Eco-efficiency of passivhaus in Mediterranean climate

Monica Lavagna

Building Environment Science and Technology (BEST) Department, Politecnico di Milano, Italy

ABSTRACT: Energy evaluation of buildings service life is important to individualize strategies for energy saving and environmental impacts decreasing: the role of passivhaus from this point of view is obvious. Besides to evaluate eco-efficiency we should not be concentrated alone on building's life, but goes stretched to all the proceeded upstream and downstream.
To show these, it is stretched out a *Life Cycle Assessment* (LCA) articulated in two moments: evaluation of environmental impacts from the production of insulating materials and evaluation of environmental impacts from energy consumption of a building, in Mediterranean context.
Different stratifications of envelope (from high insulation to low insulation) were compared with the energy consumptions in service life (for heating), emphasizing from a side environmental advantages obtained from energy saving (for better performance in thermal insulation of high insulated envelope) and from the other side environmental impacts of the production's phase.
Results emphasize the role of thermal insulation for energy saving and the reduction of environmental impacts (building's use phase produces more environmental impacts than material production phase). However, the use of high thicknesses of insulating material (like Passivhaus standard) in Mediterranean climate doesn't reduce in significant way consumptions in use phase and therefore increases the impacts in production phase.

Keywords: energy, environment, life cycle assessment, eco-efficiency

1. INTRODUCTION

Energy and environmental evaluation of buildings service life is important to individualize project's strategies for energy saving and for environmental impacts decreasing.

Besides we should not be concentrated alone on buildings, but we should go stretched to all the proceeded upstream and downstream of building activity.

To show these propositions, it is stretched out an experimental application of LCA developed in parallel on building production and on building service life.

Environmental evaluation on product had as object insulating materials (in particular stone wool insulating material).

Environmental evaluation on building service life had as object the role of insulation for energy saving (for heating).

2. INSULATION IN PASSIVHAUS STANDARD

2.1 The role of thermal insulation for energy saving

In research and experimental technologies related to energy saving, thermal insulation is indicated as possible solution to reduce energy consumptions for heating.

In Germany actually are spread “3 litres haus”, whose energy request for heating is less than 3 litres of oil equivalent/m^2 year, and “Passivhaus”, whose thermal consumption is less than 1,5 litres of oil equivalente/m^2 year (less than 15 kWh/m^{2}year). This corresponds to about 10% of energy consumption in a conventional building (that consumes 150-250 kWh/m^2 year) and is, apparently, a good example of eco-efficiency [5].

While “3 litre house” is characterized to have 15-20 cm of insulating materials thickness in vertical closure and 30 cm in horizontal closure, “Passivhaus” has 30-40 cm of insulating materials in wall envelope (to obtain 0,15-0,10 W/m^{2}K thermal transmission values of opaque envelope), 40-50 cm of covering insulation, triple glass windows (with mechanical system of ventilation with heat recover).

In Central and Northern Europe one thousand Passivhaus were already built, a lot of which in the program CEPHEUS (Cost Passive Efficient Houses as European Standars), that spreaded the Passivhaus model.

This experience is starting to be applied in the Mediterranean context, where heating consumption is lower than in North Europe and where big problems related to energy consumption for cooling are emerging. The question is: the “Passivhaus” construction model, which is energy-efficient in North Europe, can be considered energy-efficient in Mediterranean climate as well?

2.2 Passive house versus “Passivhaus”

There is a great distinction between the traditional interpretation in Mediterranean areas of passive house and the new definition of “Passivhaus” standard by Wolfgang Feist and the Passivaus Institute.

The “Passivhaus” standard is an energy-based standard: the annual heating requirement correspond to 15 kWh/m^2year. In order to achieve this goal, in North Europe, the following building design strategies are pursued: a compact building form (with a low surface-to-volume ratio), a high insulated building envelope with 0,15-0,10 W/m^2K thermal transmission values for opaque envelopes (generally obtained with light envelope made of 40 cm insulating materials), mechanical ventilation. There is no specific attention on cooling loads (low in North Europe) and summer comfort (hot summer days are not frequent in North Europe).

In the Mediterranean context there are a lot of examples of “Passivhaus”, with less than 15 kWh/m^2year, because heat losses from external walls are less than in North Europe and the heating period is shorter. In Mediterranean climate the level of envelope insulation and thermal transmission to achieve the ‘Passivhaus’ standard of energy requested for heating can be less than in North Europe.

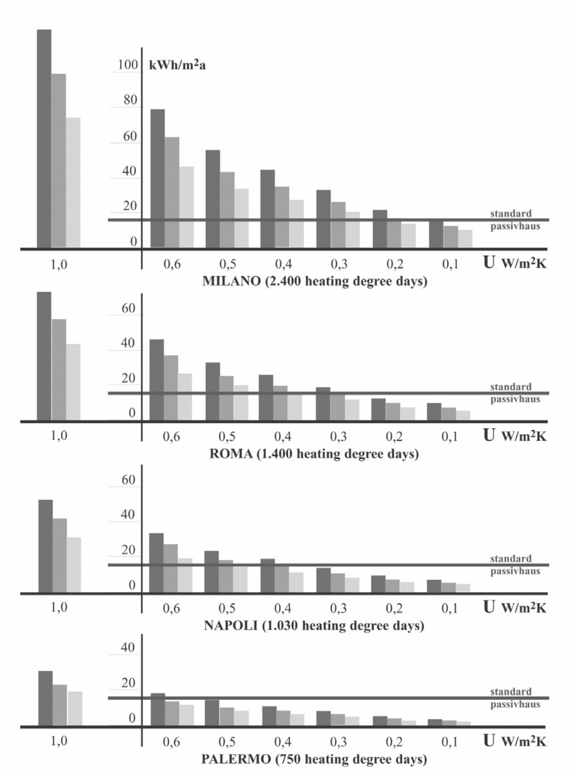

Figure 1: energy requirements for heating in Mediterranean climate in different building types (see Fig. 3) and with different thermal transmission values

In Mediterranean climate it is not necessary to build a “Passivhaus” construction model (with Germany standard) to obtain a “Passivhaus” energy standard. Generally, passive houses in Mediterranean climate are built with massive building technologies (masonry, concrete, stone), in order to collect the heat during the winter and, on the contrary, to maintain lower temperatures indoor during summer; (for heating captation during winter and cooling captation during summer), and porosity form (think about Spanish patios); furthermore, buildings are clustered together with porous shapes, to increase natural ventilation during summer

A scepticism roses to import “Passivaus” construction models into Mediterranean climate, especially regarding high insulation thickness standards (defined for North Europe). Anyway, many buildings have been realized following those rules.

It is necessary, therefore, to find out which is the right thermal insulation level to Mediterranean climate.

3. LCA COMPARISON OF ENERGY SAVINGS IN BUILDING’S LIFE AND INSULATION MATERIAL PRODUCTION

3.1 The role of Life Cycle Assessment

Life Cycle assessment (LCA) is a systematic method of analysis that quantifies and evaluates environmental impacts of a product or a service during its life cycle, across evaluation of matter and energy flows (input and output in extraction, transport, production, use phase, end of life).

Environmental evaluation methods can prime profitable synergies between choice of building products and choice of building construction techniques, supporting building design strategies to eco-efficiency.

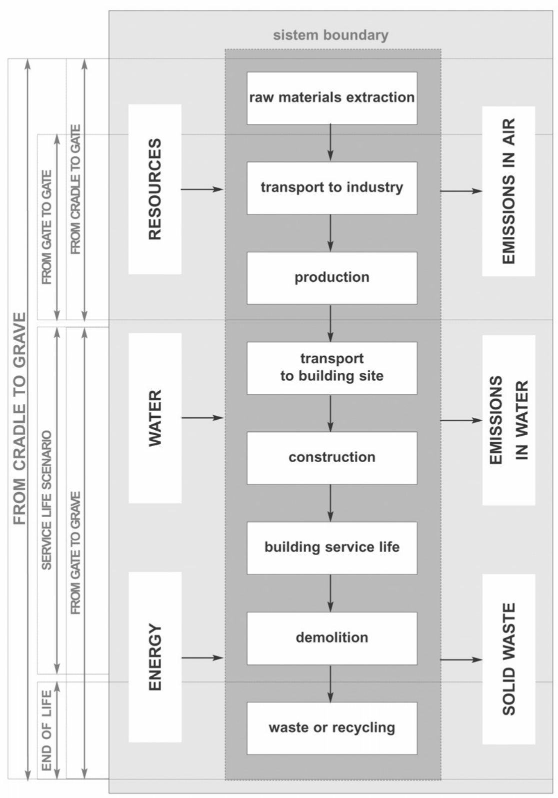

Figure 2: LCA input and output in different phases

3.2 The object of the LCA study on Passivhaus

One of the fundamental objectives of energy saving is the reduction of environmental impacts (above all the production of CO_2). To decrease energy consumption, an important (and simple) design strategy is to increase insulation.

But increasing the use of building materials raises environmental impacts.

It is important to understand which is the relation between the environmental increase of impacts in the production phase (due to the increment of the employed insulating material) and the decrease of the impacts in the use phase (thanks to energy saving guaranteed by high insulation).

The energy saving obtained from low insulated buildings versus high insulated buildings provides the greater impacts produced during the production phase of insulating material. But the question is if energy savings from high insulated buildings balance the greater impacts produced during the production phase of thermal insulating material.

If it is obvious, that buildings with low insulation (and few quantity of insulating materials) cause more environmental impact for energy consumption than environmental impact for insulating materials production, the focus of the analysis is on the increment of insulating material generated in the passage from the low energy building to the Passivhaus: in this transition, by reducing the thermal transmittance from 0,25 W/m^{2}K to 0,15 W/m^{2}K it is necessary to double the quantity of insulating material (and at the same time to double environmental impacts for material production).

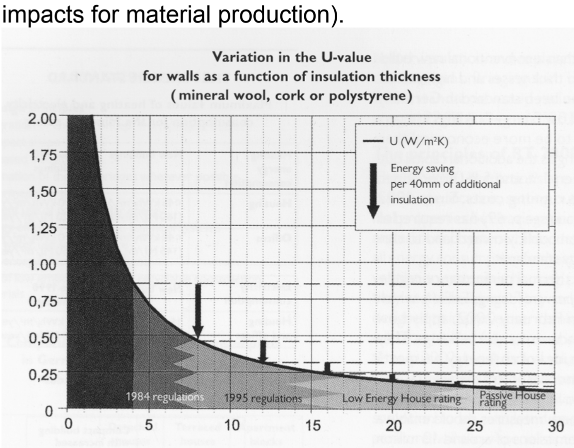

Figure 3: insulating material thickness to reduce heat transmission (Gauzin-Müller, 2001)

The aim of the LCA study on Passivhaus is to individualize the right level of thermal insulating material for eco-efficiency of buildings in Mediterranean climate, comparing environmental benefits during the use phase obtained with energy saving with environmental costs during production and end of life phases for the increased quantity of insulating material.

3.2 The case studies of LCA on Passivhaus

The present study of LCA on Passivhaus compares different situations: three building types (from 0,53 to 0,33 Area/Volume value), different quantity of thermal insulating materials used in the envelope (from 0 to 22 cm of stone wool in the vertical envelope and from 0 to 36 cm of stone wool in the horizontal envelope) and different Mediterranean context (from Milano, with 2.400 heating degree days, to Palermo, with 750 heating degree days).

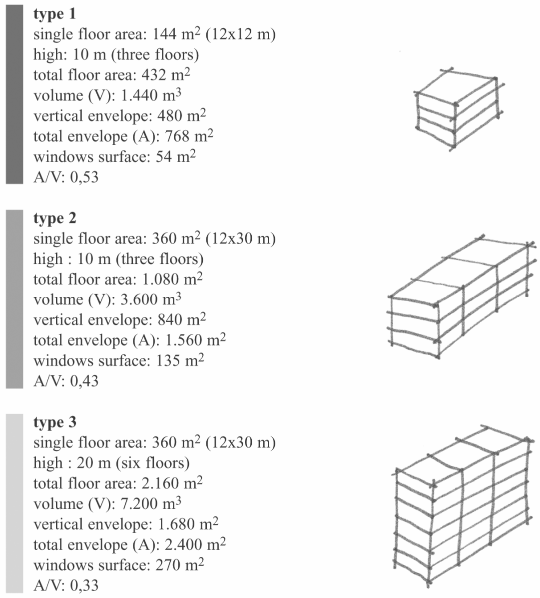

Figure 4: Building type and Area/Volume value

Different envelope stratifications, compared by the study, starting from the "basic" solution of the brick block wall without insulating materials (with 1,00 W/m^{2}K U-value), a traditional solution for the Italian and Mediterranean construction context, and implementing it with insulating material thicknesses (to obtain from 0,60 to 0,10 W/m^{2}K U-value).

Table 1: Insulating material (stone wall) thickness related to thermal transmission (starting from a 'basic solution of brick wall with 1,00 W/m2K).

U value W/m2K	insulating material thickness cm
1,00	brick wall + 0 cm
0,60	brick wall + 3 cm
0,50	brick wall + 4 cm
0,40	brick wall + 6 cm
0,30	brick wall + 9 cm
0,20	brick wall + 16 cm
0,15	brick wall + 22 cm

Different envelope stratifications (from low insulated to high insulated) were compared with energy consumptions in service life for heating (with natural gas use), emphasizing environmental advantages obtained from energy saving (for better performance in thermal insulation of high insulated envelope) and environmental impacts of production phase (for the high insulating material quantity).

The Environmental evaluation is articulated in two moments: the evaluation of the environmental impacts from the production of thermal insulating materials (stone wool) and the evaluation of the environmental impacts from energy consumption of a building for heating.

Other building components were neglected in environmental impacts inventory. The analysis focuses on the role of thermal insulating material and this is the only material taken in account. Environmental impacts of insulating material production change on the grounds of different quantity of insulating material put in envelope to decrease thermal transmission value.

Environmental impacts of energy consumption change on the grounds of thermal dispersion from envelope based on thermal transmission value. Solar and interior gains, thermal dispersions by windows and by ventilation were not considered, because they do not vary in the different hypotheses. Energy efficiency or energy produced by renewable sources were not assumed in this study, that focuses on the role of high insulation.

3.3 Life Cycle Assessment results

Results emphasize the role of thermal insulation for energy saving and reduction of environmental impacts (the use phase of building produces more environmental impacts than the material production phase). For a building located in Milan (2.400 heating degree days), making a choice of 0,30 W/m2K (10 cm of insulating materials) instead of 0,60 W/m2K (3 cm of insulating materials) can halve yearly energy consumption for heating. The increase of environmental impacts for insulating materials production (of 10 cm instead 3 cm) can be recovered in few years of building use (by reduction of environmental impact for energy saving).

However the use of excessive thicknesses of thermal insulating material (like “Passivhaus” standard) in Mediterranean climate doesn’t reduce in significant way consumptions in use phase and therefore increases the impacts in production phase. If a building is in Milan (2.400 heating degree days), to make a choice of 0,20 W/m2K (16 cm of insulating materials) instead of 0,30 W/m2K (10 cm of insulating materials) increases environmental impacts for insulating materials production (of 16 cm instead 10 cm) with a really low reduction of environmental impact for energy saving.

The study shows that in Italy (and so in Mediterranean areas with the same climate) insulating materials thickness of 15-30 cm produce more environmental impacts during production than the respective energy saving during building use. Insulating material thickness of 5-10 cm produce environmental impacts during production that can be recovered in 5-10 years by energy saving during building use. Insulating materials thickness of 1-5 cm produce environmental impacts during production that can be recovered in a years by energy saving during building use.

Generally, in Mediterranean climate 5 cm of insulating material are an important minimum, 5-15 cm go to save energy and reducing environmental impacts, high insulation material quantity (15-30 cm) produce environmental impacts (for insulating material production) without a significant benefit in energy saving.

Particularly, the study shows insulation ‘sustainable’ level in Mediterranean climate.

In Milan (2.400 heating degree days) insulation ‘sustainable’ level can be choose during building design considering that:

- a maximum thermal standard is 0,40 W/m2K (using not less than 6 cm of insulating material in building envelope);
- a better eco-efficiency standard is about 0,30-0,20 W/m2K (using 10-15 cm of insulating materials in building envelope);
- the increase of insulation beyond this, with a thermal standard less than 0,20 W/m2K (using more than 15 cm of insulating materials in building envelope), become a impact for environment;

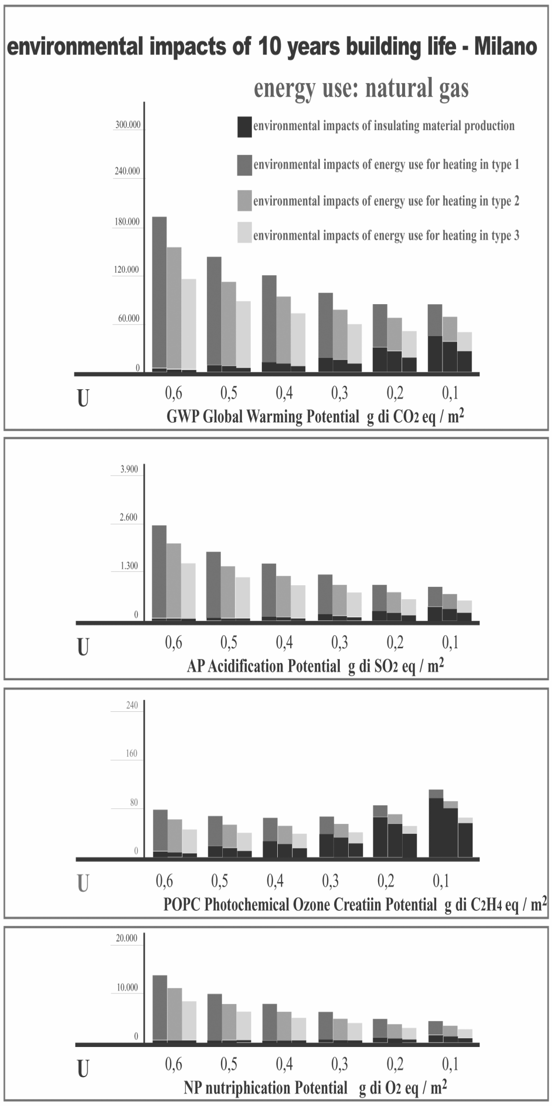

Figure 5: LCA comparison of environmental impact from insulating materials production (black) and energy consumption for heating (with natural gas use) in different building type (see fig. 04) and different insulated envelope (from 0,6 to 0,1 W/m2K) in Milan climate (2.400 heating degree days). Impacts on the entire building were normalized in value/m2 to compare different building type

In Rome (1.400 heating degree days) insulation 'sustainable' level can be choose during building design considering that:
- a maximum thermal standard is 0,50 W/m2K (using not less than 4 cm of insulating material in building envelope);
- a better eco-efficiency standard is about 0,40-0,30 W/m2K (using 6-10 cm of insulating materials in building envelope);
- the increase of insulation beyond this, with a thermal standard less than 0,30 W/m2K (using more than 10 cm of insulating materials in building envelope), become a impact for environment;

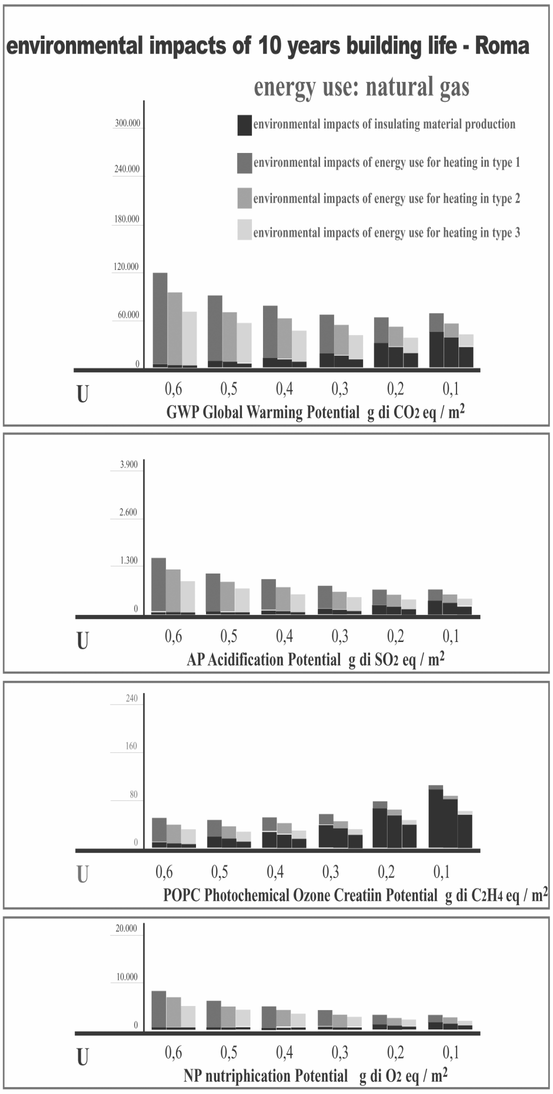

Figure 6: LCA comparison of environmental impact from insulating materials production (black) and energy consumption for heating (with natural gas use) in different building type (see fig. 04) and different insulated envelope (from 0,6 to 0,1 W/m2K) in Rome climate (1.400 heating degree days). Impacts on the entire building were normalized in value/m2 to compare different building type

In Napoli (1.030 heating degree days) insulation 'sustainable' level can be choose during building design considering that:
- a maximum thermal standard is 0,60 W/m2K (using not less than 3 cm of insulating material in building envelope);
- a better eco-efficiency standard is about 0,50-0,40 W/m2K (using 4-6 cm of insulating materials in building envelope);
- the increase of insulation beyond this, with a thermal standard less than 0,40 W/m2K (using more than 6 cm of insulating materials in building envelope), become a impact for environment;

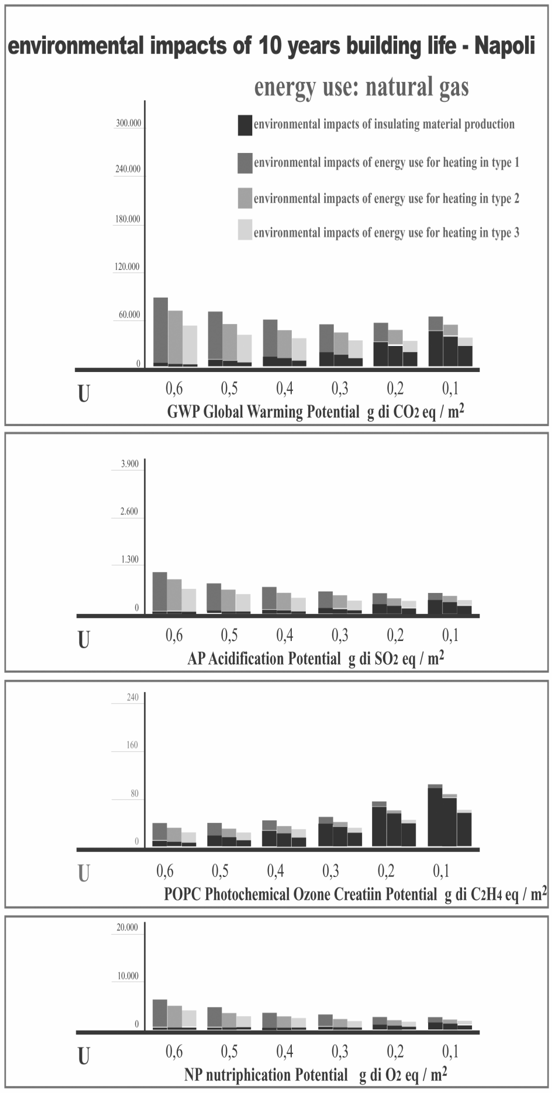

Figure 7: LCA comparison of environmental impact from insulating materials production (black) and energy consumption for heating (with natural gas use) in different building type (see fig. 04) and different insulated envelope (from 0,6 to 0,1 W/m2K) in Napoli climate (1.030 heating degree days). Impacts on the entire building were normalized in value/m2 to compare different building type

In Palermo (750 heating degree days) insulation 'sustainable' level can be choosen during building design considering that:

- a maximum thermal standard is 0,80 W/m2K (is possible to obtain it without insulating material in building envelope);
- a better eco-efficiency standard is about 0,60-0,50 W/m2K (using 3-4 cm of insulating materials in building envelope);
- the increase of insulation beyond this, with a thermal standard less than 0,50 W/m2K (using more than 4 cm of insulating materials in building envelope), become a impact for environment;

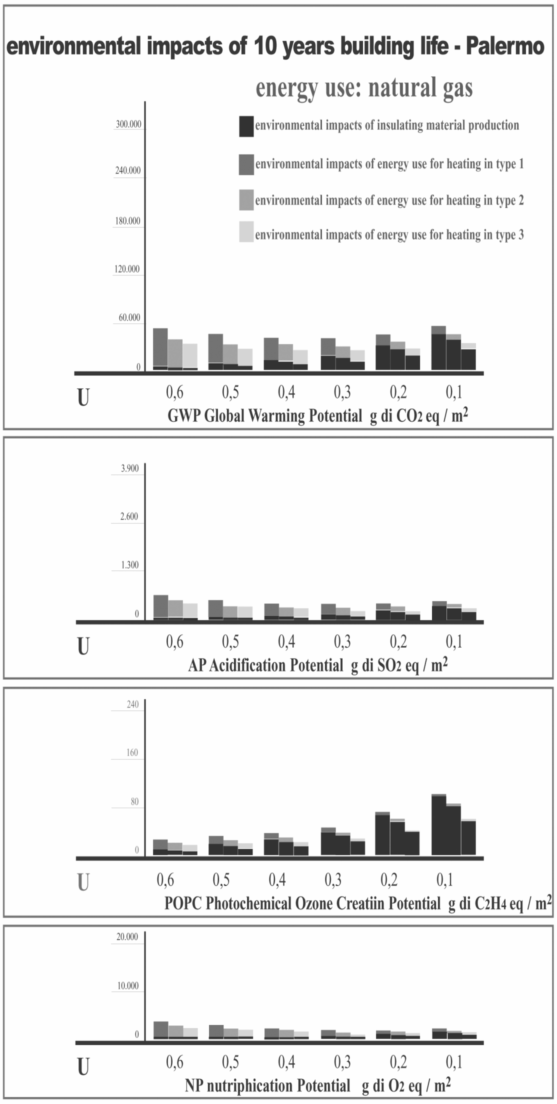

Figure 8: LCA comparison of environmental impact from insulating materials production (black) and energy consumption for heating (with natural gas use) in different building type (see fig. 04) and different insulated envelope (from 0,6 to 0,1 W/m2K) in Palermo climate (750 heating degree days). Impacts on the entire building were normalized in value/m2 to compare different building type

5. CONCLUSION

Scientific papers on eco-efficiency [5] suggest "Passivhaus" standard has a model of eco-efficiency, because this kind of building drastically reduce energy consumption for heating. This interpretation of eco-efficiency look only to use phase but doesn't look at environmental damage in the other phases of building process.

The life cycle assessment presented in this paper emphasizes that the increase of insulating materials quantity request by Passivhaus standard can cause an increase of environmental impacts in a life cycle lookout, especially in Mediterranean climate.

Life cycle approach (and assessment) can be a support to building design decision and can be useful to verify environmental benefits of building design strategies to eco-efficiency.

A technical solution (for example, in this case study, thermal insulation) can appear to increase benefits positively if we are looking only at energy saving during building service life (more insulation, more energy saving, theoretically at infinity). But if we look at the environmental benefits and damage in the entire building life cycle, with a life cycle assessment approach, we can specify the border line of environmental benefits and eco-efficiency obtainable with a specific technical solution (for example, thermal insulation) and define the 'sustainable' use of a specific technical solution in a specific project context.

REFERENCES

[1] Raimund Bleischwitz, Peter Hennicke, Eco-efficiency, Regulation and Sustainable Business, Edward Elgar Publishing, Cheltenham, 2004.
[2] European Environment Agency, Greenhouse gas emission trends and projections in Europe, Copenhagen, 2002.
[3] Dominique Gauzin-Müller, L'architecture écologique, Le Moniteur, Paris, 2001.
[4] Andera C. Schmidt, Anders U. Clausen, Ole Kamstrup, Allan A. Jensen, Comparative Life Cycle Assessment of Three Insulation Materials: Stone Wool, Flax and Paper Wool, Eco-Informa, Austria, 2003.
[5] Ernst Ulrich von Weizsacher, Hunter Lovins, Amory Lovins, Factor Four: Doubling Wealth, Halving Resource Use, Earthscan, London, 1997.