TOWARDS ZERO EMISSIONS
CO_2-REDUCTION IN MEDITERRANEAN SOCIAL HOUSING

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ABSTRACT

An in-depth study of the construction, use and deconstruction of a 60 apartment social housing complex to be built close to Barcelona revealed the importance of the application of life-cycle analysis, as the materials' embodied energy showed to be responsible for half of the building's life-cycle emissions. A 72% energy reduction compared to conventional housing projects is expected by implementation of centralised HVAC and DHW systems, based on ground source heat pumps and solar thermal energy, introducing an in Catalonia innovative facility management approach where energy and flow meters are installed in each flat for internet-based control of energy consumption, invoicing and supervision of the installation. A second study showed that up to 90% CO_2 reduction considering the overall lifecycle is feasible at reasonable cost by giving priority to organic building materials like wood (CO_2 storage effect), minimizing underground construction and increasing energy supply based on renewable energies.

1. INTRODUCTION

In 2005, the Catalan Social Housing Agency INCASOL contracted the architects Sabaté associats to design a housing complex of 60 apartments and nearly 8,000 m^2 gross floor area in Tossa de Mar on the Mediterranean coast, 50 km North of Barcelona. At the request of the architects, specialised in sustainable building design and innovation, the Catalan Government's Department of Environment and Housing financed a detailed study on the possibilities of CO_2-reductions in the Catalan social housing sector, to be analysed on the example of the housing complex in Tossa de Mar. The detailed analysis of the building's life-cycle was elaborated by a multidisciplinary team of experts and was presented in December 2006. In May 2007, further studies setting milestones towards a 90% CO_2-reduction in the overall building process were presented at the construction fair CONSTRUMAT in Barcelona, in an exhibition on Sustainable Building Design at the Catalan Government, Department of Environment and Housing stand.

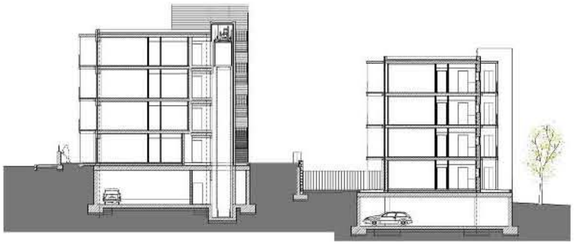


Figure 1. Section of the Social Housings

Figure 2. Render of the Social Housings

2. METHODOLOGY OF THE LIFE-CYCLE-ANALYSIS, TOSSA DE MAR

The objective of the study was clearly defined: to evaluate the possibilities of CO_2-reductions in the Catalan social housing sector. Within the broad range of approaches it was important to respect two premises: to focus on building technologies well known regionally and not to exceed the overall construction costs by more than 5% compared to a conventional building.

The methodology chosen applied a very holistic approach analysing the projected buildings' overall energy consumption and associated emissions over an expected 50 year lifecycle. These included: energy consumption and CO_2-emissions related to the extraction of raw-materials, production of end-materials, the construction process and the building's use and deconstruction. In parallel, the same parameters were studied for a conventional building of the same size that fulfils minimum requirements of the actual Spanish and Catalan building regulations, the "*Código Técnico de Edificación* and *Decret d'Ecoeficiència en Edificis"*, in force since autumn 2006.

Although evaluating the overall process, the analysis focuses on the two phases of production of materials and use of the building, as these concentrate the main environmental impact. Also, these phases represent those of major influence on CO_2-reductions by architectural design and they are also the most experimented phases concerning existing simulation tools and accessible information. To complete the overall analysis, the energy consumption and emissions related to the construction and deconstruction processes were estimated on the premise of previous studies.

The calculation and analysis of the CO_2-emissions related to the extraction and production of the construction materials (embodied energy and emissions) followed the same process commonly used to determine the cost of the different categories incorporating the values of mass, energy, and associated emissions. The necessary data were mainly extracted from the data bases of the Catalan Technology Institute ITeC (BEDEC-PR/PCT), in which 90% of the categories include detailed information of energy consumption and CO_2-emissions of the construction materials, including packaging and expected construction waste material. Other sources (mainly Hegger *et al.* 2006, [1]) as well as original research complemented the existing data.

Listing an important number of alternative systems for each construction element in determined units (commonly m^2), it was possible to evaluate the different options, taking all mentioned parameters into account at a glance. This allowed the best solutions of functional units for the building project to be determined in terms of environmental as well as economic aspects, keeping to conventional structural models in concrete or steel. In the case of the building's skin, other parameters such as thermal behaviour (transmittance, ventilation, solar protection) were also taken into account in order to minimize the energy demand for the future use of the building. In parallel, the base line for comparison was established by defining the materials that would have been used for the construction of a conventional building.

The energy consumption and associated CO_2-emissions for the building in use are determined primarily by the Heating Ventilation and Air Conditioning (HVAC) and the Domestic Hot Water (DHW) systems and secondly by energy used for cooking, electric appliances and artificial lighting. In this study, only HVAC and DHW consumptions are considered, as together they account for 60% of total consumption and are those where the designer's decisions are of maximum influence. The other uses (cooking, electric appliances and artificial lighting) depend mainly on the user behaviour and therefore were not taken into account in the comparison, but were reflected based on low energy consumption appliances and environmental conscious user behaviour in the overall final balance.

In the case of HVAC, energy consumption depends mainly on the demand due to climate, microclimate, building orientation, form and skin of the building, its use, etc. and on the energy systems and their efficiency to meet the defined demand. Correspondingly, in the present study, all described aspects are analysed in form of a cascade as some decisions depend directly on former ones. Most of the conditions concerning orientation, topography and disposition of the buildings were given by the urban planning regulations for Tossa de Mar and therefore could not be modified. The energy demand for heating and cooling was calculated with four different simulation tools, each one taking into account different aspects:

- LIDER was used to verify that the demand meets the minimum requirements of the building codes, and also provided the profiles for use and internal loads for the other simulation tools.
- Ecotect was mainly used to study the effect of the shading produced by some of the buildings on others.
- Both LIDER and Ecotect helped to determine the energy demand when different building skins were tested.
- Mc4 suite, a load calculation software, followed by a degree-day method, was used to compare the energy demand of the 3 buildings of the project. Due to the small difference between the demands for these buildings, inferior to 5%, further studies concentrated exemplarily on building B.
- The detailed hourly simulation of building B was undertaken with TRNSYS, in order to obtain the hourly, monthly and yearly demand for the project and the reference building, fulfilling the minimum Spanish and Catalan Building Codes.

Finally, for the project building, hourly demand data were introduced in Energyplus in order to determine the consumption of the designed system, with the centralised HVAC and DHW systems with geothermal heat pumps and central support boilers. A parallel simulation was carried out to evaluate the yearly consumption of the reference building with a conventional decentralised system, based on domestic boilers. Both systems include solar collectors for DHW production. The EnergyPlus simulation provided the seasonal efficiency ratios of both systems for the project and the reference building.

3. ANALYSIS OF THE EMBODIED ENERGY IN THE CONSTRUCTION MATERIALS

A detailed analysis of different materials and compositions and of various alternatives for the main construction elements (foundations, structures, opaque façade, openings, roof, finishes, etc.) revealed the materials with less embodied energy and CO_2-emissions. Table 1 gives an example of this comparison for different roof systems. Based on the detailed data for all building components from the categories which could be substituted with the current technologies and at an affordable price, the most environmentally relevant categories turned out to be, first of all, the façade, window frames and solar protections and, secondly, the structure, interior finishes (mainly flooring) and grey and waste water drainage. Table 2 gives an overview of the selected construction elements of both, the reference and the project buildings. Table 3 shows the associated CO_2-emissions, energy consumption and weight per square meter gross floor area as well as the reductions achieved by applying more sustainable building materials.

Table 1. Cost, weight, embodied energy and CO$_2$-emissions of analysed roof systems

Roof systems (values per m^2 of functional unit)	**Cost (€)**	**Weight (kg)**	**Energy (MJ)**	**Emissions (kgCO$_2$)**
Green flat roof (I)	100.13	386.75	1027.76	137.33
Green flat roof (II)	88.74	372.53	1098.23	157.64
Inverted transitable flat roof (Terrazzo finish)	98.49	396.62	977.56	122.71
Inverted flat roof (PVC - recycled gravel)	54.44	350.81	615.49	84.68
Inverted flat roof (EPDM - recycled gravel)	51.61	350.15	606.87	83.48
Inverted flat roof (Bitumen - recycled gravel)	55.28	353.29	677.77	93.74
Conventional flat roof (Recycled gravel)	46.31	352.76	616.34	84.67
Conventional flat roof (cork - recycled gravel)	*49.06*	*361.69*	*35.73*	*44.60*

Table 2. Construction Elements selected for Reference and Project Building

	Reference building	Project building
Structure	25+5 cm waffle slab. On site concrete for pillars and beams.	25+5 cm prefabricated pre-stressed concrete slab, prefabricated pillars and beams.
Façade	14cm lime finished light brick wall, painted with two coatings of primer and two coatings of latex paint. Insulation: expanded polystyrene foam. 4 cm light brick wall, interior finish.	Ventilated façade composed of fibrocement sheets on wooden framework. Insulation: rock wool. 14 by 24 cm width of light ceramic brick
Window carpentry	Exterior carpentry made of lacquered aluminium with interruption of thermal bridge.	Exterior carpentry made of laminated Northern pine, controlled forest management and valid certificate.
Solar protection	Venetian blind of lacquered aluminium with vertical, manually adjustable lamella, 200 to 250 mm wide.	Fixed Northern pine lamella on galvanized steel frame and Northern pine movable shutters.
Pavements	Fine terrazzo 40 x 40cm, with cement mortar on 2cm sand bed.	Linoleum 3 mm
Waste water drainage	PVC of different diameters	Polypropylene of different diameters

Table 3. CO$_2$-Emissions, Embodied Energy and Weight of Reference and Project Building.

Construction element	**CO$_2$-emissions**			**Energy**			**Weight**		
	Reference	Project	Red.	Reference	Project	Red.	Reference	Project	Red.
	KgCO$_2$/m^2	KgCO$_2$/m^2	%	MJ/m^2	MJ/m^2	%	Kg/m^2	Kg/m^2	%
Foundations and protection walls	93.67	93.67	0	1,018.23	1,018.23	0	793.21	793,21	0
Structures	168.88	154.75	8.37 %	1,912.80	1,755.53	8.22 %	556.06	548.10	1.43 %
Roofs and opaque façades	102.99	39.86	61.30 %	1,187.99	402.23	66.14 %	606.19	117.42	80.63 %
Interior divisions and elements	25.54	25.54	0	340.70	340.70	0	38.74	38.74	0
Exterior finishings	9.84	9.84	0	105.46	105.46	0	6.90	6.90	0
Interior finishings	35.94	28.83	19.78 %	350.25	263.68	42.72 %	104.12	23.93	77.02 %
Windows and solar protections	58.40	2.64	95.48 %	400.57	40.76	89.82 %	2.61	4.3	-64.75 %
Grey and waste water, drainage	16.43	13.13	20.09 %	125.25	99.46	20.59 %	39.57	19.11	51.71 %
Supply water, DHW, grey water	5.96	5.96	0	47.60	47.60	0	1.96	1.96	0
Electricity and lighting	17.13	17.13	0	145.01	145.01	0	13.34	13.34	0
Gas/fuel	0.24	0.24	0	2.36	2.36	0	0.02	0.02	0
Space conditioning and ventilation	14.25	14.25	0	139.42	139.42	0	2.95	2.95	0
Audiovisual installations, data	1.60	1.60	0	11.00	11.00	0	0.52	0.52	0
Fire protection	1.31	1.31	0	11.10	11.10	0	0.34	0.34	0
Fixed equipment	3.20	3.20	0	35.96	35.96	0	1.93	1.93	0
Total	**555.38**	**411.95**	**25.77 %**	**5,833.70**	**4,418.50**	**24.25 %**	**2,168.46**	**1,572.77**	**27.44 %**

The overall reduction of CO_2-emissions by acting upon the five main areas: structures, façades, windows, solar protections and interior finishes, as well as grey and waste water drainage, is shown to be of nearly 26% of the overall embodied emissions (from 555 to 412 $kgCO_2/m^2$ gross floor area), at minimum cost increase (see Figure 2).

Another remarkable result is that even in the improved project building, just two categories: foundations / protection walls and structures account for over 60% of the total emissions (248 out of 412 $kgCO_2/m^2$). It is obvious that, if more CO_2-reductions are to be achieved, attention must therefore be given to reducing underground built volume (parking areas) and utilising light weight structures as these concrete and steel intensive foundations have high associated emissions levels.

4. ANALYSIS OF THE EMISSIONS ASSOCIATED TO THE USE OF THE BUILDING

Within the mentioned constraints due to existing urban planning, a first step to improve the energy efficiency of the project building consisted in optimizing the shape and setting of the apartment blocks on the site. By simulating the sun tracking and corresponding shadowing with ECOTECT, the optimum implantation of the building volumes on the site was determined. The relation of openings to opaque façade was fixed at 35% in order to allow solar contributions in winter and avoid overheating in summer, and fixed solar protections in the form of balconies on the South-West façade got designed.

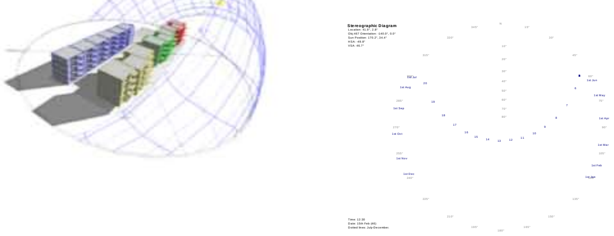


Figure 3. Sun Tracking and Shadow Simulation

In a second step, the energy demands of both reference and project building were analysed, taking into account the increased insulation standard of the project building with a thermal transmittance of about 40% below the actual legal requirements (opaque façade: $U=0.37\ W/m^2{\cdot}K$, $U_{limit}=0.73\ W/m^2{\cdot}K$; roof: $U=0.26\ W/m^2{\cdot}K$, $U_{limit}=0.41\ W/m^2{\cdot}K$). The energy demand was calculated with four different simulation tools, one of them being the official tool LIDER to prove the compliancy of the Spanish Building Code. Table 4 shows the energy demand calculated with TRNSYS, which was used for the detailed analysis, as an hourly demand output was required for an hourly consumption simulation later on in the analysis.

Table 4. Heating and Cooling Demand for Reference and Project Building.

Demand	Reference building	Project building	Reduction
	$kWh/m^2{\cdot}a$	$kWh/m^2{\cdot}a$	%
Heating	39.9	25.6	36%
Cooling	3.9	3.1	20%
Total	**43.8**	**28.7**	**34%**

In terms of the energy demand for HVAC, a total reduction of more than one third has been predicted, mainly on the heating demand side due to increased insulation and the avoidance of thermal bridges. This reduction becomes less significant when taking the existing demand for domestic water heating into account. The demand for DHW of 25.6 $kWh/m^2{\cdot}a$ has to be added for both reference and project building so that the overall demand is of 69.4 $kWh/m^2{\cdot}a$ for the reference building and 54.4 $kWh/m^2{\cdot}a$ for the project building. The overall reduction in thermal energy demand therefore gets reduced to 22%.

In the case of the reference building, the cooling demand is supposed to be met by individual electric heat pumps with a Seasonal Performance Factor of 1.4 (Ministerio de Fomento and IDAE, 1999, [2]), while the heating demand for domestic water (50%) and space heating is met by individual gas fired boilers with an average seasonal efficiency of 70%. In case of the project building, a common heat storage tank for heating and DHW is heated first by solar thermal, then by geothermal heat pumps and finally, if required, by the centralised gas boilers. The gas boilers are also used to meet the peak space heating demand, which allows the installed capacity of the heat pumps and the associated investment costs to be reduced significantly, as well as to increase their operational efficiency. The heat pumps are designed to cover 70% of the peak power demand and 90 % of the heating energy demand in winter. No legionellosis treatment is required in the storage tank, as being a closed circuit. The cooling peaks are slightly higher than the heating peaks and therefore cannot be fully met by the heat pumps. Nevertheless, as most social housing projects do not include any cooling systems, no auxiliary system for the summer case is foreseen. In a pre-dimensioning, the geothermal exchange was supposed to be of 35 bore holes, each 50 m deep assuming a subsoil temperature of 13.375ºC. Figure 4 shows the evolution of the soil's temperature at maximum cooling demand with the resulting slight heating of the subsoil during August and September.

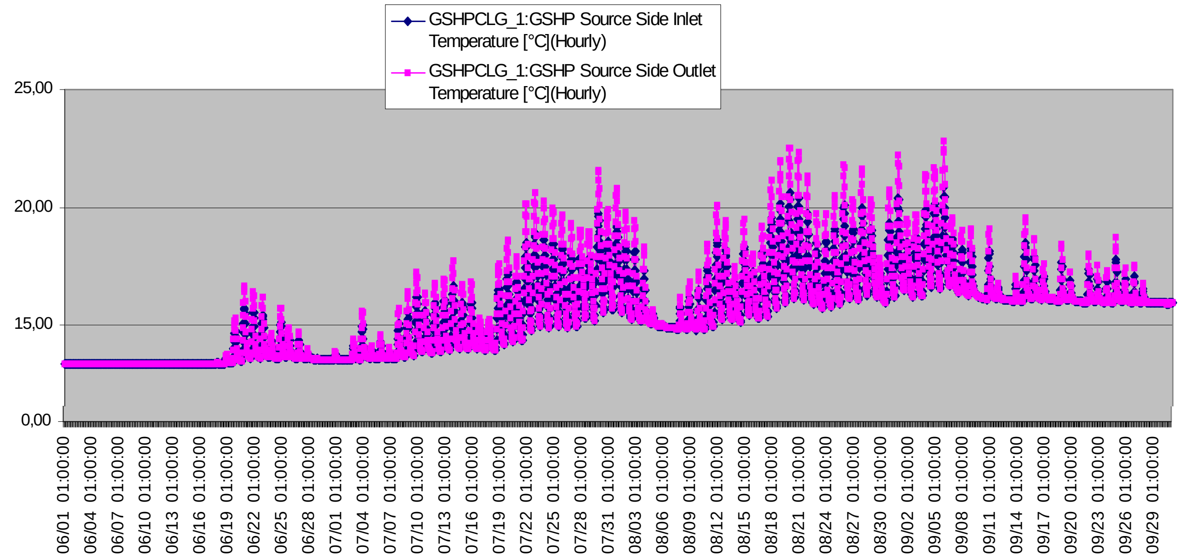


Figure 4. Temperature Profile of the Geothermal Exchange in Summer.

Table 5. Energy Consumption in the Project Building with Conventional Installation for Space Conditioning and DHW.

Block B/C Individual systems: heat pumps for cooling, gas-fired boilers, solar thermal installation for DHW	Unit	Energy demand for space conditioning and DHW (TRNSYS)	Consumption for space conditioning and DHW (Energy Plus)	
			Electricity	Gas
Summer (cooling only)	kWh	39,675	28,339	
Winter (heating only)	kWh	188,367		269,096
DHW (50% solar fraction)	kWh	66,048		47,177
Total	kWh	294,090	28,339	316,273
Total	kWh	**294,090**	**344,612**	
Total	kWh/m^2	**114.0**	**133.6**	
Average COP	**0.85**			

Table 6. Energy Consumption in the Project Building with Geothermal Heat Pumps for Space Conditioning and DHW.

Block B/C Centralized system: geothermal, auxiliary gas-fired boiler, solar thermal installation for DHW	Unit	Energy demand for space conditioning and DHW (TRNSYS)	Consumption for space conditioning and DHW (Energy Plus)	
			Electricity	Gas (only DHW)
Summer (cooling and DHW)	kWh	72,699	9,901	6,408
Winter (heating and DHW)	kWh	221,391	93,701	11,550
Total	kWh	294,090	103,602	17,958
Total	kWh	**294,090**	**121,560**	
Total	kWh/m^2	**114.0**	**47.1**	
Average COP	**2.42**			

Table 7. Heating and Cooling Demand for Reference and Project Building.

Final energy consumption	Reference building	Project building	Project versus reference
Average seasonal COP	0.85	2.42	+ 283 %
Consumption	22.5 kWh/m^2·a	81.4 kWh/m^2·a	**- 72 %**

The 60 apartments are placed in three different blocks, one of which is for rent and the other for private owners. Two independent energy supply systems will be installed with geothermal heat pumps of 80 kW (Block A – 24 apartments) and 120 kW (Blocks B/C - 36 apartments) and two condensing boilers of 56 kW each. A two-pipes circulation system supplies hot water to the individual heat exchange units installed in the entrance of the apartments, where the supply water is heated instantly to tap water temperature and therefore any risk of legionellosis is avoided. Simultaneously, the heat exchange units can deliver heat for the fan-coils for heating, while in a parallel circulation system cold water is supplied to separate heat exchange units for delivering cold to the fan-coils in summer. The decentralized DHW installation also includes warm water taps in every flat for direct supply for dishwashers and washing machines.

Due to the important difference of the systems used, the average seasonal coefficient of performance in the case of the project building is nearly three times that of the reference building. Combined with the reduced energy demand in the case of the project building, the estimated overall energy consumption for this building turns out to be over 72% less than in the reference building with conventional HVAC and DHW installations (see table 7):

Centralized energy supply, very common in other countries and regions of Spain but not in Catalonia, requires an innovative approach concerning the management of this service. While used to managing common resources for maintenance of lifts, green spaces and swimming-pools, no experience exists concerning energy management in privately owned apartment blocks. In this case, a Barcelona based water supply company agreed to start a pilot project in energy services for the social housing sector and to take over the overall energy management of the blocks. The individual heat exchange units incorporate energy and flow meters to allow internet-based control of energy consumption, invoicing and supervision for the correct operation of the installation. This energy services can be provided by transferring the data in a bi-directional mode via bus system to/from the central computer in the machine room, and via internet to/from the energy service company. A display in the entrance of each dwelling allows the owner to have absolute control on the energy performance of the dwelling due to the availability of real-time consumption data. Upon these data, the owner can decide on the optimal use of hot water or the heating/cooling setpoint temperatures in order to reduce the apartment's consumption. Moreover, information on the hourly, weekly and annual heating profile, as well as the integrated information on energy and water consumption in kWh and litres per time period will be available via internet.

As collateral effect, the supply water distribution will also be innovative by individual metering in the same unit located in the exterior part of the dwellings' entrances. Instead of the conventional metering in the underground floor and individual mounting pipes for every dwelling, only one central supply tube will serve all flats in a vertical axis with the corresponding savings in piping material and space.

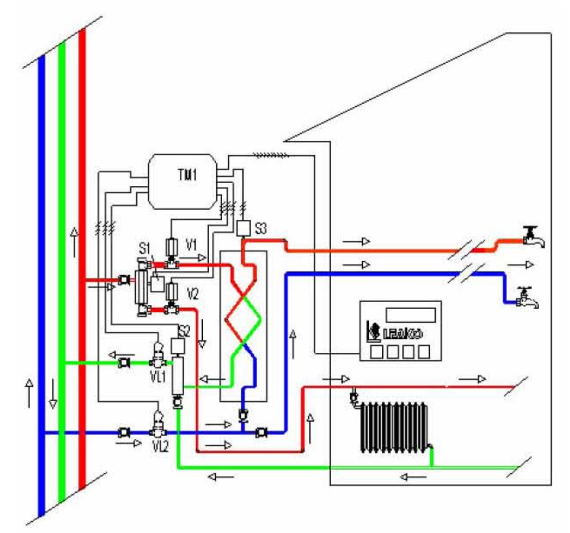


Figure 5.. Operation scheme of the heat exchange unit

The development of an Intelligent Building Management System (IBMS) that will manage both data on the centralized HVAC system and the individual user's behaviour in terms of energy use will be further supported by a European project of the 7th Framework Programme. IntUBE, acronym for Intelligent Use of Building's Energy Information, has as a main goal to optimize the building energy performance using ICTs (see Pietiläinen *et al.*,2003 [3], to evaluate new business models for energy supply, and to test and further develop the required hardware and software to support such models.

The remaining energy consumption for other uses such as cooking and electric appliances is supposed to be the same for both buildings of the study, conventional and project building, as they are mainly user conditioned. Only electricity consumption for lighting has been assumed to be considerably reduced in the project building by supposing the overall use of low energy consumption bulbs.

Table 8. Specific Energy Consumption and CO_2-Emissions for the Phase of Use for Reference and Project Building.

Energy use	**Energy consumption**			**CO_2-emissions**		
	Reference	Project	Red.	Reference	Project	Red.
	kWh/m²	kWh/m²	%	$KgCO_2/m^2$	$KgCO_2/m^2$	%
Space conditioning and DHW	81.40	22.50	72%	16.28	4.50	72%
Cooking	11.67	11.67	0	2.33	2.33	0
Electric appliances	12.71	12.71	0	2.54	2.54	0
Lighting	6.85	2.06	70%	1.37	0.41	70%
Total	**112.63**	**48.94**	**57%**	**22.52**	**9.78**	**57%**

Table 9. Life-Cycle Energy Consumption and CO_2-Emissions for Reference and Project Building.

	Reference (kWh)	Project (kWh)	Reduction	Reference ($kgCO_2$)	Project ($kgCO_2$)	Reduction
Materials	16,333,265	12,589,017	22.9%	5,590,408	4,226,504	24.4%
Construction	166,843	288,736	-73.1%	71,158	117,704	-65.4%
Use	23,387,620	10,162,391	56.5%	5,593,073	2,430,368	56.5%
Deconstruction	251,281	193,677	22.9%	86,006	65,023	24.4%
Total	**40,139,009**	**23,233,821**	**42.1%**	**11,340,645**	**6,839,599**	**39.7%**

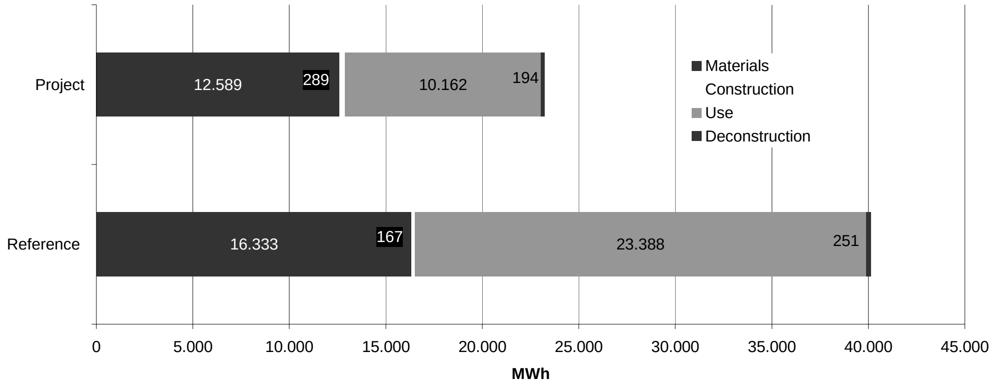


Figure 5. Life-Cycle Energy Consumption for Reference and Project Building.

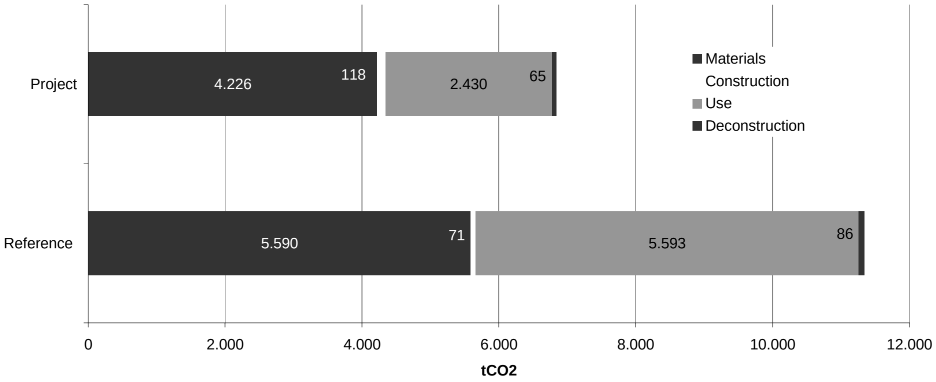


Figure 6. Life-Cycle CO_2-Emissions for Reference and Project Building.

Regarding DHW demand, this is partly to be met by solar thermal energy. This has been compulsory all over Spain since October 2006. In the climate zone where the building will be constructed, the fraction of demand to be met by solar energy is at least 50%. Thus, only half of the energy demand for DHW is used for the system consumption calculation, further reducing the previously calculated values. As in the case of the DHW demand, taking into account these reductions in appliances, DHW and lighting, a final consumption estimate is made for both, the reference and project building.(see table 8). The corresponding CO_2-emissions were determined on the basis of the fuel and energy efficiency mix of the Spanish electricity generation system.

5. OVERALL LIFE-CYCLE ANALYSIS OF THE BUILDINGS

The life-cycle for the buildings has been determined, in accordance to other analysis, as 50 years. While the embodied energy in the construction materials and associated emissions as well as the emissions related to the use of the building were precisely defined, the emissions related to the construction, maintenance and deconstruction process were directly copied from the ITEC database or estimated as a fixed percentage of the materials' embodied emissions. The overall CO_2-reductions for this case-study therefore can finally be determined as more than 42%, analogue to the reduction in energy consumption (see table 9, figures 5 - 6).

Finally, with the objective of obtaining data comparable to other buildings, the transposition into surface related values for energy consumption and CO_2-emissions is required. In the previous calculations of this study, all material related data, such as production, construction and deconstruction, are related to the gross floor area of the building, while the energy consumption and CO_2-emissions for the operation of the building are related to the net floor area. The importance of choice of related areas is obvious in tables 11 and 12. The reduction potential, evidently, stays the same.

Table 10. Life-Cycle Energy Consumption and CO_2-Emissions per Net Floor Area (4,140 m^2).

Life-cycle phase	Energy consumption (NFA)		
	Reference	Project	Red.
	kWh/m²	kWh/m²	%
Materials	3,945	3,041	23%
Construction	40	70	-73%
Use	5,649	2,455	57%
Deconstruction	61	47	23%
Total	**9,695**	**5,612**	**42%**

Life-cycle phase	CO_2-emissions (NFA)		
	Reference	Project	Red.
	$KgCO_2/m^2$	$KgCO_2/m^2$	%
Materials	1,350	1,021	24%
Construction	17	28	-65%
Use	1,351	587	57%
Deconstruction	21	16	24%
Total	**2,739**	**1,652**	**40%**

Table 11. Life-Cycle Energy Consumption and CO_2-Emissions per Gross Floor Area (7,916 m^2).

Life-cycle phase	Energy consumption (GFA)		
	Reference	Project	Red.
	kWh/m²	kWh/m²	%
Materials	2,063	1,590	23%
Construction	21	36	-73%
Use	2,954	1,284	57%
Deconstruction	32	24	23%
Total	**5,071**	**2,935**	**42%**

Life-cycle phase	CO_2-emissions (GFA)		
	Reference	Project	Red.
	$KgCO_2/m^2$	$KgCO_2/m^2$	%
Materials	706	534	23%
Construction	9	15	-73%
Use	707	307	57%
Deconstruction	11	8	23%
Total	**1,433**	**864**	**42%**

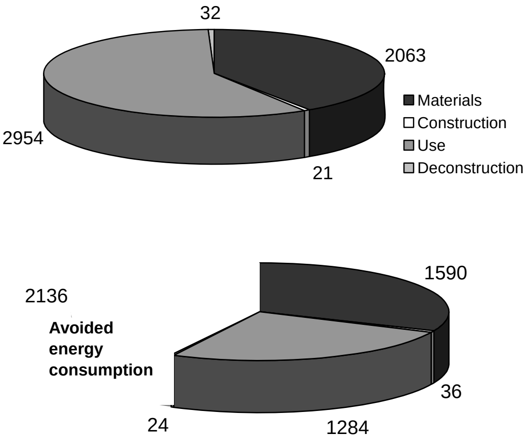


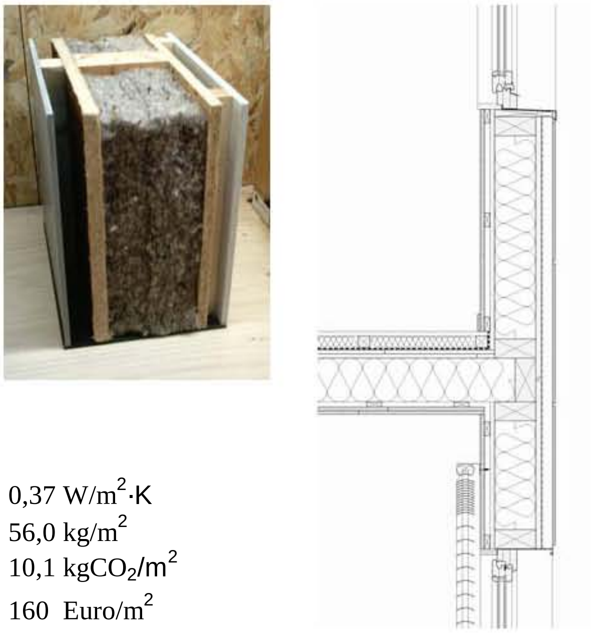
Figure 7. Life-Cycle Energy Consumption per Gross Floor Area for Reference and Project Building (kWh/m^2 GFA).

In a second part of the study, the replicability of the adopted measures for other similar public social housing projects was proved. Recently, the Catalan Governmental Housing Agency asked the architects for a guideline to set this project as a standard for future housing developments. The additional cost for this 40% CO_2-reduction did not exceed 4% of the costs for conventional housing, without taking into account the short pay-back period of the additional investment thanks to the important energy savings in operating the building.

6. FURTHER DEVELOPMENT TOWARDS 90% CO_2-REDUCTION

One of the main results of the study is the importance of the material's embodied energy and related CO_2-emissions. After optimising the energy consumption in the operation of the buildings, strategies for further CO_2-reduction in the building's overall life-cycle clearly have to face this fact and try to shift to materials with less environmental impact. The most effective way in this direction is the use of organic material, which have much lower emissions for the manufacturing process of the end-product. It also functions as CO_2-storage, as the CO_2 absorbed during the growth of trees or other plants remains immobilized in the building components during the building's life-time.

The research developed for the exhibition on Sustainable Building Design in the frame of the stand of the Catalan Government's Department of Environment and Housing on the construction fair CONSTRUMAT in Barcelona showed a decrease in CO_2-emissions related to the materials of nearly 80% by consequent use of wood products for structural elements and façade and by avoiding underground construction. Figure 8 shows one of the proposed façade compositions based on organic material.



0,37 W/m^2·K
56,0 kg/m^2
10,1 kgCO_2/m^2
160 Euro/m^2

Figure 8. Example for organic material based façade.

Finally, a consequent use of renewable energy sources can easily improve the overall energy and emissions balance to even more than 90% reduction. Biomass boilers, electricity production with solar photovoltaic energy or solid waste co- and tri-generation plants are just some examples to reach this standard. The additional cost depends on the existing local resources and adopted technology as well as on the ambitions of the set objectives of CO_2-emissions.

7. CONCLUSION

First conclusion is that the design and construction of social housing with up to 50% CO_2-reductions in the building's overall life-cycle is absolutely feasible, using in Catalonia well established technology and with an additional cost of less than 5%. In the presented research, the main contribution to this reduction was made by demand reduction and HVAC and DHW systems using geothermal heat pumps and solar thermal collectors. The second conclusion is that up to 90% CO_2 reduction considering the overall lifecycle is feasible at reasonable cost by giving priority to organic building materials like wood (CO_2 storage effect), minimizing underground construction and increasing energy supply based on renewable energies, achieving a value of less than 6 kgCO_2/m^2·a. But it has to be stressed, that in a holistic approach, considering more than only the operation phase of the building, a zero energy building necessarily requires a plus energy production during its operational phase in order to come up for the energy and emissions related to materials, their transport, construction and deconstruction.

8. REFERENCES

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