Social and energy redevelopment of an old building

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Abstract

The experiment wants to show how a projection exploiting the knowledge of the life cycle analysis of materials has less impact than the same project without the use of this kind of analysis.

Recently, the life cycle analysis (LCA) has been commonly used as a check instrument in the design of new buildings, but it is not yet used regularly in existing redevelopments, most of all if they concern a very old building as the example below.

The life cycle assessment was introduced in 1993 by the SETAC (Society of Environmental Toxicology And Chemistry) and it is a method of systematic analysis that values the environmental impacts of a product, the process of production and its activities throughout the life cycle. The life cycle of products surrounds all the phases of the production and also the use and the end of the components of the process itself. The analysis starts from the extraction of the natural resources and the production of energy for the productive process; material and energy are parts of the phases of production, transport and use, as they are part of the phase of recycling, reuse and disposal.

We have decided to use a life cycle approach, because we can obtain knowledge of the damage and the environmental potentials, due to what happens in each single operative phase. Our goal is to use solid notions about the environmental impacts of a production choice like the renovation of a building from 1836.

1. Introduction

1.1 The fortress of Sant'Andrea in Venice

The fortress of Sant'Andrea was constructed in the 15th century on the stones of a previous fortress and was built there to protect the "Bocca di Lido" from attack by the Turks who had just broken the peace treaty and had occupied Cyprus. The architect Michele Sanmicheli from Verona drew up the project, he knew the defence works very well because of his curiosity and the knowledge of other kinds of defences near Treviso, and because of this interest he was put in prison accused of being a spy.

The fortress situated at the entrance of the "Bocca di Lido" went through several restyling interventions in order to follow the different military functions based on changes in defence strategies. Because of their very static and tough shape, the redevelopments have never kept up with the real need (Marchesi P., 1978).

We do not have much historical information about this because of military classified information which has only recently been lifted. The most important interventions can be summarized in some historical ages: the birth of the Sanmicheli fortress in the 15th century, the addition of the officers' house during the 17th century, the building of two sleeping barracks in the 1830s, the addition of the stores at the end of the 19th century.

We are interested in the sleeping barracks, because after a structural renovation they will be used for a cultural centre with the following facilities: library, newspaper library, managing area, offices, multifunctional room, bar, a small bookshop, exposition area and a room for building up the expositions. The nearby areas will be reused, but we are not interested in them for the moment.

The main intervention to be undertaken in order to redevelop the barracks and change the use is the rebuilding of a definite volume. The external walls are in a good state: they just need to be cleaned and to have a sufficient insulating layer inside while

the roof is mostly collapsed, so it is going to be destroyed and rebuilt in the same shape but with a strong energy performance improvement, thanks to the use of an insulating layer. The floor is quite damaged and largely absent due to tree growth. It is going to be completely destroyed and rebuilt at the same level but with the insert of better thermal and hygrometric materials.

1.2 LCA methodology

The elaboration of a LCA, following the SETAC procedure, is divided in 4 steps:

- Goal and scope definition
- Life cycle inventory (LCI) in which we make an inventory of incomes (materials, energy, natural resources) and outgoings (air, emissions, water, soil) relevant in the system
- Life cycle impact assessment (LCIA) of environmental potentials, related to these input and output
- Analysis of the results and the evaluation of the improvements (life cycle interpretation) of the two previous steps

The description of the structure of the life cycle evaluation can be found in the UNI ISO 14040 standard (EN/ISO 14040, 2000).

The richer the database of the substances taken and released in the environment by the industrial process to obtain the product, the more accurate is the LCA. The evaluation of the results of LCA depends on the choice of methods used to connect the substances emitted in the environment, to the impact categories and on the importance that we gave to those substances. Those choices are very important and difficult, because they involve several technical, social and economic problems, like the environment impact and the link between costs and benefits.

1.3 The IMPACT 2002+ method

This was developed by the Swiss Federal Institute of Technology of Lausanne. As shown in Figure 1, the damage categories are:

- Human health, compared in DALY and coming from the 5 following impact categories Human toxicity, Respiratory (inorganics), Ionizing radiations, Ozone layer depletion, Photochemical oxidation;
- Ecosystem quality, expressed in PDF*m2*yr, coming from impact categories Acquatic ecotoxicity, Terrestrial ecotoxicity, Terrestrial acidification/nutrification, Acquatic acidification, Acquatic eutrophication and Land occupation;
- Climate change, expressed in kgCO2eq to air, come from the only impact category Global warming;
- Resources, in MJ, built from midpoint categories, Non renewable energy and Mineral extraction.

1.3.1 The characterization

In Impact 2002+ the results are first connected to the 14 impact categories, and then to the damage categories. Characterizations factors of the different substances are based on the principle of equivalence. This means that each category has its own referent substance and the points given to the different substances are given in Kgeq related to the referent point established for each category. The main goal for all impact categories is the determination of the long term effects obtained by the use of an infinitive temporary horizon.

The process of the impact characterization finds the link between the midpoint categories and the damage categories. The factors of midpoint characterization “Respiratory Effects”, “Photochemical oxidation”, “Ionizing radiation”, “Ozone layer depletion”, “Terrestrial acidification/nutrification”, “Land use occupation” and “Mineral extraction” are obtained by Eco-Indicator 99, adopting the equalitarian cultural perspective.

For climate change, the most recent global warming potentials are employed with a temporary horizon of 500 years to consider the long-term effect of changing climate gas emissions. The characterization factors for “Aquatic acidification” and “Aquatic eutrophication” are adapted from Hauschild and Wenzel’s research (Wenzel 2001).

The characterization factors for the consumption of renewable resources are calculated with the superior warming power. The calculation for

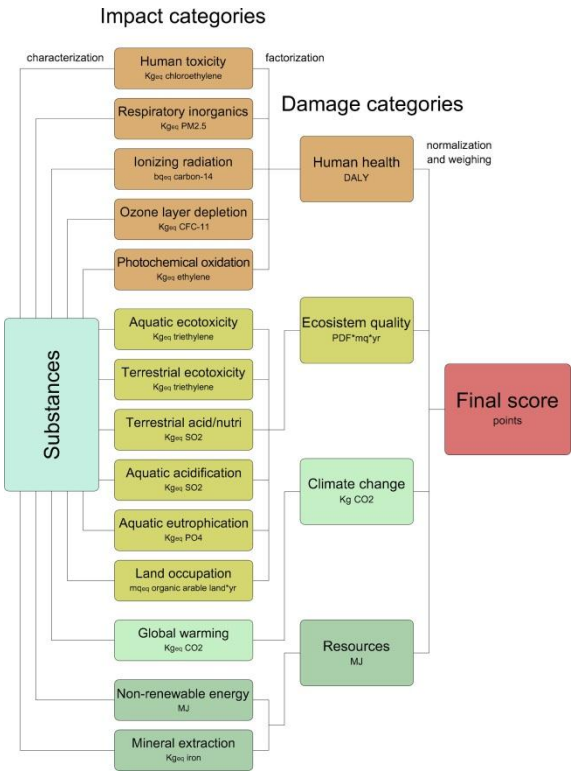

Fig. 1 – Scheme of IMPACT 2002+ method

"carcinogens" and "non carcinogens" impact categories is more difficult. The link between the substance and the effect is calculated by a code.
It is almost the same for the aquatic ecosystem impact.

1.3.2 The normalization

The normalization aims to analyze the relative weight of each class of impact related to the total damage adding a normalization factor to the impact categories and to the damage categories in order to easily understand the results. The normalizations come comparing the specific impact per unit of global impact emission determined by the whole substances of each category.
The normalization factors are found in the following ways:

- In Human Health the normalization factor is calculated in agreement with Eco-Indicator 99 with two exceptions: the impacts caused by climatic changes are not considered, but the toxicity of the polluting substances for humans is calculated like a sum of carcinogenic and non carcinogenic effects.
- Even in the Ecosystem Quality, the normalization factor is calculated in the same way as in Eco-Indicator 99 with two differences: the damage to the quality of the ecosystem caused by the transformation of the soil and by the photo chemical oxidation is not considered and the damage to the quality of the ecosystem is divided among the damage categories for the water and the earth's ecosystem
- In Climate Change the valuation of the normalization is based on the total annual emissions of CO_2 produced in Europe, multiplied by the potentials of global warming in a horizon of 500 years.
- In Resources the valuation of normalization is calculated as the total consumption of non renewable energy in Europe, including nuclear energy consumption.

1.3.3 The evaluation

Each of the four damage categories are considered separately without further evaluation. The weight factor is simply equal to 1.

1.4 The choice of a method

All the analyses are made in several ways -Eco-Indicator (Eco-Indicator 99, 2000), IMPACT 2002+ (Frischknecht R., 2007), EPS 2000 (Steen B., 1999) EDIP 2003 (Frischknecht R., 2007), IPCC (Frischknecht R., 2003), ReCiPe (Goedkoop M., 2008)-, but we have chosen the IMPACT method, because (Neri, 2008; Neri, 2009):

- it measures the impact categories comparing the quantities of equivalent emissions which represents the most accepted standards, because it is surely measureable;
- it measures the damage categories comparing the effects they produce on the people (life years lost), on the environment (number of vegetarian species influenced), on the resources available (non renewable used energy). Those effects are measurable with difficulty, but easily understood by the community;
- it holds all the most important impact categories;
- the weights given to the emissions and to the impact categories reduce the damage due to the use of the territory of Eco-Indicator 99 even if it

makes the ecotoxicity of the Earth to come out, especially if this is due to heavy metals;
- it measures the energy consumption by non renewable combustibles (fossils and uranium), it is one of the best ways to value the environmental damage of a product;
- it considers the European basin to measure the effects of emissions.

1.5 The LCA applied to the restructuring of the buildings.

In this process we have adopted a different way of thinking (Neri, 2008), because the roofs of the barracks have already collapsed. We have split the building life in two parts: the first part with its own LCA analysis for everything which is no longer there because it has been destroyed, and the second part with its own LCA analysis with the impact of all the new materials added and with the resources needed to ensure the restored building remains standing for at least 100 years. All the ancient parts not substituted, for example the walls made by bricks, weigh on the LCA for their life part, as 100/(2011+100-1836). 2011 is the date of the renovation project, 100 is the life time used for the LCA, 1836 is the date of the building construction.

2. Simulation

2.1 The LCA of the building

The building was built over several periods: between 1554 and 1559 the external walls were constructed with stones from Istria and bricks; after 1750 the 3 storey house on the north-west corner; in the 1830s the 2 sleeping barracks behind the fortress and in the 1900s the store houses (Fortuna, 2011; giabon). The LCA concerns:
- the structural components which are unchanged adding an allocation equivalent 100/275 for the sleeping barracks for the production and for their end life
- the structural components which are dismissed (the roof and the floor) adding an allocation equivalent to 100/100
- the building of the new roof, the insulation of the external wall, the maintenance and the life end with an allocation equivalent to 100/100
- the air-conditioning and heating systems
- the photovoltaic plant made of special bent tiles designed to hold the panel and able to satisfy almost the whole electrical power need
- the power consumption for 100 years of air-conditioning and lightning of the cultural centre situated in the barracks.

2.1.1 Life end of the several existing packages

We are using the database of SimaPro (the software used for the LCA analysis, Goedkoop M., 2008) for all the materials we are going to add to the barracks.
What remains of the ancient roof is probably 30%, but it will be dismantled because it has not been well preserved: wooden parts will be used to build some panels of MDF; the roofing flat bricks, still perfect, will be re-used to make the new roof, the bent tiles still existing will be re-used with some others. We are using the broken bent tiles, after crushing, for the preparation of the foundations.
The renovation includes for the floor a layer of insulation, but this material would create some problems (a new step) for handicapped people, so we have decided to destroy completely the floor using the remains after crushing.

2.1.2 The materials for the renovation

Material	Quantity	Unit	Eco points
Bricks	201446	kg	$5{,}4E^{-5}$
Concrete	121	m^3	0,0475
Cork slabs	23572	kg	$2{,}53E^{-7}$
Fiber wood	236	m^3	0,131
Plaster	41544	kg	$4{,}02E^{-5}$
Plasterboard	12983	kg	0,00011
Steel	15747	kg	0,000543
Wood (fir)	67	m^3	0,056

Table 1 – Database of the main materials and related damage expressed in Eco points

The materials needed to renovate are mostly some insulating materials useful for the energy system of the building and elements to make the new floor. On the roof we have to use new trusses, some virgin wood, while on the wall we will use

plasterboard everywhere.
For the insulation we have compared a chemical material, the XPS, with a natural material, cork. The first one can be thinner and lighter than the second, but cork is stronger against wet and salty water, and it probably wil only need to be substituted in 50 years. Therefore, we preferred to use cork.

3. Discussion and result analysis

In order to choose the less impacting materials, several packages of the same termohygrometric and thermal qualities have been compared through the LCA. The less impacting ones have been chosen and then the impact factors based on the different phases of the life of the whole building have been compared.

3.1 Comparison between technological packages

The solution of the ventilated roof with roof tiles in "cotto" is less impacting than the non ventilated one: 0.22427 vs. 0.24477 Pt (each square metre, -8,38%). This is due to a smaller damage of the impact categories: Carcinogens, Respiratory inorganics, Global warming and Non renewable Energy.

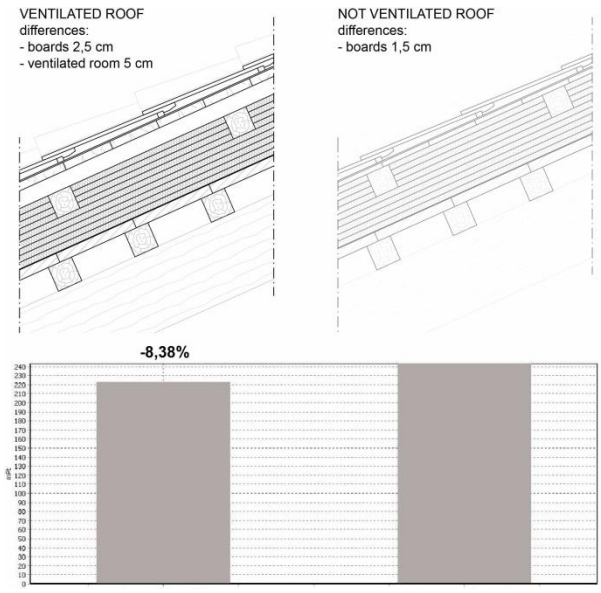

Fig. 2 – Comparison between roofs expressed in Eco points

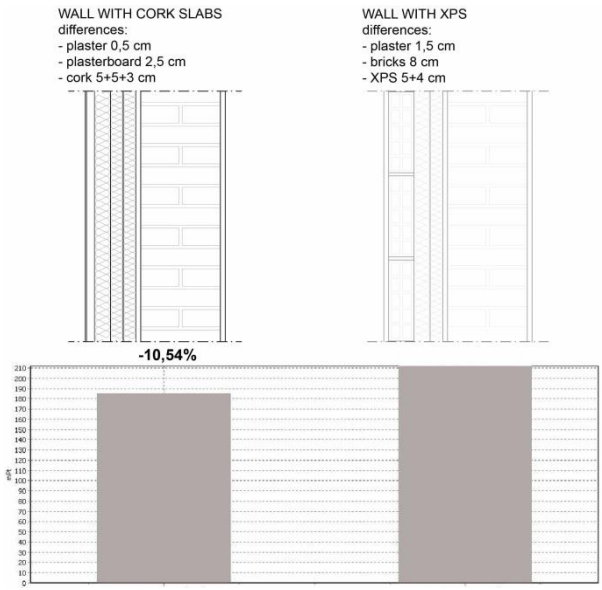

Fig. 3 – Comparison between external walls expressed in Eco points

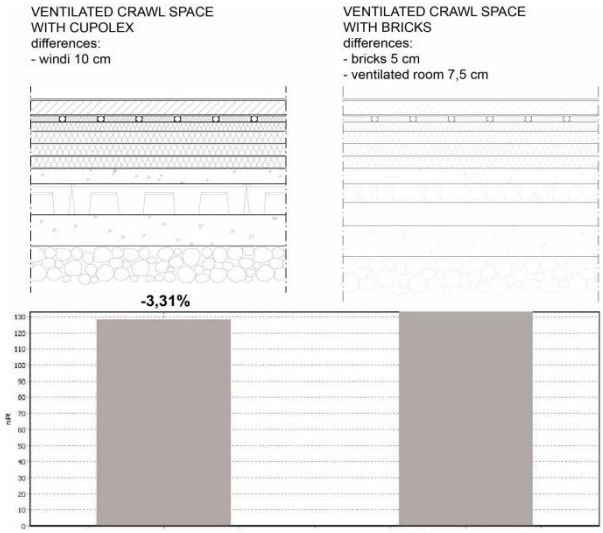

Fig. 4 – Comparison between ventilated crawl spaces expressed in Eco points

The cork solution is less impacting: 0.23781 vs. 0.26584 Pt (each square metre, -10,54%), which is due to a smaller damage of the impact categories: Respiratory inorganics, Global warming and Non-renewable energy.
The solution with cupolex is less impacting: 0.12953 vs. 0.13396 Pt (each square metre, -3,31%), due to a smaller damage of the impact categories: Respiratory inorganics, Global warming.
From the analysis of the results of the evaluation we noticed that:

- the total damage is worth 1.19E3 Pt due to the lightening electricity at 30%, to the electricity for instruments at 17.48% and to the auxiliary systems electricity at 16.64%.
- the damage is also due to the Human Health at 22.94%, to the Ecosystem Quality at 9.66% and to the Resources at 67.73%.

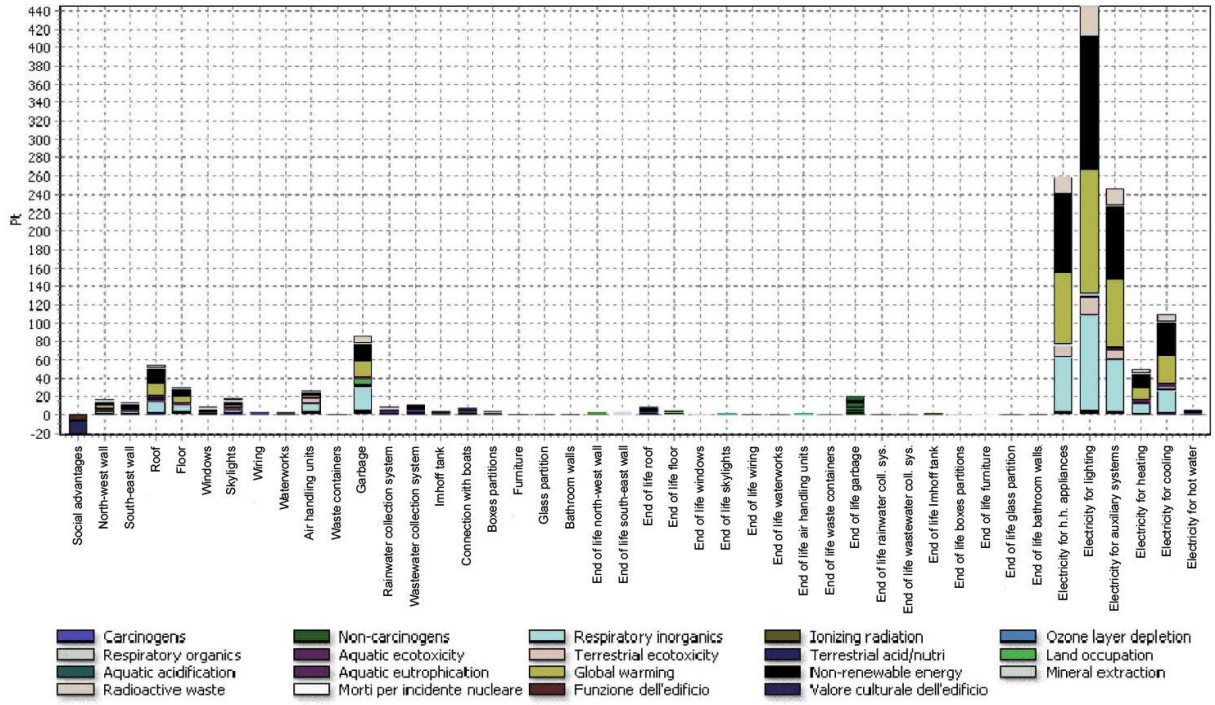

Fig. 5 – Analysis of all single elements

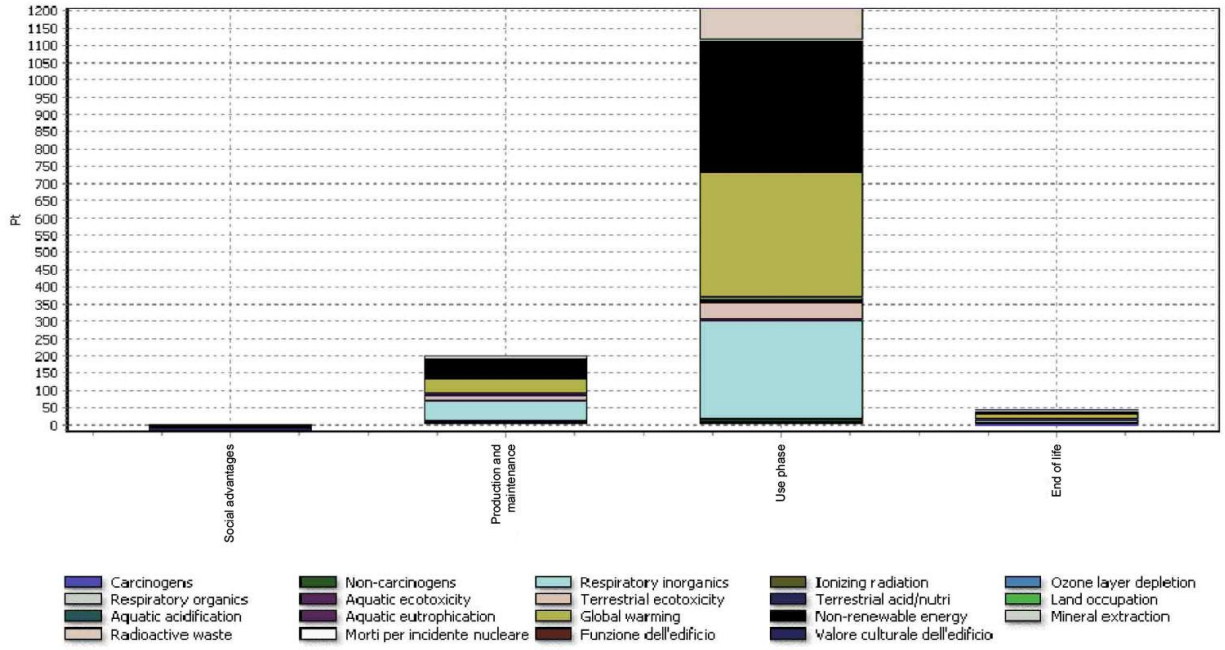

Fig. 6 – Analysis divided for phases of life: (social advantages) construction, use, end of life

From the analysis of the results we notice that:
the total damage is worth 1.19E3 Pt
the production and keeping phases need the 14.1%, the use phase needs 83.3% and the life end the 2.6%
the first column is negative because of social advantages

3.2 The sensitiveness analysis

3.2.1 The photovoltaic roof

The architectural constraints do not allow the installation of photovoltaic panels in cities' historic centres, and this also has an effect on the fortress. We decided to analyze the photovoltaic roof made with PV roof tiles, which are almost like traditional tiles, but they can give us a part of the electricity we need for the cultural centre. The information about these tiles given to us by the firm indicates an area of 18 square metres to produce 1 kWp, with an inclination of 30 degrees and the south direction. So we used the free program Simulare and, with a comparison of all this information, we found a result of 20000 kWh year at the beginning of the life cycle of the PV roof and 17000 kWh year after 30 years.
So we did a LCA to control the impact of the roof if using photovoltaic roof tiles and traditional terracotta tiles, and we found that the photovoltaic roof has more impact compared to traditional roof tiles fitted , although the photovoltaic energy has about 9 times less impact related to the same Wh from the electricity grid in Italy. This big difference is due to the use of plastic materials (polymer PMMA for the realization of the covering and techno polymer ASA for the remaining part of the roof tile) in the construction of the photovoltaic tile. These materials are able to cancel the visual difference that exists between terracotta roof tiles and solar roof tiles, but the solution of the problem of the vision creates a disadvantage for PV tiles.

3.2.2 Determination of the minimum wall damage

At the end we decided to define the meeting point of minimum environmental damage is between the thickness of insulation and the fuel consumption for air conditioning. In fact, with an increase in the thickness of the insulating material, the consumption of energy for heating and cooling decreases. After this point the damage caused by the extra material used for the insulation is not covered by lower consumption.
We chose the north-west wall for this study because the surface mass is so huge that we have to use the maximum expected value for the summer equivalent temperature, which corresponds to a wall weight of 700 kg per square metre. So on this wall all the values were kept constant, except for the amount of insulating material and the transmittance.

3.3 Analysis of the whole building

From the analysis of the results of the evaluation we noticed that:

- the total damage is worth 1.19E3 Pt due to the lightening electricity at 30%, to the electricity for instruments at 17.48% and to the auxiliary systems electricity at 16.64%.
- the damage is also due to the Human Health at 22.94%, to the Ecosystem Quality at 9.66% and to the Resources at 67.73%.

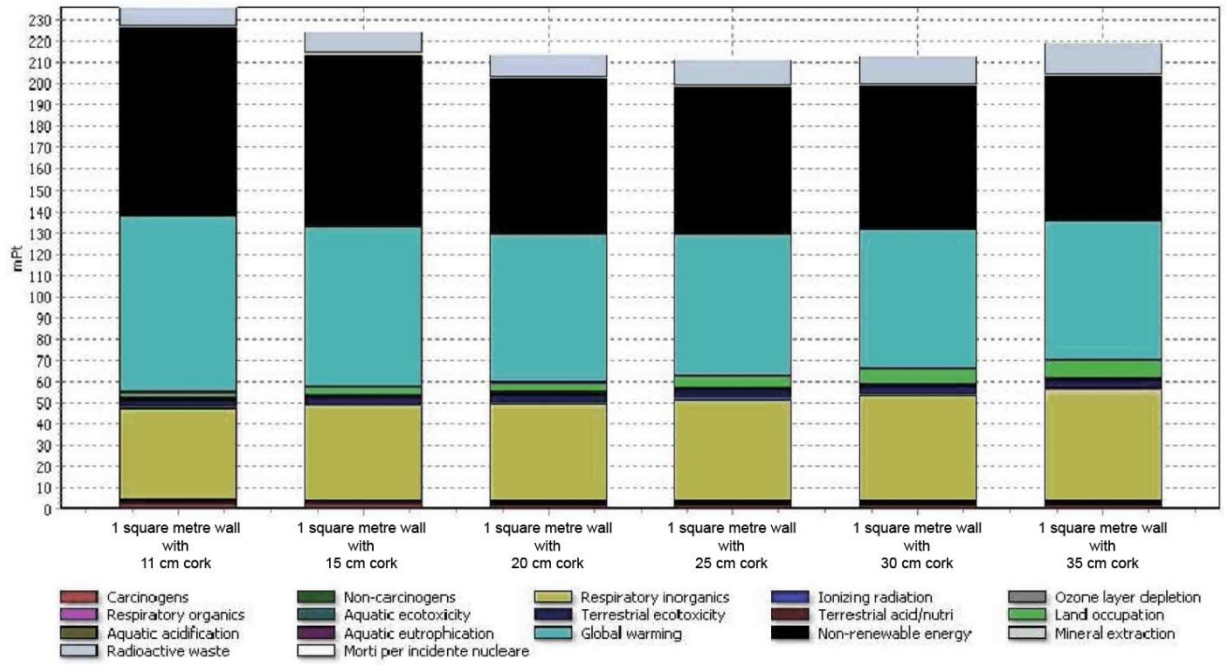

Fig. 7 – Minimum damage for the wall

4. Conclusion

Summarizing this study we can obtain the following conclusions:

- The best roof is the one which is ventilated because you can save a lot of energy for cooling in the summer
- It is better not to use a PV roof with PV roof tiles because of the PMMA which has a lot of environmental impact
- We used the less impacting end of life for all components, i.e. the one which requires the reuse of a material when it is possible. We also used for the new concrete the old one in situ after a crush treatment.
- For this LCA we keep in consideration existing materials only for the years we are going to use them.
- The most important part of the damage comes from the consumption of the electrical energy during the life of the building.
- The maximum damage comes from the depletion of the resources.
- The XPS has a better environmental impact related to cork
- For the use of insulation, it is better to have a lower transmittance than the one given us by the law. With the LCA we can define the better bend which describes the damage in relation to the depth of the insulation. For the external wall of this case study the optimum is with 25 cm of insulation.

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