**Table 1. Monthly data for electricity consumption**

| Month | Electricity consumptiom | Month | Electricity consumption |
|---|---|---|---|
| January* | --------------- | July | 12830,13 kWh |
| February* | 9064,00 kWh | August | 14196,82 kWh |
| March | 17310,92 kWh | September | 11826,03 kWh |
| April | 13955,56 kWh | October | 14753,26 kWh |
| May | 10086,99 kWh | November | 14640,30 kWh |
| June | 13132,75 kWh | December* | 7660,42 kWh |
| TOTAL | | | 139458,00 kWh |

*The visitors centre is closed from December 15 to February 15

**Table 2. Annual energy consumption and $CO_2$ emissions**

| Primary source | Annual energy consumption | Conversion in kWh | Annual emissions CO2 | |
|---|---|---|---|---|
| Electricity | 136.829 kWh | 136.829 kWh | 0,25 kgCO2eq/kWh* | 34,2 Tn |
| Electricity - Photovoltaic | 2.629 kWh | 2.629 kWh | 0 | 0 Tn |
| Propane gas | 23.314 kg | 324.512 kWh | 2,94 kgCO2eq/kg | 68,5 Tn |
| Diesel | 10.577 l | 26.500 kWh | 2,72 kgCO2eq/l | 28,8 Tn |
| Solar Thermal | 15.194 kWh | 15.194 kWh | 0 | 0 Tn |
| | **TOTAL** | **505.664 kWh** | **TOTAL** | **131,5 Tn** |
| | Ratio (kWh/m2year) | 202 | Ratio (kg/m2year) | 53 |

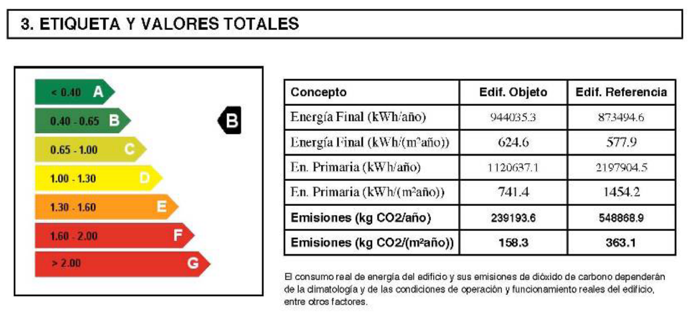
For assessing the $CO_2$ emissions, we have taken into account the annual energy consumption from different sources and emission coefficients per unit (Table 2)

## ENERGY CERTIFICATION OF THE CURRENT BUILDING

A simulation was conducted with Leader and Calener software (Table 3) providing the following results: the building has a significant heating load (G) that can be attributed to the area's climatic conditions and a significant cooling load (C). Its CO2 emissions are average, being awarded a D, which is some way off the optimum level (A).

According to Spanish regulations the building's energy certification is graded as a B and the environmental conditions achieved inside the building must be: 23ºC - 25ªC temperature / 45% -60% relative humidity range in sumer and 21ªC-23ªC temperature / 40%-50% relative humidity range in winter.

**Table 3. Energy certification**



3. ETIQUETA Y VALORES TOTALES

| Concepto | Edif. Objeto | Edif. Referencia |
|---|---|---|
| Energía Final (kWh/año) | 944035.3 | 873494.6 |
| Energía Final (kWh/(m²año)) | 624.6 | 577.9 |
| En. Primaria (kWh/año) | 1120637.1 | 2197904.5 |
| En. Primaria (kWh/(m²año)) | 741.4 | 1454.2 |
| **Emisiones (kg CO2/año)** | **239193.6** | **548868.9** |
| **Emisiones (kg CO2/(m²año))** | **158.3** | **363.1** |



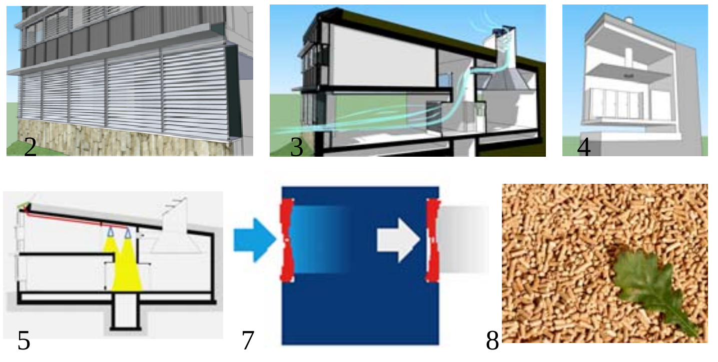
## ACTION CHECK LIST

This section describes the actions planned to reduce the building energy consumption and achieve Nearly Zero Energy Building while improving indoor environmental quality. Will also detail the software tools that have been used for energy modeling.

Improvements employing passive strategies

1. Increasing wall insulation and replacement of existing windows by Higher-efficiency windows
2. Installation of motorized venetian blinds for protection from solar radiation on the south-facing façade (simulation with Ecotec)
3. Improving natural ventilation system for cooling in the summer (simulation with Phoenics)
4. Installation of highly efficient light tubes for channeling natural lighting into the bathrooms
5. Installation of a solar collector for channeling natural lighting in the corridors

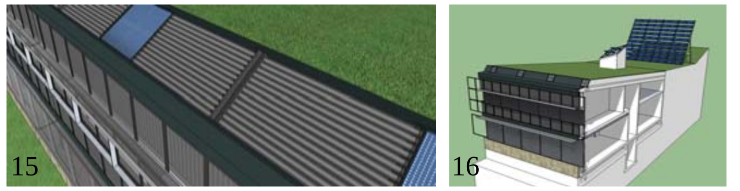
**Figure 2** Improvements





Improvements based on energy efficient systems

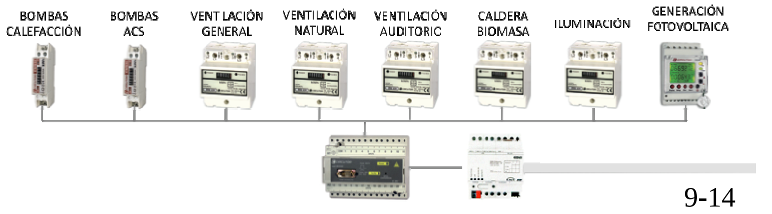
6. Optimization of artificial lighting by adjusting power installments (simulation with Dialux)
7. Installation of free cooling system in the auditorium
8. Replacement of gas boiler with a biomass boiler for heating and air conditioning





Enhancing the equipment of the building's management systems to increase energy efficiency

9. Control and regulation of blinds
10. Control and regulation of natural ventilation
11. Regulation system for lighting and light levels
12. Control and regulation of the free cooling system in the auditorium
13. System of measurement and monitoring of power consumption
14. System management of all the proposed services





Substitution of conventional energy sources with renewable sources

15. Production of air conditioning with solar thermal vacuum tubes, (48 modules, 62,48 m2. of catchment)
16. Electricity production using a photovoltaic installation on the roof, (78,75 kWp)

While it is evident that to increase energy efficiency of the building, the first action should be to improve the insulation, in some well-designed buildings of our modern built heritage like this one, specific constructive solutions to improve thermal performance of the building envelope are very difficult to implement, due to its high cost and the modification of its image. Therefore in this particular case study it was decided to use other strategies that do not damage the outward appearance and the interior finishes

## ENERGY BALANCE

Among the different actions proposed we have included a new primary energy source, namely, biomass. Propane gas and diesel consumption has been virtually eliminated, limited now solely to the kitchen. We have not taken into consideration the fuel used in the electric generator as consumption is restricted to exceptional occasions (when there is a power outage) and so this does not form part of the building's normal operating conditions. The building's electricity consumption has undergone a significant reduction (in the order of 37%), which has considerably improved the ratio of energy consumed per square meter/year.

## $CO_2$ EMISSIONS

Taking into account the reductions in consumption outlined in the previous section (and ignoring fuel consumption for the reasons presented above), the CO2 emissions can now be assessed. The electrical energy harvested from the photovoltaic system makes a negative contribution to CO2 emissions because it is clean energy fed into the grid, which helps improve the energy mix. This output also improves the ratio of energy consumed per square meter, as it offsets a significant proportion of the total, reducing the ratio from 202 kWh/m2 to 131 kWh/m2 year in the initial year of the proposed scenario.

Without taking the photovoltaic system into consideration, CO2 emissions are significantly reduced from an initial 302 tons/year to 131.5 tons/year, thanks to the marked reduction in the total amount of electricity consumption and virtual elimination of propane gas consumption. If we consider the total energy harvested from the photovoltaic system, we see this generates all the electricity consumed, thus enabling us to certify our building as a net zero energy building.

Energy consumption and CO2 emissions are summarized in Table 4.

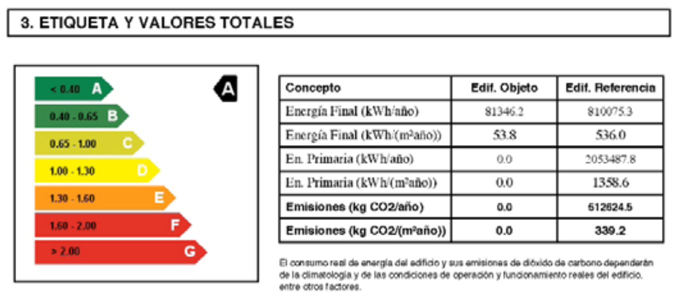
**Table 4. Final annual energy consumption and $CO_2$ emissions**

| Primary source | Annual energy consumption | Conversion in kWh | Annual emissions $CO_2$ | |
|---|---|---|---|---|
| Electricity | 105.313 kWh | 105.313 kWh | 0,25 kgCO2eq/kWh* | 20,3 Tn |
| Electricity - Photovoltaic | -119.640 kWh | -119.640 kWh | 0,25 kgCO2eq/kWh* | -29,9 Tn |
| Gas propane | 1.314 kg | 1.290 kWh | 2,94 kgCO2eq/kg | 3,9 Tn |
| Biomass | 80.213 kg | 300.800 kWh | Balance neutral | 0 Tn |
| Solar Thermal | 38.913 kWh | 38.913 kWh | 0 | 0 Tn |
| | **TOTAL** | **326.676 kWh** | **TOTAL** | **0,3 Tn** |
| | Ratio (kWh/m2year) | 131 | Ratio (kg/m2year) | 0 |

## FINAL ENERGY CERTIFICATION

After implementing the above actions a new simulation was conducted with the Leader and Calener software providing the following results: improvements in the passive design mean that the load demand has been reduced by 10%. The use of energy efficient active systems and the harvesting of energy from renewable sources now ensure the provision of 100% of the uilding's requirements. In this respect, the building's initial D rating has been raised to an A.

**Table 5. Final energy certification**


3. ETIQUETA Y VALORES TOTALES

| Concepto | Edif. Objeto | Edif. Referencia |
|---|---|---|
| Energía Final (kWh/año) | 81346.2 | 810075.3 |
| Energía Final (kWh/(m²año)) | 53.8 | 536.0 |
| En. Primaria (kWh/año) | 0.0 | 2053487.8 |
| En. Primaria (kWh/(m²año)) | 0.0 | 1358.6 |
| **Emisiones (kg CO2/año)** | **0.0** | **612624.5** |
| **Emisiones (kg CO2/(m²año))** | **0.0** | **339.2** |

El consumo real de energía del edificio y sus emisiones de dióxido de carbono dependerán de la climatología y de las condiciones de operación y funcionamiento reales del edificio, entre otros factores.

Production of ACS using vacuum tubes also satisfies 100% of demand.

Improvements in artificial lighting mean the building's initial B rating has been raised to a final A rating. CO2 emissions have been reduced to a minimum. The building obtains a final A rating, recording optimum scores in all categories.

## INFERENCES AND CONCLUSION

**Table 6. Actions, quality improvements, saving and investment**

| Improvements | Annual quantitative improvements: Decrease emissions Tn CO2/year | | Savings/year | | Investment | |
|---|---|---|---|---|---|---|
| Louvers (installation and regulation) | | | | | 114.217 € | 14,5 % |
| Natural ventilation (installation and regulation) | | | | | 103.420 € | 13.2 % |
| Natural lighting bathrooms | 0,18 Tn $CO_2$ | 0,2 % | 110 € | 0,2 % | 5.018 € | 0,6 % |
| Natural lighting hallways | 3,65 Tn $CO_2$ | 3,3 % | 2.187 € | 3,9 % | 67.811 € | 8,6 % |
| Lighting (control and regulation) | 13,46 Tn $CO_2$ | 12,2 % | 8.078 € | 14,3 % | 23.518 € | 3,0 % |
| Auditory cooling (installation and regulation) | | | | | 39.170 € | 5,0 % |
| Biomass Boiler | 56,85 Tn $CO_2$ | 51,4 % | 12.682 € | 22,5% | 39.865 € | 5,1 % |
| Solar Thermal Energy | 4,40 Tn $CO_2$ | 4,0 % | 2.215 € | 3,9 % | 55.959 € | 7,1 % |
| Photovoltaic energy | 29,9 Tn $CO_2$ | 27,1 % | 29.910 € | 53,1 % | 327.994 € | 41,7 % |
| Electrical lines losses reduction | 1,98 Tn $CO_2$ | 1,8 % | 1.189 € | 2,1 % | 6.497 € | 0,8 % |
| Electrical consumption measurement | | | | | 2.729 € | 0,3 % |
| Total | 110,42 Tn $CO_2$ | 100 % | 56.371 € | 100 % | 786.198 € | 100 % |

In a not too distant future, the progressive implementation of the Energy Performance of Buildings Directive in the building sector will lead a transition to the design of new buildings in which the energy concept constitutes a fundamental premise. This clearly represents a major challenge for architects, radically changing the way we design buildings.

This paper has made various contributions to this debate. In terms of methodology, it has stressed the importance of using specific software tools to verify the behavior of the solutions proposed. As shown with the corresponding architectural modifications, any existing building can achieve the nearly zero energy standards and produce its energy requirements from renewable sources in the building or in its surrounding environment. The building in our case study today generates 100% of its energy. This is a clear example of energy efficient architecture employing the tools of the bioclimatic design process. Active energy efficiency and the use of renewable energy sources are the way to shrink a building's carbon footprint.

Finally, we conclude that the most useful contributions of our applied research lie, first, in its ability to inspire and lead architects and engineers in the future energetic refurbishment of built heritage as they convert them into NZEBs. This proposal is a practical demonstration that sustainability is not an obstacle to design but rather a challenge to creativity. And, second, our proposal has the ability to revive those productive sectors suffering the effects of the current economic crisis. The example reported here should reduce resistance within the construction sector to adopt these principles, thereby allowing a successful theoretical concept to become a reality that can be accepted by the market and so generate renewed economic activity.

## ACKNOWLEDGMENTS REFERENCES

This applied research has been developed by C-06239 Agreement between the Polytechnic University of Catalonia and "fundacio territori i paisatge" It has enjoyed the cooperation of the students of the Master Architecture and Sustainability Carles Carreras, Juli Fernandez, Anré Lopes, Midory Monroy, Alvaro Quiroga, that under our leadership have developed graphical approach, drawing plans and renderings, and thus have greatly helped us in the development of this proposal.

## REFERENCES

ATLAS DE RADIACIÓ SOLAR A CATALUNYA. EDICIO 2000, Generalitat de Catalunya, Departament d'Industria Comerç i Turisme, Institut Catalá d'Energia (ICAEN)
http://www20.gencat.cat/docs/icaen/02_Energies%20Renovables/Documents/Arxius/Atlas%20de%20radiacio%20solar.pdf

DIRECTIVE 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union, L153, 18.6.2010, pp. 13–35. (recast) (COM) (2008) 0780-C6-0413/2008-2008/0223 (COD), 2009.
http://www..europarl.europa.eu/meetdocs/2009_2014/documents/cls/cons_cons(2010)05386(rev3)/cons_cons(2010)05386(rev3)_en.pdf

FUNDACIO TERRITORI I PAISATGE , Tabla resumen de consumos de agua y electricidad del centro de visitantes de les Planes de Son.

LES PLANES DE SON, EULEB European High Quality Energy Buildings, Inteligent Energy Europe, 2005-2006 www.new-learn.info/packages/euleb/es/home/index.html

MLENICK, E.; ATTIA, S.; VAN LOON, S. y KONDRATENKO, I. IEA Net zero energy building: a review of current-SHC, 2011, http://task40.iea-shc.org/data/sites/1/publications/DA-TP11-Mlecnik-2011-11.pdf .

NEWTON, P. y TUCKER, S. Hybrid Buildings: a Pathway to carbon neutral housing. Transforming markets in the built environment: adapting to climate change. In: Architecture Science Review, 53 (1): 95-106, 2010.

PLESS, S. y TORCELLINI, P. "Net-Zero Energy Buildings: A classification System Based on Renewable Energy Supply Options", NREL National Renewable Energy laboratory. Technical Report NREL/TP-550-44566, June 2010
http://www.nrel.gov/sustainable_nrel/pdfs/44586.pdf

PLESS, S. y TORCELLINI, P. Towards Net Zero Energy Solar Building .IEA SHC Task 40, (2010), pp.25 , Net Zero Energy Buildings: A classification System Based on Renewable Energy Supply Options. Technical Report, NREL/TP-550-44586, (2010), pp. 1 URL: http://www.iea-shc.org/task40.

VOSS K., SARTORI I. LOLLINI R. "Nearly-zero, NetZero and Plus Energy Buildings-How definitions & regulations affect the solutions." REHVA journal- December 2012, p.24
http://task40.Iea-shc.org/publications.pdf