CARBON FOOTPRINT STUDY OF A ZERO ENERGY COSUMPTION RESIDENTIAL CONSTRUCTION

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1. Introduction

Nowdays, our society must deal with two main issues for this century: the progressive exhaustion of fossil fuels (carbon, oil, gas and coal), which provides currently more than 80% of the primary energies marketed in the world and the climate change. Greenhouse gas emissions are considered to be the main reason of the climatic warming for the last fifty years and a progressive concern about this matter has been observed.

In a report realized by the ,,European Commission for Energy,, the major issues of EU citizens is the energy security which was translated by "shortages of fossil fuel supplies compared to increasing world demand", "high fossil fuel prices", "supplier or transit countries using their positions to exert political pressure" , "inadequate energy efficiency measures in Europe" or "impact of EU climate strategy" (EU Report 2008). Energy is essential for socio-economic progress both in developing and industrialized countries and the demand for energy will increase with the global population, currently growing at a rate of 250,000 people per day (Elani et al, 1996). In the year 2001, the use of fossil fuels released about 23.7 Gigatonnes of carbon dioxide (CO_2) into the atmosphere with a continuous increase compared to previous periods (International Energy Agency, 2004).

For this reason, an increased understanding of the environmental effects of burning fossil fuels has led to rigorous international agreements, policies and legislations concerning the control of the harmful emissions related to their use (European Commission Report). The industrialized states signed the Kyoto protocol in 1997, which is an agreement to reduce the greenhouse gas (GHG) emissions by 2008-2012. The objective is a reduction from 25% to 40% of the emissions compared to the level of 1990 from here 2020.

In order to stabilize CO_2 concentrations in the atmosphere several strategies have been proposed. Increasing the efficiency of energy use, and increased reliance on renewable energy sources or sustainable design are among these strategies. Sustainable design can be described as that which enhances ecological, social and economic well being, both now and in the future [7]. The global requirement for sustainable energy provision will become gradually more important over the next fifty years as the environmental effects of fossil fuel use turn out to be very pessimistic.

The buildings sector – i.e. residential and commercial buildings - is the largest user of energy and CO_2 emitter in the EU and is the major energy consumer of the EU's total final energy consumption and CO2 emissions. Buildings account for 40–45% of energy consumption in Europe and China (and about 30–40% world-wide) (International Institute for Sustainable Development). Most of this energy is for the supplying the energy for lighting, heating, cooling, and ventilation. Increased awareness of the environmental impact of CO_2 and NOx emissions triggered a renewed attention in environmentally friendly cooling and heating innovative technologies (Abdeen, 2008). Buildings are important consumers of energy and thus important contributors to the emission of GHC into the atmosphere. The development and integration of appropriate renewable energy technologies in buildings has an important role to play. However, issues of cost, investment and ownership along with technical risk provide disincentives to the uptake of embedded energy technologies. More frequently the term of zero energy building (ZEB) is called when designing a new building. A net zero-energy building is in general a residential building with significantly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.

The way the zero energy goals are defined influence the choices that designers make to attain this goals and whether they can claim success. An emissions-based ZEB produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. Compared to actual buildings it is clear that the greenhouse gas (GHG) emissions of ZEB are lower on using the energy to heat or cool the space. However it is not obvious that the construction of such house has a lower carbon dioxide emission. This is due to innovative systems that are to be installed and the higher amount of insulation. GHG emissions sources are often easy to identify – for example burning fossil fuels for electricity generation, heating and transport. It is sometimes less obvious that products and services also cause indirect emissions throughout their life-cycles. Energy is required for production and transport of products, and greenhouse gases are also released when products are disposed of at the end of their useful lives. A 'carbon footprint' is a measure of the greenhouse gas emissions and it is an interesting index for comparing 'classic' houses with ZEB. The main reason for calculating a carbon footprint is to inform decisions on how to reduce the climate change impact of the construction and use.

This article purpose is to show with precise data the carbon footprint of a zero energy consumption residential house. On this construction, several active systems were installed along with a good insulation, with the objective to reduce at maximum the energy consumption for the heating and electricity. The question that was put is: *What is the impact on the environment of these systems and insulation, starting from their manufacture and mounting?*

2. ZERO ENERRGY BUILDING

To model and build a house with positive energy, it is necessary to reduce all aspects of building energy consumption (heating, cooling, domestic hot water and specific electricity). The analyzed building has its design concept in our laboratory (see Figure 1).

Fig. 1: Zero Energy Building plans (ground floor, first floor and lateral view)

The first step in simulation modeling of the ZEB is to separate the whole house into zones coupled each other. The separation of different areas of the house is based on the location, occupation and use (14 zones have been identified). Each area is considered a separate cell for which we have to set the volume and wall surfaces. For every wall its characteristics must be defined and the adjacent areas: for example the kitchen has an outside wall facing east with a window wall overlooking the greenhouse. The exterior walls and roof are well insulated with 25 cm, respectively 20 cm of insulation. The windows are highly energy efficient with $U_{glazing}$=1.43 W/m^{2}K, g_{window}=0.596 and U_{window}=1.56 W/m^{2}K. The greenhouse adjacent to the ZEB is used as a buffer zone to the north orientation and it's constructed from simple glazing (U_{window}=5.2 W/m^{2}K).

The building and its systems has been modeled using Trnsys software. The Trnsys building model, known as, Type 56, is compliant with general requirements of European Directive on the energy performance of buildings and has been used with success by engineers to design efficient buildings, but also for scientific research. The type 56 building model subroutine also accounts for radiative solar gains, thermal mass effects, and the capacitance of the air in the building. In addition to the construction of the building, the model also requires inputs for heating, cooling, ventilation, infiltration, and human comfort factors. The weather file (Lyon city) used for the simulations are hourly based values of solar radiation, air temperature, wind velocity. The heating and cooling set point temperature were set up to 19^{o}C and respectively 26^{o}C. The ventilation systems assure a fresh air rate of 1 ach and the infiltrations of the house are supposed to be 0.2 ach. The internal heat gains have been also taken into account during the simulation. These gains included occupants, lighting, electrical equipments and their time scenario. It was found that the heat gains can reduce with 14% (-3000 kWh) the building heating energy consumption but increase the cooling demand with + 1100 kWh. Using a heating scenario (19°C to 15°C during non occupational time) reduce the heating demand with 1000 kWh/year. A number of passive systems were installed in order to reduce the energy consumption. First an air-air heat exchanger is installed having an efficiency of 80% and a total air flow of 135.3 m^3/h. The heat exchanger reduces the winter heating needs by 40% or 2400 kWh savings which confirms the importance of the temperature of the air introduced in the house. During the summer period the system is not used. A second passive system used is the "canadian well" that allows the external air to be heated or cooled in the buried ground pipes before being introduced in the building. This system is composed of two tubes of 20 cm diameter and it buried in the ground at a depth of 2 m on 10 m length. The system was found to be not so efficient during the winter period when the air heating consumption was reduced only by 340 kWh. However it was found to be more interesting to use such system during the summer period when it reduced by 200 kWh the cooling need. Despite this measure, during certain periods was found that the building presents overheating. To reduce them a longer length of the "canadian well" is proposed (up to 30 m) and a higher ventilation rate for certain periods (three times higher).

Another passive element is the thermal mass that plays an important role in the design of passive solar houses. The mass allows for more heat to be captured, and the heat distribution is modulated allowing for less temperature swings in the house. The designed house has a good thermal mass with a time constant higher than 100 h. A ZEB cannot be attained if not using a certain number of active systems that use a renewable energy. A first system installed on the propose ZEB is the geothermal heat pump system. This system has the advantage of having a very high efficiency. It allows in the case of low consumption buildings to reduce to maximum the energy demand by using a good control system. The system is suitable for the use of a low-temperature heating as radiant floor heating and ceiling, with good impact on the thermal comfort of occupants as it was found during the analysis of the PMV index. The heat pump is a 7 kW power water–water system and the ground heat exchanger was calculated to 90 m. The internal diameter (d_{int}=7 cm) of the exchanger was calculated to increase the heat exchange and to limit the pressure loss. Another active system was the solar thermal panels used to heat the domestic hot water. It was sized for 5 occupants with a daily water consumption of 200 liters at 45°C. The circulation pump between the boiler and the panels consumes 56.7 kWh/year. The necessary surface of the panels was found to be 7.5 m^2 (see Table 2).

Tab. 1: Monthly solar thermal energy produced and the DHW demand

Month	Produced solar energy kWh	DHW demand kWh	Auxiliary energy kWh
January	114.00	287.09	173.15
February	145.85	259,57	131,83
March	237.96	278,72	76,19
April	249,05	254,39	50,13
May	267,77	244,46	27,89
June	261,55	220,77	1,47
July	286,85	218,43	0,53
August	272,11	218,02	3,23
Septembre	267,99	219,60	6,91
October	185,89	242,87	69,12
Novembre	120,34	252,86	151,48
Decembre	99,15	277,44	184,64

These systems were modeled under the Trnsys Environment as indicated in Figure 2.

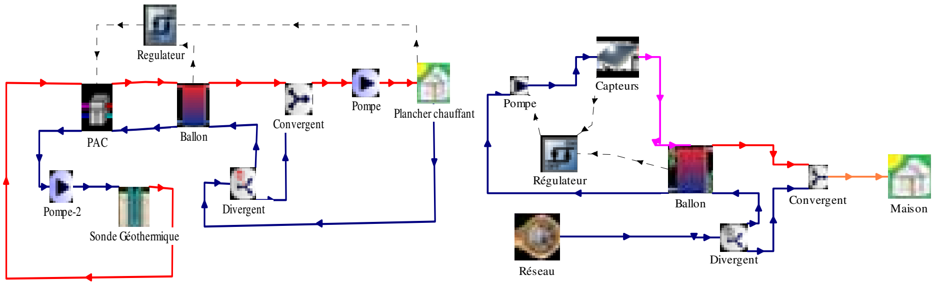

Fig. 2: Active systems modeling (geothermal heat pump and solar thermal panels) under TRNSYS software

The house features a solar ready design, to facilitate on-site installation of the PV net metering system and the solar water-heating system. The building roof area is 60 m^2 which give a maximum are of photovoltaic panels to be installed of 52.5 m^2. The PV panels were installed at a tilted angle of 45°C orientated to South.

The passive, active and building consumption are summarized in the Table 2.

Tab. 2: Monthly energy demand and production of the ZEB

Month	Energy demand kWh							Production kWh
	Heating		DHW		Vent.	Electricity	Total	
	GHP	Aux	Solar	Aux.				
January	209,83	64,00	135,10	3,00	133,92	176,67	722,51	301,13
February	116,23	35,40	90,82	3,93	120,96	176,67	544,01	388,47
March	43,96	13,20	41,26	5,53	131,08	176,67	411,71	651,20
April	2,02	0,60	23,68	5,40	89,50	176,67	297,87	711,28
May	0,00	0,00	5,04	5,83	74,50	176,67	262,04	740,47
June	0,00	0,00	0,00	5,57	81,91	176,67	264,14	806,02
July	0,00	0,00	0,00	5,90	90,34	176,67	272,90	886,75
August	0,00	0,00	0,00	5,45	87,64	176,67	269,76	825,56
Septembre	0,00	0,00	0,00	5,17	78,00	176,67	259,83	724,29
October	8,72	2,60	44,39	4,37	87,66	176,67	324,41	492,55
Novembre	99,31	29,80	115,88	3,60	129,58	176,67	554,84	314,40
Decembre	214,18	65,40	150,19	2,65	133,92	176,67	743,01	256,99
Year	694,27	211,0	606,35	56,40	1239,01	2120,00	4927,03	7099,11

GHP-geothermal heat pump, Aux-auxiliary energy, Vent.-ventilation energy demand

The overall measure of efficiency used to evaluate the performance of each of the near-zero-energy houses in this study is the amount of energy consumed in relation to the energy consumed in a conventionally built house of the same size.

3. BUILDING CARBON FOOTPRINT

It was seen from the previous chapter that the building energy flow is positive due to an extensive use of renewable energy systems and high amount of envelope insulation. These measures demand however a certain energy to be manufactured and transported to the building site. Further on we will proceed to a calculation of the carbon footprint of the ZEB. To estimate this we will use an internal scale for the building normal use while for the active systems a global scale will be used. The life cycle of the building and its amenities is an important part in the carbon footprint calculation and a particular attention was allocated. The pollutants don't have the same „power" or impact on the environment so the use of a common index is required; the expression of equivalent CO_2 and equivalent carbon C (1 tC=3.67 tCO_2) will be further used. The particularity of the analyzed building is obvious the high amount of active systems or multi-source systems. It is true that these systems are non-polluting the atmosphere when in use but is important to know the amount of energy and emission especially from their fabrication. The study starts with the analysis of emission for the solar thermal panels, which in our case is of 7.5 m^2. Based on the technical characteristics of the panels it was found that for 1 m^2 the amount of glass is 7.5 kg, 2 kg of insulation, 2 kg of copper and 2 kg of aluminum. As concerns the photovoltaic for 1 m^2 are necessary 2.33 kg of silicium, 7.5 kg of glass and 2 kg of aluminum. The heating floor was also accounted and for 1m2 are necessary 3.66 kg of copper, 200 kg of cement and 52.5 kg of polystyrene. Table 3 summarized the entire systems:

Tab. 3: Carbon footprint of active systems

Fabrication						Surface/ Number	Total
Solar thermal panels	*Glass*	*Insulation*	*Copper**	*Aluminum**			
Weight (kg)	7.5	2	2	2			
Equivalent index (keC/t)	418	584	804	2900			
Equivalent C (kgeC/m^2)	3.14	1.17	1.61	5.6	11.71	5	58.56
Solar photovoltaic panels	*Glass*		*Silicium*	*Aluminum**			
Weight (kg)	7.5	-	2.33	2	-	-	

Equivalent index (keC/t)	418		800	2900			
Equivalent C (kgeC/m^2)	3.14		1.86	5.8	10.8	51.62	557.44
Heat pump	***Steel***	***R407C***	***Copper****	***Aluminum****			
Weight (kg)	90	0.008	40	2			
Equivalent index (kgeC/t)	850	417231	804	2900			
Equivalent C (kgeC/m^2)	76.5	3.34	32.16	5.80	117.8	1	117.8
Geother. heat exchanger			***Copper****				
Weight (kg)	-	-	9.0984	-			
Equivalent index (kgeC/t)			804				
Equivalent C (kgeC/m)			7.32		7.32	180	1316.72
Heating floor	***Cement***	***Insulation***	***Copper****				
Weight (kg)	200	52.5	3.6572	-			
Equivalent index (kgeC/t)	250	1050	850				
Equivalent C (kgeC/m^2)	50	55.13	3.11		108.23	82.92	8974.7
Canadian Well		***Insulation***					
Weight (kg)	-	8.4	-	-			
Equivalent index (kgeC/t)		1050					
Equivalent C (kgeC/m)		8.82			8.82	20	176.4
TOTAL Emission							11201.65

*-materials that may be recycled

The amount obtained corresponds to a maximum value that did not considered the fact that copper and aluminum may be recycled. This may be compensated by the fact that the emissions from transportation and drilling operation for the geothermal system were not considered. If we distribute this emission for the lifetime of the equipments we arrive to approximately 500 kg equivalent C /year. Systems like geothermal heat exchangers and heating floor are likely the most polluting due to high amounts of copper or cement. On the opposite side, the photovoltaic system has a low carbon footprint and the payback time is less than 5 years, due to tax reduction and the sell price when injecting the over-necessary flow it in the public network. The next step in establishing the carbon footprint of the ZEB was to estimate the auxiliary electrical energy of the house which in our case is 1303 kWh or a total of 29.98 kgeC/year (0.023 kgeC/kWh in France). Building the construction is another point that must be deal with. The amount of materials was calculated for the ZEB with a maximum value of 36199 kgeC/building life time or 724 kgeC/year divided in:

- Cement – 233 846.8 kg or 35077 kgeC/building life time or 702 kgeC/year
- Plasterboard – 11429 kg or 491 kgeC/building life time or 10 kgeC/year
- Glass -1523.8 kg or 691 kgeC/building life time or 13 kgeC/year

The building waste was divided in garbage, glass, paper, plastic and cardboard. The carbon emission for the food necessary for the five occupants of the house was estimated based on Jancovici and Manicore (Manicore-website) on six persons where they obtain a value of 1261 kgeC/year. For the analyzed ZEB this value is 1050 kgeC/year. The balance of carbon equivalent emission of the ZEB is close to 500 kgeC/person value that is actually wanted to be reached by the French Energy Guidelines. However the study was conducted on a building where most of the energy is supplied by renewable energy systems and it was thought that we will have lower values. To better understand the dilemma a comparison with a classic house with the same architectural plans and occupation was necessary to solve this problem. If considering a 40 years life time of the construction the ZEB has a carbon footprint of 934 kgeC/year while a classic house has 1106 kgeC/year. The reduction of emission is done mainly on long term and not reporting to an annual comparison.

4. CONCLUSIONS

In this research paper a detailed analysis of a zero energy building was conducted by focusing on the active renewable energy systems and the house carbon footprint. To calculate the carbon footprint of a zero energy construction house the assumptions and results have been divided into the three sections of construction, maintenance and energy performance. A number of aspects have been analyzed, like the emissions from the building construction, energy use, waste and meals of the occupants. The ZEB energy demand is highly reduced to an extensive use of solar and geothermal energy. It is important to check the carbon emission for the fabrication of the renewable energy systems installed on the house. It was found that a ZEB it is not a non-polluting house with values of around 500 kgeC/person and a construction emission of more than 36160 kgeC. By comparison, the construction of a classic house has 2.3 less emissions, but in use may go to 23 higher values. At a certain moment, a compromise between the building carbon emission and energy reduction must be done. The values presented in this article corresponds to France emission (0.023 kgeC/kWh) a value that is not high due to highly use of nuclear power to produce the electricity. The comparison and the difference between a ZEB and a classic house may differ for other countries; in generally will have a more positive impact of the ZEB.

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