**Brás, A and Gomes, V**

**LCA implementation in the selection of thermal enhanced mortars for energetic rehabilitation of school buildings**

**http://researchonline.ljmu.ac.uk/id/eprint/11648/**

**Article**

**Citation** (please note it is advisable to refer to the publisher’s version if you intend to cite from this work)

**Brás, A and Gomes, V (2015) LCA implementation in the selection of thermal enhanced mortars for energetic rehabilitation of school buildings. Energy and Buildings, 92. pp. 1-9. ISSN 0378-7788**

# LCA implementation in the selection of thermal enhanced mortars for energetic rehabilitation of school buildings

ANA BRÁS[1], VANESSA GOMES[2]

[1] *Construction and Environment Section, ESTB – Polytechnic Institute of Setúbal, Portugal*

[2] *School of Civil Engineering, Architecture and Urbanism, University of Campinas, Campinas, SP, Brazil*

Corresponding author: Ana Margarida Armada Brás. Tel: +351212064660, Fax: +351 212 075 002, e-mail: ana.bras@estbarreiro.ips.pt

## Abstract

The first aim of the present work is to assess the environmental impact of specific rendering mortars able to be applied in the vertical opaque envelopes of an existing school building from the 80's built in Portugal, to reduce condensation effects and heat transfer. Ordinary cement and hydraulic lime mortars where compared to cork added and EPS added mortars. Energy performance and energy audit of the building was estimated and compared to the original behaviour of the school building. LCA variant called cradle to gate was used to compare the environmental impacts of building thermal rehabilitation and its effect on the energy consumption for heating and operational energy (OE), for different mortars service life. The simulation made in the school show that ordinary cement or hydraulic lime mortars, leads to much higher global warming potential, where CO2 emissions are more than 3 tonnes per building intervention. The use of mortars with cork addition, leads to a reduction of CO2 emission up to 30% and 20% reduction in embodied energy (EE), when compared to traditional mortars. Cork mortars present smaller EE than EPS mortars. Results shows that it is possible to slightly reduce OE by using materials with lower EE value.

*Keywords*: Thermal rehabilitation building envelope; Embodied Energy; LCA; green solutions; sustainability; cork mortars; mortar service life.

## 1. Introduction

Nowadays, a material's environmental impact is often equated with its effect on greenhouse gas emissions (GHGs) and climate change. From this point of view, a great variance of so-called 'green' concepts have been developed over the years. Since the cement industry alone was estimated to be responsible for 5–7% of all anthropogenic CO2 generated [1–4] usually a green solution for construction focus on partially replacing the cement, the concrete and mortars constituent responsible for the highest CO2 emissions, by other materials [5].

However, the implementation of these 'green' concepts implies that certain parameters in the mix design need to be changed to obtain a sufficiently workable, strong and durable concrete and mortar. Moreover, the specific application and the environment in which the mortar or concrete will be used, needs to be considered. Here, its service life characterization is crucial.

The Life Cycle Assessment (LCA) methodology compares the environmental impact of a strength and durability/service life of a certain functional unit of traditional and 'green' concretes and mortars over their entire life cycle (production, use and end-of-life phase) for predefined system boundaries. This is a process that consist in: the definition of goal and scope, the inventory analysis, the impact analysis and the interpretation (Fig.1).

Fig. 1: LCA framework according to ISO 14040 [6].

The importance of a LCA analysis to select the optimum constructive material increase when it is correlated to the energy use of the building. This is particularly important as buildings use larger quantities of materials and systems to achieve minimum energy consumption or even “zero energy” in operation (according to the European Energy Performance of Buildings Directive (EPDB) [5]).

Building energy assessment, namely in Europe, is measured by using regulations and standards generally focused on limiting heat transmission values of construction elements – as the cork and EPS mortars presented in this paper-, including the assessment of the energy use for space conditioning. Nevertheless, most of the time building energy evaluation only takes into account the energy that is used in the operation of the building, ignoring aspects of energy use related to the construction and delivery of the building and its components (their embodied energy).

From the LCA point of view, most of the studies are carried out in buildings that have been designed and constructed as low energy buildings, but there are very few studies on “traditional buildings”, which are the mostly common buildings in cities [7]. Thus, this enhances the importance of a study like the one presented in this paper - the application of LCA in current buildings together with their building energy analysis.

## 2. Objectives and motivation

The first goal of the present work is to assess the environmental impact of specific rendering mortars able to be applied in the vertical opaque envelopes of a school building (especially in the thermal bridges correction) to reduce condensation effects and heat transfer.

In view of the previous, several mortars for rendering were developed and optimized from a thermal behaviour point of view. Cement-cork, cement-EPS mortars and hydraulic lime–cork mortars were analysed and compared [8, 9].

The previous mortars where developed with the intention to be applied in the correction of thermal bridges of an existing building school from the 80’s built in Portugal. The original building is compact with one floor above ground level. The exterior vertical opaque envelope of the building was made of a single brick wall without thermal insulation inside, with an external plaster similar to CRef-CEM II mortar. The building envelops construction technique has proved to be the cause of great thermal loss and condensation.

Thus, the energy performance of the building with the original and new mortars was estimated and compared to the original energy behaviour of the school building. Simultaneously, an energy audit of the school was performed to estimate the real operation energy.

The main goal was to measure and compare the environmental impacts of those human activities from cradle to gate and its effect on the energy consumption for heating and operational energy, for different mortars service life. The adopted procedures help to clarify the relative importance of operating and embodied energy in a building.

The tests carried out on the studied mortars are listed below:

- Calculation of a cradle-to-gate inventory (up to the finished/sold product) using the direct requirements matrix and environmental exchange data;
- Analysis of the most relevant impact categories for the previous mortars;
- Analysis of the specific energy consumption for heating and cooling of the school building carried out according to the ISO 13790 [10] and according to an energy audit made *in situ*;
- Comparisons between the embodied energy and emissions of the previous mortars for rehabilitation purpose and the building energy consumption at the use stage, for different mortars service life.

## 3. Environmental-based methods for building evaluation and building energy analysis

### 3.1 LCA evaluation of building envelopes solutions for rehabilitation

The use of mortar rendering for external envelops, a product which is largely used by the construction segment, causes significant environmental impacts. Starting by its composition, formed by non-renewable raw-materials (cement, lime and sand), and, secondly, by the possible reduction of its service life due to the lack of adherence to the substrate, solar exposure, rain, among others, which increases the civil construction environmental liability.

It is known that the selection of products for the civil construction that cause as little as possible impact on nature is a way to reduce the damages caused to the natural environment during the extraction of raw-materials. The reduction of those environmental impacts in the building sector requires appropriate evaluation methods [11,12] to achieve the following targets:

- Definition of technical specifications concerning environmental performance levels to be integrated into municipal policy and building programmes;
- Advice to be provided to designers, architects and consultants, in order to reach such targets;
- Definition of methods and tools to evaluate the most cost effective actions for energy savings and reduced environmental impact over the whole life cycle;
- Guidance for efficient operation and management of buildings, so that actual performance corresponds to design performance.

Based on existing detailed LCA tools such as SIMAPRO [13] or GABI [14], a wide range of environmental aspects of building materials could be aggregated and quantified in the inventory analysis into a limited set of recognizable impact categories (e.g. global warming, ozone depletion, acidification). It is also possible to estimate the embodied energy (renewables, non-renewables) of a specific building rehabilitation material, gathered in most cases through life cycle inventory analysis such as described in ISO 14040 and relative standards [15].

In relation to the system boundary between the technical system and the environment, it can be noted that an LCA should cover the entire life cycle. However, the truncating of the chain of stages offers partial life cycles that, in some cases, can be sufficient for the analysis requested by the objectives of the study.

There are three partial LCA variants:

- Cradle-to-Gate: analysis of the partial life cycle of the product, from the manufacturing stage ("cradle") to its delivery to the “gate” of the plant, meaning before being transported to the consumer’s premises. Inputs should ideally be traced back to raw materials as found in nature.
- Cradle-to-cradle: type of life cycle assessment in which the final post-use stage is a recycling process. The recycling yields either new products identical to the recycled ones, or different.
- Gate-to-Gate: partial LCA that takes into consideration only a single process that adds value to the entire chain of production.

Based on the LCA study, it is possible to take into consideration the following categories of environmental impact [16]:

- Contribution to the greenhouse effect
- Impact on the stratospheric ozone layer
- Contribution to acid rains (through SO2 emissions)
- Pollution of groundwater, waste water, treatment systems, cooling water
- Energy consumption (electrical, gas, oil, etc.)
- Pollution of air, toxic gas
- Soil erosion, forest degradation
- Noise, vibrations
- Dust and particles
- Explosions, spills, solid waste material, dangerous waste material.

### 3.2 Building energy analysis and relation with embodied energy

Over the past few decades, some studies concerning building energy evaluation have taken into consideration a new concept: the embodied energy. Embodied energy is referred to the energy necessary to deliver products and services and it can effectively serve as a form of ‘net energy’ analysis when compared to the energy used by the building in operation over the life cycle. However, most of the time building energy evaluation only takes into account the energy that is used in the operation of the building, ignoring aspects of energy use related to the construction and delivery of the building and its components.

Patxi and Kenny in their paper [17] present a study concerning the concept of ‘net energy’ and its relation within the built environment, based on a methodology accounting for the embodied energy of building components together with energy use in operation. A definition of life cycle zero energy buildings (LC-ZEB) is proposed, as well as the use of the net energy ratio (NER) as a factor to aid in building design with a life cycle perspective. A LC-ZEB is defined here as a building whose primary energy use in operation plus the energy embedded in materials and systems over the life of the building is equal or less than the energy produced by renewable energy systems within the building. Most regulations refer to ‘net-zero’, focusing on energy in use only and ignoring factors such as embodied energy. According to Patxi and Kenny, this paper proposes that a life cycle perspective should be added to the ‘equation’.

Bribián *et al* [18] presented the state-of-the-art regarding the application of LCA in the building sector, proposes a simplified LCA methodology and applies this to a case study focused on Spain. The thermal simulation tools considered in the Spanish building energy certification standards are analyzed and complemented with a simplified LCA methodology for evaluating the impact of certain improvements to the building design. The simplified approach proposed allows global comparisons between the embodied energy and emissions of the building materials and the energy consumption and associated emissions at the use stage. The results show that embodied energy can represent more than 30% of the primary energy requirement during the life span of a single house. Usually the top cause of energy consumption in residential building is heating, but the second is the building materials, which can represent more than 60% of the heating consumption.

In Iddon and Firth study [19] a Building Information Model (BIM) tool is developed to simultaneously estimate embodied and operational carbon over a 60 year service life for a typical four bedroom detached house. Using the tool, four different construction scenarios are evaluated, representing a range of current construction methods used in present day UK house building. The results show that cradle-to-gate embodied carbon represents 20–26% of the total 60 year carbon emissions, with operational carbon representing 74–80% of total emissions. Construction scenarios that reduce operational carbon by improving the thermal envelope led to a 1–13% increase in embodied carbon but a 4–5% decrease in operational carbon compared to the original scenario construction method. Results also indicate that a reduction in operational carbon is likely to lead to an increase in embodied carbon, both in real and proportional terms, further strengthening the conclusion of previous studies that have demonstrated that embodied carbon increases as operational carbon decreases.

In Ibn-Mohammed *et al* study [20] the relationship between embodied and operational emissions over the lifecycle of buildings is analyzed. It is demonstrated the increasing proportion of embodied emissions that is one consequence of efforts to decrease operational emissions. The paper draws on a wide array of issues, including complications concerning embodied emissions computation and also discusses the benefits that come with its consideration. The implication of neglecting embodied emissions and the need for an urgent policy framework within the current climate of energy and climate change policies are also discussed.

Consideration of embodied emissions in lifecycle emissions analysis of buildings is important for several reasons:

- Construction/refurbishment projects are energy-intensive [21,22].
- In building construction / refurbishment projects, savings in embodied CO2 emissions can achieve significant reductions that will take many years to achieve through operational emissions savings alone [23,24,25].
- Operational emissions reductions depend on the performance of the building. This performance, however, could be lost through sub-optimal management or accelerated refurbishment cycles. Shorter design lives and refurbishment/retrofit cycles increase lifetime emissions. This impact can only be reflected when embodied emissions are considered in lifecycle building emissions analysis [25].

According to the previous results, it became obvious the importance of taking into account the embodied energy in the selection of the best measures to minimize operational energy. Generally, embodied energy (EE) increases as operational energy (OE) decreases. The authors of this paper will also demonstrate that it is possible to promote building walls thermal rehabilitation, minimizing OE and simultaneously reducing EE, when compared to traditional interventions in walls, by doing the adequate selection of the best mortars thermally improved.

## 4. Thermal rehabilitation of a school building – Case study

### 4.1. Assessment of the energy performance of an existing building school – original situation

It was intended to apply specific mortars for the thermal rehabilitation of an existing building school from the 80’s, built in Portugal. The original building (composed by two symmetric edifices) is compact with one floor above ground level and the exterior vertical opaque envelope of the building was made of a single brick wall without thermal insulation inside, with an external ordinary cement rendering. This construction technique for the building envelops has proved to be the cause of great thermal loss and condensation.

Fig. 2 and 3 presents the general view of the two similar school buildings and its orientation.

Fig. 2: General view of the school buildings and their orientation [26].

Fig.3: Front side of the school.

The energy performance of the building with the new mortars was estimated and compared to the original energy behaviour of the school building. Simultaneously, an energy audit of the school was performed to estimate the real operation energy.

The performance assessment of the building starts with the calculation of the thermal energy needs which take account of energy losses (transmission and ventilation), heat gains (solar, internal and system heat sources) and thermal inertia driven by building mass.

The main structural details of the building that were used for simulation studies are summarized in Table 1. Vertical opaque envelopes and support frames represent more than 30% of the total construction area (Table 2), which underlies a detailed analysis concerning energy evaluation of building vertical opaque envelopes.

Table 1: Structural details of the school buildings.

Table 2: Area of each structural element of the each school building.

The analysis of the specific energy consumption for heating of the building was carried out according to the ISO 13790 [10], stipulating a maximum consumption of heating energy in winter (Ni), cooling energy in summer (Nv), energy for heating sanitary waters (Na) and primary energy, as a conversion of the last three parameters in kgoe (Nt). This adopted method relies on steady-state methodologies. This methodology aims at:

- ✓ Correlating particular structural and engineering situations to the high/ low consumptions of the building;
- ✓ Identifying possible improvements to energy management.

Concerning the original scenario, the total thermal energy need is calculated and used to assess the energy efficiency performance of the architectural design (without any systems information). Then, the system energy consumption to meet the thermal energy demand to obtain thermal comfort is determined based on the data obtained in the energy audit of the building.

The energy audit enabled to compare the distribution of energy consumption in all school fractions. In this particular case, there is a different distribution of the various categories, where heating consumption corresponds to the most important energy need (97%), while lighting (2,5%) and cooling needs (0,5%) are negligible. According to the energy audit information, the total operational energy (OE) consumed in each building is equal to 0.2 GJ/m$^2$.yr, where heating need represent 97% of the total OE.

The previous evidences and the fact that it was intended to optimize financial resources for the thermal building rehabilitation, show that heating season is the one that most affect building energy behaviour, when compared to the energy spend at summer period.

The following figure (Figure 4) presents the heat losses for the dwelling in the winter season.

Fig. 4: Heat loss in one of the buildings school– original condition (winter season).

In the heating phase (Figure 4), it is shown that the power of heat dissipation (Q) in the walls (vertical opaque external envelopes) is the most important one, followed by the heat loss in openings and roof. This situation is partially responsible for the condensation phenomenon found inside the building (Figure 5) (especially in the structural thermal bridges made of reinforced concrete), where the indoor RH was equal to 80% inside the classrooms and the indoor temperature is equal to 10ºC (without heating devices) and an average temperature of 19ºC if heating devices where used inside (due to the significant heat loos inside the buildings). During the winter season, electrical heaters in each class room work 8h/day and are only turn off during 1 week in December, due to Christmas holidays. This period was also take into account in the energy audit, in order to properly estimate the total operational energy of the school building.

Fig.5: Example of the condensation effects at the first floor of the building school.

Since it was intended to optimize financial resources for the thermal building rehabilitation, the analysis of different scenarios were made in order to look into what possible building changes on field may imply as regards energy consumption (for heating and cooling).

The first goal of the present work is to assess the environmental impact of specific rendering mortars able to be applied in the vertical opaque envelopes of a school building (especially in the thermal bridges correction) to reduce condensation effects and heat transfer. In view of the previous, several mortars for rendering were developed and optimized from a thermal behaviour point of view. Cement-cork, cement-EPS mortars and hydraulic lime–cork mortars were analysed and compared [8,9].

### 4.2. Selection of mortars for thermal rehabilitation according to the most relevant impact categories

Several mortars were developed and tested. Those compositions are presented in the following table (Table 3) (where w/b – water/binder ratio). More detailed properties of those mortars are presented in [8,9].

Table 3: Mortar compositions with CEM II/B-L 32,5N – cork, HL5 – cork granulate (CH) and CEM II/B-L 32,5N – EPS (CE) (expanded polystyrene granulate).

The most convenient functional unit to perform LCAs of mortars with different mix designs was considered to be 1 kg, in order to enable comparison between different mortars for the same application. The system boundaries adopted characterize a cradle to gate analysis, which covers all stages - from the extraction of raw material for manufacturing to the (cement and concrete) factory's gate - but transportation and use. The support platform chosen for performing the LCA was SimaPro 7.3, which accommodates a wide range of research goals and allow database adaptation, ensuring data adherence to the context of interest.

The inventory analysis of each mortar was developed based in the information presented in Table 3. Cement, hydraulic lime, aggregates, EPS granulate and water data were adapted from the Ecoinvent v.2.2 database, by switching into the Portuguese energy grid, since such processes were considered as sufficiently adherent to national practice. Cork granulates data was adapted from the Environment Product Declaration (EPD) of the manufacturer (SOFALCA Company, Portugal).

Life cycle inventory data are converted into specific impact categories inputs, covering impacts on natural resources, human health and ecosystem quality. The impact assessment method implemented as CML (Center of Environmental

Science of Leiden University) methodology is defined for the midpoint approach. Normalization is provided but there is neither weighting nor addition. In this article it was used a ‘baseline’ version with 10 impact categories. The impact categories present by CML 2 baseline 2000 V2.05 include: Abiotic depletion; Acidification; Eutrophication; Global warming (GWP100); Ozone layer depletion (ODP); Human toxicity; Fresh water aquatic ecotox.; Marine aquatic ecotoxicity; Terrestrial ecotoxicity; Photochemical oxidation. LCA also enables the calculation of the predicted embodied energy (EE) used in the mortars manufacturing.

The authors of this paper proposed to focus on specific life cycle indicators as Global warming and EE of each tested mortar. The purpose was to do a comparison between the embodied energy and emissions of the previous mortars for rehabilitation purpose and the building energy consumption at the use stage, for different mortars service life.

It was intended to simulate the application of 4 cm thickness of the previous mortars in the external walls of the school buildings. Thus, environmental impact was first estimated per square meter. The following figures (Fig. 6 and 7) presents the results of the environmental impacts per $m^2$ concerning global warming produced by each mortar and respectively embodied energy.

Fig. 6: Global warming contribution for each type of mortar / $m^2$.

Fig. 7: Embodied energy of each mortar / $m^2$.

Traditional mortars used in construction and rehabilitation (the cement based – CB and hydraulic lime mortar – CH) are the ones that more contribute to the global warming (Figure 9) However, the addition of cork granulate represent the most positive measure to reduce global warming impact, especially when 70% of cork is added to cement based or hydraulic lime based mortars. In fact, when compared to EPS addition, cork granulate presents good behaviour.

Figure 10 results point out the embodied energy of each mortar. Hydraulic lime is the one that presents the negative contribution, followed by the cement-EPS based mortars. Once again, it seems that cork granulate leads to an expressive reduction of the embodied energy when compared to EPS granulates contribution.

In order to implement rehabilitation measures of the school buildings, all mortars quantities should be take into account. The following figures (Fig. 8 and 9) presents the contribution results of each mortar when compared to CB (ordinary cement mortar) and CH (ordinary hydraulic lime mortar).

Fig. 8: Global warming contribution for each type of mortar for external vertical envelope rehabilitation (absolute values).

Fig. 9: Embodied energy of each mortar, for external vertical envelope rehabilitation (absolute values).

The results show that the use of CB and CH leads to must higher global warming potential (GWP), where CO2 are more than 3 tonnes per building intervention. From this point of view, CC70 and CH70 are the mortars composition that behave better, leading to the emission of 2 tonnes of CO2 per building intervention, which represent a decrease of 30% of the total CO2 emissions when compared to the traditional intervention using CB or CH mortars.

In the year of 2002, the EU building stock belonging to the residential sector was the main contributor (77%) to the total heating related CO2 emissions (725 Mt/yr) while the remaining 23% was originated from non-residential buildings [27,28], which means that the correct materials selection for building rehabilitation will significantly contribute to the reduction of CO2 emissions.While new buildings can be constructed with high performance levels, it is the older buildings, representing the vast majority of the building stock, not only in Portugal but also in all Europe, which are predominantly of low energy performance and subsequently in need of renovation work. With their potential to deliver high energy and CO2 savings as well as many societal benefits, energy efficient buildings can have a pivotal role in a sustainable future.

In the European context, the high level of energy consumption and Greenhouse Gas Emissions (GHG) emissions in buildings makes this an obvious sector to target in order to determine the potential and improve energy performance. While there has already been significant effort to improve energy performance in buildings, considerable potential still remains, as was noted by the European Commission's Communication on the proposal for the recast of the EPBD, recently approved by the European Parliament [5].

Based on the report produced by Buildings Performance Institute Europe (BPIE) [29], it is possible to summarize some justification for focusing on the energy efficiency in buildings:

- Lower GHG, which means a major contribution to climate change strategies - [Societal point of view]
- Reduced energy costs for consumers, which can be important in avoiding "fuel poverty" (where energy costs represent a disproportionate and unsustainable share of disposable income) - [Public and Private point of view]
- Cheaper than investing in increased energy capacity - [Societal point of view]
- Improved comfort - [Private point of view]
- Contribution to the rehabilitation of certain building types in the new Member States of Central and Eastern Europe - [Both]

Since it is clear that there is the need to correlate the embodied energy and emissions of the previous mortars for rehabilitation purpose and the building energy consumption at the use stage, the authors estimated the energy consumption for heating and cooling of the school building when one of each mortar was used. Fig.10 present those results.

Fig. 10: Building Energy needs (kWh/m2.yr) when each mortar is used for external vertical envelope rehabilitation.

It is obvious that there are more benefits by using these mortars in winter than summer season, which suits perfectly with the scholar period (from September to June). Thus, results comparison will be made by using only heating needs. When compared to the ordinary mortars, hydraulic lime-cork mortar CH70 is the one that definitively contribute to an effective reduction of those energetic needs.

Assuming that a reduction of the energy building needs means a reduction of the operational energy used (which is essentially due to heating needs) it was intended to correlate the embodied energy of the previous mortars with the their contribution to the OE reductions. The following figure (Fig. 11) presents the normalized results taking into account the EE and OE value of CB as a reference.

Fig. 11: Normalized Operational Energy and Embodied Energy evolution when different mortars compositions are used in envelope rehabilitation. Bars in the left side of the y-y axis means a reduction.

Generally, results show that it is possible to slightly reduce OE (the grey bar) by using materials with lower EE value (white bar) when compared to an ordinary cement based mortar. Cement – cork mortars once again show the best behaviour in both energies, especially hydraulic lime-cork mortars. Cement – EPS mortars present the worse contribution in terms of EE and slightly contribute to the minimization of OE.

### 4.3. Influence of mortar service life in the selection of the best solutions for thermal rehabilitation – LCA influence and OE

At this stage it is clear that the use of mortar rendering for external envelops, a product which is largely used by the construction segment, causes significant environmental impacts. Starting by its composition, formed by non-renewable raw-materials (cement, lime and sand), and, secondly, by the possible reduction of its service life due to the lack of adherence to the substrate, solar exposure, rain, among others, which increases the civil construction environmental liability.

Thus, in order to understand what could be the influence of a reduction of the mortar service life (for example due to one of the mentioned reasons) in choosing the best composition for thermal rehabilitation, the following figures (Fig. 12-17) present the evolution of GWP and EE as a function of building heating needs. Those results are presented for each adopted mortar composition and for 4 different mortar service life: 5, 10, 20 and 50 years.

Fig. 12: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CB, CC50 and CC70, for different mortar service life.

Fig. 13: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CB, CE50 and CE70, for different mortar service life.

Fig. 14: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CH, CH50 and CH70, for different mortar service life.

Fig. 15: Embodied Energy for CB, CC50 and CC70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

Fig. 16: Embodied Energy for CB, CE50 and CE70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

Fig. 17: Embodied Energy for CH, CH50 and CH70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

For the analyzed mortars, Figs. 12, 13 and 14 show that mortars service life present an important effect in global warming until 20 years. After that, mortars composition start to become less relevant. The introduction of cork granulate in mortars composition leads to faster benefits concerning the reduction of heating needs and reduction of GWP, when compared to EPS contribution.

Figs. 15, 16 and 17 show that all mortars present almost the same embodied energy contribution evolution for different service life if it is higher than 20 years, which enhance the important of mortar durability in the analysis of energy efficiency in buildings.

It was shown that as long as mortar service life increase, the smaller will be the contribution of its embodied energy. This energy can represents more than 30% of the school building operational energy (OE). Those results are presented in Fig. 18. The contribution of the building materials decrease to 3% of the OE for a mortar service life higher than 8 years.

Fig. 18: Embodied Energy for all tested mortars as a function of the building operational energy, for different mortars service life.

OE is directly associated to the building heating consumption. Thus, when compared to the traditional solutions (cement based or hydraulic lime mortars), the cement- cork mortars are the ones that less represent heating consumption. On the other side, hydraulic lime mortar (CH) can represent more than 30% of heating consumption.

The simplified approach proposed allows global comparisons between the embodied energy and emissions of the building materials used in building rehabilitation and the energy consumption at the use stage.

## 5. Conclusions

The first goal of the present work is to assess the environmental impact of specific rendering mortars able to be applied in the vertical opaque envelopes of an existing building school from the 80's built in Portugal (especially in the thermal bridges correction) to reduce condensation effects and heat transfer. Cement-cork, cement-EPS mortars and hydraulic lime–cork mortars were analysed and compared.

Thus, the energy performance of the building with the original and new mortars was estimated and compared to the original energy behaviour of the school building. Simultaneously, an energy audit of the school was performed to estimate the real operation energy.

Most of the time building energy evaluation only takes into account the energy that is used in the operation of the building, ignoring aspects of energy use related to the construction and delivery of the building and its components. The Mail goal of this paper was to show and compare the environmental impacts of those human activities from cradle to gate and its effect on the energy consumption for heating and operational energy, for different mortars service life.

The previous results show concerning traditional mortars used in construction and rehabilitation (the cement based – CB and hydraulic lime mortar – CH) are the ones that more contribute to the global warming.

The introduction of cork granulate in those mortar compositions represent the most positive measure to reduce global warming impact, especially when 70% of cork is added to cement based (CC70) or hydraulic lime (CH70) based mortars.

EPS addition to the traditional mortars significantly increase the embodied energy of mortars, which exactly the opposite behaviour of cork granulate.

The simulation made in the school building show that CB (cement based mortar) and CH (hydraylic lime mortar) leads to must higher global warming potential (GWP), where CO2 are more than 3 tonnes per building intervention. From this point of view, CC70 and CH70 are the mortars composition that behave better, leading to the emission of 2 tonnes of CO2 per building intervention, which represent a decrease of 30% of the total CO2 emissions when compared to the traditional intervention using CB or CH mortars.

This means that the correct materials selection for building rehabilitation will significantly contribute to the reduction of CO2 emissions.

Assuming that a reduction of the energy building needs means a reduction of the operational energy (OE) used (which is essentially due to heating needs) it was intended to correlate the embodied energy (EE) of the previous mortars with the their contribution to the OE reductions. Results show that it is possible to slightly reduce OE by using materials with lower EE value when compared to an ordinary cement based mortar. Cement – cork mortars once again show the best behaviour in both energy demands. Cement –EPS mortars present the worse contribution in terms of EE and slightly contribute to the minimization of OE.

Concerning the mortars service life as an important issue in the choice of the best mortar composition for thermal rehabilitation, mortars service life present an important effect in global warming until 20 years. After that, mortars composition start to become less relevant concerning GWP. The introduction of cork granulate in mortars composition leads to faster benefits concerning the reduction of heating needs and reduction of GWP, when compared to EPS contribution. The same effect occurs concerning mortar EE.

It was also shown that as long as mortar service life increase, the smaller will be the contribution of its embodied energy. This energy can represents more than 30% of the school building operational energy (OE). During the all OE consumed, mortars EE represent the first 8 years.

## Acknowledgments

The authors of this paper wish to acknowledge the support of Santander Bank who funded this R&D work, Eng. Marcella Saade for helping in SimaPro analysis and the cork manufacturer SOFALCA Company - Portugal, for providing EPD.

## References

[1] Malhotra VM. Role of supplementary cementing materials in reducing greenhouse gas emissions. In: Gjorv OE, Sakai K, editors. Concrete technology for a sustainable development in the 21st century. London: E&FN Spon; 2000. p. 226–35.

[2] Humphreys K, Mahasenan M. Toward a sustainable cement industry. Substudy 8: climate change. Geneva: WBCSD; 2002.

[3] Bernstein L, Roy J, Delhotal KC, Harnisch J, Matsuhashi R, Price L, et al. Industry. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the IPCC. Cambridge and New York: Cambridge University Press; 2007. p. 447–96.

[4] Meyer C. The Greening of the concrete industry. Cem Concr Compos 2009;31(8):601–5.

[5] EU Directive on the Energy Performance of Buildings (recast) (2010/31/EU), 19 May 2010

[6] International Organization for Standardization, ISO 14040:2006 Environmental Management—Life Cycle Assessment—Principles and Framework, 2006.

[7] [Cabeza et al, Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review, Renewable and Sustainable Energy Reviews, Volume 29, January 2014, Pag. 394-416]

[8] Brás A., Gonçalves F., Faustino P., (2014) Cork-based mortars for thermal bridges correction in a dwelling. Thermal performance and cost evaluation, Energy and Buildings 72: 296-308

[9] Bras A., Leal M., Faria P. (2013) Cement-cork mortars for thermal bridges correction. Comparison with cement-EPS mortars performance Construction and Building Materials Journal 49: 315-327, Elsevier.

[10] EN ISO 13790: Energy performance of buildings —Calculation of energy use for space heating and cooling, 2008

[11] Jonsson A. Tools and methods for environmental assessment of building products – methodological analysis of six selected approaches. Building and Environment 2000;35:223–38.

[12] Bribián, Alfonso Aranda Usón, Sabina Scarpellini, Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification, Building and Environment 2009; 44: 2510-2520

[13] PRe´ Consultants, SIMAPRO, http://www.simapro.com/

[14] PE International, GABI, http://www.pe-international.com/

[15] International Organization for Standardization, ISO 14040:2006 Environmental Management—Life Cycle Assessment—Principles and Framework, 2006. [16] Kellenberger D., Althaus H.-J., Relevance of simplifications in LCA of building components, Building and Environment, 44, 2009, Pag. 818-825

[17] Hernandez P., Kenny P., From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB), Energy and Buildings 42 (2010) 815–821

[18] Bribián et al, Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification, Building and Environment 44 (2009) 2510 2520

[19] Iddon C, Firth S., Embodied and operational energy for new-build housing: A case study of construction methods in the UK, Energy and Buildings 67 (2013) 479–488

[20] Ibn-Mohammed et al, Operational vs. embodied emissions in buildings—A review of current trends, Energy and Buildings 66 (2013) 232–245

[21] United Nations Environmental Programme-Sustainable Buildings and ClimateInitiative, Protocol for Measuring Energy Use and Reporting Greenhouse GasEmissions from Building Operations, 2008.

[22] H.M. Government, Innovation and growth team, in: Low CarbonConstruction-Final Report, 2010 http://www.bis.gov.uk/assets/biscore/business-sectors/docs/l/10-1266-low-carbon-construction-igt-final-report.pdf(accessed 25.06.12).

[23] M.K. Dixit, J.L. Fernandez-Solis, S. Lavy, C.H. Culp, Identification of parametersfor embodied energy measurement—a literature review, Journal of Energy andBuildings 42 (2010) 1238–1247.

[24] A. Acuqaye, A Stochastic Hybrid Embodied Energy and CO2-eq Intensity Anal-ysis of Building and Construction Processes in Ireland, Dublin Institute ofTechnology, Republic of Ireland, 2010 (PhD thesis).

[25] S. Rawlinson, D. Weight, Sustainability-Embodied Carbon, 2007http://www.building.co.uk/data/sustainability-%E2%80%94embodiedcarbon/3097160.article (accessed 13.06.11).

[26] Google earth image

[27] Petersdorff C, Boermans T, Stobbe O, Joosen S, Graus W, Mikkers E, et al. Mitigation of CO2 emissions from the building stock. Cologne, Germany: ECOFYS GmbH; 2004

[28] Balaras, C. et al, European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings, Building and Environment 42 (2007) 1298–1314

[29] Buildings Performance Institute Europe (BPIE), Europe's buildings under the microscope - A country-by-country review of the energy performance of buildings, October 2011

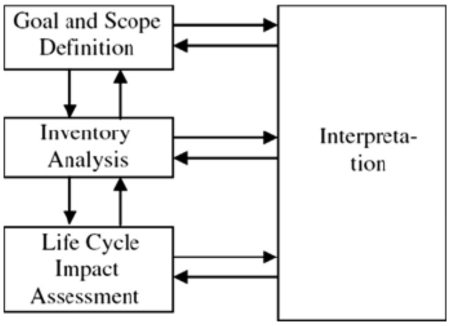

Fig. 1: LCA framework according to ISO 14040 [6].

Fig. 2: General view of the school buildings and their orientation [26].

Fig.3: Front side of the school.

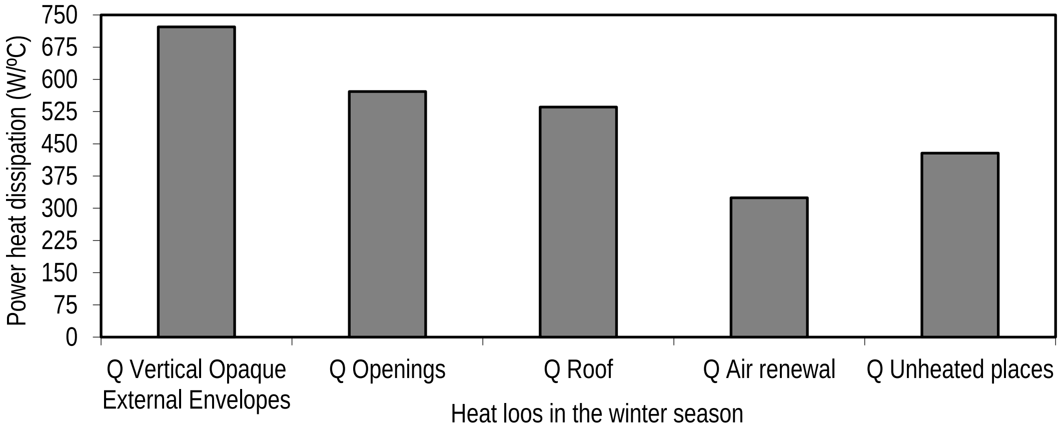

Fig. 4: Heat loss in one of the buildings school– original condition (winter season).

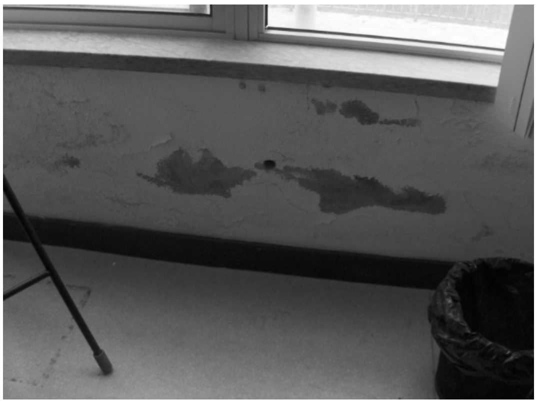

Fig.5: Example of the condensation effects at the first floor of the building school.

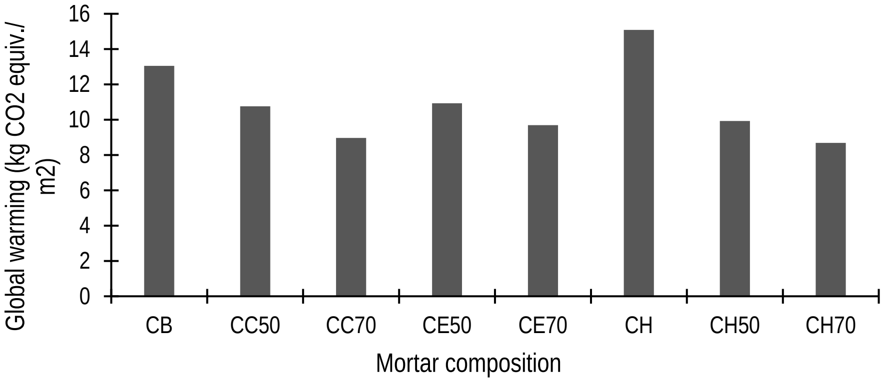

Fig. 6: Global warming contribution for each type of mortar / m$^2$.

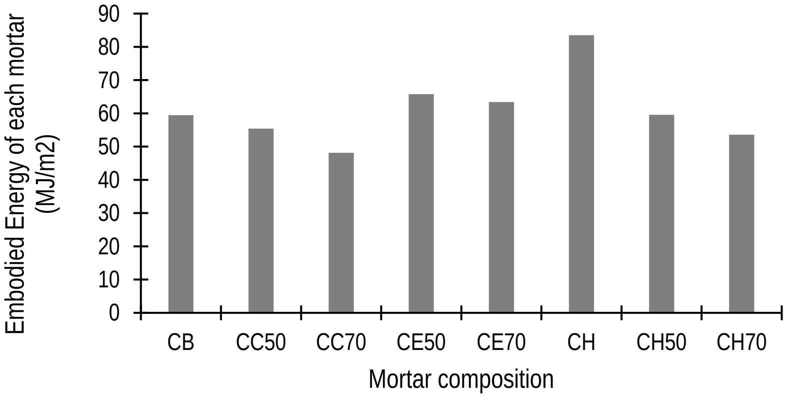

Fig. 7: Embodied energy of each mortar / m$^2$.

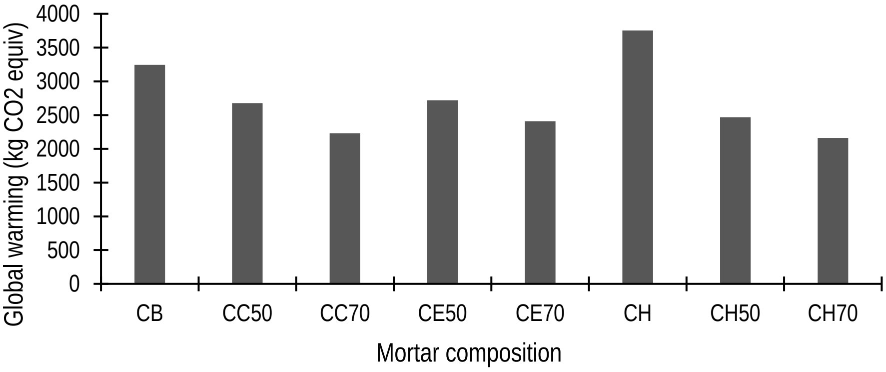

Fig. 8: Global warming contribution for each type of mortar for external vertical envelope rehabilitation (absolute values).

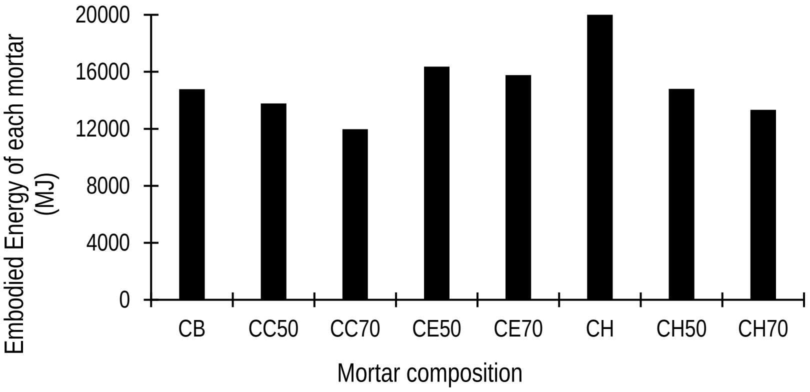

Fig. 9: Embodied energy of each mortar, for external vertical envelope rehabilitation (absolute values).

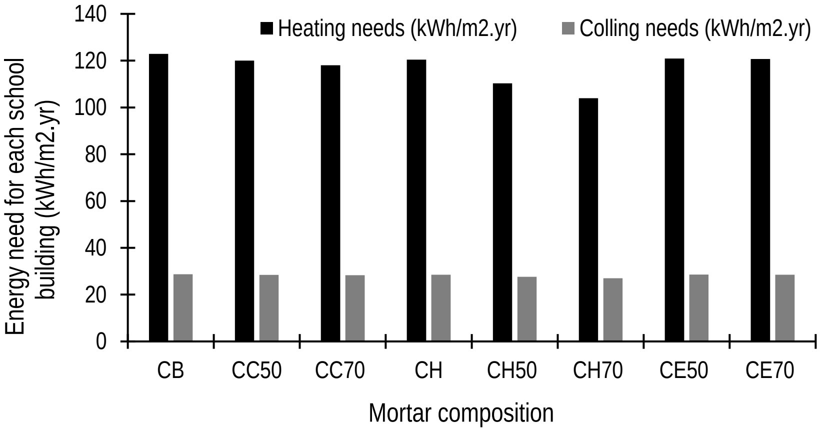

Fig. 10: Building Energy needs (kWh/m2.yr) when each mortar is used for external vertical envelope rehabilitation.

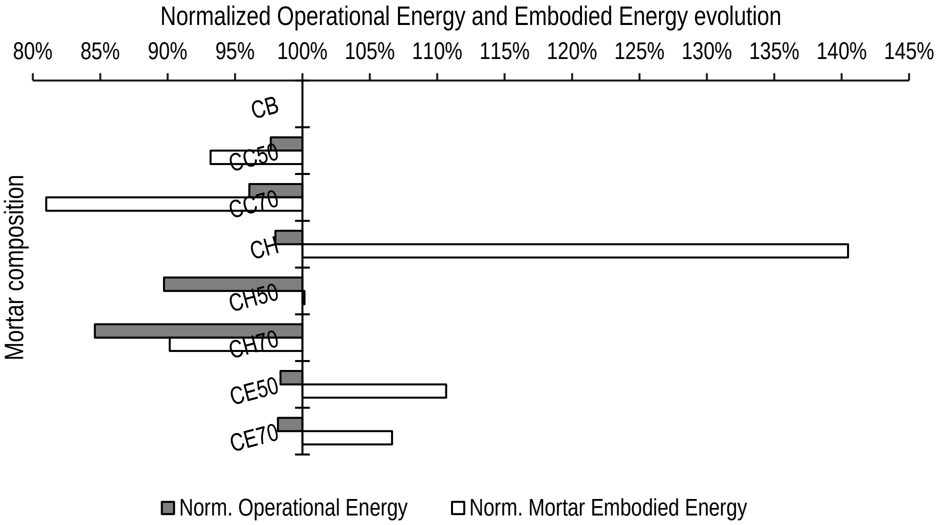

Fig. 11: Normalized Operational Energy and Embodied Energy evolution when different mortars compositions are used in envelope rehabilitation. Bars in the left side of the y-y axis means a reduction.

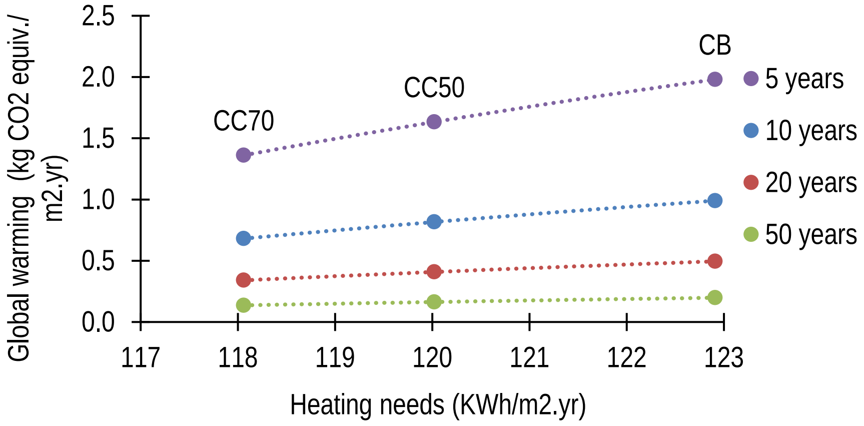

Fig. 12: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CB, CC50 and CC70, for different mortar service life.

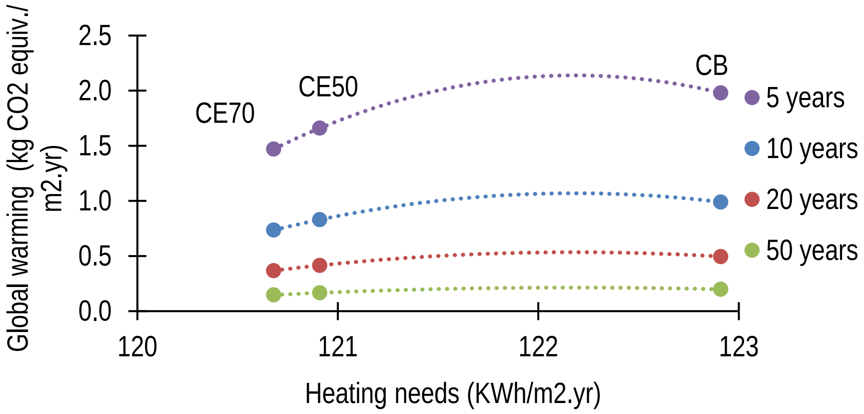

Fig. 13: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CB, CE50 and CE70, for different mortar service life.

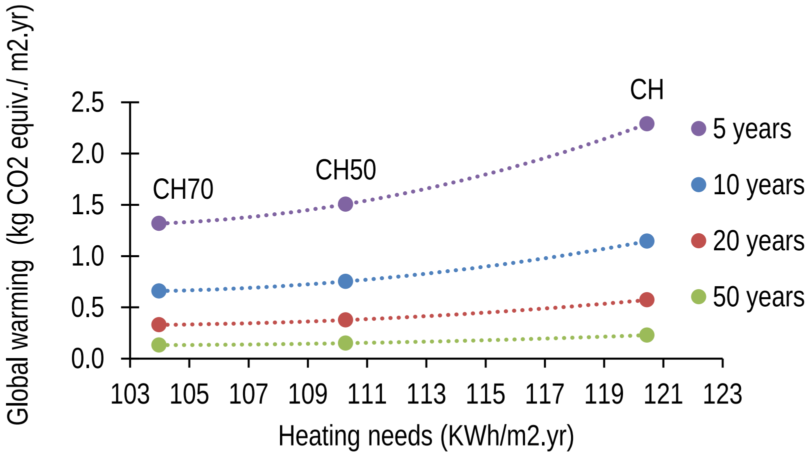

Fig. 14: Global warming (kg CO2 equiv. /m2.yr) as a function of heating needs of the school building for CH, CH50 and CH70, for different mortar service life.

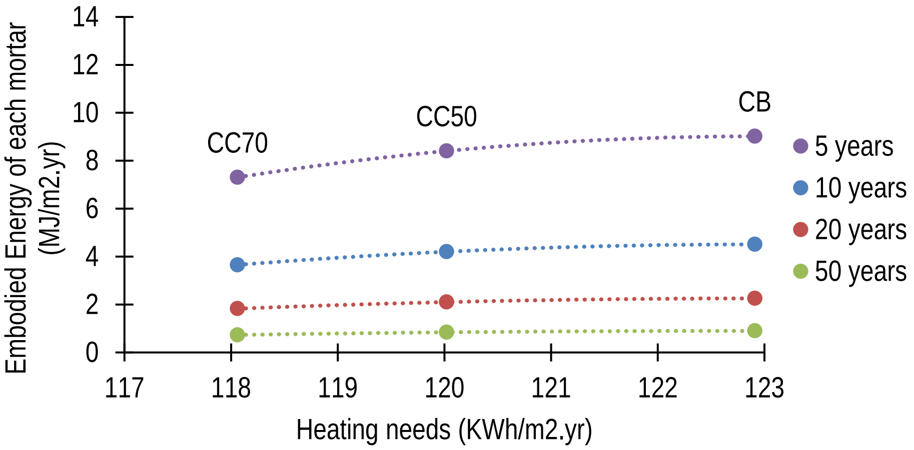

Fig. 15: Embodied Energy for CB, CC50 and CC70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

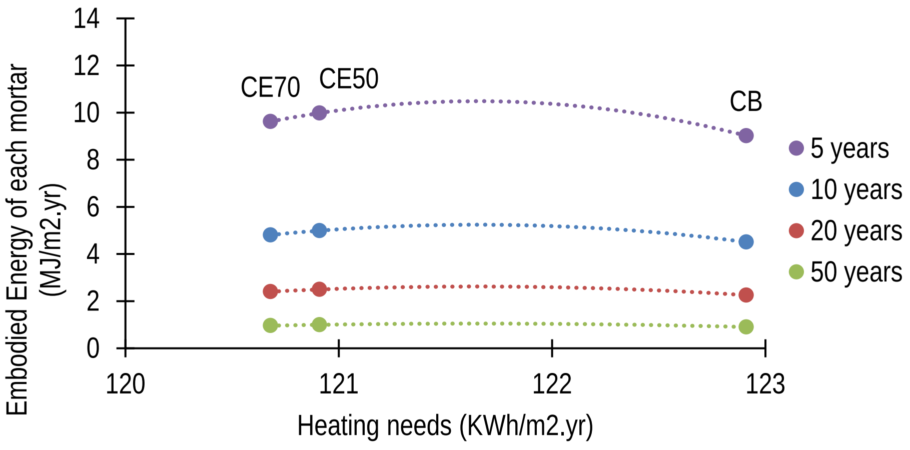

Fig. 16: Embodied Energy for CB, CE50 and CE70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

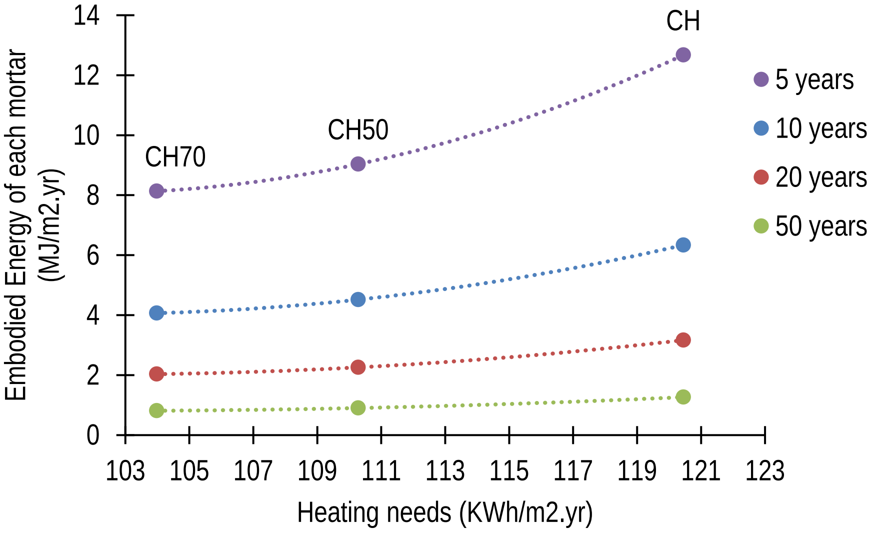

Fig. 17: Embodied Energy for CH, CH50 and CH70 (MJ/m2.yr) as a function of heating needs of the school building, for different mortar service life.

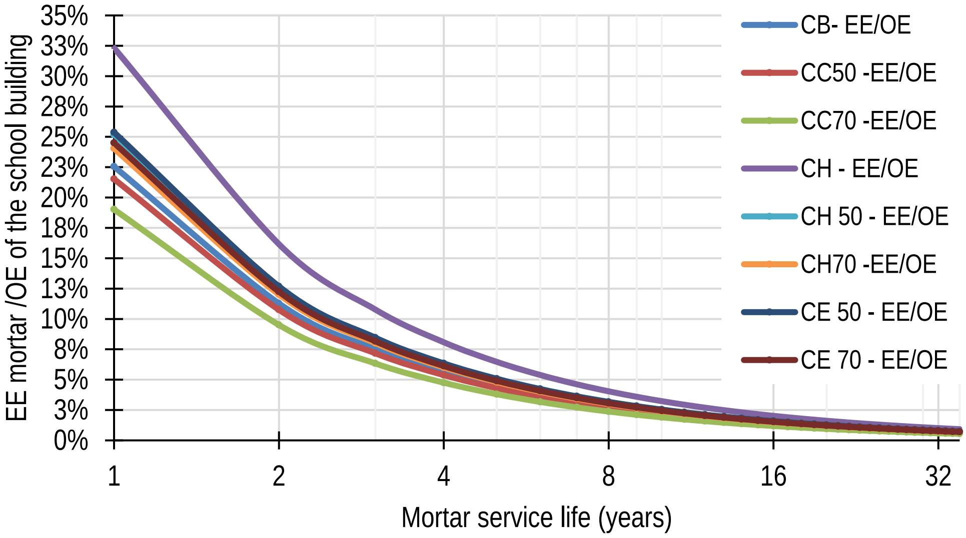

Fig. 18: Embodied Energy for all tested mortars as a function of the building operational energy, for different mortars service life.

Table 1: Structural details of the school buildings.

| Structural element | Characteristics | Thermal characteristics |
|---|---|---|
| Support frame | Reinforced concrete (RC) | Without thermal insulation in RC wall |
| Envelope | Brick walls | No thermal insulation |
| Terrace Roof | Reinforced concrete (RC) | No thermal insulation |
| Openings | Extruded aluminium system with simple glazing | Extruded aluminium system: simple glazing |
| Floor on ground | Reinforced concrete (RC) | No thermal insulation |

Table 2: Area of each structural element of the each school building.

| Structural element | Areas ($m^2$) |
|---|---|
| Envelope | 248 |
| Terrace Roof | 168 |
| Openings | 113 |
| Usable area ($m^2$) | 328 |

Table 3: Mortar compositions with CEM II/B-L 32,5N – cork, HL5 – cork granulate (CH) and CEM II/B-L 32,5N – EPS (CE) (expanded polystyrene granulate).

| Mortars | Identification | Percentage replacement (%) | Thermal conductivity (W/mK) |
|---|---|---|---|
| Ordinary cement mortar (Original scenario) | CB | 0 | 1,7 |
| CC=50% | CC50 | 50 | 0,68 |
| CC=70% | CC70 | 70 | 0,48 |
| Ordinary hydraulic lime mortar | CH | 0 | 0,76 |
| CH=50% | CH50 | 50 | 0,18 |
| CH=70% | CH70 | 70 | 0,10 |
| CE=50% | CE50 | 50 | 0,87 |
| CE =70% | CE70 | 70 | 0,80 |

Notation: CC – cement-cork mortar, CE – cement-EPS mortar, CH – hydraulic lime–cork mortar, =X% - percentage of cork or EPS..