Energy Life Cycle Approach in two Mediterranean Buildings: Operation and Embodied Energy Assessment

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Abstract: In the proposed work two case-studies were selected: the first one is a multifamily, high energy performance nearly Net ZEB located in central Italy; the second one is an existing standard Mediterranean single-family house in Sicily. The embodied energy and the operation energy were assessed for the case-studies, following a life-cycle approach, in compliance with ISO 14040 standards. In detail, when shifting from the standard building towards the high energy performance one, the relative share of operation energy decreases, while the embodied energy one increases. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach. The introduction of the life-cycle analysis introduces a further deficit in the energy balance from the neutral condition for the nearly Net ZEB case study. However, it emphasizes the embodied energy of the building as a key issues not to be neglected in the exhaustive evaluation of the energy demand of low energy buildings.

Keywords: Energy, Life-cycle approach, Net ZEB

Introduction

The reduction of energy requirement and the mitigation of environmental impacts in the building sector have become key targets of energy policies in different countries, to be matched by means of strategies aimed at the reduction of operation energy through the enhancement of energy efficiency and the spread of renewable energy technologies (Beccali et al., 2013). The Directive 2010/31/EC (the recast of EPBD 2002/91/EC) establishes the ‘nearly Zero Energy Building (ZEB)’ as the target within 2018 for all public owned buildings and within 2020 for all new buildings, pointing out that the energy required should be produced on-site or nearby renewable energy systems, thereby to reduce the consumption of primary energy and the related emission of greenhouse gases (Cellura et al., 2014). Buildings require energy over their life span; thus an exhaustive assessment of the environmental impacts may not neglect energy consumption, exploitation of natural resources and pollutant emissions in a life-cycle perspective. Until recently, only operating energy has been considered in many literature studies (Beccali et al., 2007), owing to its significant share in the total life-cycle energy consumption of standard buildings (70–90%). Conversely, embodied energy of building materials and components has been generally neglected in
building energy analyses, as in standard buildings it amounts up to 10–20% of the life cycle energy consumption. The definition of low-energy building strictly depends on climate, country, indoor climate and the user behaviour, which affects the energy consumption in each end-uses. Furthermore conversion factors from end-use to primary energy depend on the energy carriers used and the energy system of a specific country. Design of low energy buildings directly addresses the target of reducing the operating energy, by improving the thermal insulation of the building envelope, reducing infiltration losses, recovering heat from ventilation air and/or waste water, installing alternative energy using systems and renewable energy technologies for heating, domestic hot water and electricity generation. However, when shifting from standard houses to low energy buildings and to Net ZEBs the relative share of operating energy decreases, while the relative share of embodied energy increases. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach to compare the energy savings achieved in the building operation with respect to the overall life-cycle energy consumption (Blengini et al., 2010). Literature shows that low energy buildings have embodied energy in the range 10-100 kWh/(m²y), of which the highest values refer to the embodied energy of buildings sited in temperate and hot climate zones, while the lowest values refer to the embodied energy of cold climate buildings (Ramesh et al., 2010). The operating energy varies from nearly 0 to around 350 kWh/(m²y), moving from the NetZEBs to conventional houses in both climatic zones (Cellura et al., 2014). On the basis of the above considerations, in the following sections life-cycle approach is applied in order to assess embodied energy and operational energy in two building case-studies, in compliance with ISO 14044 standards (UNI EN ISO 14044, 2006): 1) the first one is a multifamily low energy building, which is located in central Italy; 2) the second one is a standard Mediterranean single-family house in Sicily. Tab.1 reports the main features for the two buildings under study.

**Tab.1. Building features**

<table>
<thead>
<tr>
<th>Building features</th>
<th>Low energy building</th>
<th>Standard building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of levels</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Heated floor area (m²)</td>
<td>610</td>
<td>110</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>1475</td>
<td>402</td>
</tr>
<tr>
<td>Heated floor to volume</td>
<td>0.33</td>
<td>0.27</td>
</tr>
<tr>
<td>S / V overall ratio</td>
<td>0.73</td>
<td>1.02</td>
</tr>
</tbody>
</table>

**Case study 1: the low energy building**

Starting from the results of the SubTask B activities in the International Energy Agency (IEA) joint Solar Heating and Cooling (SHC) Task 40 and The Energy Conservation in Buildings (ECB) Annex 52 titled “Towards Net Zero Energy Solar Buildings”, the authors introduced apply the life-cycle perspective in the energy balance of a Net ZEB case-study (Cellura et al., 2011). Thus, not only the annual energy demand of Net ZEBs for operation energy, but also
the sum of all energies incurred in the other life cycle phases are assessed. For this purpose, embodied energy of the building and its components, including both initial and recurring one, and demolition energy for the building end-of-life are annualized and summed to the annual operating energy loads.

The building under study is an Italian multifamily house, the Leaf House (LH), located in central Italy, built according to the Italian requirements of the energy regulation in force, integrating different sources of renewable energy. The building is composed by three levels, each one containing a couple of twin flats. The heat generation is carried out by a geothermal heat pump (GHP), connected to 100 m long vertical probes, the solar thermal collectors and the auxiliary boiler. Each flat is heated by means of a radiant floor supplied by the GHP. The solar thermal system is installed to integrate the GHP in the DHW generation. The electricity requirement of the LH is supplied by a grid-connected PV system, with 20 kW peak power and 12% module nominal efficiency. To reduce the electricity consumption for lighting large windows face the south, while at the rear of the building facing the south solar tubes convey the sunlight indoor. Furthermore efficient fluorescent lamps are used. Water consumption is reduced by means of the collection of rainwater for sanitary and garden uses. A suitable building automation system optimizes energy performances of the LH, by stopping the HVAC system when windows are open, by regulating the inlet temperature of the water in the radiant floors according to the external temperature, and by regulating air flow rate according to the CO₂ level in each apartment.

**LH life cycle energy analysis**

*Operation energy: monitoring of annual load and generation*

Operation energy is accounted starting from the outcomes of a one-year monitoring activity carried out in 2010. Electricity is required in the LH operation for space heating and cooling, ventilation, indoor lighting and plug loads, depending on the thermal performances and size of the building envelope, on the number of occupants and the activities inside. The flats account for around 34% of the total electricity consumption, while the thermal plant and, to a much smaller extent, the external lighting together account for the remaining 66%. With regard to the on-site energy generation, the PV system produces 24,664 kWh in 2010. Tab. 2 shows the outcomes of the annual LH final energy balance, assessed with regard to electricity. The annual energy balance is calculated. It shows a 0.9 MWh deficit. This outcome highlights that the LH can be considered a nearly Net ZEB, when the encountered energy flows are measured at the final level. However, when the annual energy balance is calculated in terms of primary energy, a shifting from the nearly Net ZEB condition, as final energy, to a non-Net ZEB condition, essentially due to the large difference between the conversion factors of PV electricity and imported electricity. The third column of Table 2 shows a significant increase of the deficit, in comparison with the first one. Such a deficit is about 57% of the imported primary energy not covered by the on-site generation according to the energy balance.
Embodied energy and demolition energy of the LH are assessed following a life-cycle approach, including the steps related to material and plant production, building erection and installation process, operation, maintenance/refurbishment and end-of-life. Embodied energy is estimated as the energy content, valued as primary energy, of the building related materials and components, and technical installations, including all the steps from the raw material acquisition to manufacturing processes. In such a definition, recurring embodied energy is also included, representing the primary energy consumption related to the maintenance and/or refurbishment of some building components and technical installations. In detail, energy consumption, owing to the transportation from the manufacturing gate to the construction site and to the erection step is also included in accounting for embodied energy. Furthermore, taking into account a lifespan of 70 years for the LH, and assuming one or more replacement for all the components with shorter lifespan, production and installation process of the replaced components are taken into account.

Demolition energy is estimated, including all the processes, which occur in the end-of-life of the building. Proper scenarios of dismantling and disposal/recycling of the C&D waste foreseen, depending on the distance from the LH to the site of disposal/recycling. All the energy consumption and environmental impacts due to transportation, demolition and recycling operations are calculated. The end-of-life of the replaced components in the refurbishment phase are also taken into account. The saved energy arisen from the avoided use of virgin raw materials, owing to the material recycling, is not assessed. The transportation of C&D wastes to recycling plants and/or disposal sites, when the end-of-waste stateis reached, is also included. Data related to the existing building derive from Loccioni Group¹ and from some producers of building materials and plant components. Inventory datasets on energy supply (electricity and fuels) and transportation derive from (Öko-Institut, 2011). Life cycle inventory model is carried out by using the SimaPro software (PRè, 2010). Fuel consumption from transportation is calculated, depending on the transport mode and the distance between sites. With regards to the thermal plant equipment and the PV and solar thermal plants, the service life is estimated based on manufacturer’s guarantees. Fig.1 shows the outcomes of the above described embodied energy (initial and recurring), demolition energy and operating energy, valued as primary energy and annualized taking into account the building lifespan. Globally, the annualized net primary energy consumption due to the whole life cycle of the LH is 89 MWh/y, of which the embodied energy and the demolition energy

¹ Loccioni Group, Angeli di Rosora, Ancona, Italy
result around 66 MWh/y, while operation energy results 32.6 MWh/y. With regard to the gross heated area (610 m²), the life-cycle net primary energy consumption is nearly 146 kWh/(m²y), of which 38 kWh/(m²y) is the operation energy and 108 kWh/(m²y) is the sum of the embodied energy and the demolition one. These results allow stating that compared with the literature case studies, the LH is representative of low energy buildings when life cycle perspective is taken into account.

Case study 2: Life-cycle energy in the standard single-family house

The standard building under study is a Mediterranean single-family house, located in Palermo in Southern Italy, 270 m above sea level, currently used by three occupants. It was built on one level with a heated area of 110 m². The local climate has hot and wet summers, which affect significantly the energy demand for the building winter heating. The structural frame is made of reinforced concrete with masonry block walls. The external walls construction include 20 cm bricks with a 9 cm of cavity filled with foam vermiculite. The floor is 20 cm thick, including perforated bricks and prefabricated reinforced concrete rafters. The roof has a wooden structure with composite materials and clay roof tiles cover. The ground floor lays on a structure made of reinforced concrete and cave crushed stones. The external walls have a U-value of 0.96 W/m²K. The roof and the ground floor have a U-value of 0.60 W/m²K and 1.6 W/m²K, respectively. With regard to the transparent surfaces, the building is only equipped with wooden frame and double-glazing windows (U = 2.8 W/m²K). Heating and domestic hot water (DHW) are provided by a LPG (Liquefied Petroleum Gas) boiler. The heating system is equipped with steel radiators with insulated steel pipes for distribution. Summer air cooling is provided with reversible electrical heat pumps with an average seasonal energy efficient ratio of 3.3 in cooling mode. The life-cycle primary energy of the building is 25.9 MWh/y of which embodied energy represents the 26% (6.7 MWh/y) and demolition energy accounts only for 2% (0.56 MWh/y). The operation energy accounts for the highest contribution, that is about
72% on life-cycle primary energy (around 18.6 MWh/y). Considering 50 years of lifespan for the building, the operation energy is estimated as the primary energy consumption for end-uses such as heating, cooling, domestic hotwater (DHW), lighting, electric devices, and cooking. A 3-year monitoring of the building end-uses is carried out to estimate electricity use for household appliances and cooling, LPG consumption for winter heating, DHW and cooking. The monitoring of the user behaviour during the operation step showed that the building annual operating energy mostly arises from the electricity consumption for lighting, electrical appliances and summer cooling, followed by the energy consumption for heating and DHW.

**Discussions and conclusions**

Fig. 2 compares the life cycle energy results for the two assessed buildings, highlighting the contribution of each energy items to the total. In the standard house case study, the annualized life cycle primary energy consumption is 235.5 kWh/(m²·y), with regard to the gross heated area (110 m²). The operation step involves the highest contribution to the life cycle primary energy consumption, accounting for 72% (about 169 kWh/(m²·y)). It is mostly due to the electricity use for household appliances and summer cooling (108 kWh/(m²·y)), while the remaining 61 kWh/(m²·y) are due to energy consumption thermal uses. With regard to embodied energy, it accounts for 26% of the life-cycle primary energy consumption, that is 61.5 kWh/(m²·y) while the demolition energy results 5 kWh/(m²·y).

Unlike the standard house, in the low energy building case study the life-cycle energy consumption is dominated by the contribution of the embodied energy, which accounts for 75% while operation energy amounts to 34%. Demolition energy results -9 kWh/(m²·y), thereby reducing the global life-cycle primary energy.

**Fig. 2. Contribution to the life-cycle primary energy for the two assessed buildings [MWh/(m²·y)]**
The assessed case studies show that there is a strict interplay among all the phases of a building life-cycle, as each one can affect one or more of the others, highlighting the relevance of the life-cycle approach to perform a liable and complete building energy and environmental assessment. When shifting from standard building to low energy ones, embodied energy increases, while the operation energy remarkably decreases. Obviously, the introduction of the life-cycle energy analysis increases the complexity of the energy balance calculation and introduces a further deficit in the energy balance from the neutral condition. However, it emphasizes the embodied energy of the building as a key issue to not be neglected in the exhaustive evaluation of the energy demand of low energy buildings.

References


