Introduction: Options for Sustainable Design in Building

In the design and development of projects we can follow different paths to achieve sustainable architecture:

- Adopt obligatory environmental measures
- Adopt voluntary environmental measures
- Adopt the management system proposed by the regulation *UNE 150.301, Environmental management of the design and development process. Eco-design,* as a tool that considers all variables that affect sustainable building.

In recent years European Directives (DE 1989/106 about construction products and DE 2002/91 Energy Efficiency of Buildings) have appeared that have framed the topic of sustainability; these directives have materialized partially in the Código Técnico de la Edificación (Technical Building Code, CTE). From the environmental point of view, the CTE gathers conditions and requirements of energy savings (DB-HE1, DB-HE2, DB-HE3, DB-HE4 y DB-HE5) and health (HS1, HS2, HS3, HS4 y HS5) that carry out the adoption of environmental measures (we could say obligatory measures) in order to comply with the fixed requirements.

On the other hand, beyond the minimums established in the regulations, other environmental measures or construction solutions can be adopted and defined as more sustainable because they surpass the minimum requirements. Examples of these include the use of flat green roofs or roofs flooded with water, double-skin glass facades, energy control facades, alternative energies not considered in the CTE, etc. The adoption of these measures is often done without any serious study of efficiency and without quantifying the contributions they make relative to the climatic zone. Even public architectural design competitions reflect the myths of sustainable building: they award points for the adoption of environmental measures that appear in various sustainability guides, in particular regulations, in architectural journals and that have been used in other climatic zones, in other municipalities and in other sites. With the passing of time, reality demonstrates the inefficiency of these measures, since the conditions are different, in terms of both climate and surroundings. This results in new urban developments full of bioclimatic inventions taken out of context, as opposed to the solution of a well-studied opening towards the south, greenhouses and enclosed balconies that produce more harm in summer than benefit in winter. It begs the question, why these measures are adopted instead of others? Perhaps there is little knowledge and few data to quantify the results obtained in the application of environmental measures in projects.

The third path, presented in the regulation UNE 150.301 takes a step forward. It intends to introduce an environmental management system from the design and development process that establishes a methodology to design buildings that generate the least possible environmental impact throughout their lifecycle (fabrication of products, building construction, use and maintenance and destruction), from concept to demolition, considering the efficiency of the adopted environmental measures.

Methodology of the Eco-design Management System

This methodology involves the following steps:

- Identification and evaluation of environmental aspects significant to this project.
- Identification of legal requirements
- Environmental objectives of projects.
- Operational control; verification and quantification of objectives
- Communication to all interested parties regarding the adopted measures and the pursued objectives

At the beginning of each project, applicable environmental aspects in the project should be identified and evaluated to detect those that are significant. This evaluation can be realized following criteria of magnitude or quantity, among other criteria, and criticality (toxicity, seriousness or danger), attending to the specific circumstances of the associated environmental impacts.

Once the significant environmental aspects are identified, improvement objectives should be set for each one of these aspects. In order to achieve these objectives it will be necessary to employ diverse environmental measures (selecting those that are effective). Each one of these measures will contribute to achieving a percentage of the established objective, which requires a close following of these measures as the design of the project is developed, verifying at the end of the design process that the objective has been achieved.

The environmental aspects that should be taken into account in building are fundamentally:

- energy, water and material consumption
- atmospheric emissions
- liquid discharges
- waste generation: dangerous and non-dangerous
- sound generation
- visual impact
- land occupation

Applied Example in the Rehabilitation of the Envelope of an Existing Building

This example is a building of 36 living units, characteristic of suburban zones, constructed in 1970 in Pamplona (climatic zone D1); it has an H-shaped plan, one ground floor and nine floors of residential units, four per floor. Each unit has a useable area of 80 m2. Given the year of construction, the building's rehabilitation is considered due to problems caused by the building envelope.

Identification of Significant Environmental Aspects

The different environmental aspects that are influenced by rehabilitation are assessed in order to evaluate their significance in function of quantity and criticality. It is found that energy consumption is a significant environmental aspect, both in the usage phase and in the fabrication phase.

Objectives

The following objectives are considered:
- Reduction of energy consumption in the usage and maintenance phase: 30%
- Choice of systems of envelope rehabilitation whose energy consumption in fabrication is less than 1500Mj/m2.
- Lowered energy consumption in the fabrication of the rehabilitation system employed with savings during the use and maintenance phase (in less than 5 years)

Environmental Measures to Adopt in Order to Achieve the Objectives

The following is proposed:

Insulation in facades
Insulation in roofs
Window rehabilitation

Verification and quantification of the first objective. Savings in heating energy consumption in the use and maintenance phase

The original facade is composed of courses of double hollow-core brick. The roof is flat: above the slab it has a layer of sloped concrete and a waterproof membrane. The window frames are wood with single-pane glazing.

It is proposed to rehabilitate the facades using a cross-ventilated facade system, since its environmental performance in winter and summer is optimum, not to mention that it resolves problems of thermal bridges, stagnated water and air, movement stability and the increased thermal inertia of the envelope.

Likewise, the rehabilitation of the roof is designed according to an inverted roof system: removing the existing membrane, repairing the sloped concrete, installing a bituminous membrane, 5 cm of extruded polystyrene insulation and a layer of gravel with a minimum depth of 5cm. For the window frames the single-pane glazing is replaced with double-pane glazing.

Table 1 shows the energy consumption calculated before rehabilitation and the consumption that will be obtained after rehabilitation of the envelope.

Table 1 : Quantification of energy savings in heating

	Un-insulated building	**Insulated building**	**Savings**	**% Savings**
U facade	1'43 W/m^{2}K	0'45 W/m^2 K		
U roof	2'08 W/m^2 K	0'50 W/m^2 K		
U openings	5'70 W/m^2 K	3'5 W/m^2 K		
Annual consumption of building heating	619.400 KWh	334.124 KWh	285.276 KWh	46%
Annual consumption per dwelling	17.205,55 KWh	9.281,22 KWh	7.924,33 KWh	46%
CO_2 Emissions of the building	124.487,01 $KgCO_2$	67.152,24 $KgCO_2$	57.334,77 $KgCO_2$	46%
CO_2 per dwelling	3.457,97 $KgCO_2$/dwelling	1.865,34 $KgCO_2$/dwelling	1.592,63 $KgCO_2$/dwelling	46%

It achieves the proposed objective.

Verification and quantification of the second objective. Quantification of energy consumption of the façade rehabilitation in the construction phase

Having seen the annual energy savings in heating consumption during use and maintenance, we will now see the effect of the adoption of a façade rehabilitation system on construction energy consumption, that is, in the first phase of the lifecycle of the construction process.

In the first place, data referring to energy consumption in the fabrication of construction materials are calculated in order to later study energy consumption of the different solutions for façade rehabilitation.

Data for energy consumption of materials are taken from different databases: IDAE [1] and NZCBPR. [2]. Likewise, data about the energy cost of other materials not represented in these tables have been obtained from the database METABASE of the ITEC. [3]

The components that are employed in the rehabilitation systems of these facades are: thermal insulation (extruded polystyrene, polyurethane or mineral wool), substructures (of galvanized steel, stainless steel, aluminum or wood) and the exterior veneer (stone, ceramic, wood, GRC, Naturvex, metal plating, multilayer metallic panels, metal sheeting and glass). The energy cost of these products is shown in Tables 2 and 3.

Table 2 : Comparative energy study of insulation materials and substructures for cross-ventilated facades

Insulating materials for facade rehabilitation on the outside

Material	Thickness (m)	Density (Kg/m3)	Density (Kg/m2)	Energy Cost (Mj/Kg)	Partial energy cost (Mj/m2)
Expanded polystyrene. EPS	0,05	20,00		120,00	120,00
Extruded polystyrene. XPS	0,05	40,00		100,00	200,00
Polyurethane. PUR	0,04	40,00		70,00	112,00
Fiberglass	0,06	30,00		30,00	54,00
Rockwool	0,06	50,00		18,00	54,00

Substructures of cross-ventilated facades for facade rehabilitation on the outside

Material	Thickness (m)	Density (Kg/m3)	Density (Kg/m2)	Energy cost (Mj/Kg)	Partial energy cost (Mj/m2)
Wood Preventative treatments			6,4 3 x 0'15	3,00 93	61,05
Aluminum			5,74	215,00	1.234,1
Galvanized steel			4,56	37,00	168,72
Stainless steel			4,56	177,00	807,12

Analyzing the tables in figures 2 and 3 we can see:

- Regarding the **thermal insulation,** plastic materials (extruded polystyrene: 100 Mj/Kg, polyurethane: 70 Mj/kg) present a greater energy consumption compared to natural materials (rock wool: 18 Mj/kg and fiberglass: 30 Mj/kg). However, the minimal weight of the isolative material makes its influence on the façade system assembly negligible (Table 4).
- Among the substructure materials, there is a great difference between aluminum (215 Mj/kg) and stainless steel (177 Mj/kg), compared to galvanized steel (37 Mj/kg) and wood (3 Mj/kg + preventative protection) (Table 3).

  Although the wood substructure has a lower energy cost than the metallic substructures, it should be kept in mind that technical limitations make the use of steel or aluminum substructures more appropriate in terms of durability.

In spite of the high energy cost of aluminum and stainless steel fabrication, these materials offer optimal qualities of durability and resistance. It is necessary to insist that both steel and aluminum permit three of the four Rs of sustainability: reduce, reuse and recycle. [4]

The different substructures have been quantified for their repercussion of weight per m2.

Regarding **exterior veneers** we find ourselves with a great variety (Table 3). In the different solutions that are presented the influence can be seen of each one. Stone veneer stands out with its low consumption of 1'8 Mj/kg (169'2 Mj/m2) and vitrified ceramic at 10 Mj/kg, 1111,56 Mj/m2) and the multilayer aluminum panel and polyethylene (533 Mj/kg, 1074'9 Mj/m2).

Table 3 : Comparative energy study of veneers for cross-ventilated facades

Material	**Thickness (m)**	**Density (Kg/m3)**	**Density (Kg/m2)**	**Energy cost (Mj/Kg)**	**Partial energy cost (Mj/m2)**
Stone	0.0400	2,350.00		1'80	169'2
Vitrified ceramic			16.00	10.00	160.00
Ceramic. Hollow pieces			59.20	4.50	266.40
Natural wood	0.0250	800.00		3.00	60.00
Wood. Resin panels	0.0100	1,400.00		14.00	196.00
GRC (cement + sand + FV)			40.00	7.60	304.00
Naturvex (cement+silica+Fcelulose)	0.0100	2,000.00		9.00	180.00
One-layer galvanized steel plate	0.0008	7,850.00		34.80	218.54
One-layer stainless steel plate	0.0008	7,850.00		35.00	219.80
One-layer Corten steel plate	0.0015	7,850.00		35.00	412.13
One-layer aluminum plate	0.0010	2,700.00		215.00	580.50
One-layer copper plate	0.0010	8,900.00		90.00	801.00
One-layer zinc plate	0.0010	7,200.00		51.00	367.20
Multilayer panel Al+Pe+Al					1,074.90
Aluminum	0.0005	2,700.00		215.00	290.25
Polyethylene			4.80	103.00	494.40
Aluminum	0.0005	2,700.00		215.00	290.25
Metallic zinc sheet with continuous support					237.96
zinc	0.0006	7,200.00		51.00	220.32
wood panel	0.0018	700.00		14.00	17.64

Metallic copper sheet with continuous support					498.24
copper	0.0006	8,900.00		90.00	480.60
wood panel	0.0018	700.00		14.00	17.64
Metallic stainless steel sheet with continuous support					182.49
stainless steel	0.0006	7,850.00		35.00	164.85
wood panel	0.0018	700.00		14.00	17.64
Glazing					
Laminated 6+6	0.0120	2,600.00		19.00	592.80
Double 4/6/6	0.0100	2,600.00		19.00	494.00
D. lam4/6/6+6	0.0160	2,600.00		19.00	790.40
Artificial stone	0.0140	210.00		2'3	
Glasal	0.0100	2,000.00		??????	
Corrugated polyester panel	0.0010			53.57	
Trespa	0.0130	1,430.00		???????	

Table 4 shows the summary of the quantification of construction energy of the different façade rehabilitation systems as a function of the type of veneer, thermal insulation and substructure used; it allows the choice of one type of system or another based on lowest energy consumption.

Table 4 :. Summary of construction energy consumption of facade rehabilitation systems

Exterior veneer	Extruded polystyrene				Polyurethane				Mineral wool			
	Sub. Alum.	Sub. Galv. Stee	Sub. St. steel	Sub. Wood	Sub. Alum.	Sub. Galv. Stee	Sub. St. steel	Sub. Wood	Sub. Alum.	Sub. Galv. Stee	Sub. St. steel	Sub. Wood
F1.Stone	1,607.09	541.71	1,180.11		1,519.09	453.71	1,092.11		1,461.09	395.71	1,034.11	
F2.Vitrified ceramic	1,597.89	532.51		432.52	1,509.89	444.51		344.52	1,451.89	386.51		286.52
F3.Hollow-core ceramic	1,704.29	638.91	1,277.31		1,616.29	550.91	1,189.31		1,558.29	492.91	1,131.31	
F4.Natural wood	1,589.96	524.58		424.59	1,501.96	436.58		336.59	1,443.96	378.58		**278.59**
F5.Wood and resins	1,633.89	568.51		468.52	1,545.89	480.51		380.52	1,487.89	422.51		322.52
F6.GRC	1,741.89	676.51	1,314.91		1,653.89	588.51	1,226.91		1,595.89	530.51	1,168.91	
F7.Naturvex	1,617.89	552.51	1,190.91	452.52	1,529.89	464.51	1,102.91	364.52	1,471.89	406.51	1,044.91	306.52
F8.Galvanized steel plate	1,670.25	604.87	1,243.27		1,582.25	516.87	1,155.27		1,524.25	458.87	1,097.27	
F9.Stainless steel plate	**2,549.45**	1,484.07	2,122.47		2,461.45	1,396.07	2,034.47		2,403.45	1,338.07	1,976.47	
F10.Aluminum plate	2,018.90	953.01	1,591.41		1,930.39	865.01	1,503.41		1,872.39	807.01	1,445.41	
F11.Copper plate	2,238.89	1,173.51	1,811.91		2,150.89	1,085.51	1,723.91		2,092.89	1,027.51	1,665.91	
F12.Zinc plate	1,805.09	739.71	1,378.11		1,717.09	651.71	1,290.11		1,659.09	593.71	1,232.11	
F13.Multilayer panel Al+Pe	2,512.79				2,424.79				2,366.79			
F14.Zinc sheet	1,834.61	769.23	1,407.63	669.24	1,746.61	681.23	1,319.63	581.24	1,688.61	623.23	1,261.63	523.24
F15.Copper sheet	2,094.89	1,029.51	1,667.91	929.52	2,006.89	941.51	1,579.91	841.52	1,948.89	883.51	1,521.91	783.52
F16.Stainless steel sheet	2,447.96	1,382.58	2,020.89	1,282.59	2,359.96	1,294.58	1,932.98	1,194.59	2,301.96	1,236.58	1,874.98	1,136.59
F17.Laminated glass 6+6	2,030.69	965.31	1,603.71		1,942.69	877.31	1,515.71		1,884.69	819.31	1,457.71	
Average value	1,923.32	821.07	1,523.89	665.64	1,835.29	733.07	1,435.90	577.64	1,777.29	675.07	1,377.90	519.64

Average value Sub. Alum.	1,845.30	Average value Sub. Alum.	1,845.30
Average value Sub. Galv. Steel	743.07	Average value Sub. Galv. S	743.07
Average value Sub. St. steel	1,445.89	Average value Sub. St. stee	1,445.89
Average value Sub. Wood	587.64		
Average value total	1,248.48	Average value total	1,349.04

If we analyze the obtained results, we can see that:

The energy consumption of the facade rehabilitation varied between 2496'10 Mj/m2 (multilayer aluminum panel and polyethylene, extruded polystyrene insulation and aluminum substructure) and 150'36 Mj/m2 (wood veneer and substructure and mineral wool insulation). The factor that most influences is the type of substructure. However, as has already been commented, in spite of the low energy consumption of wood, from the technical point of view it would be more appropriate to utilize an aluminum or galvanized steel substructure and restrict the use of wood to facades of lesser heights and of lightweight veneers.

The median value is 1349'04. Our objective was to choose a system whose fabrication energy was less than 1.500 Mj/m2. We could choose the stone veneer system (1.460 Mj/m2), with mineral wool insulation and aluminum substructure (for durability).

Verification and quantification of the third objective. Fabrication energy consumption is offset by the savings incurred during use and maintenance in less than 5 years

We calculate the repercussion that this construction energy cost has in the heating energy savings that we saw in section 3.4.

Table 5 : . Offset of energy consumption in the fabrication phase with the savings obtained during the use and maintenance phase

Area of facade	2.423'88 m2	
Area of glazing	401'04 m2	
Facade rehabilitation energy cost	2.423,88m2 x 1.460 Mj/m2	3.538.864 Mj
Energy cost of window rehabilitation	401,04 x 494 Mj/m2	198.114 Mj
Energy cost of Roof rehabilitation	407 m2 x 524 Mj/m2	213.268 Mj
Total cost of rehabilitation		3.950.246'8 Mj = 1.098.168,39 Kwh
Heating energy savings from rehabilitation	571.352 – 329.137 Kwh	242.215 Kwh
Pay-off		4'5 YEARS

We would comply with the third proposed objective.

Conclusion

The methodology of the ecodesign management system is an efficient tool for sustainable design, since it is based on the identification and evaluation of the significant environmental aspects. It establishes measures that allow us to reach objectives of environmental improvement, whose procedure is realized as the design is developed. Finally, the effectiveness of its compliance is verified. Measures are not adopted because they may be the most commonly employed in the majority of projects; rather those of greater efficiency are analyzed relative to the surroundings and to the particular characteristics of the project.

The application of this methodology to a specific project: "Rehabilitation of the envelope of an existing building" has permitted us to corroborate that it is possible to achieve a savings of 46% in heating consumption, while paying off the fabrication energy consumption of the system employed within four and a half years.

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