



VITROHOUSE. A Demountable House Built Entirely with Flat Glass. Technical, Bioclimatic, and Sustainable Analysis

Luis De Garrido

*PhD Architect, PhD in Fine Arts, PhD in Neuroscienc, PhD Computer Science Engineering, Spain
PhD in History of Art, PhD Building Engineering. Polytechnic University of Valencia, Spain
PhD. student Aerospacial Engineering, Polytechnic University of Madrid, Spain*

Citation: Luis De Garrido (2025) VITROHOUSE. A Demountable House Built Entirely with Flat Glass. Technical, Bioclimatic, and Sustainable Analysis. J. of Sci Eng Advances 1(4) 1-33. WMJ/JSEA-106

Abstract

This study shows a technical, bioclimatic, and sustainable analysis of the first demountable house built entirely from glass components, Vitrohouse. The technical analysis details the construction challenges overcome to create a demountable house using only flat glass for all components (foundations, slabs, supporting structure, beams, roof, envelope, furnishings, kitchen fixtures, appliances). Secondly, we analyze the thermal and bioclimatic behavior of this demountable all-glass house to evaluate its energy efficiency. We also assess the contribution of Vitrohouse's bioclimatic design to its sustainability level, using 11 of the most internationally recognized Green Building Rating Systems (GBRS), demonstrating that it achieves a higher degree of sustainability than a conventional, non-bioclimatic home of the same size. Thirdly, we analyze the contribution of Vitrohouse's demountable nature, showing that it has a higher level of sustainability than a conventionally built house. Finally, the sustainable analysis of its demountability is quantified using 11 GBRS. The results show that it is perfectly feasible to construct buildings solely from flat glass, achieving high energy efficiency and sustainability. Furthermore, the glass components can be easily disassembled and reused, or recycled to manufacture new components with minimal energy consumption.

***Corresponding author:** Luis De Garrido, PhD Architect, PhD in Fine Arts, PhD in Neuroscienc, PhD Computer Science Engineering, Spain.

Submitted: 14.10.2025

Accepted: 20.10.2025

Published: 27.10.2025

Keywords: Flat Glass Construction, House Made with Glass, Bioclimatic Design, Sustainable Assessment, Demountable Construction, Green Building Rating System

Introduction

This study explores the potential of constructing buildings entirely from flat glass. To this end, we analyze the first house built solely with this material, Vitrohouse. Specifically, we examine the key construction challenges that were overcome, its bioclimatic behavior and its overall level of sustainability.

While there is vast literature on the use of flat glass in construction, no studies focus on buildings made exclusively from it. Similarly, the advantages of bioclimatic design -such reduced energy consumption, emissions, and waste, alongside improved quality of life and occupant health -are well documented. However, most studies focus on a single comparative variable, such as energy consumption. There are very few studies evaluating bioclimatic design with various GBRS, and the literature lacks references to bioclimatic buildings made entirely with glass, as they are often assumed to perform poorly (e.g., lower insulation, less solar protection, greater overall warming due to the greenhouse effect, etc.) [1-21].

Likewise, demountable construction has been extensively studied, with many references highlighting its environmental and sustainability advantages, but there are very few studies evaluating bioclimatic design with various GBRS [22-41].

However, there are no references to demountable buildings made solely of glass, nor are there quantitative analyses of how demountability contributes to the sustainability of glass buildings.

To evaluate the overall level of sustainability of buildings, multivariate assessment tools, called GBRS (Green Building Rating Systems) have been developed. GBRS use multiple indicators, (energy, resources, emissions, waste, etc.), to provide a final score on sustainability. However, these tools have not previously been used to quantify the sustainable level of demountable construction.

Therefore, this study analyzed Vitrohouse from three perspectives: Section 2 describes the house and analyzes the innovative technical and construction solutions. Section 3 studies the bioclimatic strategies and quantifies the sustainability level achieved through bioclimatic design. Section 4 quantifies the level of sustainability achieved by its demountable design, which allows for the easy repair, reuse and recycling of its components.

Technical Analysis of Vitrohouse

Vitrohouse. General Information

Vitrohouse is a house with a surface area of 126 m², and consisting of a living-dining room, a kitchen, two bathrooms, two bedrooms, a central patio and two machine rooms. (Figure. 1-5). Vitrohouse was built in 2005 and can be assembled and disassembled as many times as desired. In fact, since its construction it has been disassembled and reassembled twice [42,43].

The most important feature of Vitrohouse is that it was built entirely with flat glass: foundations, walls, pillars, beams, enclosures, kitchen furniture, toilets, floors, roofs, plumbing, etc. Vitrohouse was built to demonstrate that fully disassemblable buildings can be constructed without mortar, adhesives, screws, rivets, etc., simply by fitting the pieces together with an elaborate design. Therefore, the most difficult material possible was chosen: glass. And it was demonstrated that a demountable glass building can be constructed, capable of withstanding all exterior stresses and any habitability requirements. Undoubtedly it was a technological challenge undertaken with the desire to promote the industrialization and complete demountability of buildings.



Figure 1: Vitrohouse Was Built Using Only Removable Components Made of Flat Glass (Project by Luis De Garrido)

Since glass is transparent, several strategies have been used to ensure the privacy of its occupants, to protect them from solar radiation, and to ensure proper thermal insulation.

To ensure privacy and solar protection, three strategies have been implemented:

- Use of glass whose transparency can be adjusted using a small electric current
- Use of several layers of colored glass
- Adjustable blinds have been installed between the layers of flat glass.

To ensure thermal insulation, three layers of glass have been arranged in the envelope, creating two air chambers. The inner chamber is airtight, and the outer is ventilated.



Figure 2: Vitrohouse is an Energy-Self-Sufficient Home that Integrates Fresh Air-Capturing Chimneys, Solar Thermal Collectors, and Photovoltaic Solar Collectors (Project by Luis De Garrido)



Figure 3: Vitrohouse Integrates Green Roofs, Water Roofs, and Vertical Gardens Despite Being Built with Glass



Figure 4: The Central Roof of Vitrohouse Is Composed of Two Layers of Flat Glass and Integrates Solar Panels on Its Exterior, Which in Turn Provide Thermal Insulation and Solar Protection to The Interior

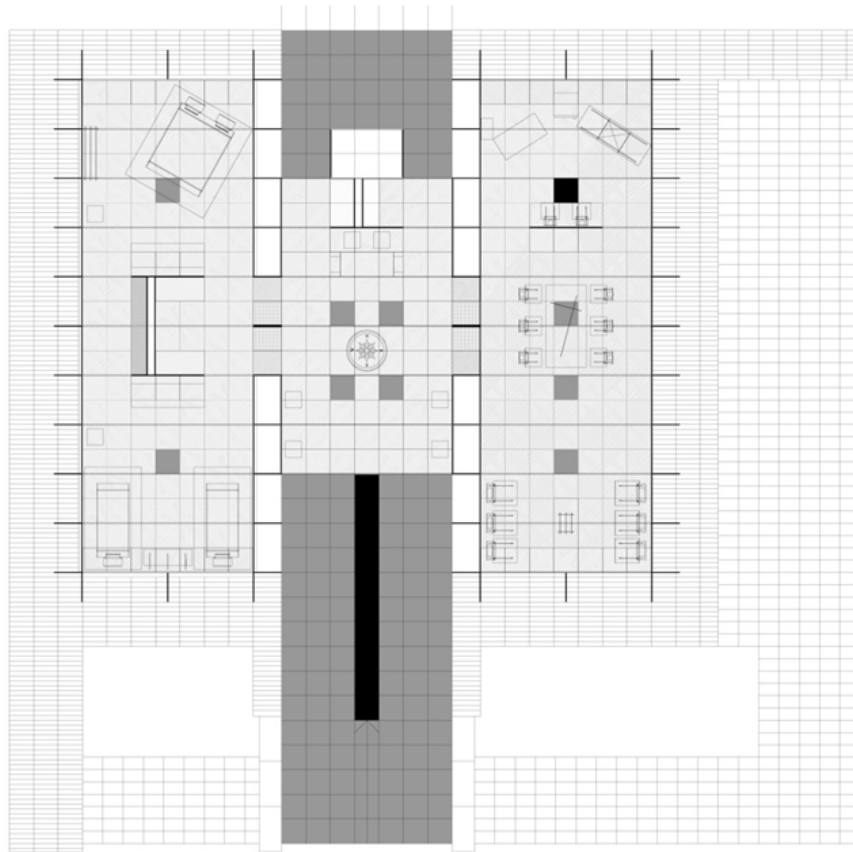


Figure 5: Vitrohouse Ground Floor Layout



Figure 6: Vitrohouse was Built in Barcelona and has been Dismantled and Reassembled Twice

Demountable Design with Flat Glass Componentes

Vitrohouse is built using flat glass components assembled without adhesives or screws, simply by fitting together (Figures. 6-10). The structure of Vitrohouse is composed of flat glass porticos. Each glass portico consists of two groups of three laminated flat glass pillars 25 mm thick (8 + 8 + 8) and 70 cm wide on each side, and a laminated flat glass beam, also 25 mm thick (8 + 8 + 8) and 70 cm wide. The beams are joined to each group of three pillars by a simple and ingenious metal profile (Figure. 11). This small profile holds the three flat glass pillars together at the top and also serves as a support for the flat glass beams. The laminated flat glass pillars are also supported at the bottom by the laminated glass panels that serve as their foundation. The laminated glass beams have small sheets of laminated flat glass on their upper parts (8+8+8), which in turn support horizontal panels of laminated flat glass (6+6+6) (Figure. 12). These panels slope along the perimeter of the house, forming a container to house the soil for the roof garden (Figure. 12, 13). As a result of this articulated and assembled arrangement of laminated flat glass panels, all Vitrohouse components can be easily removed, repaired, and reused indefinitely. In this way the building can have a durability that tends to infinity and the least possible need for maintenance.



Figure 7: Vitrohouse's architectural envelopes are highly varied and include a triple glass skin with two air chambers: a sealed inner chamber and a ventilated outer chamber. The outer chamber includes blinds that regulate sunlight from zero to 100%



Figure 8: The Left Side of Vitrohouse Incorporates Glass whose Opacity Changes Through Small Electric Currents, Regulating Privacy and Solar Protection



Figure 9: The Right side of Vitrohouse is Completely Transparent, and Thermal Insulation is Achieved by Injecting Hot or Cold air into the Triple Skin of the Architectural Envelope. The air is Drawn in from Inside the House as it is Renovated

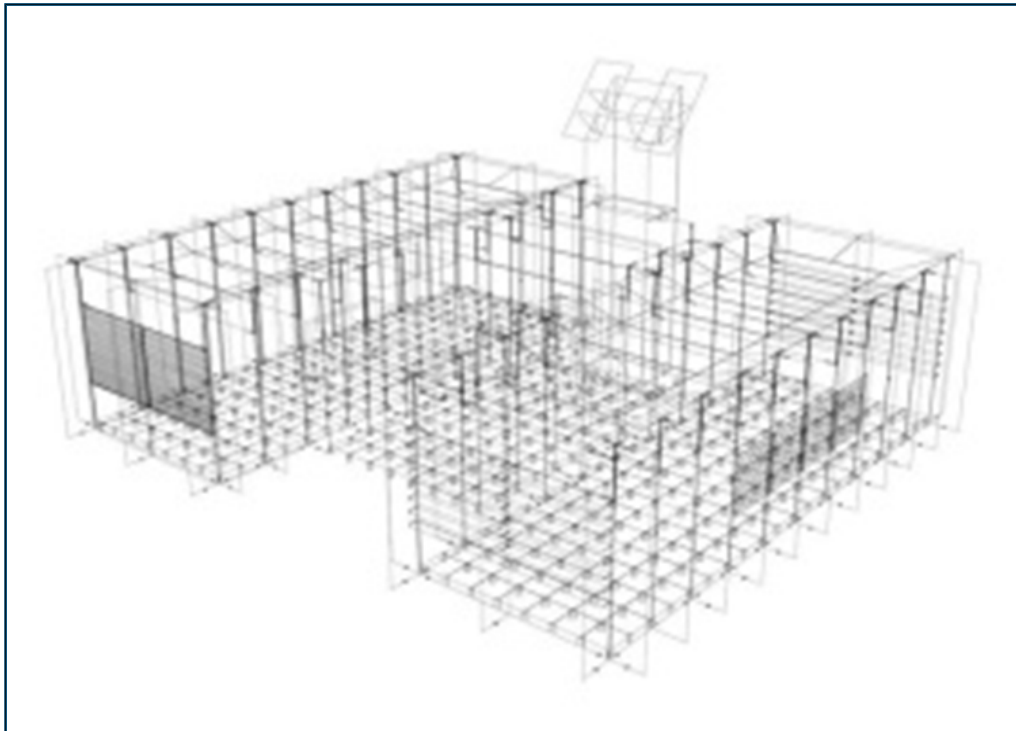


Figure 10: Exploded view of all Vitrohouse's Removable Components. All have been Joined Together without Adhesives, Screws, or any other Mechanical Means

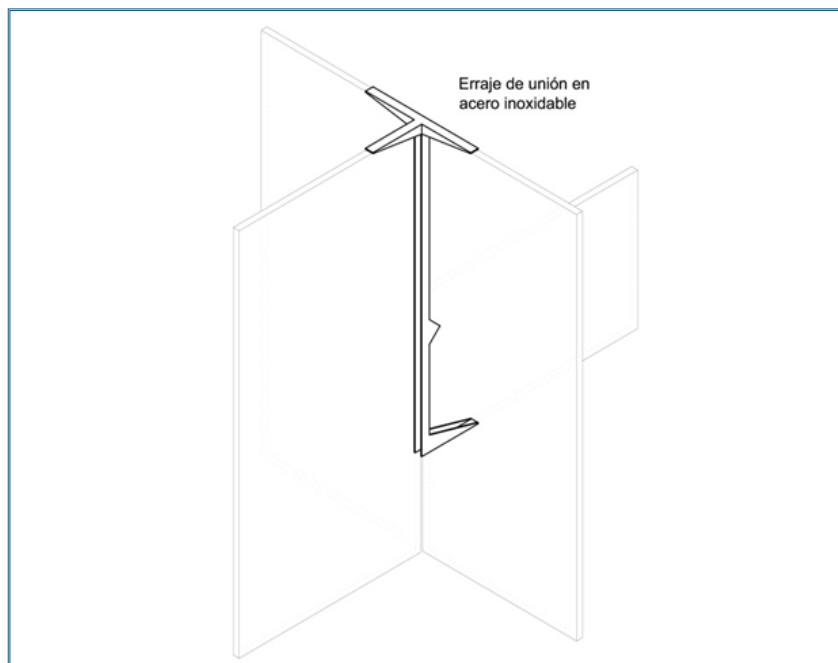


Figure 11: This special profile is the only Vitrohouse element not made of glass. It holds three flat glass pillars together with a flat glass beam without the use of glue, screws, or any other fastening method

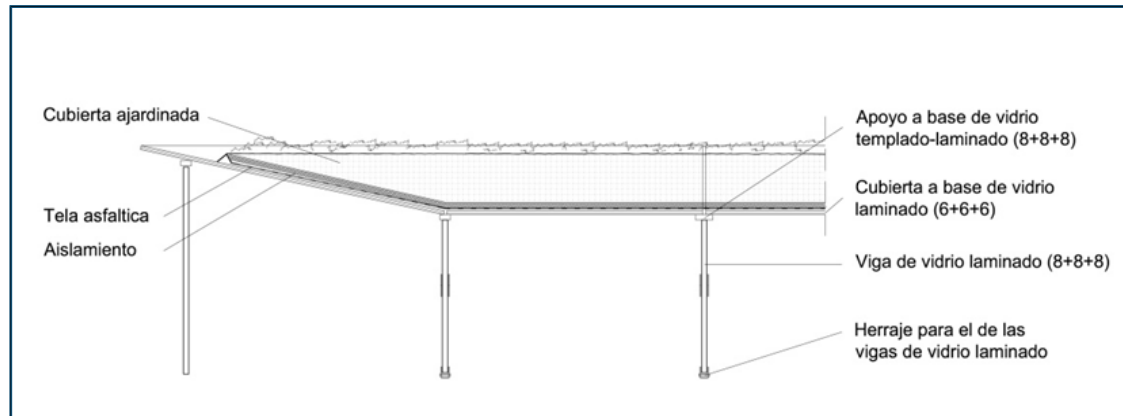


Figure 12: Detail of the Vitrohouse green roof

Vitrohouse is composed of flat laminated glass porticos assembled together, creating an articulated spatial grid capable of absorbing all types of external stresses and remaining stable everitime. The most complicated structural element to construct was the wind catcher, as it was constructed from laminated glass panels resting on their perimeter edges, one on top of the other, and in turn had to support the weight of the solar thermal collectors.

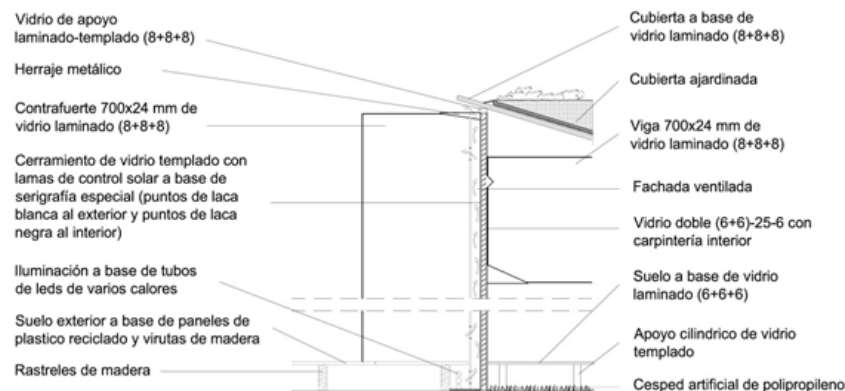


Figure 13: Detail of the junction of the architectural envelope with the green roof. The two insulating chambers can be seen: the ventilated outer chamber and the sealed inner chamber with adjustable sunshades
Interior Design and Removable Glass Furniture

The furniture and all the interior elements of the home are also made of flat glass. All the furniture has been designed solely from pieces of flat glass assembled together, without using any connecting elements. The furniture is sturdy and stable, yet can be easily disassembled (Figure: 14-18).



Figure 14: Wall-hung glass toilet. Faceted glass walls



Figure 15: Glass Floors, Walls and Sinks



Figure 16: Glass Overlay on Natural Grass. Flat glass Beds and Furniture

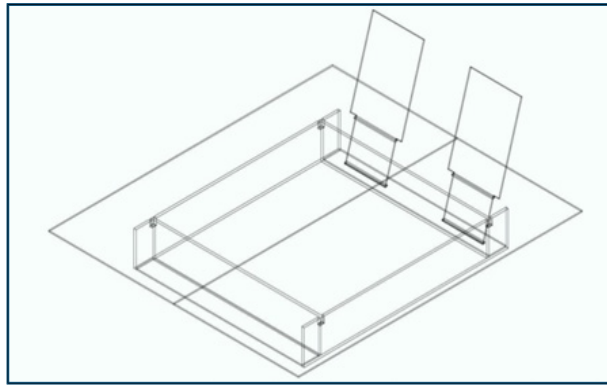


Figure 17: Glass Bed made with only 8 Pieces of Flat Glass Assembled by Pressure, without Glue or Screws

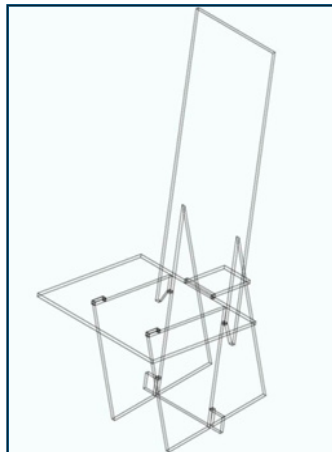


Figure 18: Glass Chair made with only 4 Pieces of Flat Glass Assembled by Pressure, without Glue or Screws

Research and Testing on the Strength of Flat Glass

There is no precedent for using flat glass as a structural element in foundations, pillars, beams, etc. Therefore, a large number of laboratory tests were conducted to determine the strength characteristics of flat glass. Multiple load tests were also performed to verify the resistance of the designed porticos to different combinations of external loads. A safety factor of 2.33 was also used (Figure. 19).

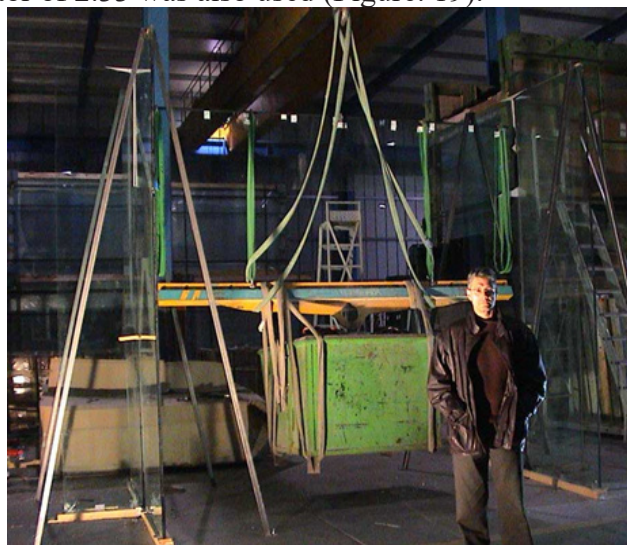


Figure 19: Load testing of one of the glass frames. The glass beam and pillars withstood point loads of 7,000 kg on several occasions. The maximum load the frame can withstand in the building is 3,000 kg, so the safety factor adopted is 2.33 (Luis de Garrido in front of the load test, confident in his calculations. The rest of the workers barricaded themselves behind protective barriers)

Vitrohouse's Sustainable Features

Vitrohouse meets high ecological and sustainable standards [42, 43], including the following:

Resource Optimization

Optimization of industrialized manufacturing
Ease of repair and reuse
Easy disassembly
Ease of recycling

Energy Consumption

Bioclimatic design, despite being built with glass
Energy self-sufficiency

Waste and Emissions Generation

Zero waste or emissions generation

Price

Market price
Very fast construction

Health and well-being

No emissions, noise, vibrations, unpleasant odors, nothing that affects health and well-being
Technical safety in construction

Maintenance

Minimal maintenance

Adaptability to New Uses and Easy Reconfiguration of the Building

However, the two most important features of Vitrohouse are its bioclimatic design and the fact that it is a demountable building, despite it was built only with flat glass. Therefore, the contribution of Vitrohouse's bioclimatic design to its overall sustainable level is quantified below, and the contribution that detachability provides to Vitrohouse's sustainable level is likewise quantified.

Bioclimatic Analysis of Vitrohouse

This section analyzes its overall thermodynamic and bioclimatic behavior and quantifies the contribution of bioclimatic design to Vitrohouse's overall sustainability.

It might seem that a building made entirely of glass would become excessively hot in the summer and too cold in the winter, but this is not the case.

Vitrohouse's architectural envelope features a triple glass skin (with two air chambers), and in some places a quadruple glass skin (with three air chambers), which provide the necessary insulation and adequate solar protection. Furthermore, the highly insulated green roofs with high thermal inertia provide significant solar protection.

Bioclimatic Design

In this study, bioclimatic design is defined as the ability to maintain a comfortable and constant indoor temperature (19-25°C) without the need for heating or air conditioning. Achieving this requires good professional skills, although in extreme climates, heating may occasionally be necessary. The energy savings of bioclimatic design are often measured as the "bioclimatic level".

Description of the Bioclimatic House: Vitrohouse Heat Generation Due to Bioclimatic Design

The house heats itself in winter thanks to several special design features (Fig. 20), including:

- North-south orientation
- Most windows on the south facade
- High thermal inertia inside the enclosure
- Adequate insulation on the exterior of the enclosure
- Adequate greenhouse effect that generates the necessary thermal energy
- Solar shading allows maximum solar radiation in winter
- Main rooms facing south and service rooms facing north

The windows located on the east, west and south side of the house (with a surface area of approximately 45 m²) generate an average of 13,500 W of heating in winter (as approximately 300 W/m² passes through the glass). The house's occupants and the energy losses from the refrigerator and other appliances provide an additional 1,500 W of heating. In other words, the house is capable of generating around 15,000 W of thermal power, enough to heat its main rooms (it is estimated that the entire house has a need of 14,210 W). Vitrohouse thus maintains an interior temperature of 22 °C in winter and does not need heating appliances.

Cold Generation Due to Bioclimatic Design

The house cools itself in summer thanks to several special design features (Figure. 21), including:

- North-south orientation
- High thermal inertia inside the enclosure
- Adequate insulation on the exterior of the enclosure
- Cooling generation in underground galleries
- Cooling generation through optimized interior nighttime ventilation
- Solar shading minimizes solar radiation into the building in summer
- Served spaces to the south and auxiliary service spaces to the north

In addition, Vitrohouse has underfloor cooling powered by a small geothermal heat pump powered by photovoltaic panels. The photovoltaic panels have a power of 7,000 W, 3,000 W for the needs of the house and 4,000 W for the geothermal heat pump.

Energy Consumption of Vitrohouse

Thanks to the bioclimatic design, the house does not require heating, air conditioning, or mechanical ventilation. Since the owners are committed to minimizing energy consumption, the house has very few appliances, with a total power of 3,406 W (Table 1) and an annual consumption of 43.37 kWh/m² (Table 2).

Fridge	75 W (average power)
Induction hob	900 W
Microwave	200 W
Washing machine	800 W
TV	150 W
PCs	100 W
Lighting	196 W
Water purification	985 W
Total power: 3.406 W	

Table 1: Total Power of the Appliances in Vitrohouse

Surface 126 m ²	Power	active time	energy per year	energy year/m ²
	W (watts)	(hours)	(kwh/year)	(kwh/m ² /year)
Fridge (average power)	75	24 h. * 365	657	5.21
Induction hob	900	2 h. * 365	657	5.21
Microwave	200	1 h. * 365	73	0.57
Washing machine	800	1 h. * 365	292	2.31
TV	150	8 h. * 365	438	3.47
PC's	100	8 h. * 365	292	2.07
Lighting	196	8 h. * 365	572.3	4.54
Water purification	985	1 h. * 365	359.5	2.85
Cooling devices	2.000	6 h. * 180	2,160	17.14
Total energy consumed per m ² : 43.37 kwh/m ² /year				

Table 2: Total Energy Consumption per m² of Vitrohouse

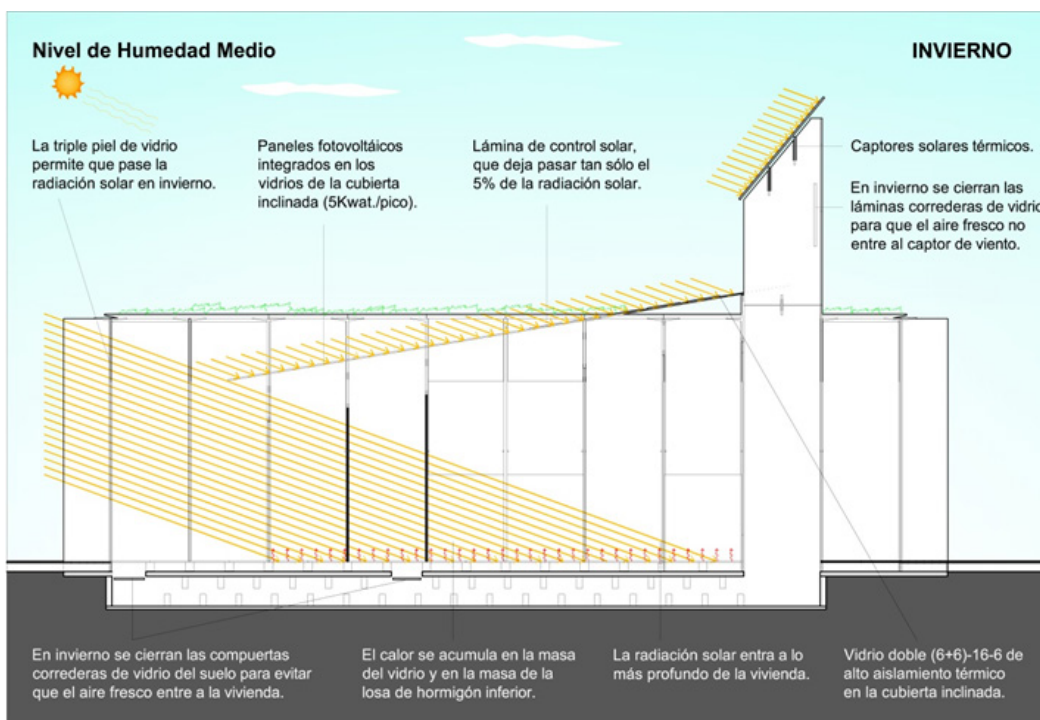


Figure 20: Bioclimatic behavior of Vitrohouse in winter

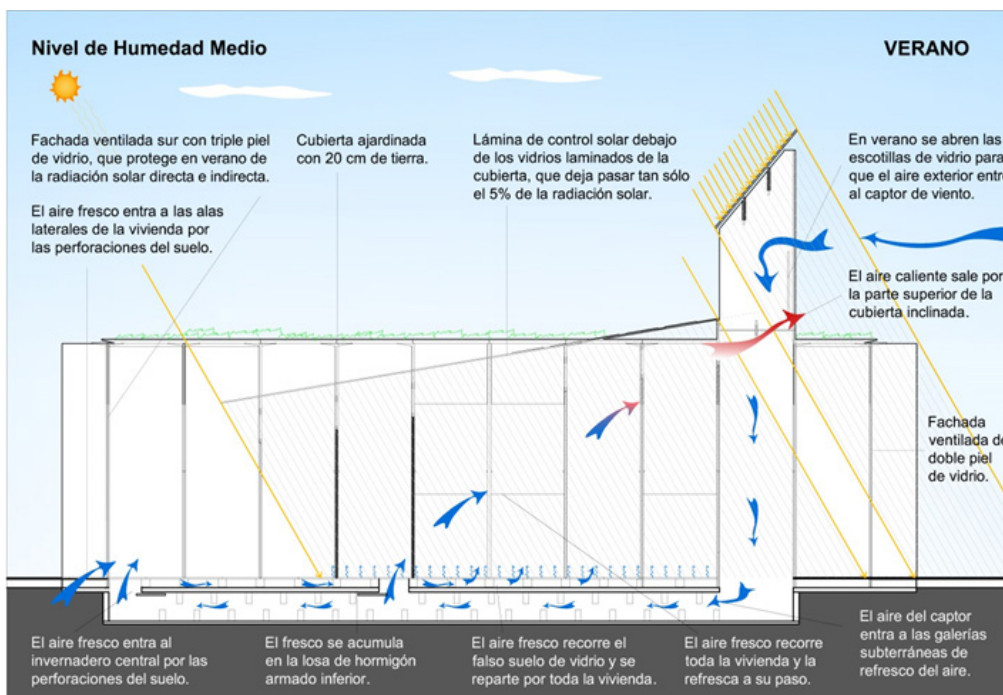


Figure 21: Bioclimatic behavior of Vitrohouse in summer

Description of the no-Bioclimatic House: Vitrohouse-no-Bio

To measure the differential score that each Green Building Rating System (GBRS) system gives to bioclimatic design, the Vitrohouse sustainability score was compared to that given to a reference baseline: a no-bioclimatic house with the same characteristics, known as Vitrohouse-no-bio. It was assumed that the Vitrohouse-no-bio house has the same shape and characteristics as the Vitrohouse, but has not a bioclimatic design. Therefore, the remaining characteristics are not important.

In Barcelona, the average power required for heating and air conditioning systems is at least 70 W/m², although systems are typically sized with an average power of 90 W/m². Therefore, the Vitrohouse-no-bio house should incorporate a heating and air conditioning system with a minimum power of 8,820 W (126 m² * 70 W/m² = 8,820 W). In this way, the total power of Vitrohouse-no-bio devices would be at least 12,226 W (8,820 W + 3,406 W) (Table 1), and their energy consumption (per m²) would be 77.65 kWh/m²/year (Table 3).

	Power	active time	energy year	energy year/m ²
	W (watts)	(hours)	(kwh-year)	(kwh/m2/year)
Fridge (average power)	75	24 h. * 365	657	5.21
Induction hob	900	2 h. * 365	657	5.21
Microwave	200	1 h. * 365	73	0.57
Washing machine	800	1 h. * 365	292	2.31
TV	150	8 h. * 365	438	3.47
PC's	100	8 h. * 365	292	2.07
Lighting	196	8 h. * 365	572.3	4.54
Water purification	985	1 h. * 365	359.5	2.85
Heating / cooling (soft temp.)	2.000	12 h. * 90	2,160	17.14
Heating / cooling (hard temp.)	4.000	12 h. * 90	4,320	34.28
Total energy consumed per m2: 77.65 kwh/m ² /year				

Table 3: Total Energy Consumption per m2 Vitrohouse-no-bio.

Therefore, Vitrohouse consumes only 55.85% of the consumption of Vitrohouse-no-bio (43.37 kWh/m²/year / 77.65 kWh/m²/year = 55.85%), so the bioclimatic design of Vitrohouse has generated a minimum energy saving of 44.15%.

Comparative Evaluation of Vitrohouse and Vitrohouse-no-Bio

The evaluation of Vitrohouse, and Vitrohouse-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. The 11 GBRS chosen for the evaluation are among the 16 most important and internationally representative ones [44].

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 [45], BEAM [46], BREEAM [47], CEDES [48, 49], DNGB [50], GBI [51], GG [52], GS [53], IGBC [54], LEED [55] and SBTools [56].

Comparative Evaluation Results of Vitrohouse, and Vitrohouse-no-Bio

To evaluate the contribution of the bioclimatic design to the general level of sustainability, an evaluation of Vitrohouse with respect to Vitrohouse-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, a value is obtained (from 0 to 100), which is the contribution of each indicator in the total score. Adding the score of all the indicators of the “bio-group” gives the total score of each group to both Vitrohouse and Vitrohouse-no-bio. By subtracting both scores, 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 Vitrohouse, 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 Vitrohouse-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), Vitrohouse has a score of 5.74%, compared to 3.72% for Vitrohouse-no-bio, i.e. according to ASGB, a bioclimatic house like Vitrohouse-no-bio has a higher sustainability level of 2 % (5.74 - 3.72) than a conventional building (Table 4).

ASGB Evaluation

Involved Indicators		Vitrohouse						Vitrohouse-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.L. ^{(*)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%							

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.

Table 4: ASGB Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-bio.

ASGB contains 5 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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%							

Notes: *1 Design for climate change adaptation, *2 Low carbon passive design, *3 rReduction 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.

Table 5: BEAM Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio

BEAM contains 6 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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		Vitrohouse						Vitrohouse-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 Vitrohouse and Vitrohouse-no-Bio.

BREEAM contains 4 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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).

CEDES Evaluation

Involved Indicators		Vitrohouse						Vitrohouse-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%	

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.

Table 7: CEDES Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-bio.

CEDES contains 4 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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%

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.

Table 8: DNGB Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

DNGB contains 7 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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%

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

Table 9: GBI Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

GBI contains 3 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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%							
Difference								10.5%							

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

Table 10: GG Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

GG contains 2 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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	MGM(*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%							
Difference								19.09%							

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.

Table 11: GS Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

GS contains 10 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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		Vitrohouse						Vitrohouse-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%						
Difference								10.67%					
								9.33%					

Table 12: INDICATORS of IGBC Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

IGBC contains 2 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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

Involved Indicators		Vitrohouse						Vitrohouse-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%						
Difference								24.54%					
								8.18%					

Notes: Indicators of the manual for single-family housing

*1 EAc Annual Energy Use

*2 Energy and Atmosphere

Table 13: LEED Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-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 Vitrohouse, and Vitrohouse-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.).

SBTools evaluation

Involved Indicators		Vitrohouse						Vitrohouse-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%

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.

Table 14: SBTools Indicators Involved in Bioclimatic Design. Score differences between Vitrohouse and Vitrohouse-no-Bio.

SBTools contains 18 bioclimatic design indicators, each of which gave different scores when evaluating Vitrohouse, and Vitrohouse-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 of Vitrohouse to its sustainable level, 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).

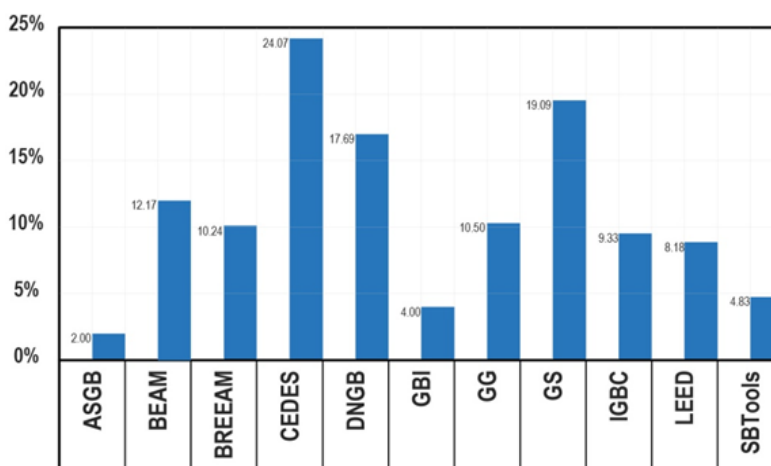


Table 15: Contribution of Bioclimatic Design to a Building's Sustainability Level, using 11 GBRS

Therefore, all GBRS detected that Vitrohouse, due to its good bioclimatic design, despite being built solely with glass, has a higher sustainability level than a conventional home of the same size.

Taking into account the average scores of the 11 GBRS, the contribution of the bioclimatic design to the level of sustainability of Vitrohouse is 10.28% $((2.00 + 12.17 + 10.24 + 24.07 + 17.69 + 4.00 + 10.50 + 19.09 + 9.33 + 8.18 + 4.83) / 11 = 10.28)$.

However, if only CEDES, DNGB and GS are taken into account, the contribution of bioclimatic design of Vitrohouse to the level of sustainability of buildings is 13.91% $((24.07 + 17.69 + 19.09) / 3 = 20.28)$.

Contribution of Demountability to Vitrohouse's Sustainable Level

To accurately quantify the contribution of flat glass demountable construction to its sustainable level, Vitrohouse was compared with a baseline: its non-demountable hypothetical version, called ND-Vitrohouse.

The evaluation was conducted using the 11 GBRS following the same assessment process described in the previous section. To simplify the study, only those indicators whose scores varied from one household to another are shown in the comparison. The remaining indicators are not taken into account because they would give the same score to one building as another. Therefore, only indicators related to demountability (those whose scores vary depending on whether a building is demountable or not) have been included in the evaluation tables.

Comparative Evaluation Methodology

To evaluate the contribution of demountable construction to its general level of sustainability, Vitrohouse was compared with ND-Vitrohouse using the eleven GBRS, considering only the indicators with different scores in each case, creating a comparative table for each GBRS. The set of indicators whose score varies when comparing a demountable with a non-demountable building is referred to as a "demountable group".

Comparative Evaluation Results of Vitrohouse, and Vitrohouse-no-Bio ASGB Evaluation

Demountable group		Vitrohouse						ND-Vitrohouse						
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)	
BA (*1)	SD (*6)	18	18	18/100	10%	1.80	1.64%	12	18	18/100	10%	1.20	1.09%	
LULC (*2)	SD	10	10	10/100	10%	1.00	0.91%	6	10	10/100	10%	0.60	0.55%	
IIDP (*3)	RC (*7)	8	8	8/200	20%	0.80	0.73%	4	8	8/200	20%	0.40	0.36%	
URRWM (*4)	RC	12	12	12/200	20%	1.20	1.09%	6	12	12/200	20%	0.60	0.55%	
SSIC (*5)	II (*8)	10	10	10/190	10%	0.53	0.48%	5	10	10/190	10%	0.27	0.24%	
Partial Score							4.85%							2.79%
Difference														2.06%

Notes: ASGB provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110

(*1) Building adaptability, (*2) Longer useful life of components, (*3) Industrialized interior design parts, (*4) Use of recyclable, reusable and waste materials, (*5) Structural system and industrialized components, (*6) Security and durability, (*7) Resource conservation, (*8) Improvement and innovation

Table 16: ASGB Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

ASGB has 5 indicators involved in demountable construction and therefore, their scores vary in the evaluation of Vitrohouse, and ND-Vitrohouse. The score difference for both cases is only 2.06 % because ASGB does not consider many important factors such as: Economic cost, Resources needed, Level of exploitation of resources, Energy consumption in building construction and in demolishing/disassembling.

BEAM evaluation

Demountable group		Vitrohouse						ND-Vitrohouse						
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	
MSD (*1)	MW (*4)	2	2	2/35	9%	0.51	0.47%	1	2	2/35	9%	0.26	0.23%	
PREF (*2)	MW	4	4	4/35	9%	1.03	0.93%	1	4	4/35	9%	0.26	0.23%	
AD (*3)	MW	2	2	2/35	9%	0.51	0.47%	0	2	2/35	9%	0.00	0.00%	
Partial Score							1.87%							0.47%
Difference														1.40%

Notes: BEAM provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110

(*1) Modular and standardized design, (*2) Prefabrication, (*3) Adaptability and deconstruction, (*4) Materials and waste

Table 17: BEAM Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

BEAM has only 3 indicators involved in demountable construction and therefore, their score varies in the evaluation of Vitrohouse, and ND-Vitrohouse. The score difference for both cases is only 1.40% and this is because BEAM does not consider many important factors such as: Economic cost, Resources needed, Level of exploitation of resources, Energy consumption in building construction and in demolishing/disassembling.

BREEAM Evaluation

Removable group		Vitrohouse						ND-Vitrohouse					
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)
MAN02	MAN (*1)	4	4	19.05%	11%	2.10	1.91%	1	4	19.05%	11%	0.52	0.47%
MAT05	MAT (*2)	1	1	7.14%	15%	1.07	0.97%	0	1	7.14%	15%	0	0%
WST01	WST (*3)	3	5	45.45%	6%	1.64	1.49%	0	5	45.45%	6%	0	0%
WST06	WST	1	2	18.18%	6%	0.55	0.50%	0	2	18.18%	6%	0	0%
Partial Score							4.87%						
Difference								4.40%					

Notes: BREEAM provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110

(*1) Management, (*2) Materials, (*3) Waste

Table 18: BREEAM Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

BREEAM has only 4 indicators involved in demountable construction, each of which gave different scores when evaluating both homes. The score difference in both cases is only 4.40% because BREEAM does not consider many important factors such as: Economic cost, Energy consumption in building construction and in demolishing/disassembling.

CEDES evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)
1.2.1	RO (*1)	5	5	0.072	18%	-	1.30%	2	5	0.072	18%	-	0.52%
1.2.4	RO	4	5	0.306	18%	-	4.41%	1	5	0.306	18%	-	1.10%
1.2.6	RO	4	5	0.225	18%	-	3.24%	3	5	0.225	18%	-	2.43%
2.4	ECIC (*2)	5	5	0.115	34%	-	3.91%	2	5	0.115	34%	-	1.56%
2.7	ECID (*3)	5	5	0.024	34%	-	0.82%	1	5	0.024	34%	-	0.16%
4	WE (*4)	5	5	1	12%	-	12%	1	5	1	12%	-	2.4%
6	EC (*5)	5	5	1	10%	-	10%	5	5	1	10%	-	10%
Partial Score							35.68%						
Difference								17.51%					

Notes: (*1) Resources optimization, (*2) Energy consumption in building construction, (*3) Energy consumption in demolishing/disassembling, (*4) Reduction of Waste and emissions, (*5) Economic cost

Table 19: CEDES Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

CEDES is the best-performing GBRS and has 7 indicators involved in demountable construction and therefore their scores vary in the evaluation of Vitrohouse, and ND-Vitrohouse. The score difference for both cases is 17.51%.

DNGB evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)
ENV1.1	ENV (*1)	122.5	130	10/24	25%	-	9.82%	60	130	10/24	25%	-	4.81%
ENV1.2	ENV	120	135	5/24	25%	-	4.63%	115	135	5/24	25%	-	4.44%
ECO1.1	ECO (*2)	70	130	4/10	25%	-	5.38%	47,5	130	4/10	25%	-	3.65%
TEC1.6	TEC (*3)	110	125	3/9	25%	-	7.33%	60	125	3/9	25%	-	2.40%
PRO1.6	PRO (*4)	280	280	2/10	25%	-	5.00%	180	280	2/10	25%	-	3.21%
PRO2.1	PRO	110	110	2/10	25%	-	5.00%	85	110	2/10	25%	-	3.86%
Partial Score							37.16%						
Difference								14.79%					

Notes: (*1) Environmental quality, (*2) Economic quality, (*3) Technical quality, (*4) Process quality

Table 20: DNGB Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse.

DNGB has 6 indicators involved in demountable construction, each of which gave different scores when evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was 14.79% and this was because DNGB does not consider some factors such as: Economic cost, Resources needed, Level of exploitation of resources.

GBI evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)
SM7	SSPM (*1)	2	2	-	-	-	2%	0	2	-	-	-	0%
MR1	MRSC (*2)	2	2	-	-	-	2%	1	2	-	-	-	1%
MR2	MRSC	2	2	-	-	-	2%	0	2	-	-	-	0%
MR6	MRSC	2	2	-	-	-	2%	0	2	-	-	-	0%
Partial Score							8%						
Difference								7%					

Notes: (*1) Sustainable site plan management, (*2) Material resources

Table 21: GBI Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

GBI has 4 indicators involved in demountable construction, each of which gave different scores in evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was 7% because GBI does not consider many important factors such as: Economic cost, Resources needed, Level of exploitation of resources, Energy consumption in building construction and demolishing/disassembling.

GG Evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
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)
1.3 LCCA	PM (*1)	12	12	-	-	12	1.20%	0	12	-	-	0	0%
5.2 PLC	MAT (*2)	39	39	-	-	39	3.90%	10	39	-	-	10	1%
5.5.1 S&E	MAT	11	22	-	-	11	1.10%	0	22	-	-	0	0%
5.5.2 MROS	MAT	8	8	-	-	8	0.80%	0	8	-	-	0	0%
5.7.1 OSFC	MAT	4	4	-	-	4	0.40%	2	4	-	-	2	0.2%
5.7.2 DFD	MAT	6	6	-	-	6	0.60%	0	6	-	-	0	0%
Partial Score								8.00%					
Difference								6.80%					

Notes: (*1) Project Management, (*2) Materials

Table 22: GG Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse

GG has 6 indicators involved in demountable construction, each of which gave different scores when evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was 6.80% because GG does not consider some factors such as: Economic cost, and Energy consumption in building construction.

GS evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
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	1.818%	1	2	-	-	1	0.909%
19	MAT (*2)	7	7	-	-	4	6.364%	3	7	-	-	3	2.727%
22	MAT	1	1	-	-	3	0.909%	0	1	-	-	0	0.000%
Partial Score								9.09%					
Difference								5.46%					

Notes: GS provides a maximum score of 100 points, and can provide an additional 10 points (innovation), therefore, the total score ranges from 0 to 110 (*1) Management, (*2) Materials

Table 23: GS Indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse.

GS has only 3 indicators involved in demountable construction, each of which gave different scores when evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was only 5.46% because GS does not consider many important factors such as: Economic cost, Resources needed, Level of exploitation of resources.

IGBC Evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result (0-75)	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result (0-75)	Result (0-100)
C2	MR (*1)	1	1	-	-	1	1.33%	0	1	-	-	0	0%
C3	MR	2	2	-	-	2	2.66%	2	2	-	-	2	2.66%
Partial Score							3.99%						
Difference								1.33%					

Notes: IGBC provides a maximum score of 75, therefore, the total score ranges from 0 to 75 (*1) Material Resources

Table 24: IGBC indicators involved in modular and demountable construction. Score differences between Vitrohouse and ND-Vitrohouse.

IGBC has only 2 indicators involved in demountable construction, each of which gave different scores when evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was only 1.33% because IGBC does not consider many important factors such as: Economic cost, Resources needed, Level of exploitation of resources, Energy consumption in building construction, and demolishing/disassembling.

LEED Evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
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)
EPP (*1)	MR (*3)	4	5	-	-	4	3.64%	3	5	-	-	3	2.73%
CDWM (*2)	MR	1	2	-	-	1	0.91%	0	2	-	-	0	0
Partial Score							4.55%						
Difference								1.82%					

Notes: LEED provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110

Indicators of the manual for single-family housing

(*1) Environmentally Preferable Products, (*2) Construction and Demolition Waste Management, (*3) Materials and Resources

Table 25: LEED indicators Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse.

LEED has only 2 indicators involved in demountable construction, each of which gave different scores in evaluating Vitrohouse, and ND-Vitrohouse. The score difference in both cases was only 1.82% because LEED does not consider many important factors such as: Economic cost, Resources needed and Level of exploitation of resources, Energy consumption in building construction, and in demolishing/disassembling.

SBTools Evaluation

Demountable group		Vitrohouse						ND-Vitrohouse					
Indicators	Category	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. Score	Indicator weight	Category weight	Result	Result (0-100)
B 1.1	ERC (*1)	5	5	6.48%	-	-	6.48%	3	5	6.48%	-	-	3.89%
B 1.2	ERC	5	5	3.24%	-	-	3.24%	3	5	3.24%	-	-	1.94%
B 3.3	ERC	5	5	0.20%	-	-	0.20%	0	5	0.20%	-	-	0.00%
B 3.5	ERC	5	5	0.20%	-	-	0.20%	3	5	0.20%	-	-	0.12%
B 3.6	ERC	5	5	0.20%	-	-	0.20%	0	5	0.20%	-	-	0.00%
C 1.1	EL (*2)	5	5	4.86%	-	-	4.86%	3	5	4.86%	-	-	2.92%
C 1.2	EL	3	5	4.86%	-	-	2.92%	0	5	4.86%	-	-	0.00%
E 4.1	SQ (*3)	5	5	0.05%	-	-	0.05%	3	5	0.05%	-	-	0.03%
E 4.2	SQ	5	5	0.41%	-	-	0.41%	3	5	0.41%	-	-	0.25%
E 4.3	SQ	3	5	0.05%	-	-	0.03	0	5	0.05%	-	-	0.25%
G 1.1	CEA (*4)	5	5	0.10%	-	-	0.10%	0	5	0.10%	-	-	0.00%
G 1.2	CEA	5	5	0.10%	-	-	0.10%	0	5	0.10%	-	-	0.00%
G 1.3	CEA	5	5	0.10%	-	-	0.10%	3	5	0.10%	-	-	0.06%
Partial Score							18.89%						9.46%
Difference													9.43%

Notes: (*1) Energy and Resources Consumption, (*2) Environmental Loadings, (*3) Service Quality, (*4) Cost and Economic Aspects

Table 26: Indicators of SBTool Involved in Modular and Demountable Construction. Score differences between Vitrohouse and ND-Vitrohouse.

SBTools has 13 indicators involved in demountable construction, each of which gave different scores in evaluating Vitrohouse and ND-Vitrohouse. The score difference in both cases was only 9.43% because SBTools does not consider some factors such as: Economic cost, Resources needed, Level of exploitation of resources.

Results

The results of the comparative evaluation by each GBRS have been the following: ASGB: 2.06 %, BEAM: 1.40 %, BREEAM: 4.40 %, CEDES: 17.51 %, DNGB: 14.79 %, GBI: 7 %, GG: 6.80 %, GS: 5.46 %, IGBC: 1.33 %, LEED: 1.82 % and SBTool: 9.43 % (Table 27).

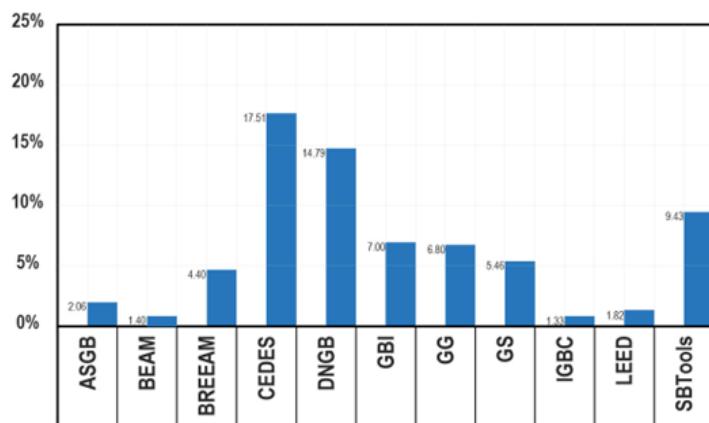


Table 27: Contribution of Demountable Construction to a Building's Sustainability Level, Using 11 GBRS

Therefore, all GBRS detected that Vitrohouse, due to the fact that it is demountable and despite being built solely with flat glass, has a higher level of sustainability than a conventional home of the same size.

Taking into account the average scores of the 11 GBRS, the contribution of demountability to the level of sustainability of Vitrohouse is 6.54% $((2.06 + 1.40 + 4.40 + 17.51 + 14.79 + 7.00 + 6.80 + 5.46 + 1.33 + 1.82 + 9.43) / 11 = 6.54)$.

However, if only CEDES, DNGB and SBTools are taken into account, the contribution of demountability of Vitrohouse to the level of sustainability of buildings is 13.91% $((17.51 + 14.79 + 9.43) / 3 = 13.91)$.

Discussion

This study demonstrates the feasibility of constructing habitable spaces using flat glass by analyzing the first all-glass house: Vitrohouse. The construction of Vitrohouse was designed to show that glass can be used to manufacture any building component, including its primary supporting structure.

The first objective of this work is to demonstrate the technical feasibility of using flat glass to create safe and habitable spaces that comply with international building codes. The second objective is to show that, despite being built with glass, Vitrohouse exhibits strong thermodynamic and bioclimatic performance. Its careful design enables a comfortable internal temperature with lower energy consumption than most conventional houses of similar size. The third objective is to demonstrate that the inherent demountability of the construction system gives Vitrohouse a higher level of sustainability than conventional houses of the same size. Vitrohouse is undoubtedly a radical construction experiment that has had to overcome numerous challenges, demonstrating the vast potential of flat glass.

The primary objective behind Vitrohouse was to promote demountable construction, enabling buildings to be easily assembled and disassembled. This approach allows components to be easily recovered, repaired, and reused, maximizing their lifespan and minimizing their environmental impact over time. The underlying premise is that if a completely demountable building can be constructed using only flat glass, it is far easier to build demountable structures using more common and suitable materials.

Conclusions

This paper analyzes Vitrohouse, a demountable house built entirely from flat glass.

The project's goal was to promote demountable construction as a paradigm of sustainable construction. Glass was chosen as the sole material to pose a significant construction challenge; if a demountable building can be constructed using only glass, and without mortar, adhesives, nails, or screws, then demountable buildings can be constructed more easily using any other material. The project overcame three primary challenges. First, the all-glass structure had to be robust, stable and durable, capable of withstanding external stresses and meeting habitability requirements. Second, the house required a specialized bioclimatic design to maintain a comfortable interior temperature. Third the house had to be fully demountable.

This study's analysis of Vitrohouse's technical and construction solutions confirms that its bioclimatic design makes it more sustainable than a conventional house. Furthermore, its demountable design provides and additional, quantifiable sustainability advantage, proving that innovative materials and methods can lead to highly efficient and circular building practices.

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.

References

1. Bos F, Louter C (2021) Structural glass in architecture. *Encyclopedia of Glass Science, Technology, History, and Culture* 2: 1071-1090.
2. Gloag J (2022) The place of glass in building. In *The Place of Glass in Building* 7-14. Routledge <https://doi.org/10.1201/9781003332701>.
3. Maiti H S (2022) Structural and Functional Properties of Architectural Glass. In *Future Landscape of Structural Materials in India* Singapore: Springer Nature Singapore 211-231. https://doi.org/10.1007/978-981-16-8523-1_9.
4. Moro J L (2024) Glass Products. In: *Building-Construction Design - From Principle to Detail*. Springer Vieweg, Berlin, Heidelberg https://doi.org/10.1007/978-3-662-61742-7_23.
5. NaqashMT, FormisanoA, FarsangiEN (2021) Structural assessment of glass used in façade industry.

- In Structures. Elsevier 33: 4817-4827.
6. Wiederhorn SM, Clarke DR (2022) Architectural glass. Annual Review of Materials Research 52: 561-592.
 7. Žegarac Leskovar V, Premrov M (2021) A review of architectural and structural design typologies of multi-storey timber buildings in Europe. Forests 12: 757.
 8. Borrallo-Jiménez M, Lopez De Asiain M, Esquivias P M, Delgado-Trujillo D (2022) Comparative study between the passive house standard in warm climates and nearly zero energy buildings under spanish technical building code in a dwelling design in Seville, Spain. Energy and Buildings 254: 111-570.
 9. Carter C, Zhao J (2018) Passivhaus lived experience: More than a spreadsheet. PLEA 2018, Conference on Passive and Low Energy Architecture <http://eprints.lincoln.ac.uk/id/eprint/35349>.
 10. Colclough S, O'Leary T, Hewitt N, Griffiths P (2017) The near Zero Energy Building standard and the Passivhaus standard – a case study. In Design to Thrive: Proceedings, PLEA 2017 conference 1: 385-392.
 11. Costanzo V, Fabbri K, Piraccini S (2018) Stressing the passive behavior of a Passivhaus: An evidence-based scenario analysis for a Mediterranean case study. Building and Environment 142: 265-277.
 12. De Garrido L (2012) Self-Sufficient Green Architecture. Monsa 96.
 13. De Garrido L (2014) Zero Energy Architecture. Editorial Monsa 112.
 14. De Garrido L (2014 b) Extreme Bioclimatic Architecture. Monsa 112.
 15. Lavaf Pour Y (2017) Self-Shading Facade Geometries to Control Summer Overheating in UK Passivhaus Dwellings for Current and Future Climate Scenarios [Doctoral dissertation]. University of Liverpool <https://doi.org/10.17638/03009183>.
 16. Zhao J, Carter K (2016) Barriers and opportunities in the design and delivery of social housing Passivhaus for adaptive comfort. Proceedings of 9th Windsor Conference: Making Comfort Relevant. Cumberland Lodge, Windsor, United Kingdom https://eprints.lincoln.ac.uk/id/eprint/32463/1/WC16_Zhao.pdf.
 17. Liu C, Mohammadpourkarbasi H, Sharples S (2020) Analysing energy savings and overheating risks of retrofitting Chinese rural dwellings to the Passivhaus EnerPHit standard. 35th International Conference on Passive and Low Energy Architecture, A Coruña, Spain <https://livrepository.liverpool.ac.uk/id/eprint/3097751>.
 18. Mitchell R, Natarajan S (2020) UK Passivhaus and the energy performance gap. Energy and Building 224: 110-240.
 19. Saldanha C M, O'Brien S M (2016) A study of energy use in New York City and LEED-certified buildings (ASHRAE and IBPSA-USA SimBuild 2016), Building Performance Modeling Conference, Salt Lake City, UT.
 20. De Garrido L, Paya-Laforzeta I (2025 a) Aportación del diseño bioclimático al nivel de sostenibilidad de los edificios. International Congress iENER, 3-4 July 2025. Universidad Politécnica de Madrid. Mining and Energy Engineering Faculty.
 21. De Garrido L, Picco N (2025) Ventajas sostenibles y eficiencia energética de la construcción modular y bioclimática. International Congress iENER, 3-4 July 2025. Universidad Politécnica de Madrid. Mining and Energy Engineering Faculty.
 22. Al-Muslih A, Al-Hadithy L (2019) Performances of Steel-Concrete Composite Construction with Demountable Shear Connectors – Review. IOP Conference Series: Materials Science and Engineering 518: 022-058.
 23. Boben Paul E (2022) Design of a Demountable Steel Timber Floor System: Design Rules and Recommendations for the Application of a Demountable Steel Timber Floor System [Master's thesis, Delft University of Technology]. Faculty of Civil Engineering and Geosciences, Delft.
 24. Braendstrup C (2017) Conceptual design of a demountable, reusable composite flooring system [Master's Thesis, Delft University of Technology]. Delft University of Technology.
 25. Girão Coelho A, Lawson R, Aggelopoulos E (2019) Optimum use of composite structures for demountable construction. Structures 20: 116-133.
 26. He J, Suwaed A, Vasdravellis G, Wang S (2021) Shear performance of a novel demountable connector for reusable steel-concrete composite structures. In A. Chen, X. Ruan, & D. Frangopol, Life-Cycle Civil Engineering: Innovation, Theory and Practice 775-781.
 27. Kollna M (2018) Demountable prototype house – from facade to water tap. Mauerwerk - European

- Journal of Masonry 22: 38-43
28. Wang J, Uy B, Li D (2018) Analysis of demountable steel and composite frames with semi-rigid bolted joints. *Steel and Composite Structures* 28: 363-380.
 29. Wang J, Uy B, Thai H T, Li D (2018) Behaviour and design of demountable beam-to-column composite bolted joints with extended end-plates. *Journal of Constructional Steel Research* 144 :221-235
 30. Akanbi L, Oyedele L, Omoteso K, Bilal M, Akınade O, et al. (2019) Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *Journal of Cleaner Production* 223: 386-396.
 31. Brambilla G, Lavagna M, Vasdravellis G, Castiglioni C (2019) Environmental benefits arising from demountable steel-concrete composite floor systems in buildings. *Resources, Conservation and Recycling* 141: 133-142.
 32. Cruz Rios F, Chong W, Grau D (2015) Design for Disassembly and Deconstruction - Challenges and Opportunities. *Procedia Engineering* 118: 1296-1304.
 33. García Marín A, Barrios Corpa J, Terrados Cepeda J, de la Casa Higuera J, Aguilera Tejero J (2015) Self-Sufficient Prefabricated Modular Housing: Passive Systems Integrated. In A. Sayigh, *Renewable Energy in the Service of Mankind Vol I*. https://doi.org/10.1007/978-3-319-17777-9_60.
 34. Liu C, Mao X, He L, Chen X, Yang Y, et al. (2022) A new demountable light-gauge steel framed wall: Flexural behavior, thermal performance and life cycle assessment. *Journal of Building Engineering* 47 <https://doi.org/10.1016/j.jobbe.2021.103856>.
 35. Nam S, Yoon J, Kim K, Choi B (2020) Optimization of Prefabricated Components in Housing Modular Construction. *Sustainability* 12 <https://doi.org/10.3390/su122410269>.
 36. Negrin F, Plitt T (2019) Designer demountable. *Sanctuary: Modern Green Homes* 48: 16-21
 37. Ortlepp S, Masou R, Ortlepp R (2015) Demountable construction for sustainable buildings. *High Performance Fiber Reinforced Cement Composites (HPFRCC) Stuttgart* 7.
 38. Ortlepp S, Masou R, Ortlepp, R (2017) Green construction methods of buildings capable for disassembly to support circular economy. In F. da Silva, H. Bártolo, P. Bártolo, R. Almendra, F. Roseta, H. Almeida, & A. Lemos, *Challenges for Technology Innovation: An Agenda for the Future*. Taylor & Francis Group <https://doi.org/10.1201/9781315198101>.
 39. Reinhardt H (2018) Demountable concrete structures – an energy and material saving building concept. *International Journal of Sustainable Materials and Structural Systems* 1: 18-28.
 40. Salama W (2018) Design for disassembly as an alternative sustainable construction approach to life-cycle-design of concrete buildings. [Doctoral thesis, Gottfried Wilhelm Leibniz University] <https://doi.org/10.15488/5121>.
 41. De Garrido L (2025 b) Aportación de los sistemas estructurales desmontables de hormigón prefabricado en el nivel de sostenibilidad de un edificio. *International Congress EDIFICATE, Burgos University. Building Engineering Faculty*.
 42. De Garrido L (2012) *A New Paradigm in Architecture*. Monsa 528 pages.
 43. Vitrohouse (2024) <https://luisdegarrido.com/es/Vitrohouse-luis-de-garrido-vivienda-ecologica-bioclimatica-autosuficiente-con-consumo-energetico-cero-real-a-precio-convencional-2/>.
 44. De Garrido L, Paya-Laforzeta I (2025 b) Análisis comparativo de los principales sistemas de evaluación sostenible de edificios. *International Congress EDIFICATE, Burgos University. Building Engineering Faculty*.
 45. ASGB (2019) *Assessment Standard for Green building*. <https://www.eia543.com/documents/14%E5%BB%BA%E7%AD%91%E8%AE%BE%E8%AE%A1%26%E5%AE%A4%E5%86%85%E7%A9%BA%E6%B0%94%E6%B1%A1%E6%9F%93%E7%A0%94%E7%A9%B6/%E7%BB%BF%E8%89%B2%E5-BB%BA%E7%AD%91%E8%AF%84%E4%B-B%B7%E6%A0%87%E5%87%86%EF%B-C%88GB%20T%2050378-2019%EF%BC%89.pdf>.
 46. BEAM (2024) *Building Environmental Assessment Method HK-BEAM Plus. 4/04 New Buildings – Technical Manua* [https://www.ibeam.hk/public/knowledgeDatabase/?tab=downloadAreahttps://www.beamsociety.org.hk/files/_4-04%20New%20Buildings%20\(Full%20Version\).pdfhttps://www.beamsociety.org.hk/en/BEAM-Plus/BEAM-Plus-](https://www.ibeam.hk/public/knowledgeDatabase/?tab=downloadAreahttps://www.beamsociety.org.hk/files/_4-04%20New%20Buildings%20(Full%20Version).pdfhttps://www.beamsociety.org.hk/en/BEAM-Plus/BEAM-Plus-)

- New-Buildings .
47. BREEAM UK New Construction (2018) 3.0 – Technical Manual <https://breeam.es/manuales-tecnicos> Building Research Establishment Group. BREEAM Worldwide. <https://www.breeam.com/worldwide>; Building Research Establishment Environmental Assessment Method [http://www.breeam.es/BREEAM International](http://www.breeam.es/BREEAM_International): Watford, <https://hbreavis.com/wp-content/uploads/2017/06/BREEAM-International-New-Construction-2016> .
 48. CEDES (2024) CEDES Technical Manual GBRS designed by National Association for Sustainable Architecture in Spain <https://www.anas-sostenible.com/> .
 49. De Garrido L (2025 a) CEDES: A Complete, Legitimate and Seamless Green Building Rating System. *Journal of Sustainable Development* 6: 42-76.
 50. DGNB (2023) Deutsche Gesellschaft für Nachhaltiges Bauen DGNB system 2023 – Technical Manual <https://www.dgnb.de/en/certification/buildings/new-construction/version-2023>
 51. GBI (2014) Green Building Index 2014 V. 3.1– Technical Manual <https://www.greenbuildingindex.org/gbi-tools>/<https://www.greenbuildingindex.org/Files/Resources/GBI%20Tools/RNC%20Reference%20Guide%20V3.1.pdf> (residential buildings <https://www.greenbuildingindex.org/Files/Resources/GBI%20Tools/RNC%20Reference%20Guide%20Amendment%20Notes%203.1.pdf>).
 52. GG (2022) Green Globes Green Globes New Construction 2021 - Technical Reference Manual Version 1.0 - https://thegbi.org/wpcontent/uploads/2022/11/Green_Globes_NC_2021_ES_BEQ_Technical_Reference_Manual.pdf .
 53. GS (2022) Green Star Green Star Design & As Built V1.2 – Technical Manual https://s3.ap-south-east-2.amazonaws.com/hdp.au.prod.app.nthbch.yoursay.files/1415/6214/8137/2018_701322_Green_Star_Design_and_As_Built_Summission_Guidelinev1.2_GBCA_1.PDF.
 54. IGBC (2019) Indian Green Building Council IGBC Green New Buildings Rating Systems V3.0 – Technical Manual <https://igbc.in/igbc-green-homes.php> .
 55. LEED (2019) Leadership in Energy and Environmental Design LEED v4.1 Residential BD+C Multifamily Homes – Technical Manual https://www.usgbc.org/tools/leed-certification/homes_CLASIFICACION.pdf
 56. SBTool (2022) SBtools for performance assessment <https://www.iisbe.org/sbmethod>.