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LIFE17 CCA/EN/000088

Application of Nature-Based Solutions for local adaptation of educational and social buildings to Climate Change

Deliverable: Help document for "Prototype Design".

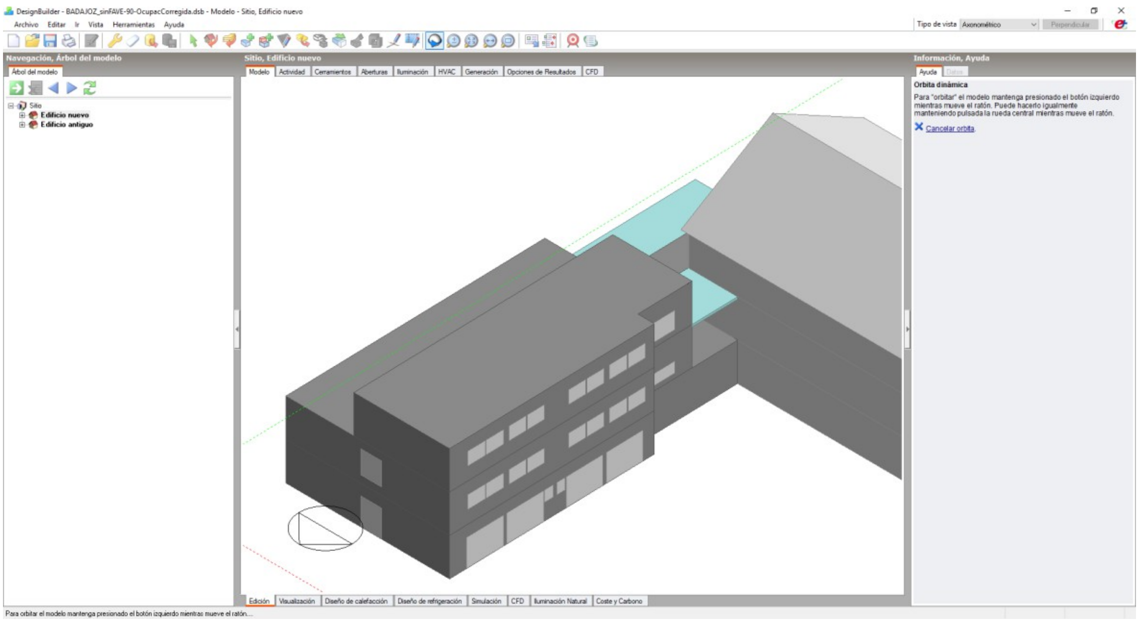
06- Study of the influence of the NBS on the reduction of cooling demand for Badajoz.

EDUARDO TORROJA Institute of Construction Sciences - CSIC Date:

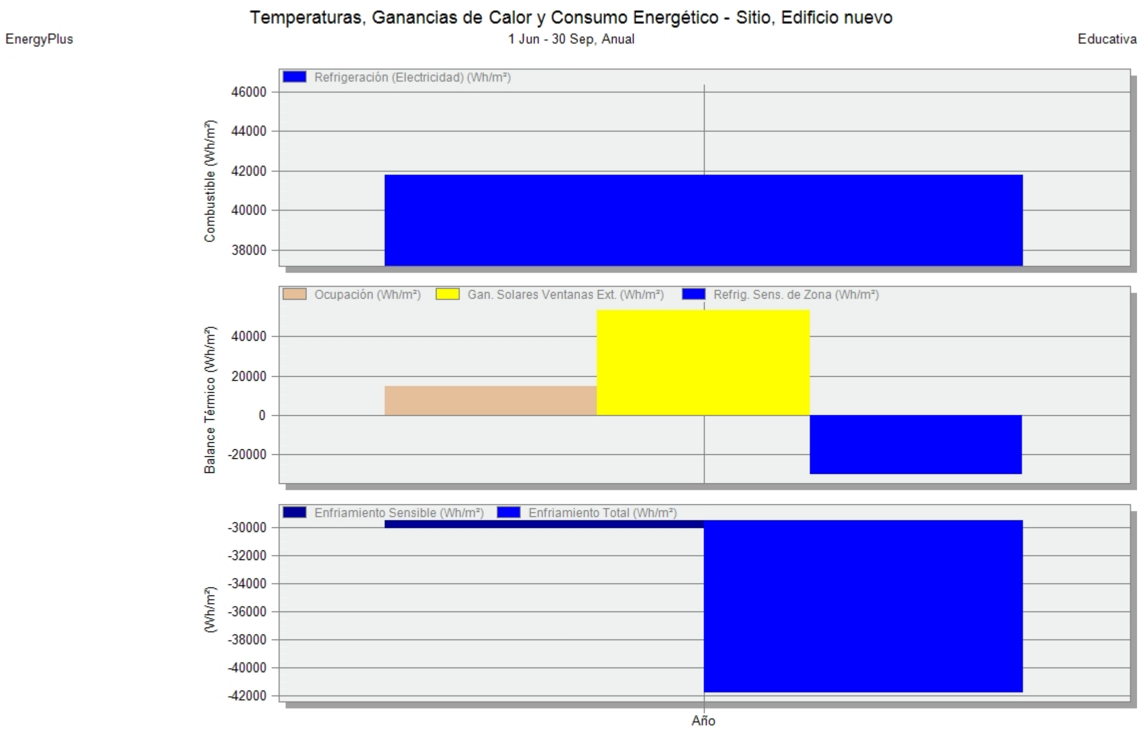
24/10/2019

Index

1. REFRIGERATION DEMAND ANALYSIS FOR THE BASE MODEL



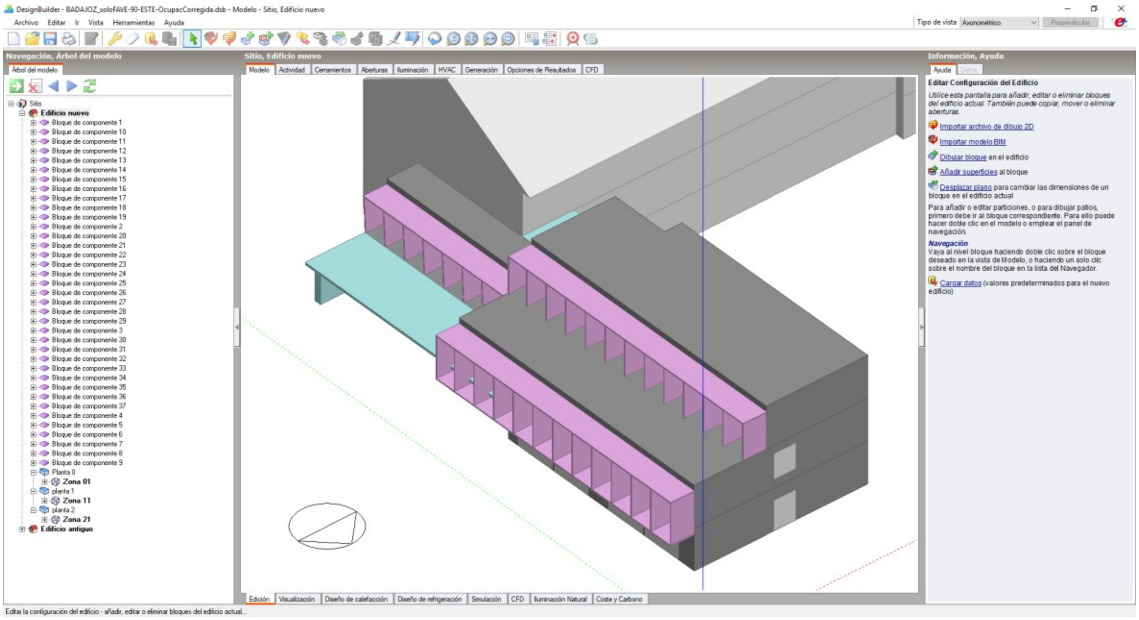
Case 0. Base simulation model (with the enclosure data provided by the EWC EA).



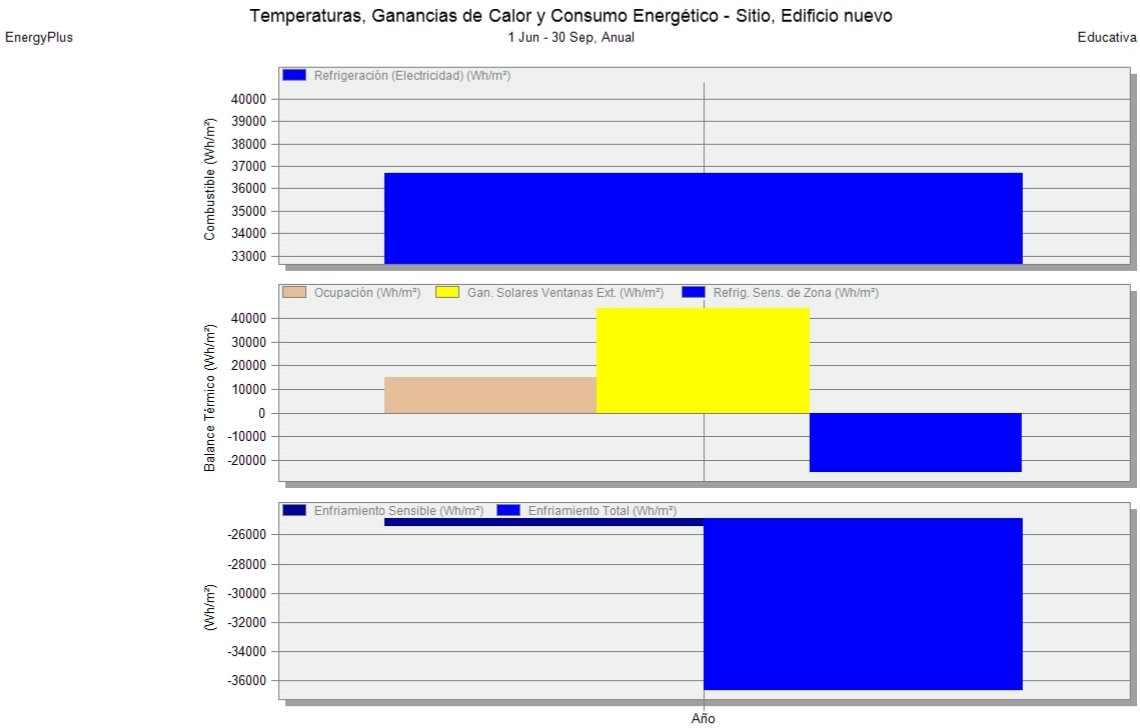
Refrigeración (Electricidad) (Wh/m²)	41789,65
Ocupación (Wh/m²)	14896,48
Gan. Solares Ventanas Ext. (Wh/m²)	53330,07
Refrig. Sens. de Zona (Wh/m²)	-30033,04
Enfriamiento Sensible (Wh/m²)	-30072,56
Enfriamiento Total (Wh/m²)	-41789,65

Demand values for the whole building = 41,78965 kWh/m²

2. ANALYSIS OF THE COOLING DEMAND FOR THE FAVE SYSTEM



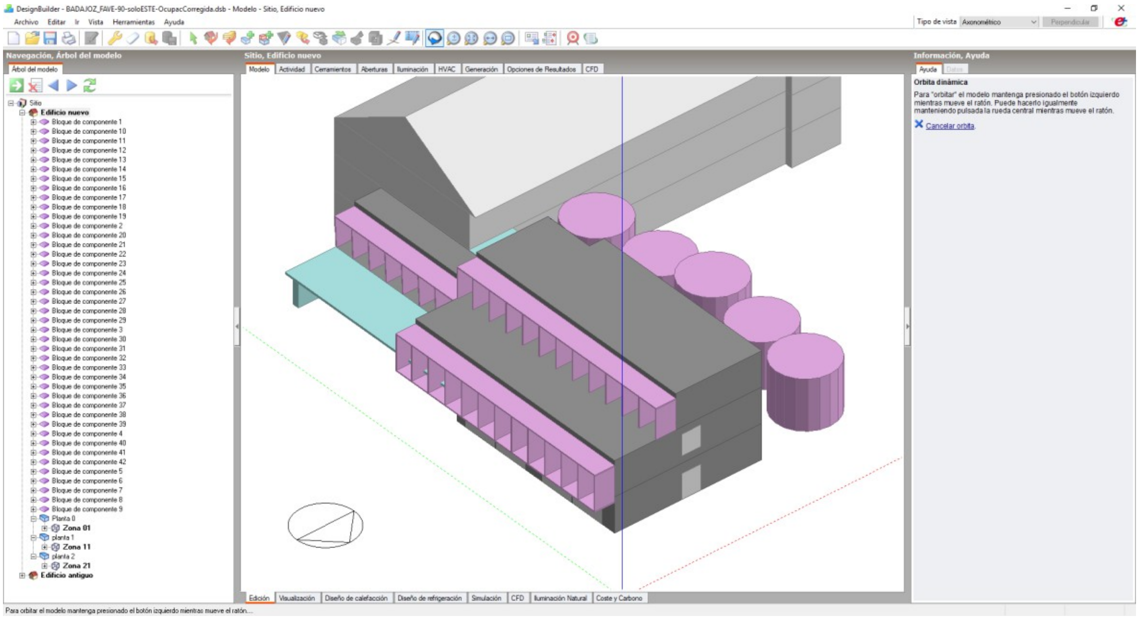
Base simulation model, incorporating only the FAVE system.



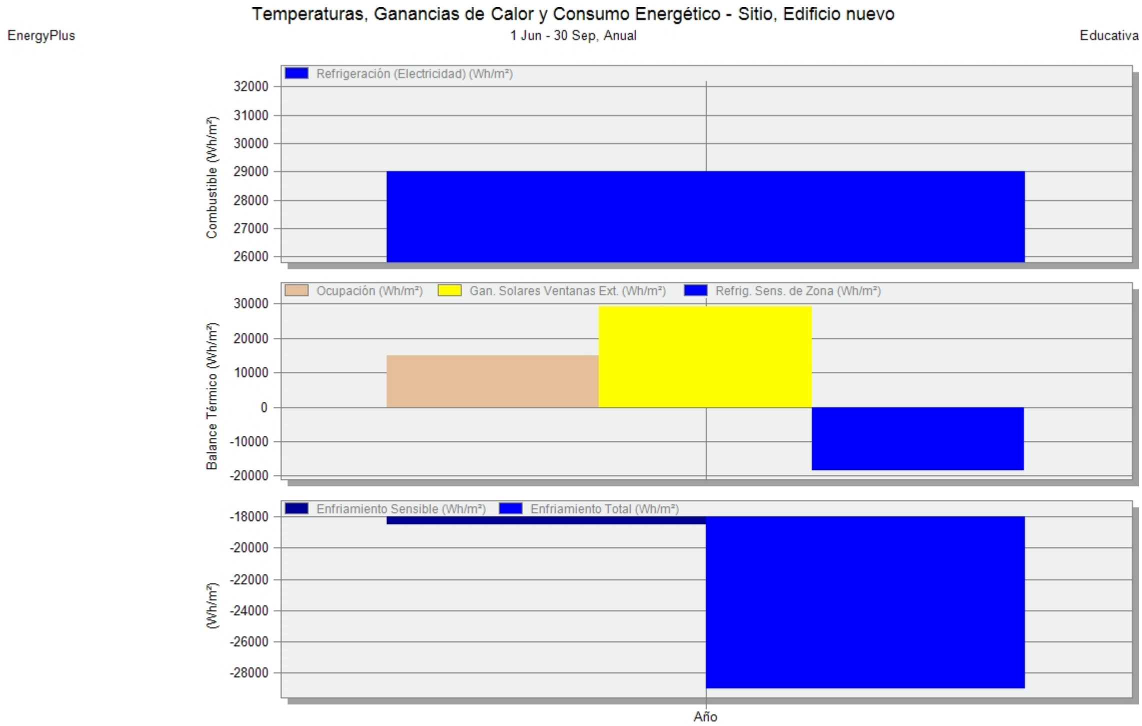
Refrigeración (Electricidad) (Wh/m²)	36688,48
Ocupación (Wh/m²)	14921,74
Gan. Solares Ventanas Ext. (Wh/m²)	44547,37
Refrig. Sens. de Zona (Wh/m²)	-25372,92
Enfriamiento Sensible (Wh/m²)	-25403,87
Enfriamiento Total (Wh/m²)	-36688,48

Demand values for the whole building = 36,68848 kWh/m^2

3. COOLING ANALYSIS FOR THE FAVE SYSTEM -EAST- AND ARBORETUM SYSTEM -WEST



Case 2. Simulation of FAVE system on the East face + trees on the West face

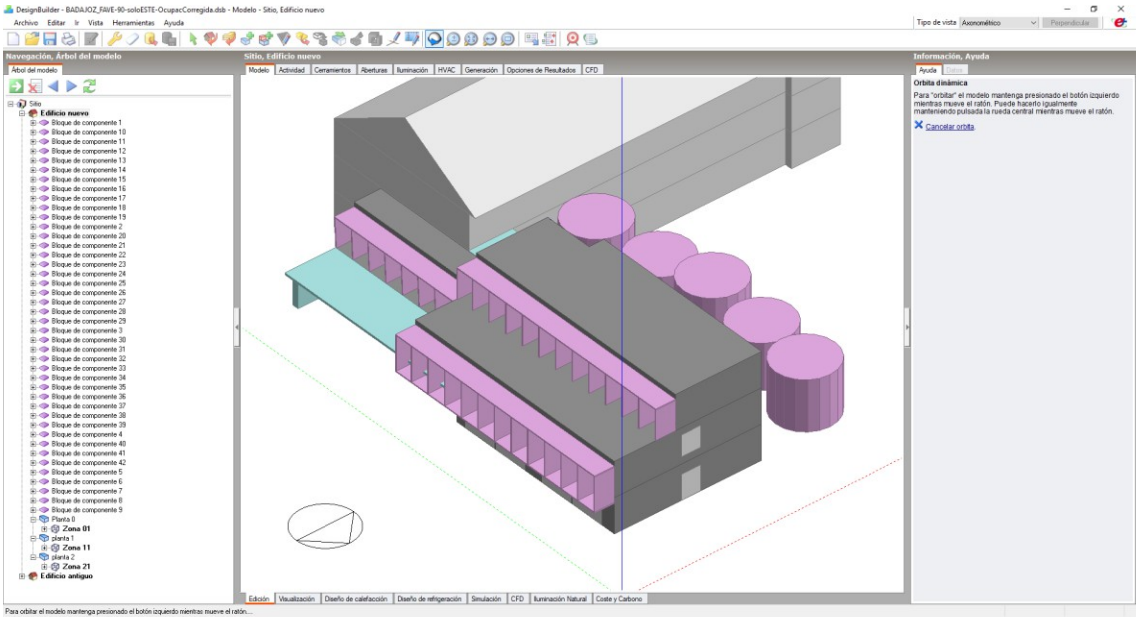


Refrigeración (Electricidad) (Wh/m²)	29011,75
Ocupación (Wh/m²)	14989,14
Gan. Solares Ventanas Ext. (Wh/m²)	29277,92
Refrig. Sens. de Zona (Wh/m²)	-18482,99
Enfriamiento Sensible (Wh/m²)	-18498,38
Enfriamiento Total (Wh/m²)	-29011,75

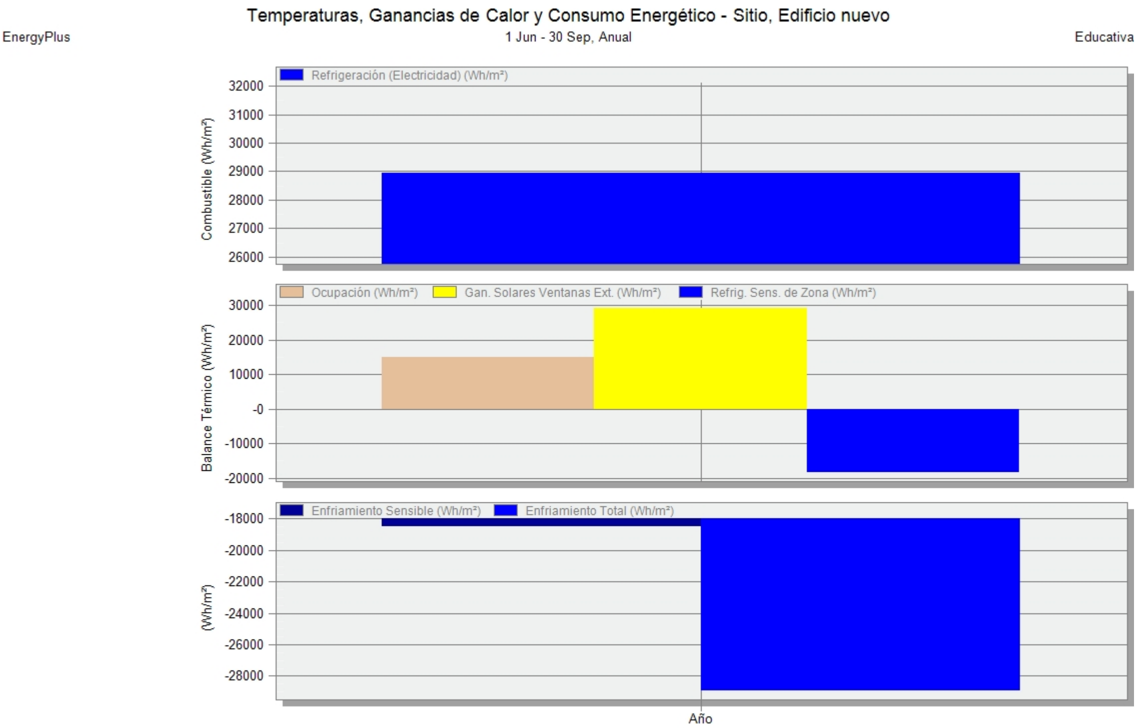
Demand values for the entire building = 29.01175 kWh/m²

4. ANALYSIS OF COOLING DEMAND FOR FAVE+ TREES + SUBSTRATE

4.1. Using an air gap substrate layer in the simulation



Case 3.1. Simulation of FAVE system on East face + trees on West face + addition of 10cm substrate layer with 5cm air chamber (eliminating gravel).



Refrigeración (Electricidad) (Wh/m²)	28947,16
Ocupación (Wh/m²)	14991,13
Gan. Solares Ventanas Ext. (Wh/m²)	29277,92
Refrig. Sens. de Zona (Wh/m²)	-18436,17
Enfriamiento Sensible (Wh/m²)	-18451,13
Enfriamiento Total (Wh/m²)	-28947,16

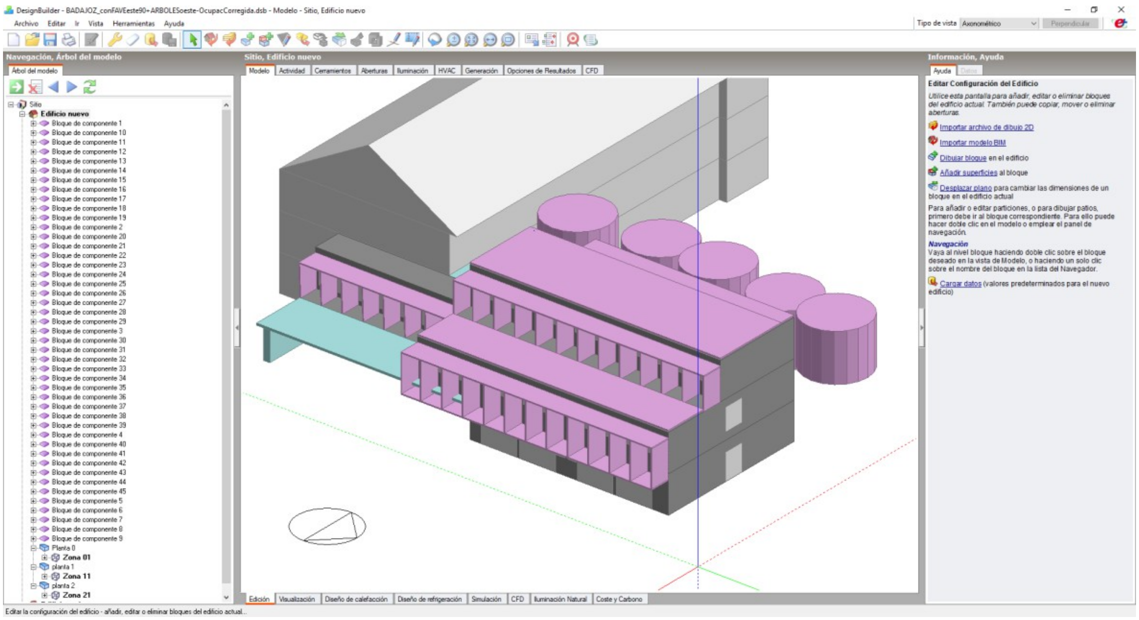
Demand values for the whole building (very similar figures after placing an air chamber and a substrate, removing the gravel layer) = 28,94716 kWh/m^2

This is a point to be made at this point, since simplifications are often assumed that can alter the results, as is the case here. Since, in order to conveniently simulate the effect of a vegetation cover, a series of detailed data on plant types, height, reflectivity, emissivity of the same, among other issues related to the definition of the cover/s implemented, a couple of studies have been considered in parallel, to analyze the effect of the vegetation cover in different ways:

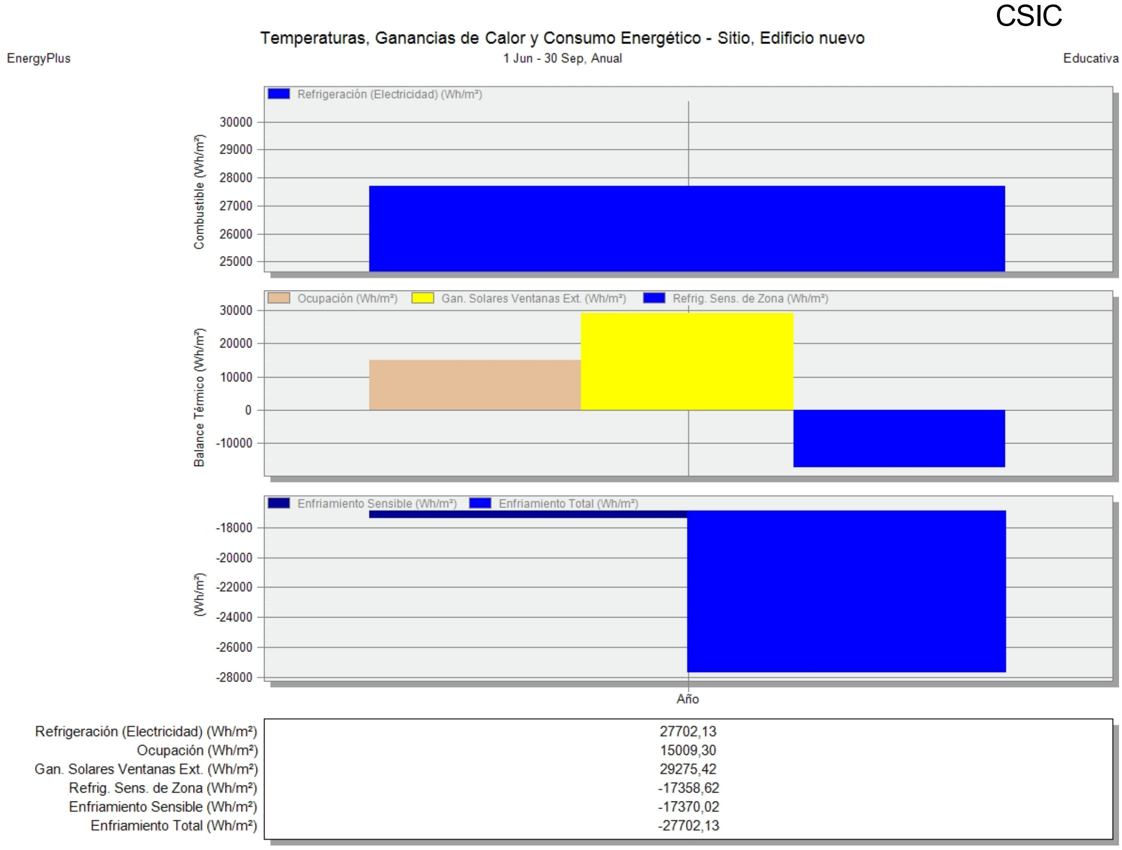
The first (4.2.), consists of placing an object (block) that produces shading on the upper floor roof, in order to simulate the effect of the vegetation on it. This object is 10 cm from the surface (simulating an air chamber) and measures 10 cm thick.

The second study (4.3.), more basic but more appropriate, allows comparing the effect of two types of roofs (predefined in the Design Builder simulation program), considering that both solutions have the same transmittance: one has no vegetation ("Non-EcoRoof") and the other has vegetation (basically defined by Design Builder as "EcoRoof", which will be broken down below to see its composition and characteristics).
Both test "cubes" have been located in Badajoz, and the same "teaching areas" template, also defined for the models described above, has been applied to them.

4.2. Using 10 cm thick adiabatic shading objects in the simulation, separated by another 10 cm from the current canopy



Case 3.2. Simulation of the FAVE system on the east side + trees on the west side + addition of a 10 cm thick flat shading object, separated 10 cm from the roof.



Demand values for the whole building (with a 4.51 % reduction in cooling demand, compared to case 2) = 27.70213 kWh/m^2

The comparison of the different cases described above (Case 0, 1, 2 and 3.1 / 3.2), resulting from the addition of solutions to the initial model, yields the following energy demand reduction data.

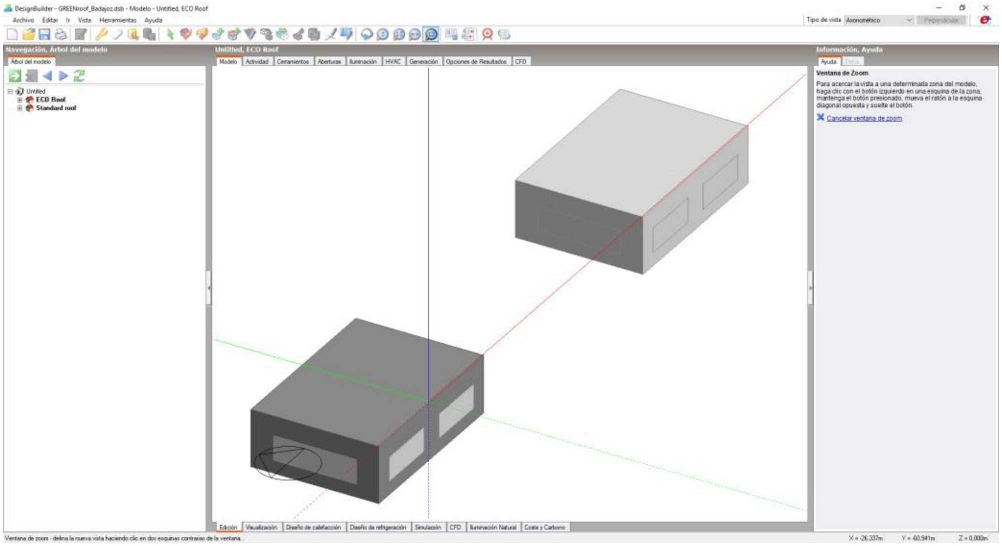
CASE 0	CASE 1	CASE 2	CASE 3.1
Without FAVE (kWh/m2)	**With FAVE -only on east façade- (kWh/m2)**	**With FAVE -East- and Trees -West- (kWh/m2)**	**With FAVE -East- + Trees -West- + Substrate (kWh/m2)**
41,78965	36,68848	29,01175	28,94716
	Reduction with respect to Case 0	**Reduction with respect to Case 0**	**Reduction with respect to Case 0**
	12,21%	30,58%	30,73%
			Values with respect to *Case 2*
			0,22%
			CASE 3.2
			With FAVE -East- + Trees -West- + ShadeCover (kWh/m2)
			27,70213
			Reduction with respect to Case 0
			33,71%
			Values with respect to *Case 2*
			4,51%

SUMMARY TABLE OF COMPARATIVE CASES OF FAÇADE AND ROOFING SOLUTIONS

The values in kWh/m² have to be taken with extreme caution, since the model has been simulated "turning off" all systems (DHW, lighting, office equipment, etc.), and only standard infiltrations have been considered (0.7 renov/h constantly), but no additional ventilation has been considered. Therefore, it is considered closed during the months analyzed above (since no real ventilation characteristics have been provided).

Therefore, the absolute values in this document are probably overestimated.

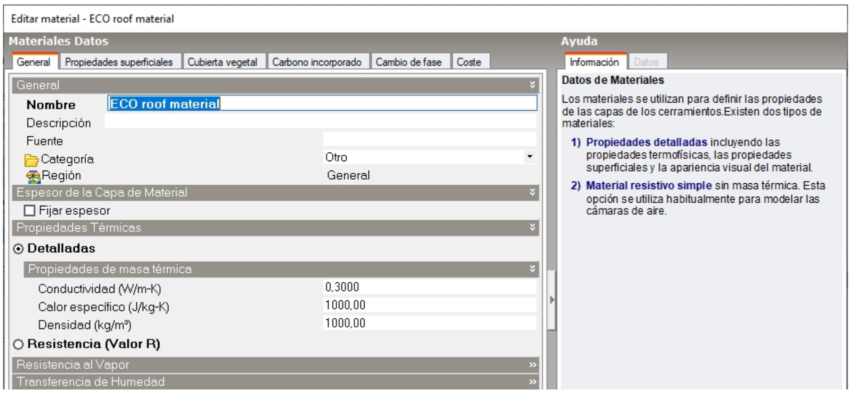
4.3. Simulating two identical "modules", with different coverings

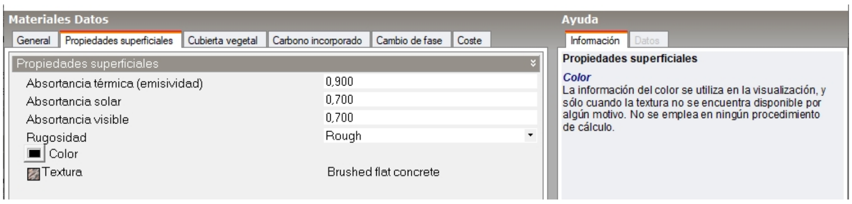


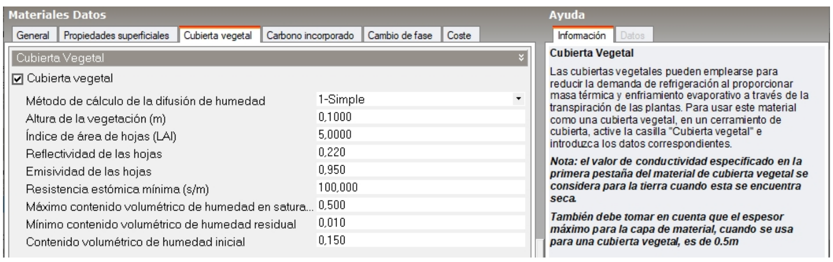
Simulation of two roof systems with identical thermal transmittance, one defined as a green roof ("EcoRoof") and the other not ("StandardRoof").

4.3.1. *Considerations to take into account when modeling a green roof in Design Builder.*

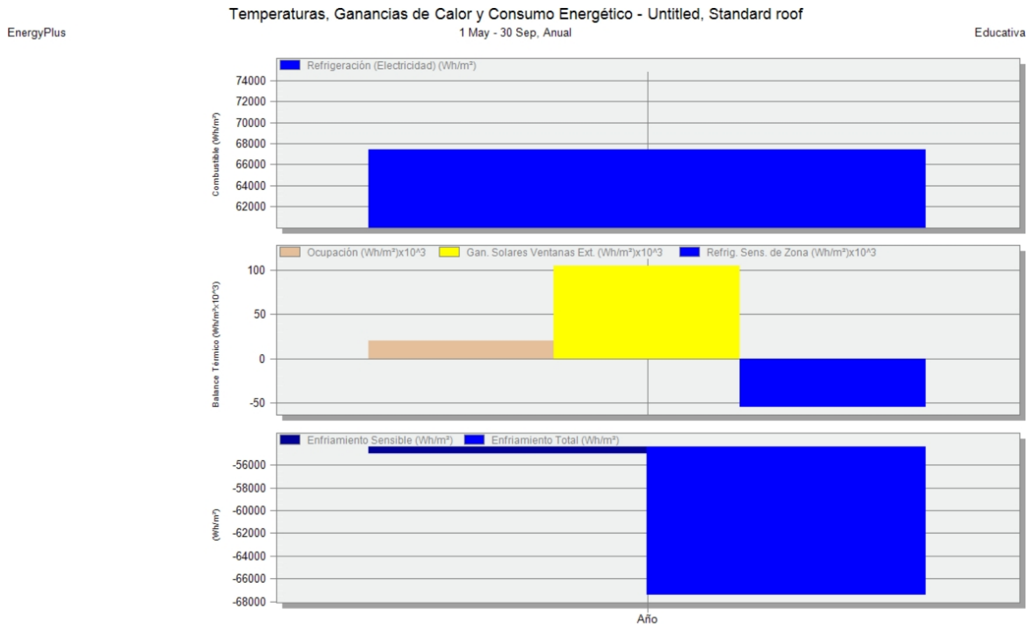
Among other things, the data that must be able to be entered to properly characterize a vegetation cover in the Design Builder program can be seen below.





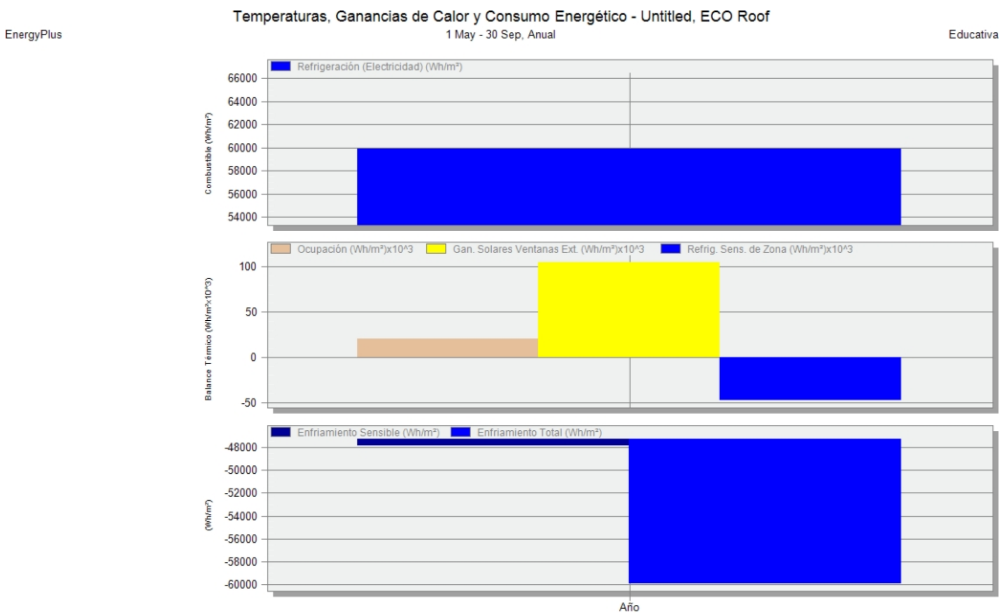


4.3.2. Simulation results in terms of cooling demand



Refrigeración (Electricidad) (Wh/m²)	67428,84
Ocupación (Wh/m²)x10^3	19,99
Gan. Solares Ventanas Ext. (Wh/m²)x10^3	105,11
Refrig. Sens. de Zona (Wh/m²)x10^3	-54,90
Enfriamiento Sensible (Wh/m²)	-54988,89
Enfriamiento Total (Wh/m²)	-67428,84

StandardRoof" values for cooling demand from May 1 to September 30



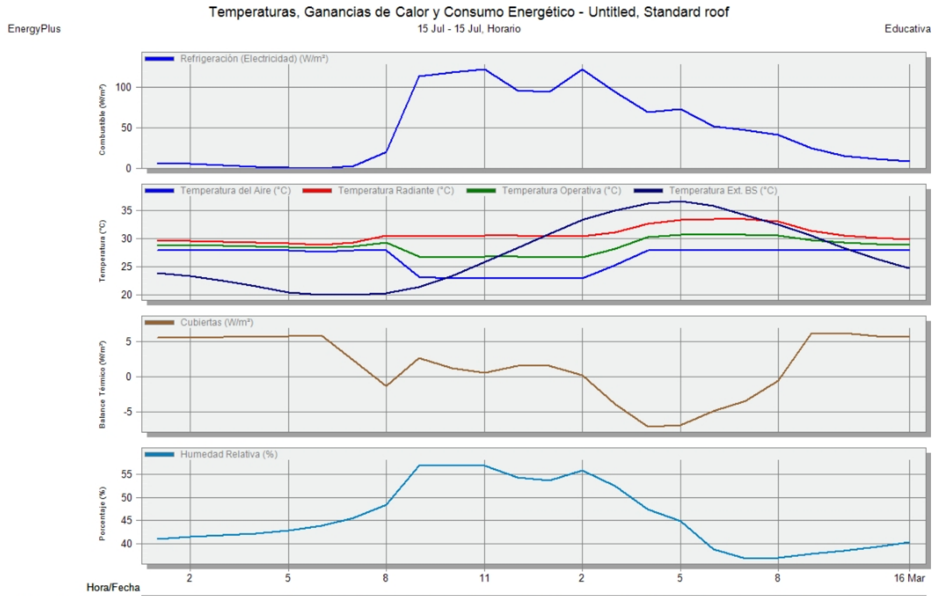
Refrigeración (Electricidad) (Wh/m²)	59917,98
Ocupación (Wh/m²)x10^3	20,05
Gan. Solares Ventanas Ext. (Wh/m²)x10^3	105,11
Refrig. Sens. de Zona (Wh/m²)x10^3	-47,78
Enfriamiento Sensible (Wh/m²)	-47850,77
Enfriamiento Total (Wh/m²)	-59917,99

EcoRoof" cooling demand values from May 1 to September 30

	Standard Roof (kWh/m2)	EcoRoof (kWh/m2)	Reduction
COMPARATIVE	67,42884	59,91799	11,14%

4.3.3. Simulation results for each of the modules by July 15.

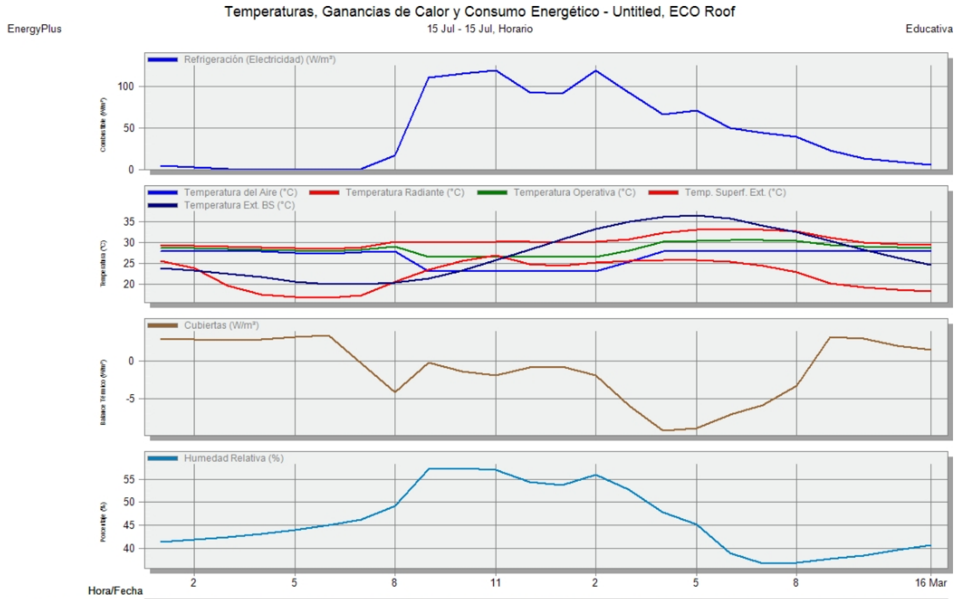
The characteristics of external temperature and solar gains through the roof of both modules are analyzed below.



Hora/Fecha																								
Refrigeración (Electricidad) (W/m²)	6,47	5,03	3,16	1,24	0,00	0,00	2,69	20,18	113,47	118,15	122,64	96,52	94,20	122,29	94,56	68,83	73,51	51,88	46,63	41,23	24,93	15,43	11,46	8,56
Temperatura del Aire (°C)	28,00	28,00	28,00	28,00	27,90	27,65	27,91	28,00	23,17	23,00	23,00	23,00	23,00	23,00	25,33	28,00	28,00	28,00	28,00	28,00	28,00	28,00	28,00	28,00
Temperatura Radiante (°C)	29,71	29,58	29,45	29,31	29,14	28,95	29,35	30,57	30,38	30,43	30,62	30,53	30,37	30,43	31,16	32,64	33,33	33,50	33,47	33,06	31,45	30,51	30,14	29,89
Temperatura Operativa (°C)	28,85	28,79	28,72	28,66	28,52	28,30	28,63	29,29	26,78	26,71	26,81	26,77	26,68	26,71	28,24	30,32	30,66	30,75	30,73	30,53	29,72	29,25	29,07	28,95
Temperatura Ext. BS (°C)	23,90	23,34	22,50	21,64	20,54	20,00	20,00	20,31	21,41	23,32	25,82	28,32	30,82	33,32	35,01	36,16	36,70	35,84	34,14	32,49	30,53	28,28	26,39	24,74
Cubiertas (W/m²)	5,65	5,66	5,71	5,74	5,86	5,97	2,35	-1,33	2,68	1,28	0,62	1,57	1,59	0,29	-3,86	-7,14	-6,81	-4,86	-3,43	-0,52	6,19	6,33	5,81	5,70
Humedad Relativa (%)	40,98	41,53	41,86	42,18	42,85	43,81	45,51	48,37	56,77	57,06	56,84	54,22	53,63	55,80	52,52	47,36	44,85	38,89	36,75	36,91	37,75	38,43	39,40	40,33

StandardRoof" values for a full summer day (July 15)

Peak hour demand (11:00 a.m. on July 15) = 122.6408 Wh/m2 Total demand on July 15 = 1,143.06 Wh/m2



Hora/Fecha																								
Refrigeración (Electricidad) (W/m²)	4,34	2,77	0,79	0,00	0,00	0,00	0,67	16,84	110,68	115,13	119,78	93,82	91,61	119,75	92,16	66,57	71,25	49,71	44,30	38,80	22,51	12,94	8,80	5,58
Temperatura del Aire (°C)	28,00	28,00	28,00	27,89	27,56	27,28	27,69	28,00	23,18	23,00	23,00	23,00	23,00	23,00	25,32	28,00	28,00	28,00	28,00	28,00	28,00	28,00	28,00	28,00
Temperatura Radiante (°C)	29,39	29,25	29,10	28,94	28,71	28,49	28,90	30,19	30,05	30,13	30,34	30,27	30,11	30,18	30,91	32,38	33,08	33,24	33,20	32,78	31,13	30,15	29,74	29,45
Temperatura Operativa (°C)	28,70	28,62	28,55	28,41	28,14	27,88	28,29	29,10	26,62	26,56	26,67	26,63	26,55	26,59	28,12	30,19	30,54	30,62	30,60	30,39	29,57	29,07	28,87	28,72
Temp. Superf. Ext. (°C)	25,52	23,78	19,58	17,45	16,92	16,64	17,37	20,52	23,45	25,53	26,96	24,89	24,49	25,16	25,58	25,83	25,83	25,33	24,36	22,96	20,23	19,14	18,70	18,21
Temperatura Ext. BS (°C)	23,90	23,34	22,50	21,64	20,54	20,00	20,00	20,31	21,41	23,32	25,82	28,32	30,82	33,32	35,01	36,16	36,70	35,84	34,14	32,49	30,53	28,28	26,39	24,74
Cubiertas (W/m²)	3,00	2,86	2,82	2,93	3,24	3,39	-0,35	-4,20	-0,21	-1,42	-1,94	-0,86	-0,73	-1,94	-5,98	-9,24	-8,98	-7,14	-5,91	-3,26	3,19	2,97	2,06	1,55
Humedad Relativa (%)	41,31	41,97	42,42	43,05	44,05	44,96	46,30	49,26	57,23	57,28	57,03	54,36	53,74	55,93	52,71	47,73	45,12	39,02	36,77	36,93	37,78	38,52	39,57	40,66

EcoRoof" values for a full summer day (July 15)

Peak hour demand (11:00 a.m. on July 15) = 119.7783 Wh/m² (2.33% reduction) Total demand on July 15 = 1,088.79 Wh/m² (4.75% reduction)

As can be seen, and in spite of being a model that contemplates very basic values to define the elements that determine the composition of the green roof, the above simulation allows us to appreciate the decrease in surface temperature throughout the day in the case of the "EcoRoof" with respect to the "StandardRoof". It can also be observed how the gains through the roof decrease, becoming negative, which indicates the heat dissipation effect of the green roof (the data for the whole day goes from +41.05 Wh/m^2 , in the case of the "StandardRoof", to -24.15 Wh/m^2 , in the case of the "EcoRoof").

This leads us to determine the need for a more exhaustive definition and investigation of the solution to be implemented on the roof, in *order to arrive at a more concrete approach to the "real" performance of what the implementation of a green roof would entail.*

5. STUDY OF NATURAL VENTILATION

Next, we will study the influence of natural ventilation applied to each of the above solutions (Case 3.1 and 3.2), starting from two different protocols, one applying natural ventilation during the occupancy period (ventilation protocol 1) and the other performing constant natural ventilation throughout the day, to take advantage of nighttime "freecooling" (ventilation protocol 2).

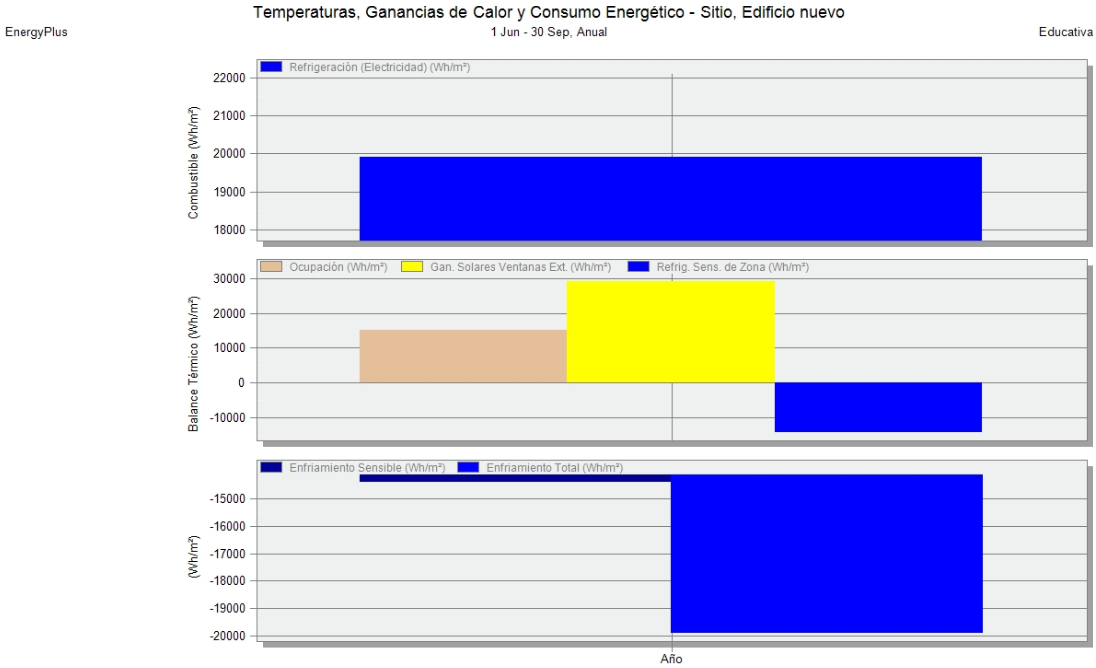
To address this point, a detailed analysis has been made of the ventilation regulations (6), which apply to schools (IDA 2 -good quality air- IDA 3 -average quality air-), applying the data on flow rates per person to the number of students per standard classroom for the case of Badajoz.

Surface area (m2)	Height (m)	No. of students	Flow (l/s) x person	Regulations	Renew/hour
54,44	2,84	25	**20,0**	RITE - IDA 1	11,6
54,44	2,84	25	**12,5**	RITE - IDA 2	7,3
54,44	2,84	25	**8,0**	RITE - IDA 3	4,7
54,44	2,84	25	**5,0**	RITE - IDA 4	2,9

54,44	2,84	25	**10,0**	EN 15251 - I	5,8
54,44	2,84	25	**7,0**	EN 15251 - II	4,1
54,44	2,84	25	**4,0**	EN 15251 - III	2,3

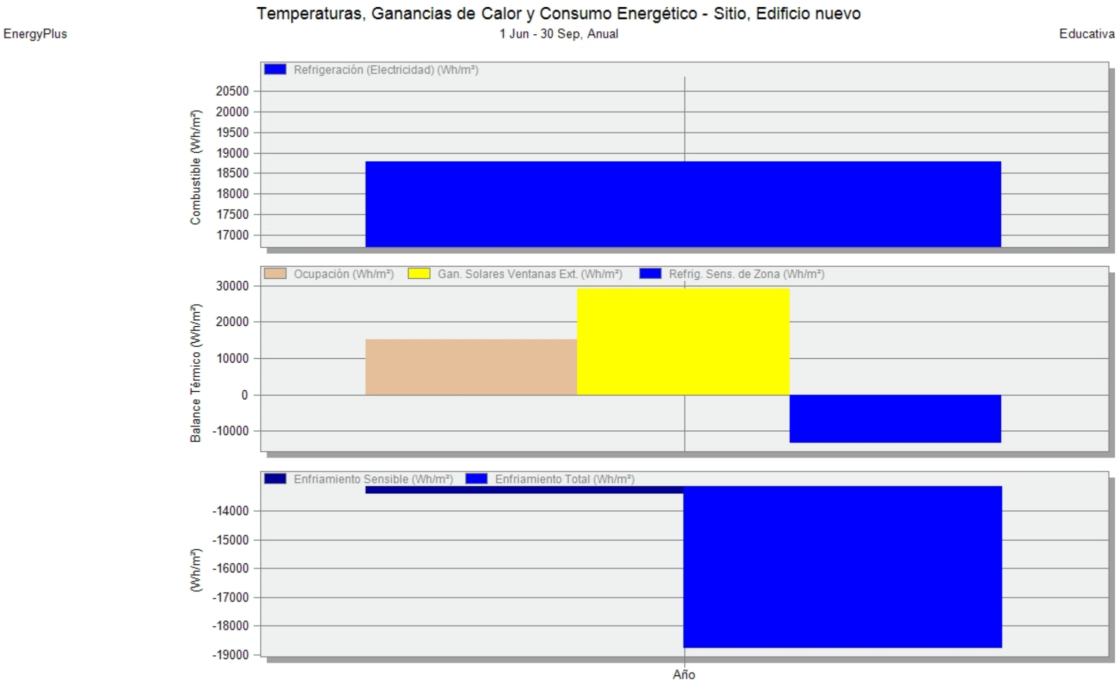
Recent studies on ventilation in educational centers would recommend a minimum of 3.5 renov/hour, for cases similar to the one studied (4), while the EN 15251 standard (5), indicates three levels (from 2.3 to 5.8 renov/hour). However, it will be taken into account to respect the minimum flow rates determined by the Spanish RITE standard for category IDA 3, so 5 renov/hour will be considered, applied in the period of occupation (v1) and all day (v2) to take advantage of the "freecooling" at night.

5.1. Ventilation during the period of occupancy



Refrigeración (Electricidad) (Wh/m²)	19909,41
Ocupación (Wh/m²)	15106,81
Gan. Solares Ventanas Ext. (Wh/m²)	29277,92
Refrig. Sens. de Zona (Wh/m²)	-14385,71
Enfriamiento Sensible (Wh/m²)	-14386,12
Enfriamiento Total (Wh/m²)	-19909,41

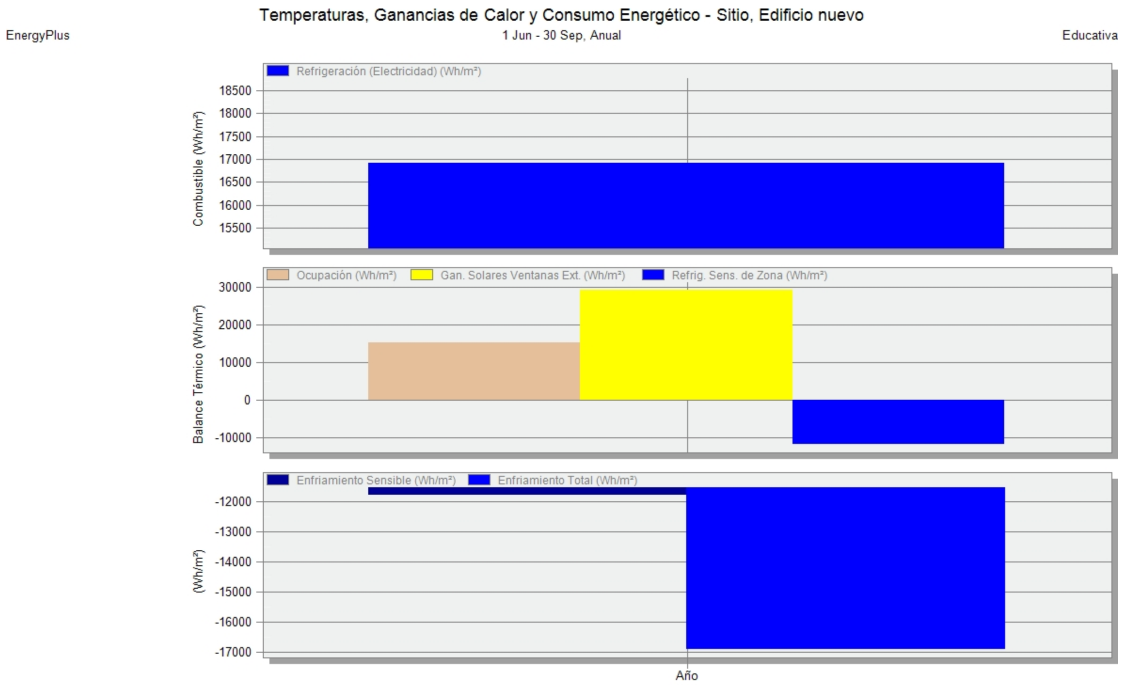
Case 3.1. with ventilation protocol 1



Refrigeración (Electricidad) (Wh/m²)	18785,09
Ocupación (Wh/m²)	15128,80
Gan. Solares Ventanas Ext. (Wh/m²)	29275,42
Refrig. Sens. de Zona (Wh/m²)	-13397,74
Enfriamiento Sensible (Wh/m²)	-13395,87
Enfriamiento Total (Wh/m²)	-18785,09

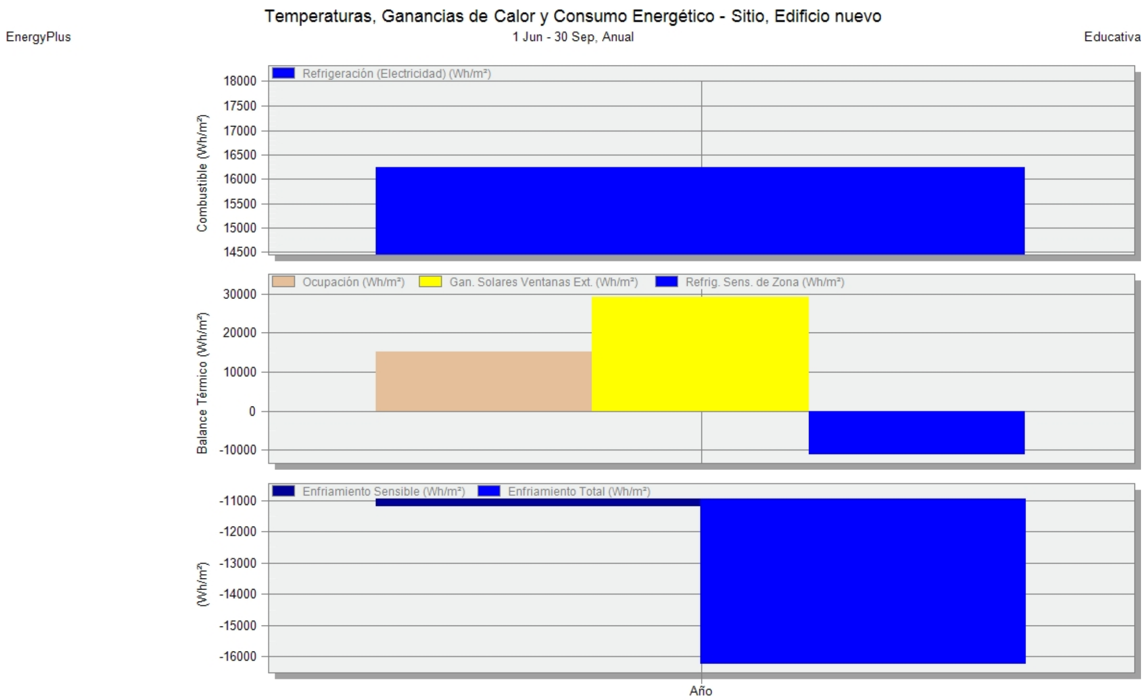
Case 3.2. with ventilation protocol 1

5.2. Ventilation throughout the day



Refrigeración (Electricidad) (Wh/m²)	16918,72
Ocupación (Wh/m²)	15281,09
Gan. Solares Ventanas Ext. (Wh/m²)	29277,92
Refrig. Sens. de Zona (Wh/m²)	-11782,97
Enfriamiento Sensible (Wh/m²)	-11770,42
Enfriamiento Total (Wh/m²)	-16918,72

Case 3.1. with ventilation protocol 2



Refrigeración (Electricidad) (Wh/m²)	16243,63
Ocupación (Wh/m²)	15284,31
Gan. Solares Ventanas Ext. (Wh/m²)	29275,42
Refrig. Sens. de Zona (Wh/m²)	-11199,95
Enfriamiento Sensible (Wh/m²)	-11188,25
Enfriamiento Total (Wh/m²)	-16243,63

Case 3.2. with ventilation protocol 2

The comparison of the different cases described above (Case 3.1 and 3.2, with the base model -Case 0-), as a result of the addition of ventilation protocols to the initial model, yields the following energy demand reduction data.

CASE 0	CASE 3.1	CASE 3.1.v1	CASE 3.1.v2
Without FAVE (kWh/m2)	**With FAVE -East- + Trees -West- + Substrate (kWh/m2)**	**With ventilation protocol 1 (kWh/m2)**	**With ventilation protocol 2 (kWh/m2)**
41,78965	28,94716	19,90941	16,91872
	Reduction with respect to Case 0	**Reduction with respect to Case 0**	**Reduction with respect to Case 0**
	30,73%	52,36%	59,51%
	CASE 3.2	**CASE 3.2.v1**	**CASE 3.2.v2**
	With FAVE -East- + Trees -West- + ShadeCover (kWh/m2)	**With ventilation protocol 1 (kWh/m2)**	**With ventilation protocol 2 (kWh/m2)**
	27,70213	18,78509	16,24363
	Reduction with respect to Case 0	**Reduction with respect to Case 0**	**Reduction with respect to Case 0**
	33,71%	55,05%	61,13%

SUMMARY TABLE OF THE VENTILATION COMPARISON

The absolute values, in kWh/m², of cooling demand represented in this document should be taken with extreme caution, as they could be oversized.

6. DISCUSSION AND CONCLUSIONS

-In terms of plant surfaces:

It is well known that, in summer, vegetation acts as a protective layer that shades the envelope elements from solar radiation (2). The effectiveness of a vegetation cover depends on the type of vegetation and the density of leaves, expressed by the *leaf area index*. The advantage of using vegetation as a cover is linked to the ability of plants to absorb part of the solar radiation received and to be able to use it for their biological functions (evapotranspiration, photosynthesis, etc.). As long as there is sufficient moisture in the substrate, evapotranspiration is proportional to the thermal stress, which means that this biological cooling mechanism adapts to the environmental conditions and is maximized when solar irradiation is high, i.e. the times of greatest cooling demand in buildings. This would not be the case when the substrate is dry (1).

Considering that the air between the leaves is kept at a relatively low temperature and the vegetation layer shades the surface, the upper part of the substrate is kept at a lower temperature than the ambient temperature. Considering the high thermal capacity of the substrate, especially when the moisture content is high, the vegetation cover has the function of lowering the temperature of the outer layer of the enclosures, thus avoiding excessive exposure to solar radiation. This cooling system works during the warm seasons of the year, greatly reducing the energy demand for cooling (3).

The conclusions of various studies on the energy savings in heating and cooling resulting from the installation of vegetation surfaces are sometimes contradictory, especially when they are based on simulations. This is partly due to the large number of parameters required to describe the physical phenomena taking place inside the vegetation volume (1). In order to facilitate the study, simplifications are often assumed that can alter the results, as could be the case here.

This induces us to determine the need for a more exhaustive definition and investigation of the solution that will be carried out on the roof, in order to reach a more concrete approach to the "real" performance of what the implementation of a green roof would entail through simulation. *(In this regard, a collaboration is being sought with a research group of the GBCe, together with the UPM; since they are groups that are investigating the different options and variants of the "GreenRoof" -collected by the DesignBuilder program-, in order to exploit to the maximum its simulation to the real performance that would have this type of roof solutions).*

-As for the calibration of the model:

In most aspects it has been possible to adapt the base model to the real conditions of the real educational center. These are, for example: constructive composition of the envelope, in terms of its dimensioning and composition, thanks to the contribution of the

Energy Efficiency Certificate, and the transmittance values of each of the elements that compose it. It has also been possible to adjust the occupancy schedule and the number of students per classroom, in each case. However, there is a lack of real data on how ventilation is currently carried out. Despite the fact that during the summer months when there is no activity, it is certain that there is no ventilation, there is no data available that would allow us to know how air renewal is carried out during the school period.

On the other hand, data from monitoring, which could have been useful for calibrating and adjusting the base model, are difficult to manage for the moment. Since the location on the map of each of the numbered sensors is not available, and the data obtained to date, in the case of Badajoz, show various gaps alternately and randomly throughout the monitoring period. Thus, it will be necessary to wait for more continuous and homogeneous information to continue adjusting the model.

-As for ventilation:

As mentioned in the previous paragraph, data on the ventilation of the current state must be available in order to be able to start from a base situation (Case 0), as close as possible to reality.

However, the brief ventilation study carried out indicates the suitability of proposing natural ventilation protocols for the summer months, compatible with the promotion of night cooling ("freecooling"), and complying with current state regulations (or the most restrictive, in each case), which guarantee average air quality (at least).

-AS A FINAL CONCLUSION:

It can be said that, through the addition of the different nature-based solutions (NBS), -analyzed gradually in this document, and whose results can be considered in any case on the safety side, in any case-, percentages of cooling demand reduction exceeding 50% can be achieved.

Nevertheless, and although this document serves as a guide as a starting point for such analysis, further research will be carried out to further investigate the behavior of the different solutions in order to achieve a greater similarity between the real performance expected from such solutions (and confirmed by different scientific studies that have been carried out to prove it) and the results obtained from the simulations of such solutions.

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