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Quantifying the Contribution of Bioclimatic Design to the Sustainable Level of Buildings. Case study: Torres Eco-House

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Abstract

In this study we evaluated the contribution of bioclimatic design to the a building's sustainability level. To do this, the scores of a bioclimatic house, Torres house, were compared with those of a conventional design. In both cases, 11 of the most important Green Building Rating Systems (GBRS) were used: namely ASGB, BEAM, BREEAM, CEDES, DNGB, GBI, GG, GS, IGBC, LEED and SBTools. All GBRS determined that the bioclimatic house was more sustainable than the conventional one. However, the resulting scores varied widely and only three GBRS clearly detected the obvious advantages of bioclimatic design (CEDES, DNGB and GS), while the rest gave it a low score, and three barely assessed it (ASGB, GBI and SBTools) despite the fact that the bioclimatic house studied consumes 70.3% less than a conventional one and has other environmental advantages. Taking into account the average results of 11 GBRS, the contribution of bioclimatic design to the sustainability level is 11.1%. However, if the average results of the 3 highest-scoring GBRS are taken into account, the contribution of bioclimatic design to the buildings' sustainability level is 20.28%.

Keywords: Bioclimatic Design, Comparative Evaluation, Deficiencies, Green Building Rating System, Improving Future Gbrs, Passive Design, Sustainable House

Introduction

This study quantifies the contribution of bioclimatic design to the level of sustainability of a building.

In this work, Bioclimatic design is defined as achieving buildings capable of thermal self-regulation without the need for energy-consuming devices [1-3]. A bioclimatic building has a very special orientation and design, which allows it to maintain a comfortable internal temperature at all times. In winter it heats itself due to its orientation and the greenhouse effect and a varied set of ingenious architectural strategies. In summer it cools itself due to its orientation, solar protection and the cooling of the night air via underground galleries with a special design.

The advantages of bioclimatic design have been analyzed in many works and notably include the following: reduction of energy consumption, reduction of emissions and waste, increase in quality of life and reduction of illnesses among its occupants [1-9]. Most of the works carried out focus on a single comparative variable, such as energy consumption [1,5,8,10-12].

However, few studies have generally evaluated the contribution of bioclimatic design to the overall level of a building's sustainability [13-15].

Multivariate tools known as GBRS (Green Building Rating Systems) were developed to assess and quantify sustainability

and are being used extensively [16-20]. Therefore, in this study, the 11 most internationally representative GBRS were selected to comprehensively evaluate the contribution of bioclimatic design to a building's overall sustainability. To this end, a house with an effective bioclimatic design, the Torres house (Figure. 1), was selected and compared to a house with a conventional design.

Torres house has a very special design that ensures a comfortable interior temperature all year round, without the need to use heating or air conditioning. It also does not need a mechanical ventilation system nor artificial lighting during the day.

Considering that this house has an energy saving of 70.3% compared to a conventional house, and that it also has other additional benefits: environmental (absence of emissions), economic (reduced costs, reduced maintenance, and fewer breakdowns) and for human health (reduced noise, emissions, vibrations, odors, etc.), it could be expected that the current GBRS would adequately assess these major factors, giving it a high score.

Description of the Houses Studied: Torres-Bio and Torres-No-Bio

To accurately determine the contribution of the bioclimatic design in the sustainable score of a building, a bioclimatic house (Torres house, called Torres-bio in this work) was compared with a reference baseline, its hypothetical non bioclimatic version, conventionally designed (Torres-no-bio). In both cases the evaluation was carried out using 11 of the best, and internationally well known, GBRS. To simplify the study, only the indicators with different scores for the two cases are shown in the comparison to obtain scores that depend exclusively on the bioclimatic design.



Figure 1: Torres Eco-House. Castellón. Spain (Projected by Luis de Garrido). South Facade

Description of the House with Bioclimatic Design. Torres-Bio General Information

Torres-bio is located in a small city in Castellón (Spain), has a constructed area of 290.5 m² on three floors (Figure. 1-6), It also has a basement with 139 m² built [21]. The ground floor has a central double-height patio, a living room, a bedroom, a bathroom, a kitchen, a studio and a laundry room. The first floor has two bedrooms, a bathroom and a main bedroom with a dressing room and a bathroom. The second floor has a bedroom with access to the two lateral green roofs (Figure. 4). The third floor is developed under the sloping roof and has direct access to the green roof (Figure. 7, 8)

Torres-bio was built in 2001 and thanks to its special bioclimatic design is capable of maintaining a comfortable interior temperature, so that its energy consumption is 70.3% less than that of a conventional house of the same surface area and characteristics. It also does not need lighting during the day nor ventilation devices. Due to its low energy consumption, Torres house is self-sufficient in energy and water at a very low price [22].



Figure 2: Torres Eco-House. Castellón. Spain (Projected by Luis de Garrido). East Facade



Figure 3: Torres Eco-House. Castellón. Spain (Projected by Luis de Garrido)

The house's design incorporates vertical and horizontal solar shading to regulate the access of solar radiation to the interior of the house as needed throughout the year. In the central section, the double glass skin provides access to the central covered patio.



Figure 4: The Torres House's Garden Roof. On the North Side, the Wind Catcher can be seen, which Collects Cool Air Coming from the East, Transports it to a Series of Underground Galleries Located below the Basement, where its Temperature is Lowered before it Enters the House to Cool it in the Summer

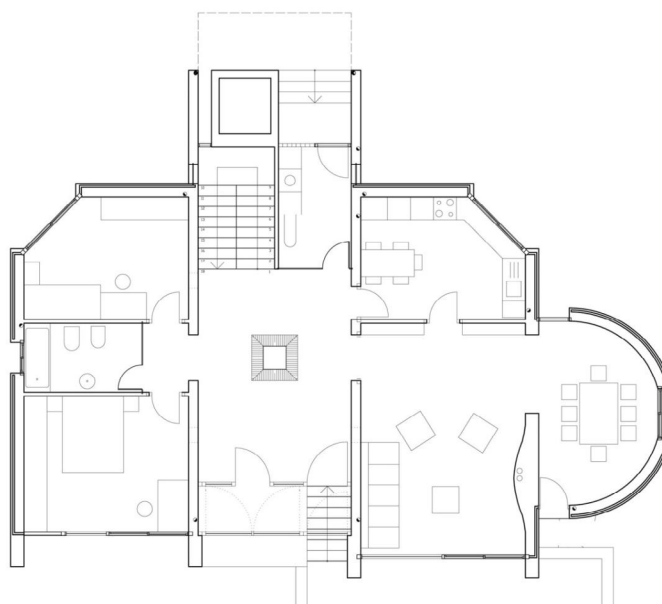


Figure 5: Torres House. Ground Floor Layout

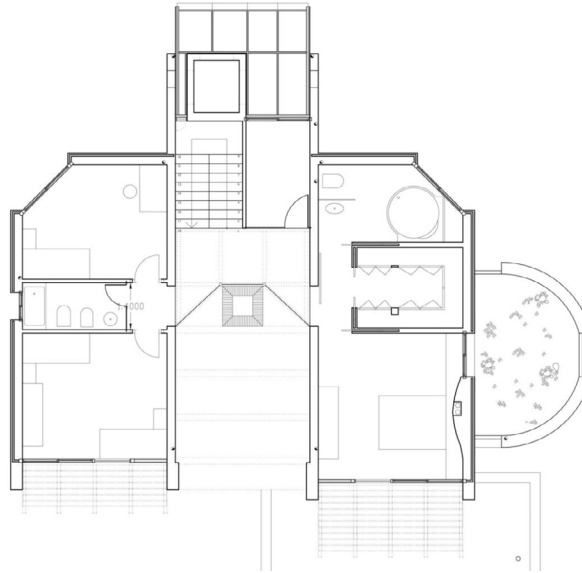


Figure 6: Torres House. First Floor Layout

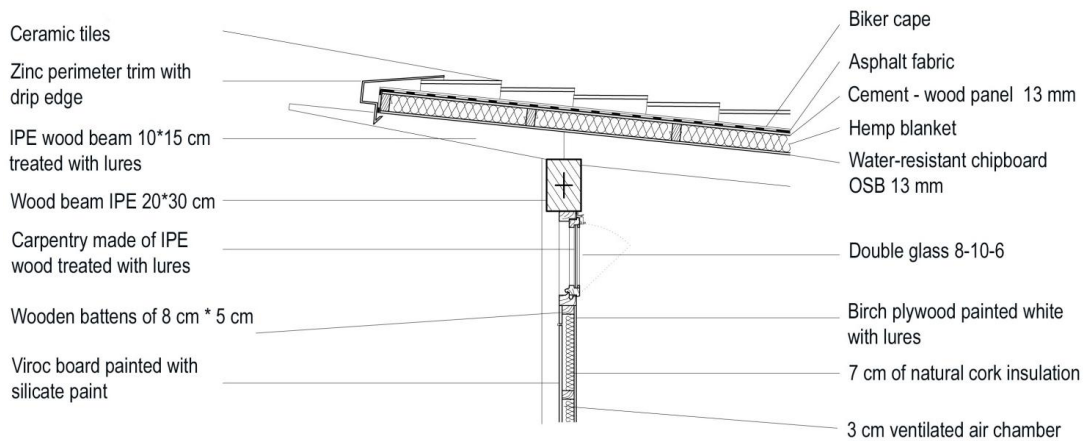


Figure 7: Construction Detail of the Sloping Roof of Torres House

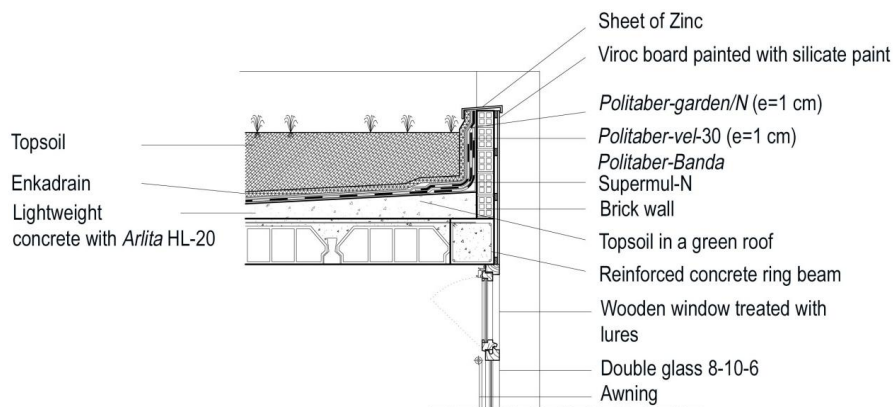


Figure 8: Construction Detail of the Green Roof of Torres House

Bioclimatic Design

In this study, bioclimatic design is defined as creating buildings capable of thermal self-regulation, providing a comfortable interior temperature (19°-25°), without the need for heating and air conditioning equipment. Achieving this requires good professional skills, although in extreme climates, occasional heating may still be needed. The energy savings of bioclimatic design are often measured as the "bioclimatic level". In this article, we focus on a 100% bioclimatic approach, in which the Torres-bio demonstrates the ability to provide comfortable indoor temperatures without any mechanical devices.

Bioclimatic Heating

The house heats itself in winter due to several special features of its design (Figure 9), among including the following:

- North-south orientation
- Most windows on the south facade

- High thermal inertia on the internal side of the enclosure
- Adequate insulation on the external side of the enclosure
- Adequate greenhouse effect that generates the required heat energy
- Solar protections allow maximum solar radiation to enter the building in winter
- Main rooms are located in the south and service rooms in the north

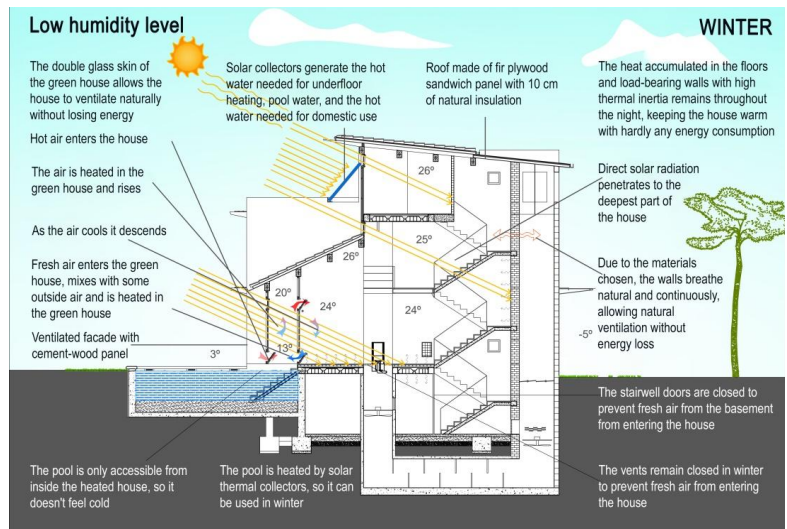


Figure 9: Torres Cooling. Special Bioclimatic Architectural Design to heat the Interior of the House in winter without the need for Heating Equipment

The windows located on the south of the house (with an area of about 32 m²) (Figure. 9) generate about 11,200 W of heating on average in winter (since about 350 W/m² pass through the glass). The occupants of the house and the energy losses from the refrigerator and other appliances provide an additional 1,500 watts of heating. In other words, the house is capable of generating about 12,700 W of heating power, which is enough to heat its main rooms. Torres-bio thus maintains a minimum temperature inside of 19°C in winter. However, the house incorporates an underfloor heating system powered by a small heat pump (2,000 W, COP: 4.5, 444 W) to ensure comfort on the harshest winter days and to heat the pool water.

Bioclimatic Cooling

The house cools itself in summer by several special features of its design (Figure. 10), among which the following stand out:

- North-south orientation
- High thermal inertia on the internal side of the enclosure
- Adequate insulation on the external side of the enclosure
- Cold generation in underground galleries (Figure. 10-12)
- Cold generation through optimized internal night ventilation
- Solar protections allow minimum solar radiation to enter the building in summer
- Served spaces to the south, serving spaces to the north

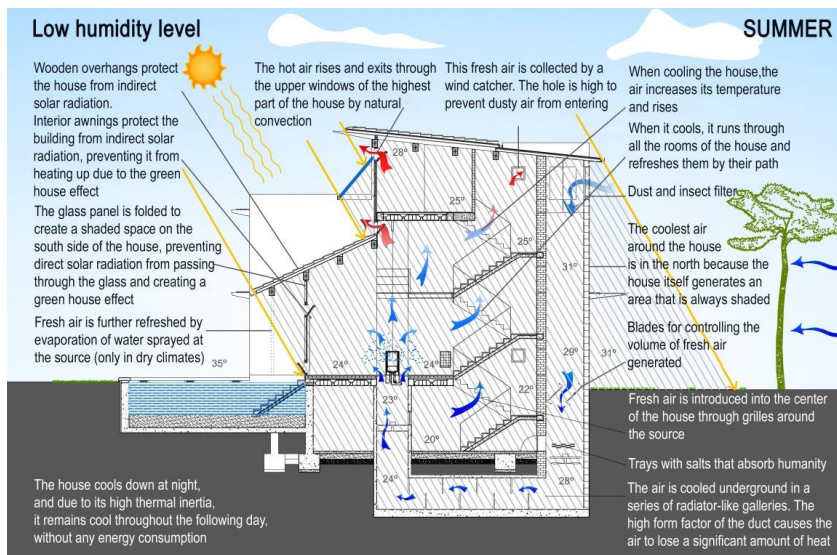


Figure 10: Torres House. Special Bioclimatic Architectural Design to Cool the Interior of the House in Summer without the need for Air Conditioning



Figure 11: Interior of Torres house. The Covered Central Courtyard can be seen, Which Cools all Rooms in Summer and Warms them in Winter. The Double-Glazed Entrance is also Noticeable. In Summer, there is Only One Glass door, and in Winter, There are Two Glass Doors Forming a Greenhouse at the Entrance to the House.



Figure 12: Glass Floors Allow for Greater Lighting inside the House

Firstly, the house cools down in summer, avoiding heating up during the day, due to its orientation, the arrangement of glass and the special solar protections. Secondly, the house is designed so that the cold night air is further cooled in the underground galleries, penetrates the interior of the house and cools it during the night, while the house remains cool during the day due to solar protections, high interior thermal inertia and its exterior insulation. A maximum internal temperature of about 26°C is maintained in summer during the night and 18-21°C during daylight.

House Energy Consumption

Due to the bioclimatic design, the house does not need heating devices, air conditioning, or mechanical ventilation, and as the owners are highly conscious of reducing energy consumption as much as possible, the house has very few appliances, with a total power of 4,671 W (Table 1) with an annual consumption of 16.44 kw h/m² (Table 2).

Fridge	150 W (average power)
Induction hob	900 W
Microwave	500 W
Washing machine	1,000 W
TV	150 W
PCs	100 W
Lighting	185 W
Garden lighting	62 W
Water purification	1.180 W
Bomba de calor	444 W
Total power:	4,671 W

Table 1: Total Power of the Appliances in Torres-Bio

290.5 m ²	Power	active time	energy per year	energy year/m ²
	W (watts)	(hours)	(kwh/year)	(kwh/m ² /year)
Fridge (average power)	150	24 h. * 365	1.31	4.52
Induction hob	900	2 h. * 365	657	2.26
Microwave	500	1 h. * 365	182.5	0.62
Washing machine	1,000	1 h. * 365	365	1.25
TV	150	8 h. * 365	438	1.50
PC's	100	8 h. * 365	292	1.00
Lighting	185	8 h. * 365	540.2	1.85
Garden lighting	62	4 h. * 365	90.5	0.31
Water purification	1,180	1 h. * 365	430.7	1.48
Heating / cooling (soft. temp.)	444	12 h. * 90	479.52	1.65
Total energy consumed per m ² : 16.44 kwh/m ² /year				

Table 2: Total Energy Consumption Per M2 Of Torres-Bio

Energy Self-Sufficiency

To achieve energy self-sufficiency at an affordable cost, a three-phase strategy has been followed:

- Informing the owners to use as few devices as possible.
- Carrying out an optimal bioclimatic design
- Correctly managing the devices incorporated into the house.

Due to its specialized bioclimatic design, the house does not need heating or air conditioning. It is estimated that the maximum total power of all the devices that can be activated at the same time is 2,000 watts, with occasional peak requirements of up to 2,500 watts. To meet these needs, a photovoltaic system with ten photovoltaic solar collectors has been installed. This system generates approximately 3,500 watts at peak output, so that the batteries can provide a power of at least 2,500 W (as usual, batteries cannot supply their full power, but rather around 80%). The photovoltaic system necessary costs €6,750 including VAT.

Description of the Non-Bioclimatic Design. Torres-No-Bio

Description and Disadvantages

A conventionally designed house requires heating and air conditioning to maintain a comfortable interior temperature and artificial lighting in some of its rooms, even during the day. As a result, the house has an additional cost (price of the equipment and price of the space to house them), requires more maintenance, generates harmful emissions, and reduces the well-being and health of its occupants (noise, odors, vibrations).

House Energy Consumption

The total constructed area of Torres-no-bio is 290.5 m². In Castellón, the average power of heating and air conditioning systems is, at least, 45 W/m², although the systems are usually sized with an average power of 90 W/m² [22]. Therefore, the Torres-no-bio house should incorporate a heating system and an air conditioning system with a minimum power of 13,072 W (290.5 m² * 45 W/m² = 13.072 W). In this way, the total power of the Torres-no-bio electromechanical devices would be at least 17.299 W (13.072 W + 4.227 W) (Table 1), and its energy consumption (per m²) would be 55.27 kWh/m² /year (Table 3).

	Power	active time	energy year	energy year/m ²
	W (watts)	(hours)	(kWh-year)	(kWh/m ² /year)
Fridge (average power)	150	24 h. * 365	1.31	4.52
Induction hob	900	2 h. * 365	657	2.26
Microwave	500	1 h. * 365	182.5	0.62
Washing machine	1.000	1 h. * 365	365	1.25
TV	150	8 h. * 365	438	1.50
PC's	100	8 h. * 365	292	1.00
Lighting	185	8 h. * 365	540.2	1.85
Garden lighting	62	4 h. * 365	90.5	0.31
Water purification	1,180	1 h. * 365	430.7	1.48
Heating / cooling (mild temp.)	6,536	12 h. * 90	7,058	24.29
Heating / cooling (peak temp.)	13,072	12 h. * 30	4,704	16.19
Total energy consumed per m ² : 55.27 kWh/m ² /year				

Table 3: Total Energy Consumption per m2 of Torres-No-Bio

Torres-bio consumes only 29.7% of what Torres-no-bio would consume (16.44 kWh/m²/year / 55.27 kWh/m²/year), from which it follows that a good bioclimatic architectural design is capable of generating a minimum energy saving of 70.3%.

Energy Self-Sufficiency

The total power of the Torres-no-bio devices is 17,299 W, and, although not all devices have to be connected at the same time, the minimum power of the photovoltaic panels that should be installed to generate electrical energy for the house would be around 12,000 W. That is, for Torres-no-bio to be self-sufficient in energy, four times as many photovoltaic panels would have to be installed than for Torres-bio, and at an economic cost four times greater.

It is thus essential to carry out an optimal bioclimatic design to achieve energy self-sufficiency at an affordable cost.

Comparative Evaluation of Torres-Bio and Torres-No-Bio

The evaluation of Torres-bio, and Torres-no-bio was carried out using a selection of the most important and representative existing GBRS (Green Building Rating Systems). GBRS are multivariate tools in which a set of indicators, grouped into categories, can evaluate various ecological and sustainable aspects of buildings.

Choice of the Most Emblematic GBRS

We chose 11 of the most important and globally well-known GBRSs and with which we have the most experience: ASGB, BEAM, BREEAM, CEDES, DNGB, GBI, GG, GS, IGBC, LEED and SBTools [24-35].

Comparative Evaluation Results of Torres-Bio, And Torres-No-Bio

To evaluate the contribution of the bioclimatic design to the general level of sustainability, an evaluation of Torres-bio with respect to Torres-no-bio was carried out using the chosen GBRS. As it is a comparative evaluation, only the indicators whose score is different in each case were taken into account. We will call the set of indicators whose score varies when comparing a bioclimatic building with another that is not a "bio-group".

The evaluation tables first show for both designs:

- The score given to each indicator
- The maximum possible score for each indicator.
- The weight of the indicator within the category to which it belongs.
- The weight of the category
- The conversion factor of the scoring scale of each method, to a scale of 0-100 (since some GBRS score from 0 to 75, others from 0 to 100, others from 0 to 110, others from 0 to 1000. The conversion factors used are therefore: 100/75, 100/100, 100/110, 100/1000).

By multiplying the percentage score of an indicator (score/maximum score) by its weight within the category, by the weight of the category, and by the conversion coefficient, yields a value (from 0 to 100), which represents the contribution of each indicator in the total score. Summing the score of all the indicators of the "bio-group" gives the total score of each group to both Torres-bio and Torres-no-bio. Subtracting the two scores yields the contribution of the bioclimatic design is obtained in the final score provided by each GBRS.

It should be noted that not all systems have a similar structure, so that the structure of the different tables is not the same. But essentially all the tables show the same: the final score of each indicator on a scale from 0 to 100, and the total score .

To describe the evaluation process and the contribution of each indicator in the final evaluation of the building, let us take an example from ASGB (Table 4).

The ASGB indicator "optimized design for natural ventilation (O.D.F.N.V.)" has a maximum score of 8 points. This indicator has a weight of 8/100 within the "Health and comfort (H.C.)" category, and in turn this category has a weight of 10 out of 110 (ASGB has a total evaluation range of 0 to 110).

- In the case of Torres-bio, the maximum score (8) was given to the O.D.F.N.V. indicator, so that the percentage score is $((8/8) = 1)$. By multiplying this value (1) by the weight of the O.D.F.N.V indicator in the H.C. category, a value of $((1) * (8/100))$ is obtained, i.e. 0.08. Multiplying this value by the weight of the H.C. category in the total score gives $(0.08 * (10/100)) = 0.008$, based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is $(0.008 * (100 / 110)) = 0.0073$, i.e. 0.73%.

- In the case of Torres-no-bio, it was given a score of 1 out of a maximum of 8, so the percentage score is, $((1/8) = 0.125)$. Multiplying this value (0.125) by the weight of the O.D.F.N.V indicator in the H.C. category gives a value of $(0.125 * (8/100))$, that is, 0.01. Multiplying this value by the weight of the H.C. category in the total score gives $(0.01 * (10/100)) = 0.001$, percentage based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is $(0.001 * (100 / 110)) = 0.0009$, i.e. 0.09%.

Repeating the process for the 5 indicators for the "bioclimatic design" of a building in ASGB (Table 4), Torres-bio has a score of 5.74%, compared to 3.72% for Torres-no-bio, i.e. according to ASGB, a bioclimatic house like Torres-no-bio has a higher sustainability level of 2 % (5.74 – 3.72) than a conventional building (Table 4).

ASGB Evaluation

Notes: *1 optimized design for natural ventilation, *2 use of devices to regulate shade inside, *3 thermal envelope performance optimization, *4 measures to reduce building energy consumption, *5 measures to further reduce heating system consumption; *6 Health and comfort, *7 Resource conservation; *8 Improvement and innovation, *9 This system does not assign a weight to the indicator, but is determined by the maximum score of the indicator divided by the maximum score of the category.

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category	Score	Max. Score	Indicator weight ^(*)	Category weight	Result (0-110)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	
O.D.F.N.V. ^{(*)1}	H.C. ^{(*)6}	8	8	8/100	10%	0.80	0.73	1	8	8/100	10%	0.10	0.09	
U.O.D.T.R.S. ^{(*)2}	H.C. ^{(*)6}	9	9	9/100	10%	0.90	0.82	1	9	9/100	10%	0.90	0.82	
T.E.P.O. ^{(*)3}	R.C. ^{(*)7}	15	15	15/200	20%	1.50	1.36	12	15	15/200	20%	1.20	1.09	
M.R.B.E.C. ^{(*)4}	R.C. ^{(*)7}	10	10	10/200	20%	1.00	0.91	6	10	10/200	20%	0.60	0.55	
M.F.R.H.S.C. ^{(*)5}	I.I. ^{(*)8}	40	40	40/190	10%	2.11	1.92	25	40	40/190	10%	1.32	1.20	
Partial Score								5.74%						3.74%
Difference														2.00%

Table 4: ASGB Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

ASGB contains 5 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 2 % because ASGB does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and increased health and quality of life).

BEAM Evaluation

Notes: *1 Design for climate change adaptation, *2 Low carbon passive design, *3 reduction of CO² emissions, *4 Peak electricity demand, *5 Enhanced ventilation, *6 indoor vibration; *7 Sustainable Site, *8 Energy use, *9 Health and wellbeing, *10 This system does not assign a weight to the indicator but is determined by the maximum score of the indicator divided by the maximum score of the category.

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category	Score	Max. Score	Indicator weight ^(*)	Category weight	Result (0-110)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	
D.C.C.A. ^{(*)1}	S.S. ^{(*)7}	2	2	2/39	15%	0.77	0.70	1	2	2/39	15%	0.38	0.35	
L.C.P.D. ^{(*)2}	E.U. ^{(*)8}	6	6	6/44	29%	3.94	3.59	2	6	6/44	29%	1.31	1.20	
R.CO ² .E. ^{(*)3}	E.U. ^{(*)8}	15	15	15/44	29%	9.89	8.99	7	15	15/44	29%	4.61	4.20	
P.E.D. ^{(*)4}	E.U. ^{(*)8}	3	3	3/44	29%	1.91	1.79	1	3	3/44	29%	0.66	0.60	
E.V. ^{(*)5}	H.W. ^{(*)9}	4	4	4/29	22%	3.04	2.76	0	4	4/29	22%	0.00	0.00	
I.V. ^{(*)6}	H.W. ^{(*)9}	1	1	1/29	22%	0.75	0.68	0	1	1/29	22%	0.00	0.00	
Partial Score								18.50%						6.34%
Difference														12.17%

Table 5: BEAM Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio

BEAM contains 6 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 12.17 % because BEAM does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design and solar energy).

BREEAM Evaluation

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-110) ^{(*)5}	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	
ENE01 ^{(*)1}	ENE	13	31	41.93%	16%	6.71	6.10	0	31	0%	16%	0	0	
ENE 04 ^{(*)2}	ENE	3	31	9.68%	16%	1.55	1.41	1	31	3.23%	16%	0.52	0.47	
ENE 05 ^{(*)3}	ENE	2	31	6.45%	16%	1.03	0.94	1	31	3.23%	16%	0.52	0.47	
INN ^{(*)4}	INN	5	10	50%	10%	5	4.55	2	10	0.20%	10%	2.00	1.82	
Partial Score								13.00%						2.76%
Difference														10.24%

Table 6: BREEAM Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

BREEAM contains 4 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 10.24 % because BREEAM does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, waste and emissions generated in maintenance and increased health and quality of life).

Evaluation using CEDES

Notes: *1 BD: Bioclimatic Architectural design, *2 SE: Solar Energy, *3 WEM: Waste and emissions generated in building maintenance, *4 HE: Increased health and quality of life of building residents.

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	
2.6	BD(*1)	5	5	45.8%	36%	0.1648	16.48	1	5	45.8%	36%	0.0329	3.29	
3.1	SE(*2)	5	5	60%	13%	0.078	7.8	2	5	60%	13%	0.0156	1.56	
4.5	WEM(*3)	5	5	20%	12%	0.0192	1.92	2	5	20%	12%	0.0048	0.48	
5	HE(*4)	5	5	100%	8%	0.064	6.4	2	5	100%	8%	0.032	3.2	
Partial Score							32.6%							8.53%
Difference														24.07%

Table 7: CEDES Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio And Torres-No-Bio.

CEDES contains 4 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was 24.07 % because CEDES is very complete and considers all the possible aspects and advantages of bioclimatic design.

DNGB Evaluation

Notes: *1 Category is named as Topic on Criteria set of DNGB, *2 This system does not assign a weight to the indicator, but is determined by the maximum score of the indicator divided by the maximum score of the category.

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category (*1)	Score	Max. Score	Indicator weight(*2)	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	
ENV 1.1	ENV	122.5	130	10/24	25%	-	9.82	60	130	10/24	25%	-	4.81	
ENV 1.2	ENV	110	135	5/24	25%	-	4.24	65	135	5/24	25%	-	2.51	
ECO 1.1	ECO	110	130	4/10	25%	-	8.46	47.50	130	4/10	25%	-	3.65	
ECO 2.6	ECO	100	110	2/10	25%	-	4.55	70	110	2/10	25%	-	3.18	
SOC 1.1	SOC	85	105	2/10	25%	-	4.05	45	105	2/10	25%	-	2.14	
SOC 1.2	SOC	105	110	2/10	25%	-	4.77	75	110	2/10	25%	-	3.41	
SOC 1.4	SOC	100	100	2/10	25%	-	5.00	70	100	2/10	25%	-	3.50	
Partial Score							40.89%							23.20%
Difference														17.69%

Table 8: DNGB Indicators Involved in Bioclimatic Design. Score Differences Between Torres-bio and Torres-No-Bio.

DNGB contains 7 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. The score difference for both cases is very high, 17.69 % despite the fact that DNGB does not take into account many basic aspects of bioclimatic design (such as: bioclimatic architectural design, waste and emissions generated in maintenance and increased health and quality of life).

GBI Evaluation

Notes: *1 Energy efficiency, *2 Indoor environment quality, *3 Innovation, *4 External shading devices.

Involved Indicators		Torres-Bio						Torres-No-Bio						
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	
EE3	EE (*1)	5	5	-	-	-	5	3	5	-	-	-	3	
EQ1	IEQ (*2)	2	2	-	-	-	2	1	2	-	-	-	1	
IN1 (*4)	INN (*3)	1	1	-	-	-	1	0	1	-	-	-	0	
Partial Score							8%							4%
Difference														4%

Table 9: GBI Indicators Involved in Bioclimatic Design.

GBI contains 3 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 4% because GBI does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, and waste and emissions generated in maintenance).

GG Evaluation

Notes: *1 Energy Performance, *2 Renewable Sources of Energy.

Involved Indicators		Torres-Bio						Torres-No-Bio					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-1000)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-1000)	Result (0-100)
3.1 EP (*1)	ENERGY	180	180	-	-	180	18	90	260	-	-	90	9
3.4 RSE (*2)	ENERGY	30	30	-	-	30	3	15	260	-	-	15	1.5
Partial Score							21%						10.5%
Difference													10.5%

Table 10: GG Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

GG contains 2 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 10.50 % because GG does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and increased health and quality of life).

GS Evaluation

Notes: *1 Management, *2 Indoor environment quality, *3 Energy, *4 Land use, *5 Emissions, *6 Green star scores up to 100 points and adds 10 for innovation.

Involved Indicators		Torres-Bio						Torres-No-Bio					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
5	MGMt(*1)	2	2	-	-	2	1.82	1	2	-	-	1	0.91
9	IEQ (*2)	4	4	-	-	4	3.64	2	4	-	-	2	1.82
10	IEQ	3	3	-	-	3	2.73	1	3	-	-	1	0.91
13	IEQ	2	2	-	-	2	1.82	1	2	-	-	1	0.91
14	IEQ	2	2	-	-	2	1.82	1	2	-	-	1	0.91
15	ENE (*3)	20	20	-	-	20	18.18	10	20	-	-	10	9.09
16	ENE	2	2	-	-	2	1.82	1	2	-	-	1	0.91
25	LU (*4)	1	1	-	-	1	0.91	0	1	-	-	0	0.00
28	EMI (*5)	1	1	-	-	1	0.91	0	1	-	-	0	0.00
29	EMI	1	1	-	-	1	0.91	0	1	-	-	0	0.00
Partial Score							34.55%						15.45%
Difference													19.09%

Table 11. GS Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

GS contains 10 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. The score difference for both cases is very high, 19.09 %, despite the fact that GS does not take into account some basic aspects of bioclimatic design (such as: bioclimatic architectural design and increased health and quality of life).

IGBC Evaluation

Involved Indicators		Torres-Bio						Torres-No-Bio					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
EE C1	EE	7	10	-	-	7	9.33	6	10	-	-	6	8
IEQ C6	IEQ	4	4	-	-	4	5.33	2	4	-	-	2	2.67
Partial Score							20%						10.67%
Difference													9.33%

Table 12: Indicators of IGBC Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

IGBC contains 2 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 9.33 % because IGBC does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance).

LEED Evaluation

Notes: Indicators of the manual for single-family housing. *1 EAc Annual Energy Use, *2 Energy and Atmosphere

Involved Indicators		Torres-Bio						Torres-No-Bio					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
AEU ⁽¹⁾	EA ⁽²⁾	36	36	-	-	36	32.72	27	36	-	-	27	24.54
Partial Score							32.72%						24.54%
Difference													8.18%

Table 13: LEED Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

LEED is the most limited GBRS when assessing bioclimatic design since it contains only 1 bioclimatic design indicator, which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 8.18 % because LEED does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and increased health and quality of life.).

SB Tools Evaluation

Notes: *1 Urban, site and infrastructure systems, *2 Energy and Resource Consumption, *3 Indoor Environmental Quality

The system score involves multiplying the project score by the indicator weight divided by the maximum score.

Involved Indicators		Torres-Bio						Torres-No-Bio					
Indicators	Category	Score	Max. Score	Indicator weight ^(*)	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)
A 2.3	USIS ⁽¹⁾	5	5	1.62%	-	-	1.62	0	5	1.62%	-	-	0
A 2.5	USIS	5	5	0.81%	-	-	0.81	0	5	0.81%	-	-	0
A 2.6	USIS	5	5	0.20%	-	-	0.20	0	5	0.20%	-	-	0
B 2	ERC ⁽²⁾	5	5	1.60%	-	-	1.60	0	5	1.60%	-	-	0
D 1.6	IEQ ⁽³⁾	5	5	0.20%	-	-	0.20	0	5	0.20%	-	-	0
D 1.7	IEQ	5	5	0.20%	-	-	0.20	0	5	0.20%	-	-	0
D 1.8	IEQ	5	5	0.10%	-	-	0.10	0	5	0.10%	-	-	0
D 1.9	IEQ	0	5	0.10%	-	-	0	3	5	0.10%	-	-	0.06
D 1.10	IEQ	0	5	0.10%	-	-	0	3	5	0.10%	-	-	0.06
D 2.1	IEQ	0	5	0.05%	-	-	0	5	5	0.05%	-	-	0.05
D 2.2	IEQ	5	5	0.05%	-	-	0.05	3	5	0.05%	-	-	0.03
D 3.1	IEQ	5	5	0.10%	-	-	0.10	3	5	0.10%	-	-	0.06
D 3.2	IEQ	5	5	0.05%	-	-	0.05	0	5	0.05%	-	-	0
D 3.3	IEQ	5	5	0.05%	-	-	0.05	5	5	0.05%	-	-	0.05
D 4.1	IEQ	5	5	0.10%	-	-	0.10	3	5	0.10%	-	-	0.06
D 4.2	IEQ	5	5	0.10%	-	-	0.10	3	5	0.10%	-	-	0.06
D 4.3	IEQ	5	5	0.10%	-	-	0.10	3	5	0.10%	-	-	0.06
D 4.4	IEQ	5	5	0.10%	-	-	0.10	3	5	0.10%	-	-	0.06
Partial Score							5.38%						0.55%
Difference													4.83%

Table 14: SBTools Indicators Involved in Bioclimatic Design. Score Differences Between Torres-Bio and Torres-No-Bio.

SBTools contains 18 bioclimatic design indicators, each of which gave different scores when evaluating Torres-bio, and Torres-no-bio. This difference in both cases was only 4.83 % because SBTools does not consider many important aspects of bioclimatic design (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance).

Results

The contribution of the bioclimatic design for the Torres house, as measured by the eleven GBRS considered, are as follows: ASGB (2%), BEAM (12.17%), BREEAM (10.24%), CEDES (24.07%), DNGB (17.69%), GBI (4%), GG (10.5%), GS (19.09%), IGBC (9.33%), LEED (8.18%), and SBTools (4.83%) (Table 15).

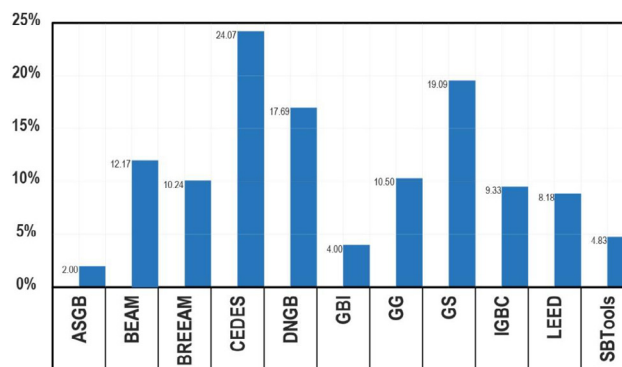


Table 15: Contribution of Bioclimatic Design to a Building's Sustainability Level, using 11 GBRS

Discussion

This study aims to quantify the contribution of bioclimatic design to the sustainability level of buildings. To this end, a bioclimatic house was evaluated and compared with a non-bioclimatic one. The evaluation was carried out using 11 of the most representative international GBRS.

The Torres house has a very special bioclimatic design, so it does not require heating or air conditioning to ensure thermal habitability inside. Therefore, the evaluation corresponds to a house with a high bioclimatic level. If houses with a lower bioclimatic level (which partially require energy-consuming appliances) were evaluated, the scores of the different GBRS would be lower.

All GBRS have assessed the contribution of deep bioclimatic design to the sustainable level of Torres house, but their evaluations show a wide disparity. Three GBRS (CEDES, DNGB and GS) have adequately assessed the contribution of bioclimatic design to the sustainable level of buildings, but the rest have undervalued it, and three of them have barely rated it at all (ASGB, GB, and SBTools), despite the obvious environmental and sustainable advantages of the Torres house bioclimatic design. It is certainly unacceptable for a building to have a sustainable level to depend on the GBRS used, which calls into question the validity and usefulness of most existing GBRS.

In fact, several studies have doubted the usefulness of GBRS [17]. Some studies concluded that GBRS do not evaluate correctly since they do not consider architectural design in their scoring system [36-41]. Some works go further, and harshly criticize all the existing GBRS, suggesting that they should all be unified and completed, and to do so the concept of "sustainability" should be agreed upon and more comparative critiques are needed [42]. Other works conclude that current GBRS are not useful, since when comparing buildings certified by some of these GBRS with conventional buildings, there are neither substantial energy savings nor resource optimization [22,39,43,44]. Therefore, they indicate that it is not worth investing time and money in GBRS, since they do not guarantee a sustainable building and only provide a certificate that does not imply any environmental improvement. Furthermore, there are more and more works that strongly criticize the usefulness of some of the best-known GBRS, such as LEED. These works show that LEED-certified buildings consume relatively more electricity than other buildings and demonstrate that there are no energy savings [12,42-48]. Many professionals contend that LEED not only lacks utility but also causes significant harm to the construction sector and its practitioners, with some even pursuing legal action against it [49].

The disparity of results obtained in this study, and the fact that most of the GBRS used have given so little value to bioclimatic design, despite its great and evident environmental benefits, calls into question the validity and usefulness of the GBRS used.

The GBRS used have a different internal structure, different scoring scales, different weights of categories in indicators, etc. This reflects the fact that they have been designed under different concepts of sustainability and therefore may be heavily influenced by commercial and political interests, far removed from ecology and true sustainability. This calls into question their validity [50].

Undoubtedly, the current GBRS must be improved. To achieve this, the concept of sustainability must be agreed upon internationally, and a conceptual framework must be proposed for the development of new, more appropriate GBRS that address the shortcomings of the current GBRS. In fact, there are already proposals for new, more valid and legitimate GBRS that can serve as a reference framework for developing new GBRS at the international level [28].

Conclusions and Future Works

The purpose of this study was to quantify the contribution of bioclimatic design to a building's sustainability. To this end, a bioclimatic house, Torres eco-house, and a non-bioclimatic baseline reference house were evaluated and compared. Both were evaluated using 11 of the most important and representative international GBRS.

All GBRSs found that bioclimatic design increases the sustainability of buildings. However, a disparity in the results was found. Three GBRSs considerably and adequately assessed the contribution of Torres house's bioclimatic design (CEDES, DNGB, and GS). However, the others rated it very poorly, and three of them barely rated it at all (ASGB, GBI, and SBTools), despite the obvious environmental benefits of Torres house's bioclimatic design.

Taking into account the average results of the 11 GBRSs, the contribution of bioclimatic design to the sustainability level is 11.1%. However, if the average results of the 3 highest-scoring GBRS are taken into account, the contribution of bioclimatic design to the buildings' sustainability level is 20.28%.

Therefore, to confirm the results obtained, it is necessary to conduct similar work, evaluating bioclimatic buildings with both the 11 GBRS used and with other GBRS.

Data Availability Statement (DAS)

The data that support the findings of this study are available from the corresponding author (De Garrido, Luis), upon reasonable request.

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