Ain Shams Engineering Journal 10 (2019) 897–905

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Architectural Engineering

Assessment model of energy performance in housing of Cuenca, Ecuador

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ARTICLE INFO

Article history:
Received 10 January 2019
Accepted 4 March 2019
Available online 19 April 2019

Keywords:
Building energy performance
Sustainable building assessment
Energy indicators
Dwellings
Ecuador

ABSTRACT

This study investigates residential energy consumption in Cuenca, Ecuador, to develop a model to assess the energy performance of homes contextualized to the local reality. The research methodology is based on an analysis of international sustainability certification methods, case studies of the locality, and the participation of experts. The results determine an assessment model of energy performance composed of seven requirements with eleven evaluation criteria for multi-family dwellings, and six requirements with nine evaluation criteria for single-family homes. Three levels of compliance were defined for each evaluation criterion: standard, best, and superior practice. To meet the standard practice, for the use of such things as heating, cooling, lighting, equipment, and appliance indicators, energy usage must fall within a range of 30.1 kWh/m^2 per year to 41.6 kWh/m^2 per year; superior practice values must not be>24.3 kWh/m^2 per year.

1. Introduction

The construction industry contributes significantly to meeting the needs of society, improving the quality of life, and fortifying the economic growth of a country, however, it has been strongly criticized for being a major contributor to carbon emissions, environmental degradation, and global warming [1]. Globally, buildings account for 30–40% of total energy consumption [2] and between 40% and 50% of anthropogenic emissions of greenhouse gases [3,4]. In the United States, Europe, and the United Kingdom, the operational contribution of a building's total energy consumption is 40%, 37%, and 29%, respectively [4].

Partly to identify problems related to environmental impact in the construction industry, and to address the most important measures of energy efficiency and resource optimization responses, authorities worldwide are establishing energy regulations that help optimize building energy consumption. In addition, several labels of energy efficiency and evaluation systems for new, existing, and rehabilitated buildings have been developed by different institutions in several countries [2,5,6], numbering around 600 evaluation methods across the globe [1].

Building Sustainability Assessments (BSA) were first applied more than twenty years ago and are still undergoing revision to its criteria, resulting in a process whereby existing versions are updated to keep pace with the challenging designs and operations of everchanging performance requirements [1,7]. The evaluation systems have certain limitations regarding their effectiveness, however, and this is due to a lack of complementary studies on residential buildings to reduce the gap between designed energy efficiency and actual energy efficiency [5]. The assumptions used in systems and equipment for internal services and the behavior of its occupants are often inconsistent with what actually happens in practice because few people who design buildings also monitor their performance [7]. However, in monitored buildings it has been shown that those with certification consume less energy than uncertified buildings, and in the case of BREEAM (Building Research Establishment Environmental Assessment Method) certified buildings, they consumed 6%-30% less energy, while LEED (Leadership in Energy and Environmental Design) certified buildings consumed between 18% and 39% less energy. There is no doubt that the above evaluation systems contribute to the objective of sustainable development [7]. Its structure consists of themes representing interactions between the pillars of sustainable development, categories that address areas of performance, and evaluation indicators covering the areas of subdivision in each category [5,8].

Energy indicators are mainly associated with the consumption of the primary energy supply and CO2 emissions [3]. In this regard,

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Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2019.03.010
2090-4479/

the International Energy Agency raises the importance of these indicators and their development in countries with a high consumption of fossil fuels [9]. In this context, Ecuador presents a production of primary energy that comes in at 92% of fossil origin [10].

Taking into account that evaluation systems are mainly comprised of indicators and weights that cannot be applied globally because of variance in the climatic, geographic, social, and cultural conditions of a locality [2,5], this study focuses on the development of an assessment model of energy performance of residential buildings in the urban area of the city of Cuenca, Ecuador, using a research methodology that follows a strategy to identify appropriate and contextualized evaluation criteria.

2. Assessment methods for sustainable building

2.1. BREEAM

BREEAM is the first building certification that emerged in 1990 [6,11]. It is operated by BRE Global Ltd. (Building Research Establishment) and applied mainly in the UK and Europe where it represents 80% of the certifications for sustainable buildings in the European market [1]. With BREEAM ES Housing schemes, you can evaluate multifamily and single-family residential buildings, the methodology evaluates several impacts through ten categories, the most important being *energy*, which accounts for 18% of the total score. Qualifying credits are then weighted by category and type of project delivery [12].

2.2. LEED

LEED is a voluntary standard developed by members of the US Green Building Council (USGBC) in the United States in 1998, but its implementation began in 2000 [6]. Although it appeared after BREEAM, LEED's certification is the most widely adopted [1,6,13]. Since its inception, successive versions have incorporated stricter sustainability parameters [11], and the latest version used to evaluate homes for LEED v4 Design and Construction Homes (updated in 2017) measures performance across eight categories, including *energy and atmosphere* [14]. The evaluation is made based on the number of points scored [2].

2.3. CASBEE

CASBEE is a tool developed in 2001 by Japan Green Build Council (JaGBC) and Japan Sustainable Building Consortium (JSBC) in collaboration with academia, industry, and local government [1]. CASBEE methodology is different from other assessment systems in that it consists of evaluating two spaces (internal and external) through two factors: Q (environmental quality of building) and L (environmental load of building), with the final result being calculated by the equation BEE = Q/L [1,15]. BEE, as indicated by its acronym, provides an indicator of the building's environmental efficiency and expresses a balance between performance inside the building and a reduction of negative impacts of the building on the external environment [6]. These two factors are each divided into three elements: Indoor Environment (Q1), quality of service (Q2), outdoor environment on-site (Q3), energy (LR1), resources & materials (LR2), and off-site environment (LR3) [11]. The *energy* category represents 40% of the *L* factor [16].

2.4. VERDE

VERDE is an evaluation tool for environmental certification of buildings of new construction or rehabilitation of single-family or multifamily housing applicable in Spain and developed by the Green Building Council Spain (GBCe). It's approach is based on an analysis of the life cycle and evaluates the reduction of impact categories, through criteria which are grouped into six evaluate categories that respond to the Technical Building Code and European Directive. Specific evaluation is required to calculate the reduction of the impacts associated with each criterion from reference values that are weighted according to regional conditions, the importance of the criterion in the comprehensive analysis of the life cycle, the number of impacts associated with the criteria, and the weight assigned to these impacts [17].

2.5. QUALITEL

The Qualitel certification was developed in 1974 by the French organization QUALITE which has been recognized as a certifying organization since 1982 and as a certification since 1985. Currently, it is accredited by COFRAC (French Accreditation Committee), and its application is focused on France [18]. The certification scheme for single-family and multifamily housing in 2012 Certification New Habitat has seven categories, including *energy*. In this evaluation system, there are no weights or scores for a global calculation, only a stipulation that a building must meet at least a score of 3 on a scale of 1 to 5 [19].

3. Materials and methods

This study is conducted in Cuenca, Ecuador (Latitude 2° 52 ′S – 2° 54′ S, longitude 78° 59 ′W – 79° 01′ W), a city considered by the Inter-American Development Bank (IDB) as emerging with the potential to promote sustainable urban growth [20,21]. Cuenca consists of a residential park in which single-family homes (73.31%) predominate [22] and it represents one of the cities with the highest number of building permits nationwide (7.8%), especially for *building new residential* construction [23,24].

There is no energy usage rating system in homes in the city of Cuenca; therefore, this study proposes to develop a model for evaluating energy performance framed within ISO 21931-1 ("Sustainability in building construction - framework for methods of assessment of the environmental performance of construction works" [25]), which requires methods to be influenced by regional characteristics. Based on research raised by Ali and Al (2009) [26], which establishes three phases (define, categorize, and evaluate), a research methodology is proposed with the following steps: (1) identifying the evaluation criteria within international methods; (2) evaluation of homes in the region to select and contextualize the evaluation criteria; and (3) definition of regional priorities in assessment issues.

3.1. Identification evaluation criteria

Since the first methods of evaluation for buildings arrived in the 1990 s, only a few have been internationally recognized for their contributions to the understanding of sustainable building. For the identification of criteria for evaluating residential buildings in the *energy* category, we selected the BSA most recognized by the scientific literature: BREEAM Es, LEED v4 for Homes Design and Construction, VERDE NE: Residential and offices, CASBEE for New Construction, and Qualitel, Habitat & Environment. Table 1 shows the evaluation criteria of each certification method with its respective score.

3.2. Building assessment

For evaluation of the houses, the criteria of Table 1 were analyzed, as the example in Table 2 shows. With these results, the cri-

Table 1
Criteria related to energy category in the examined methods.

BREEAM ES: Energy category **Evaluation Criteria**	**Credits**
External lighting	1
Low carbon design	3
Lift	2
Energy efficient equipment	2
Building emission rate	15
Buildings thermal envelope	3
Internal lighting: housing	2
Internal lighting in common areas	1
Drying space	1
LEED for Homes Design and Construction: Energy and atmosphere category	
Evaluation Criteria	**Points**
Efficient hot water distribution system	5
Advanced utility tracking	2
Active solar – ready design	1
HVAC start – up credentialing	1
Annual energy use	29
Prescriptive path	
Home size	Prerequisite
Building orientation for passive solar	3
Air infiltration	2
Envelope Insulation	2
Windows	3
Space heating and cooling equipment	4
Heating and cooling distribution systems	3
Efficient domestic hot water equipment	3
Lighting	2
High efficiency appliances	2
Renewable energy	4
VERDE NE Residential and offices: Energy and atmosphere category	
Evaluation Criteria	
Use of non-renewable energy in construction materials	
Non-renewable energy consumption in the transport of construction materials	
Non-renewable energy consumption in the building; demand and efficiency of systems	
Electrical energy demand in phase of use	
Production of renewable energies in the patch	
Emission of photo-oxidants in combustion processes	
CASBEE for New Construction: Energy category	
Evaluation Criteria	**Weighting coefficient**
Control of heat load on the outer surface of buildings	30%
Natural Energy Utilization	20%
Efficiency in building service system	30%
Efficient operation	20%
QUALITEL habitat and environment: Energy – Reduction of the greenhouse effect	
Evaluation Criteria	
Control of Electricity Consumption	
Energy performance	

teria most appropriate for evaluation were selected and reference levels leading to a rating were defined. Evaluation criteria not applicable to the characteristics of local housing, such as evaluating criteria HVAC equipment, are excluded because 98% of homes do not use a heating or cooling system [21].

3.3. Dwellings selection

Eight houses were selected as representative cases for such criteria as type, geographic dispersion, building system, socioeconomic profile of family, and willingness of people to collaborate (Fig. 1). Some related to the topic of research studies have used a similar number of analysis units [27–30]. As for typology and materiality, houses, and apartments built with concrete structures and brick walls were chosen because those materials represent the predominant construction system [24].

Housing data energy was collected:

- A survey were sent to the residential sector through a specific statistical probabilistic sampling design, randomized and stratified by urban parish type. The sample size was 280 homes distributed throughout the urban area of Cuenca. The survey is structured by a questionnaire of closed questions in order to understand their behavior with the construction, use of natural resources, characteristics of household appliances, and air conditioning needs.
- Monitoring electricity consumption for a week between September and October 2015 (cold season), with teams listed in Fig. 2 to determine consumption for lighting, equipment, and appliances. Review monthly payroll electricity consumption during 2015.
- Simulation of energy demand (kWh/m^2/per year) through the 2011 version of Autodesk Ecotect Analysis software to determine the demand for HVAC.

3.4. Local priorities

We chose expert consensus [31] through the Analytic Hierarchy Process (AHP) [32] methodology for its usefulness in identifying the interests of society [5,33,34]. Based on the structure of the AHP, a 26-item questionnaire of survey comparison situations (between criteria and sub-criteria) was graded according to the Saaty scale. Calculations were performed on a (symmetrical) positive reciprocal matrix and importance weights were obtained by the arithmetic mean of the priority vectors for all respondents.

The panel was formed using purposive sampling techniques. Stakeholders and participating institutions follow: (1) Universities: University of Cuenca, Salesian Polytechnic University, University of the Americas, and Higher Polytechnic School of the Litoral; (2) Professional independent building areas; and (3) Public Institutions: Municipal housing company Cuenca (EMUVI), Generator of the Austro S.A. (ELECAUSTRO), National Institute for Energy Efficiency and Renewable Energy (INER) and Latin American Energy Organization (OLADE). There were 33 total participants, made up of 18 academics, 9 independent professionals, and 6 officials.

4. Results and discussion

4.1. Dwellings assessment

4.1.1. Survey results

- Overall, 92.5% of users leave the curtains open to take advantage of natural light; however, 59% of the inhabitants do not have all the areas of the house well lit.
- In the mornings, 57.2% turn on the lights between 5h00 and 7h00 (50.6%); in the afternoon, 64.3% turn on the lights after 18h00, mostly until 21h00 (12.5%) and 22h00 (20.4%).
- On weekdays, the lights are turned on an average of 4.4 h; and 3.8 h on weekends.
- Ninety-five percent of the respondents dry clothing outdoors.
- Regarding the use of any alternative energy system, 53% of respondents considered it important, however, none of them used it.
- Sixty-eight percent of the respondents disconnect appliances when they are not in use.
- Overall, 59% of kitchens use gas (LPG) and 3% are induction.
- In total, 59% do not have energy efficiency refrigerator labeling.
- Fifty-nine percent heat the water in the showers with a gas water heater and 34% with an electric shower.
- Of the respondents, 65% consider their home comfortable; 13% consider the need to use some heating system, but only 2% use it.

Table 2
Example of the analysis. Lighting evaluation criteria.

	BREEAM	LEED	VERDE	CASBEE	QH&E
Evaluation method	*External lighting:* **1**: Luminaire characteristics check: Luminous efficacy, color rendering index (CRI) and power (P). **2**: Checking of automatic lighting control system. **3**: Energy rating of outdoor lighting. *Internal lighting and common areas:* **4**: Verify the use of fixed luminaires with low energy consumption. **5**: Count with an informative leaflet on low-energy lighting.	*Internal lighting:* **1**: Single-family: Checking power density to be installed. **2**: Multifamily: Verification of lighting reduction from the Energy Star baseline. *Indoor lighting:* **3**: Single-family: Checking devices for luminaires. **4**: Multifamily: Verification of lighting reduction from the Energy Star baseline.	*Demand for electrical energy in use phase: Lighting of common areas and garage.* **1**: Estimation of the reduction of electricity consumption due to the use of efficient luminaries.	*Natural energy utilization: Natural lighting* *Multifamily:* **1**: Evaluate natural lighting systems.	*Control of electricity consumption: Lighting of non-private spaces* **1**: Presence of natural lighting. **2**: Adequate lighting levels. **3**: Luminous efficacy. **4**: Checking of automatic lighting control system. **5**: Delay time in luminaires. **6**: Lighting circuit independent of other common spaces. **7**: Reflection factor surfaces. *Lighting of private spaces* **8**: Checking natural lighting in the main bathroom. **9**: Light indicators on switches.
Indicator	**1**: lm/W; CRI; W **2**: Verification **3**: Scale A to G. **4**: % in each room **5**: Verification	**1**: W/sq. m **2**: % **3**: Verification **4**: %	**1**: kWh/housing	**1**: % private areas of apartments face exterior walls on two sides	**1**: Glazed surface (sq. m) and glazed surface area and floor area (%)0. **2**: Lux **3**: lm/W **4**: Verification **5**: Minutes (min) **6**: Verification **7**: % **8 & 9**: Verification
Requirement level	**1**: Access roads and pedestrian paths: ≥ 50 lm/W and CRI ≥ 60 or 60 lm/W and CRI < 60 - Parking areas, associated roads, and lighting by projectors: ≥ 70 lm/W and CRI ≥ 60 or 80 lm/Wand CRI < 60 - Signage, illuminated signs, and vertical lighting: ≥ 60 lm/W and P ≥ 25 W or ≥ 50 lm/W and P < 25 W **2**: Luminaires controlled by daylight sensor, motion detector, or time switch. **3**: Minimum B **4**: Internal lighting minimum 75% **5**: Common zones minimum 100%	**1**: Maximum 7.7 W/sq. m **2**: Minimum 35%. **3**: Motion detector, integrated photovoltaic cells, photosensors, or astronomical clock. **4**: Minimum 50%	**1**: Does not demand a value at the minimum level of 0 kWh/housing.	**1**: At least 80%	**1**: Lobby and entrance: 2-3sq. m Semi-underground parking: lighting 2 sides **2**: Lobby and entrance: 100–150 Lux Circulation and maintenance rooms: 100–120 Lux Stairs; 150–300 Lux External stairs and covered parking: 50–80 Lux **3**: All areas ≥ 60 lm/W, except covered parking ≥ 65 lm/W **4**: Daylight sensor **5**: 2 to 3 min all areas except: Stairs: 3 to 6 min. Covered parking: 5 min. Maintenance room: 1 to 3 min. **6**: Lobby, horizontal circulation, and external stairs **9**: Balcony or terrace switches with light indicators

4.1.2. Thermal envelope

Its assessment is based primarily on an analysis of the thermal transmittance values (W/m^2K) of the roof (1.5), walls (1.8–2.5), floor (1.8), and windows (5.7). The assessment was also based on building orientation (east - west), the percentage of the area covered by glazed in the facades, which depends on the coefficient of solar gain (SGCH), and thermal transmittance of the glass (U). Taken as reference values established by local regulation which are currently under review [35], the data obtained as a result of the assessment show that none of the housing meets all of the parameters evaluated. Solar gains are evaluated based on the requirements of international methods, and as a result all homes meet minimum values ($0\ MJ/m^2$/per year ≤ [Natural energy usage] < $1\ MJ/m^2$/ per year) and 4 homes reach a higher level. Finally, the energy demands of air conditioning are evaluated, for which simulations are carried out taking as a reference the comfort zone between 16.62 and 23.62 °C [36]. The results show that on average 29.37 kWh/m^2/ per year are demanded, which cooling demand is insignificant since represents <2% (Fig. 3).

In Fig. 4, we can see that heating demand increases in the months of July and August, reaching a monthly average of 4.46 kWh/m^2, while the highest demand is 8.3 kWh/m^2. In relation to international methods, the values obtained are below the maximum allowable limits due to the climatic conditions of the city.

4.1.3. Lighting and appliances

International methods evaluate indoor lighting according to the following findings: 75% of fixed lighting should be low-energy (>55 lm/W) in habitable rooms, and of the housing evaluated only one met the percentage that corresponds to an apartment, while other dwellings obtained values between 13.7% and 70%. On the other hand, the installation potential for space must not exceed 7.7 W/m^2; the evaluations of four houses met this condition, while in others not all spaces were below this limit. It is important to mention that several of the spaces that met the maximum value of power density did not meet the optimum levels of illuminance. Also, it is desirable that 80% of the private areas of apartments face exterior walls on two sides and finally that balconies or terraces

V1	V2	V3	V4
			
Typology: Two sides townhouse Materiality: Plastered brick Construction area: 169.20m2 Number of inhabitants: 4	Typology: Townhouse on one side Materiality: Plastered brick Construction area: 438.19m2 Number of inhabitants: 4	Typology: Townhouse on one side Materiality: Plastered brick Construction area: 255.96m2 Number of inhabitants: 4	Typology: Townhouse on one side Materiality: Brick seen Construction area: 298.29m2 Number of inhabitants: 3

V5	V6	V7	V8
			
Typology: Two sides townhouse Materiality: Brick seen Construction area: 100.10m2 Number of inhabitants: 3	Typology: Two sides townhouse Materiality: Plastered brick Construction area: 171.21m2 Number of inhabitants: 5	Typology: Apartment Materiality: Brick seen Construction area: 107.28m2 Number of inhabitants: 2	Typology: Apartment Materiality: Concrete Construction area:74m2 Number of inhabitants: 2

Fig. 1. Case Studies.

Equipment	Description
	Each piece of equipment consists of a transmitter, a wireless monitor, and sensors. The sensor is connected to the phase cable of the distribution box (in this case it was installed only with the one corresponding to the outlets since the equipment does not differentiate between consumption by lighting or by electrical appliances). The electricity used in the home passes through the sensor that is connected to the transmitter, which sends the information wirelessly to the monitor for instant viewing or storage. The frequency of data transmission is 433.5 MHz, in time intervals of 6, 12, or 18 seconds. The transmission range between the transmitter and the monitor is 40-70m. According to technical specifications, they have a precision greater than 90%.

Fig. 2. Detail of equipment for electric power monitoring.

have luminaries with light indicators on the switches, with conditions being met for both apartment and a single-family housing. Household appliances are evaluated by international methods in relation to the energy rating, mainly of the kitchen and refrigerator. Assessments were carried out and only two houses do not have certification in refrigerators because of their age. In the electricity consumption data in Fig. 5, it can be seen that on average 12.20 kWh/m^2/per year is consumed by the dwellings. Consumption by equipment and appliances (outlet) is higher than consumption by lighting because they represent 75% and 25%, respectively.

4.1.4. Elevator

International methods assessing energy comparison and selection elevators present a lower energy consumption. In addition, the elevator selected must meet the following three characteristics, which offer the greatest potential for energy savings: operating in standby mode, the presence of auxiliary equipment such as ventilation, and light settings, such as lighting that is switched off when the elevator is not moving, cabins with efficient lighting, etc. In the evaluations of the two apartments, one of them had power-saving features.

4.1.5. Drying spaces

Only one of the methods discussed evaluates this condition; the international method provides that cloth drying may occur in an internal or external space, habitable or uninhabitable space, and, accordingly, must be fitted with natural or mechanical ventilation, be covered or protected from outside views that do not interfere

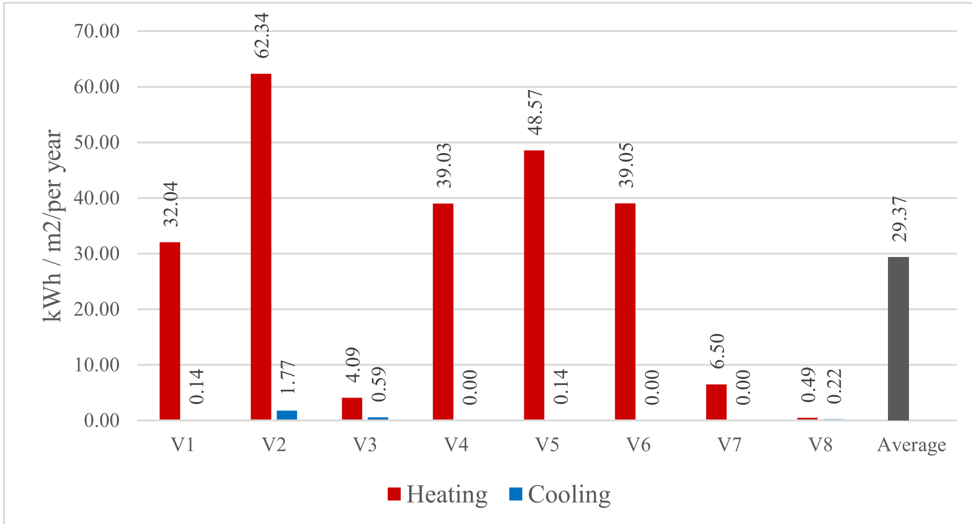

Fig. 3. Cooling and heating energy demand.

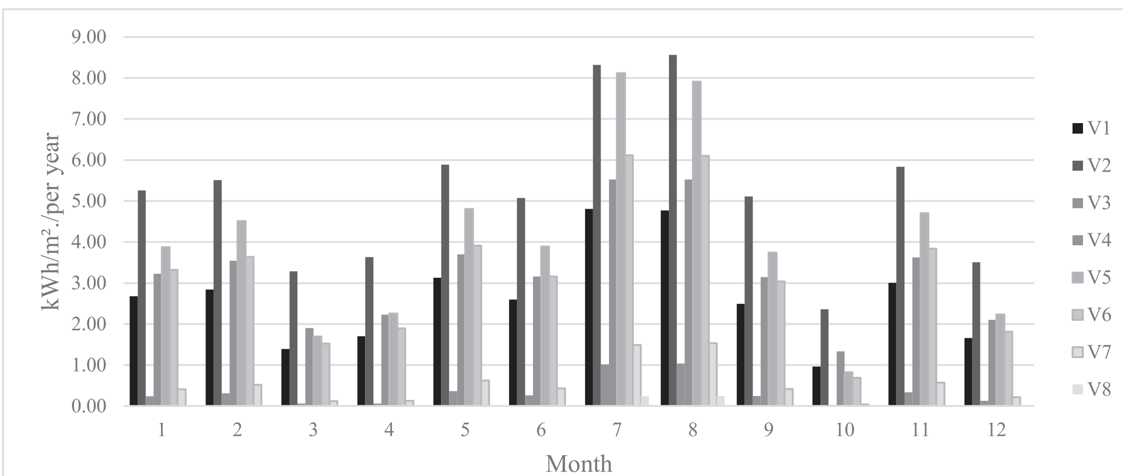

Fig. 4. Heating energy demand per month.

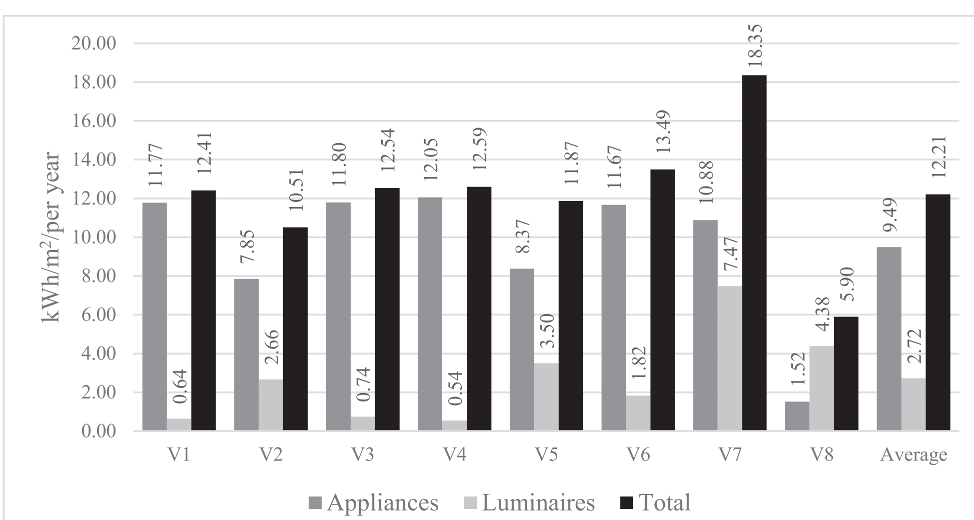

Fig. 5. Electric consumption per dwelling.

with the lighting or direct ventilation of other spaces, and that are near or within the viewing area of dwelling. It also establishes tendal lengths based on the number of bedrooms: 1 or 2 rooms, 4 or more meters of tendal; 3 or more rooms, 6 or more meters of tendal. The sections should be of 1 m length and 1.5 m minimum height. Of the homes we evaluated, four had drying spaces, but none met all specifications.

4.1.6. Renewable energy and domestic hot water

International methods evaluate the percentage share (up to 40% minimum compliance) of renewable energy systems for generating electricity and heating water. This assessment was not carried out because none of the homes had low carbon technology.

4.2. Selection evaluation criteria

For the model of integrated evaluation criteria that are objective, achievable, measurable, and appropriate for the type of existing housing in the village, 6 trials were applied [37]:

1. The evaluation criteria are compatible with the characteristics of homes.
2. Evaluation criteria helps to overcome the problems in housing.
3. The method for evaluating was feasible to implement.
4. Demand levels are in line with local conditions.
5. The type of evaluation that is done is based on performance.
6. Evaluation criteria contributes to improving the comfort of homes.

The criteria met over 4 trials were selected: building orientation; solar gains; indoor, external, and common area lighting; home appliances; lift; drying spaces; renewable energy; efficient distribution system of domestic hot water; and performance energy. Table 3 presents an example of the selection.

4.2.1. Determination of reference levels

The evaluation results show that there are different levels of performance that can be awarded assigning points based on compliance [37,38]: *Standard practice: 1 point; Best practice: 3 points; and Superior Practice: 5 points.* With this linear score escalation, which qualifies the level of housing performance, we worked on two aspects to define reference levels (benchmarks) that were established for each evaluation criterion. First, for the ¨standard¨ reference level, the requirements established in the national regulatory framework and standards of different technical documents, have been issued by government institutions and are recognized as socially accepted, as is the case with the Ecuadorian Technical Standard [39]. Secondly, based on critical analysis of the assessment of the housing (discussed in section 4.1.), and for the purpose of guiding toward sustainable practices, reference levels “best and superior” are defined. As an example in Table 4, the reference levels are presented for the evaluation of “Interior lighting and Energy performance”.

4.3. Definition of regional priorities

One of the most important aspects after defining indicators is to establish their weights. The panel of experts gave different values for each requirement that influences the energy performance and evaluation criteria (see Table 5), indicating that there are aspects that are more important than others. The order of priorities and values of the weights are as follows: performance energy 28.85%, renewable energy and domestic hot water 18.77%, surround thermal 18.05%, artificial illumination 12.56%, home appliances 10.12%, drying spaces 7.04%, and lift 4.61%. Regarding the evaluation criteria, energy demand (0.2885), thermal envelope (0.1043), renewable energy and domestic hot water (0.1042), and appliances (0.1012) represent 60% of the total value of the weights, and, therefore, are the criteria most influential on the energy performance of a dwelling.

5. Conclusion

This study, based on the *energy* category of the methods of building sustainable assessment (BSA), seven requirements with eleven evaluation criteria for multifamily dwellings and six requirements and nine evaluation criteria for single-family homes were identified, with performance levels more appropriate for housing types that predominate in the city of Cuenca. In addition, through expert consensus, we could define priorities for the evaluation of the *energy* category, establishing energy demand, the thermal envelope, renewable energy, domestic hot water, and appliances as the most important requirements.

With these results, an energy performance evaluation model is proposed, which integrates the importance of requirements and criteria, through scores and weights, respectively. In this sense, the model is a tool for predicting the future energy performance of a building and support for the architectural design of dwellings that will improve the sustainability of the city of Cuenca. Because there is no consensus on the best way to contextualize indicators, this study provides an approach that is summarized in three stages: (1) identifying the evaluation criteria within international methods, (2) select and contextualize criteria through field evaluations, and (3) define regional priorities with the participation of experts.

Finally, this type of research is needed to document evidence of the energy situation locally in order to make more appropriate and timely assessments that contribute globally to the goal of sustainability. In addition research methodologies should be further developed in order to improve contextualization of evaluation schemes for buildings and other spatial scales.

Table 3
Judgments for the selection of the evaluation criteria of the energy category. Lighting criteria.

Evaluation criteria	Selection trials					
	1	2	3	4	5	6
Lighting						
BREEAM						
Internal lighting: housing	■	■	■	■		
Internal lighting: common zones	■	■	■	■		
External lighting	■	■	■	■		
LEED						
Lighting	■	■	■	■		■
QH&E						
Lighting of non-private areas	■	■	■			■
Private areas: Bathroom natural lighting and presence of light point on balconies or terraces.	■	■	■			■

Table 4
Example of reference levels for evaluation criteria.

Reference level	Requirement	Score
INDOOR LIGHTING		
Standard Practice	75% of luminaires must be of low energy consumption (luminous efficacy > 55 lm/W)	1
Best Practice	100% of luminaires must be of low energy consumption (luminous efficacy > 55 lm/W)	3
Superior Practice	In addition to the above, the main bathroom must have a glass or surface that allows the passage of natural light.	5
ENERGY PERFORMANCE		
Standard Practice	Demand for cooling, heating, lighting, equipment, and appliances. $30.1 < D \leq 41.6$ kWh/m^2/per year	1
Best Practice	Demand for cooling, heating, lighting, equipment, and appliances. $24.3 < D \leq 30.1$ kWh/m^2/per year	3
Superior Practice	Demand for cooling, heating, lighting, equipment, and appliances. ≤ 24.3 kWh/m^2/per year	5

Table 5
Weightings obtained based on the AHP method for the energy category.

Requirement	Weight	Evaluation criteria	Factor
1. ET: Thermal envelope	18.05%	**1. OE1:** Building orientation	0.578
		2. GS2: Solar gains	0.422
2. IA: Artificial lighting	12.56%	**3. II1:** Indoor lighting	0.64
		4. IE2: External lighting	0.165
		5. IZC1: Common zones lighting	0.195
3. E: Home appliances	10.12%	**6. E1:** Home appliances	1
4. A: Lift	4.61%	**7. A1:** Lift	1
5. ES: Drying spaces	7.04%	**8. E1:** Drying spaces	1
6. ER_ACS: Renewable energy and domestic hot water	18.77%	**9. ER1:** Renewable energies	0.555
		10. ACS2: Efficient domestic hot water distribution system	0.445
7. RE: Performance energy	28.85%	**11. DE:** Energy demand	1

Funding

This research received no external funding.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgment

The authors wish to express their gratitude to the University of Cuenca and its Research Directorate (DIUC) for providing the necessary funds for the research project "Certificación Edificio Sustentable y Seguro".

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