Embodied Energy Versus Operational Energy. Showing The Shortcomings Of The Energy Performance Building Directive (EPBD)

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Abstract. Energy is a key issue for Portugal, it is responsible for the higher part of its imports and since almost 30% of Portuguese energy is generated in power stations it is also responsible for high CO_2 emissions. Between 1995 and 2005 Portuguese GNP rise 28%, however the imported energy in the same period increased 400%, from 1500 million to 5500 million dollars. As to the period between 2005 and 2007 the energy imports reach about 10,000 million dollars. Although recent and strong investments in renewable energy, Portugal continue to import energy and fossil fuels. This question is very relevant since a major part of the energy produced in Portugal is generated in power plants thus emitting greenhouse gases (GHGs). Therefore, investigations that could minimize energy use are needed.

This paper presents a case study of a 97 apartment-type building (27.647 m^2) located in Portugal, concerning both embodied energy as well as operational energy (heating, hot water, electricity). The operational energy was an average of 187,2 $MJ/m^2/yr$ and the embodied energy accounts for aprox. 2372 MJ/m^2, representing just 25,3% of the former for a service life of 50 years. Since Portuguese energy efficiency building regulation made under the Energy Performance Building Directive (2002/91/EC-EPBD) will lead to a major decrease of operational energy this means that the energy required for the manufacturing of building materials could represent in a near future almost 400% of operational energy. Replacement up to 75% of Portland cement with mineral admixtures could allow energy savings needed to operate a very high efficient 97 apartment-type building during 50 years.

Introduction

Growing global demand for energy is a major cause for unsustainable development of our Planet. It is estimated that by 2030 energy demand should grow about 40%, reaching 8.16 billion toe [1].
Portugal has a high energy consumption which accounts for nearly 60% of its total imports. Between 1995 and 2005 Portuguese GNP rise 28%, however the imported energy in the same period increased 400%, from 1500 million to 5500 million dollars. As to the period between 2005 and 2007 the energy imports reach about 10,000 million dollars.

Although recent and strong investments in renewable energy, Portugal continue to import energy and fossil fuels. This question is very relevant since a major part of the energy produced in Portugal is generated in power plants thus emitting greenhouse gases (GHGs). This GHG emissions compromises previous commitments under the Burden Sharing Agreement, defined within the European Community. Portugal emissions of CO_2e (which includes all GHG gases) in 1990 were 60 Mt/yr, and the individual target for Portugal emissions for 2010 could not overpass 76 Mt. However, in 2001 the emissions of CO_2e, had already reached 82 Mt, 36% above the maximum.

Given that the residential sector consumes 40% of all the energy produced throughout its life cycle, it is rather obvious that this sector could allow high energy savings. Cepinha et al. [3] argue that energy efficiency could easily lead to a reduction by one fifth of the energy consumed in the residential sector implying a reduction of 340 Mt of carbon dioxide. The measures taken in recent years under the EPBD, aimed at reducing the operational energy of the buildings (heating, hot water, electricity etc).This is because it was accepted that the largest energy part were due to operational energy. And indeed in inefficient buildings, the embodied energy represents just 10-15% of operational energy. However, as buildings become more energy efficient operational energy will be reduced and therefore embodied energy will become increasingly predominant.

Thormark [4] studied one of the buildings with the lowest energy consumption in Sweden ($45kWh/m^2$) stating that the embodied energy in materials, for a lifespan of 50 years may represent 45% of operational energy.

Dimoudi & Tompa [5] reported that the embodied energy in office buildings can range between 13% to 19% of operational energy for a lifetime of 50 years. The operational energy versus embodied energy them it is then a controversy issue.

The present manuscript analyses energy consumption of a building with 97 apartments (27.647 m^2). Operational energy and embodied energy are compared in order to highlight the factors that could lead to high energy savings.

The case study characteristics

The case study building is located in the Oporto region and consists of a 97 apartment-type building with a total area of $27.647m^2$. The operational energy of the building was estimated from electricity and gas consumption of eight apartments. Data of electricity and gas consumption is present in Table 1.

Table 1. Operational energy consumption in 8 apartments

Apartment	Electricity [kWh/yr]	Gas * [kWh/yr]	Area [m^2]	Total [kWh/yr]
1	3966	-	75	3966
2	6772	-	97	6772
3	2190	4287	200	6477
4	1095	3787	135	4882
5	2249	8600	138	10849
6	1095	9056	120	10151
7	913	1278	75	2191
8	2107	9678	180	11785

*Gas consumption was obtained from gas volume using the conversion factor 11, 6180 kWh/m^3 (Source EDP)

Using the median consumption and the median area we obtain respectively the value of 6625 kWh and 127.5 m^2, which will provide a unitary consumption of $52kWh/m^2/yr$. Converting this value in MJ using the factor 0.2778 [6], we get 187.2 $MJ/m^2/yr$ which represents 9359 MJ/m^2 in a 50yr service life.

Embodied energy

Current situation. The embodied energy was assessed for the following parts: concrete; steel; masonry; ceilings and roofs; doors and windows, mortars, renders, rockwool and cork insulation. Embodied energy was assess applying embodied energy coefficients (cradle to gate scenario) collected from two databases [7,8] to the mass of the materials responsible for the higher part of embodied energy (Table 2). Figure 1 shows the embodied energy (in percentage) of construction materials, corresponding to a total of 58,249,336 MJ. Embodied energy in concrete represents 70% of the total; therefore, high energy reductions can only occur by lowering the energy in this material. Assuming an average distance between the factory gate and the construction site of 30 km and an average transport energy of 1.5 MJ / (ton.km) we get 1,515,195 MJ for building materials transportation.

Table 2. Materials and embodied energy coefficients (EI)

Material	Quantity	EI (MJ/kg)	Ref.
Aluminium for windows and doors	24,3 ton.	184	[7]
Mortars and renders	1 775 m^3	1	[7]
Glass	64 798 m^2	8	[7]
Rockwool insulation	3 622 m^2	16	[7]
Clay brick	324 063 un	3	[7]
Cork insulation	12 978 m^2	4	[7]
Concrete	31 000 ton.	0,99	[8]
Reinforced steel	1 260 ton.	8,8	[8]

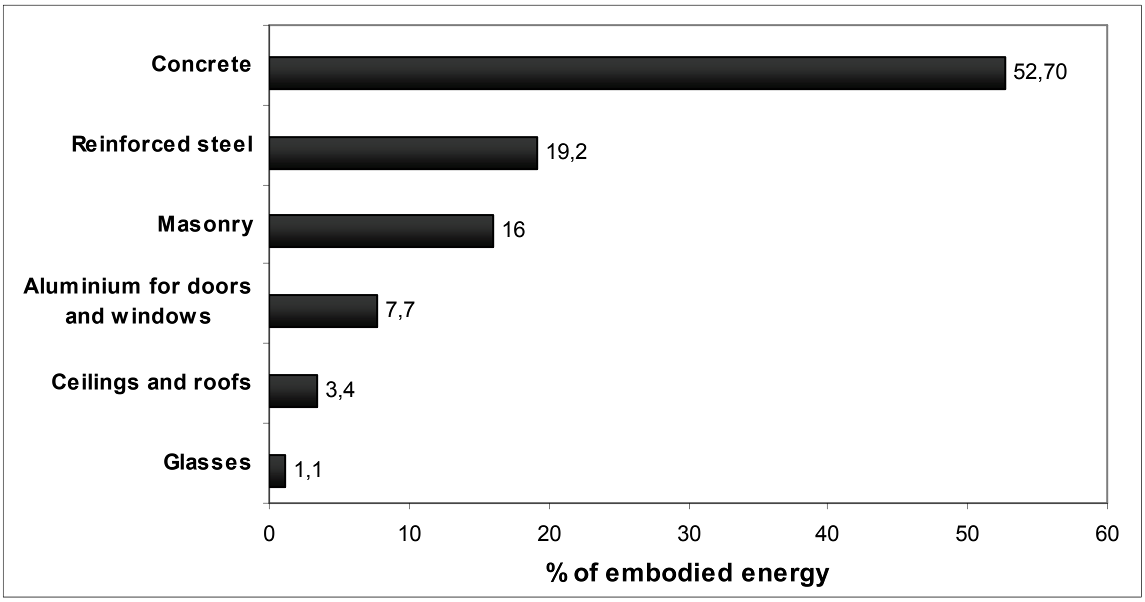

Figure 1.Embodied energy of the different materials

For the energy used during construction of the building an estimate of 10% was assumed of the energy production [9], which gives a value of 5,824,933 MJ. Then a total of 65,589,464 MJ arise, which corresponds to 2372 MJ/m^2. This represents 25.3% of operational energy for a period of 50 years, which does not differ much from the estimation presented by Dimoudi & Tompa [5].

Buildings with high and very high energy efficiency. If the building consumed just 28kWh/m^2 due to the inclusion of some measures under the EPBD leading to a more energy efficient thermal envelope as proposed by others [10], then a 100.1 MJ/m^2/yr unitary consumption could be achieved for operational energy. This would imply that the ratio embodied energy/operational energy climbed to 47.1% for a lifetime of the building of 50 years. However, if the building used just the energy needed for Portuguese AA+ class buildings of about 12 kWh/m^2 [11] this would represent 600 MJ/m^2 for the 50-year lifespan. This value is well below the amount of energy embodied, accounting for just 25% of it.

Building materials with lower embodied energy. One option to reduce embodied energy is by using high volume cement replacement mineral admixtures. Although current cement replacement levels in Portugal are set at 30%, some investigations indicate the possibility of producing high performance concrete with high volumes replacement of 60% fly ash [12], or even 80% blast furnace slag [13].

Another way to reduce embodied energy could include reinforced steel replacement by bamboo bars. Investigations in this area are very promising and show a decrease of the adhesion between concrete/bamboo that can easily be overcome with the use of pins embedded in the bamboo bars

[14-16]. With respect to the durability of bamboo based concrete, some authors reported a case of a bamboo based concrete structure that showed no sign of degradation after 15 years of service life [17]. Others confirm the high durability of concrete based bamboo [18].

For the present case study using a concrete with a replacement up to 75% of Portland cement with mineral admixtures (Embodied Energy = 0.53 MJ / kg) will allow savings of 16.43 million MJ. So the total for the materials considered above were 49,159,464 MJ, corresponding to a unitary value of 1778 MJ/m^2. This means that the mere change of concrete composition would mean a 25% embodied energy reduction. Almost as much as the energy used by a AA+ class 97 apartment-type building during 50 years. As for carbon dioxide emissions using this high volume cement replacement would represent saving 265 tones of CO^2 (the conversion rate between MJ and CO^2 was already used by others [19]).

Other authors mentioned that increasing the use of wood for building construction would reduce carbon emissions by nearly 50% [20]. Those findings show the urgency of using low embodied energy building materials as a good way to reduce energy consumption in the building sector.

Further considerations

Suggestions regarding the need for EPBD to encompass embodied energy have already been done by Szalay [21]. Also recent work done by others [22], recognize that energy savings by means of more efficient thermal insulation, as well as increasing renewable energy is an insufficient approach. Strangely, the proposal for the new EPBD [23] recently approved keeps focusing on operational energy reduction and also on renewable energy sources produced on site saying nothing about the importance of using low embodied energy building materials. As a consequence the building sector will continue to have no stimulus to choose low embodied energy materials.

Conclusions

High energy consumption is one of the most serious problems faced by Portugal. It represents a serious economic constraint and also means GHG emissions, which could involve financial penalties in a near future. Currently the largest energy consumption in the building sector are due to operational energy. However, as the legislation on energy efficiency lead to a building sector with minimal energy consumption, further energy reduction can only be achieved by using low embodied energy building materials. The use of concrete with high levels of cement replacement by pozzolanic additives will in the short term be the most obvious step in that direction.

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