level	
Thermal comfort	Annual hours of thermal discomfort [Hours/year]	[16], [23]
	Thermal comfort indices	[21], [23]
	Air temperature [°C]	[21]
	RH [%]	
	Airspeed [m/s]	
Polluting emissions	Annual emissions CO_2 [$kg_{eq}CO_2/m^2$]	[20], [23]

A review of BELS on different countries was carried out. The results of this review shown in Table 2 show two types of indicators: simple indicators and compound indicators. The most widely used simple indicator is energy demand [kW/m^2year], which is widely accepted, especially in countries with seasons where air conditioning consumption is significant. As for composite indicators, countries such as Brazil have adopted global indicators that consider the energy efficiency of the envelope, lighting, and air conditioning systems. Thermal comfort is also considered.

Table 2. Indicators of the most relevant BELS in Ibero-America.

Country	Categories considered	Indicators
Spain (Energy certification of buildings)	Several	Annual primary energy.
Mexico (SISE-VIVE-ECOCASA)	Single-family and multi-family residential	Composite indicator. Consider final energy demand, primary energy demand, water consumption, and environmental impact.
Brazil (Brazilian Labeling Program)	Residential, commercial, and public	Composite indicator. Consider the efficiency of the envelope, the lighting system, the AC system, and the interior thermal comfort
Chile (CEV housing energy rating)	Single-family and multi-family residential	Total energy demand and percentage of savings

B. Preselection of indicators

The evaluation of the indicators of the BELS of Colombia will require energy simulations. At least, while the existence of a simplified calculation tool is not defined. For this reason, the identification of the results of energy simulation tools (EST) that can be used in its estimation is of interest. Table 3 lists results provided by the EnergyPlus simulation engine and DOE-2.

Table 3. EST results.

Area	Indicator
Consume	Total energy consumption. Lighting energy consumption. Power consumption of plug-in equipment. Cooling energy consumption. Energy consumption of equipment associated with the cooling system (fans and pumps). Heating consumption.
Demand	Annual cooling demand. Annual heating demand. Domestic hot water system demand.
Thermal comfort	Air temperature, radiant and operating. RH. Thermal comfort indices. Hours of discomfort.

The selection of indicators also considered their ability to assess passive design efforts. The passive design presents a lower cost for the building as presented by Figure 2. This aspect was taken into account as a criterion for the preliminary selection.

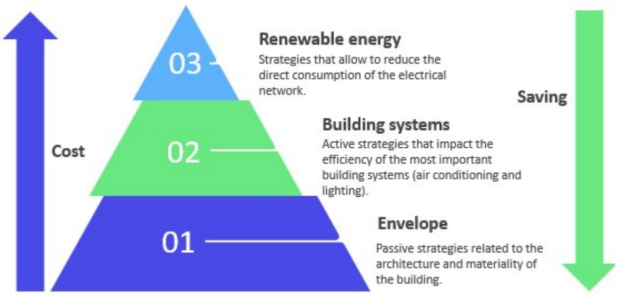

Figure 2. Pyramid of strategies.

According to the pyramid shown in Figure 2, the strategies that can have a greater impact on energy savings and less impact on the cost of a building project are those strategies that tend to improve the conditions of the envelope. Passive-type strategies related to architectural design belong to this group, such as window-wall relationship, insulation in walls and roofs, and increase in the reflectivity of exterior enclosures, among others.

Secondly, there are strategies related to improving the energy efficiency of the main building systems (motors, air conditioning, and lighting). In last place, with a lower impact on energy savings, but with a higher implementation cost, are the strategies related to renewable energies.

Considering all of the above, three indicators were pre-selected for the BELS of Colombia: energy for comfort, equipment energy, and lighting energy.

C. Analysis of relevance

The relevance of the pre-selected indicators was evaluated from an energy analysis exercise of a group of buildings belonging to the typologies of low-income multi-family housing, medium-income multi-family housing, high-income multi-family housing, and office buildings. The buildings analyzed are located in the Metropolitan Area of Bucaramanga - MAB.

The energy analysis exercise considered five (5) buildings of each building typology, which were modeled in the DesignBuilder simulation tool. The information for the energy modeling was obtained within the framework of an inter-institutional project directed by the Chamber of Commerce of Bucaramanga, in which the Industrial University of Santander participated as a co-executing entity. The energy models of the twenty (20) buildings analyzed were calibrated using measured data provided by the local energy trading company.

Figure 3 presents the energy models of the buildings analyzed belonging to the category of medium-income multi-family housing.

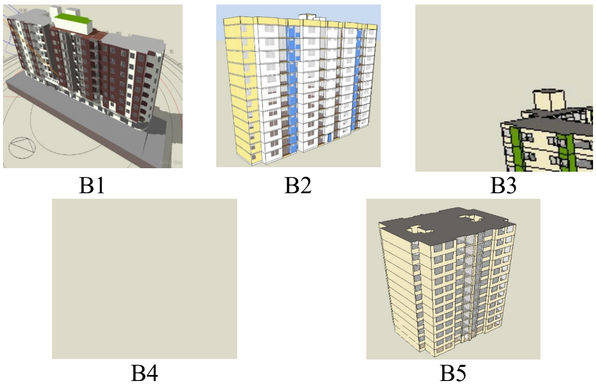

Figure 3. Calibrated energy models of the analyzed buildings belonging to the category under study.

Based on the adjusted energy models, the EST ran annual energy simulations that sought to obtain results such as the energy use intensity indicator, breakdown of energy consumption, thermal comfort indices, as well as thermal gains and losses.

The article then describes the results of the relevance analysis for the middle-income housing category. The final part of this section includes a summary of the main findings associated with the other categories analyzed.

In the first place, the analyzes included the comparison of the energy use intensity indicator of each building with the Baseline indicator of Resolution 0549. The results are shown in Table 4 reveal B1 and B3 as the projects with the lowest energy consumption per area unit. This occurs due to the inclusion of low energy consumption zones in the calculation of the areas of these projects.

Buildings B2, B4, and B5 show savings close to 20.5% concerning the Baseline indicator of the Resolution. The above differences occur due to the intensive use of LED lamps (lamps with powers between 12 W and 25 W), as well as efficient elevators with consumption equal to or less than 8 HP.

Table 4. Comparison of indicators of the intensity of energy use of the projects associated with the category under study.

Building	Annual consumption per area unit [kWh/m^{2}year]	Baseline Indicator - Resolution 0549 [kWh/m^{2}year]	Percentage difference [%]
B1	19.0	36.9	47.6
B2	31.1	36.9	15.6
B3	20.5	36.9	44.4
B4	29.7	36.9	19.4
B5	27.2	36.9	31.8
Average value	23.6	34.6	31.8

The distribution of energy consumption in the residential units of each building was included in the analysis. According to the results in Figure 4, equipment (appliances and other plug-in loads) represents the largest energy use in the category, with approximately 83% of total consumption. In the case of B5, equipment consumption is close to 97%. Due to a greater number of plug-ins loads and greater use of them with respect to the other buildings in the category. The use of lighting represents an average of 11% of energy consumption. The low representativeness of this use in B5 stands out, which is due to the use of 12 W LED luminaires.

In relation to HVAC consumption, only B1 and B2 have air conditioners in the apartments. In these cases. The other projects are naturally air-conditioned, so the use of artificial air-conditioning systems is not a common practice.

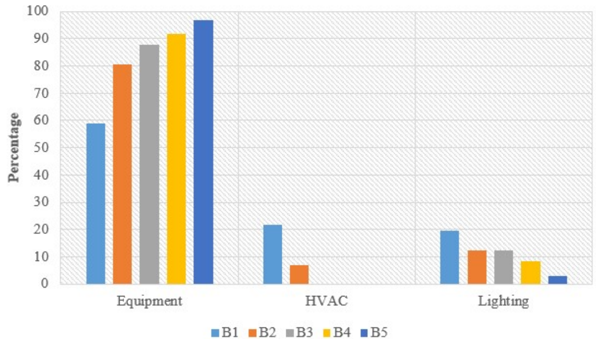

Figure 4. Distribution of energy consumption in the residential units belonging to the category under study.

The common areas represent an average of 24.64% of the total energy consumption of the buildings under study. Of this use, the highest energy consumption occurs for elevators and hydropneumatic pumps (83% on average). Lighting represents approximately 16%. The use of artificial air conditioning systems is not representative in the common areas.

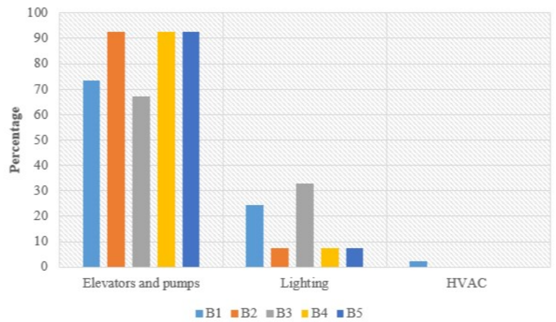

Figure 5. Distribution of energy consumption in common areas belonging to the category under study

The evaluation of the thermal comfort of the category considered indices such as the Fanger PPD and the percentage of hours of discomfort according to ASHRAE 55 simple and adaptive. The average annual comfort results shown in Figure 6 reveal PPD values between 16% and 37%.

The percentages of PPD increase on the highest floors of buildings and in those projects with a greater area of enclosures exposed to solar radiation. The orientation of the building and the presence of exterior elements that offer shade are determining factors for thermal comfort conditions. The Fanger PMV indices shown in Figure 7 suggest mildly hot to hot interior thermal conditions.

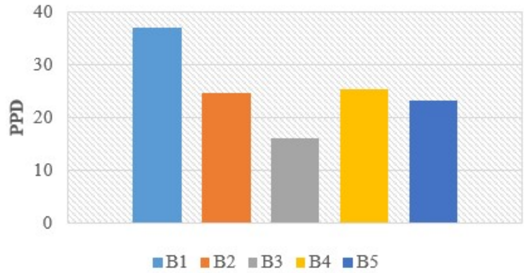

Figure 6. Average PPD for the category of medium-income multi-family housing.

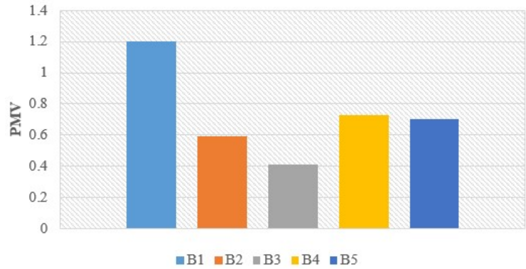

Figure 7. Average PMV for the category under study.

The evaluation of the hours of discomfort considered two standards: i) the ASHRAE 55 SIMPLE standard for the evaluation of artificially heated areas and ii) the ASHRAE 55 Adaptive standard for the evaluation of naturally ventilated areas. In air-conditioned spaces, an average percentage of discomfort close to 53% was found, due in large part to non-compliance with the humidity conditions that must be guaranteed to satisfy the ASHRAE 55 Simple standard. On the contrary, in non-air-conditioned spaces, the hours of discomfort did not exceed 20%, as shown in Figure 8. This reflects the importance of natural ventilation as a strategy to achieve thermal comfort in residential buildings in the category.

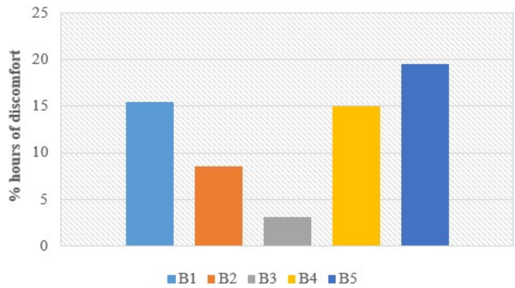

Figure 8. Percentage of hours of discomfort in the category under study.

The analysis of thermal gains and losses considered the results of the annual thermal balance. Figure 9 presents the distribution of the thermal gains of each one of the projects of the typology. According to this, approximately 50% of the thermal gains occur due to the effect of solar radiation through the glazing. These gains are critical for B4 and B1. Thermal gains by equipment and by occupancy are also representative, with 16.5% and 20.7%, respectively.

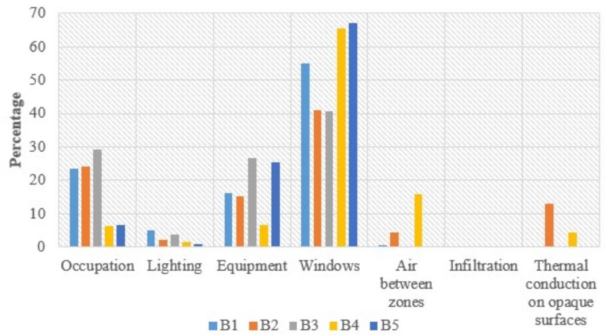

Figure 9. Distribution of thermal gains for the category of medium-income multi-family housing.

The main heat losses in the category occur through natural ventilation. This represents more than 78% of the total thermal losses.
Table 5 presents the main findings related to the energy performance of the middle-income multifamily housing typology, as well as the other building typologies considered for the BELS.

The results show that, for all the typologies considered, the highest consumption is always associated with home appliances or office equipment. On average, this consumption represents close to 83% of total consumption in housing units. The use of lighting is more representative in the Office category. Like the use of air conditioning, which reaches 38% of the total energy consumption in this category.
In common areas, the predominant consumption is associated with motors (elevators and pumps).
According to the results of the thermal comfort indices, only the artificially heated spaces have thermal comfort conditions. By contrast, naturally ventilated dwelling units experience comfort conditions that are mildly warm to hot.
In all the categories considered, solar radiation through glazing represents the greatest source of space heating. However, the annual results of thermal losses show that natural ventilation can significantly improve the thermal conditions of spaces.

Table 5. Summary of findings of the energy analysis of the different building categories considered for the BELS.

Result type		Low Income Multi-family Housing	Median Income Multi-family Housing	High-Income Multi-family Housing	Offices
Distribution of consumption in apartments/offices	Equipment [%]	95.72	83	71.27	46.4
	Lighting [%]	8.75	11	5.15	15.6
	HVAC [%]	-	14 – Only in two buildings	23.55	38
Distribution of energy consumption in common areas	Elevators and pumps [%]	56.10	83	87.4	62.4
	Lighting [%]	12.59	16	8.4	9.6
	HVAC [%]	-	2.4 – In a building	2.4	18.4
	Others [%]	11.7	-	1.8	9.6
Thermal comfort	PPD [%]	30.31	26	16.9	20.3
	PMV	Hot	Slightly hot	Slightly hot	Neutral
	Hours of discomfort [%]	29.8	12.22	5.6	41.3
Distribution of thermal gains	Occupation [%]	18.46	20.70	10.2	6.7
	Lighting [%]	1.48	3.07	1.1	6.6
	Equipment [%]	15.16	16.15	12.4	39.3
	Solar radiation through windows [%]	53.10	50.55	72.8	41.0
	Air between zones [%]	0.80	5.17	2.1	2.8
	Infiltrations [%]	0.03	0.00	0.00	0.7
	Thermal conduction through opaque enclosures [%]	10.83	4.33	1.4	3
Thermal loss distribution	Natural ventilation [%]	87.77	66.97	75.2	77.2
	Thermal conduction through opaque enclosures [%]	12.22	21.53	24.8	22.8

4. Discussion

According to the previous findings, the equipment (appliances, elevators, and pumps) and the lighting system are determinants of energy consumption in the residential type categories. Similarly, energy consumption in office buildings is also highly dependent on the equipment (plug-in and common-use equipment). In this case, lighting presents greater representativeness (≈15.6%).
For this reason, it is pertinent to consider within the indicators of a BELS for Colombia the indicators of energy for equipment and energy for lighting.
The results show that air conditioning consumption is only representative in high-income buildings and offices. The evaluation of this aspect should be considered within the parameters of comfort.
The results of comfort indices suggest thermal discomfort for many non-air-conditioned buildings. According to the results of thermal gains, the discomfort conditions are mostly associated with the incidence of the sun on the building envelope. For this reason, the design of the building, particularly its envelope, plays a fundamental role in the thermal-energy behavior of the building. A poorly designed envelope can lead building users to seek to satisfy their comfort needs through the installation of artificial air conditioning systems, thus increasing the energy consumption of their buildings. Considering the above, the BELS of Colombia needs to include an indicator that promotes the improvement of the building envelope, without losing sight of the thermal comfort of its occupants. In this sense, the Energy for Comfort indicator responds to these needs.

5. Conclusion

The literature review carried out clearly shows two trends in terms of indicators for the energy assessment of buildings within the framework of a labeling system: simple indicators and composite indicators. Several countries have chosen to evaluate the energy performance of their buildings through indicators such as the annual thermal demand or the intensity of annual energy consumption. In other cases, especially in countries with a tropical climate, the energy evaluation of their buildings tends to consider in greater depth the efficiency of the envelope and its systems.

The energy evaluation of the building typologies object of the BELS supports the previous selection of indicators. The results of the simulations reveal the equipment and the lighting system as the uses with the greatest weight in the distribution of consumption. On the other hand, the results of frequent thermal discomfort in most of the categories analyzed suggest considering this parameter as part of a comprehensive evaluation of the building. This evaluation can be achieved by considering energy for comfort as an indicator.

In the short term, work is required to help ground the considerations for the calculation of these indicators through energy simulations. Such as aspects to consider in the presence of natural ventilation.

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