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Article

Integrated approach for school buildings rehabilitation in a Portuguese city and analysis of suitable third party financing solutions in EU

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Abstract

In this paper we present an integrated approach for building rehabilitation on a group of buildings of a school located in the southern suburbs of Lisbon - Moita, Portugal. The approach includes taking into account collected data concerning the actual energy consumption for: space heating; occupants' behaviour, technical and architectural characteristics of the buildings. Detailed energy auditing was done to the buildings including construction materials used, energy consumption and lighting. Thermal images of the interior zones were generated to provide information about the temperature distribution and a notion about air or heat leak from or into the building. Based on the obtained data, 5 different energy retrofit scenarios were studied with different performance and cost-effectiveness targets, compatible with some European available financial mechanisms to promote energy retrofit of buildings. Life cycle cost analyses (LCC) should be taken into account to minimize environmental impact and some recommendations were suggested. Each scenario service life' presents an important effect in LCC. It is found that implementing those measures can cost-effectively reduce the annual energy use by 40% compared to the original building design.

Keywords: Integrated approach for school building rehabilitation; Energy consumption for heating and cooling; Payback; Thermal rehabilitation; LCC; Available financial mechanisms to promote buildings energy efficiency measures.

1. Introduction

In Portugal, one of the main sources used in electricity energy are fossil fuels in thermal power plants (coal, oil, natural gas), which cause the emission of pollutants where CO2 is the main gas released. The Kyoto Protocol imposes an upper limit of CO2 emissions and other gases in the atmosphere, responsible for increasing greenhouse effect and contributing to global warming. Each state connected to the Protocol are obliged to create their own measures and policies, which enable the reduction of emissions of those gases harmful to the environment. In this area, the Portuguese environmental policy is presented in the resolution of Council of Ministers No. 20/2013, of 10 April, approving the National Action Plan for Energy Efficiency (Strategy for Energy Efficiency - PNAEE 2016 [1]) and the National Action Plan for Renewable Energy (Renewable Energy Strategy - PNAER 2020 [2]). According to this document, PNAEE and PNAER are energy planning measures that establish how to achieve the goals and define international commitments made by Portugal concerning energy efficiency and use of energy from renewable sources.

In Europe, the energy consumption in buildings rises up to 40% of the total energy consumption in the EU. Reducing energy consumption is a priority under the "20-20-20". Regarding the new buildings, Europe has declared that in a near future, they shall be nearly zero-energy consumption buildings. However, the natural slow renewal rate of the buildings makes vital their rehabilitation.

The building retrofit optimisation problem is to determine, implement and apply the most cost effective retrofit technologies to achieve enhanced energy performance while maintaining satisfactory service levels and acceptable indoor thermal comfort, under a given set of operating constraints.

The overall process of a building retrofit can be divided into five phases (Fig. 1) [3].

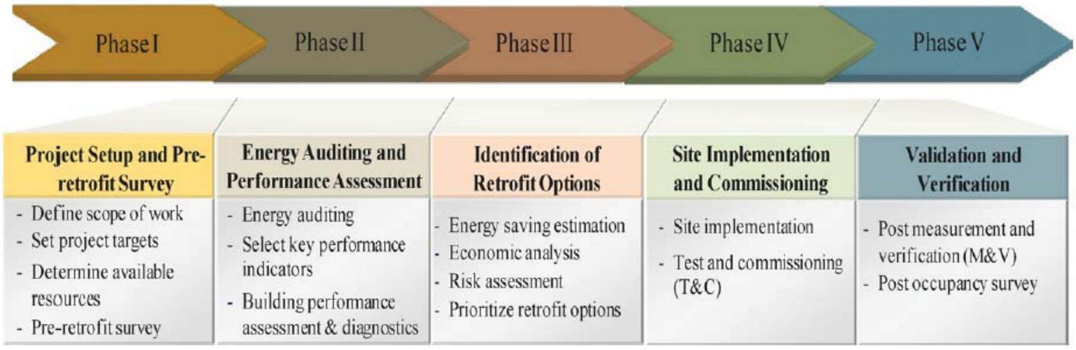


Fig.1: Key phases in a sustainable building retrofit programme (based in [3]).

The objective of an energy audit is to study the conditions of energy use in a building and subsequent identification of opportunities for improving energy performance, aiming the reduction of the energy bill and total costs at a local level (the consumer point of view) but also at a national level.

By using appropriate energy models, economic analysis tools and risk assessment methods, the performance of a range of retrofit alternatives can be assessed quantitatively. The objective is to prioritize retrofit solutions based on relevant energy related and non-energy related factors.

Thus, energy audits enable the identification of real opportunities to save energy. Their objectives are:
• Determine the forms of energy used;
• Examine how energy is used and their costs;
• Establish the structure of energy consumption;
• Determine consumption per division, category, or equipment;
• Identify opportunities for improving energy performance;
• Analyze technical and economic solutions.

Alajmi [4] analyzed the results of an energy audit to an educational building in a hot summer climate (State of Kuwait). The purpose was to identify any energy conservation opportunities. A list including energy conservation opportunities (ECOs) was made taking into account non-retrofitting measures (no or minimal cost) and retrofitting (with cost) recommendations. Interestingly, the non-retrofitting ECOs saved 6.5% of the building's annual energy consumption, while the retrofitting ECOs can save up to 49.3%.

Desideri and Provetti [5] performed energy audit analysis for school buildings of a province in the centre of Italy. They studied both thermal and electric energy consumption through energy auditing technique for 13 school buildings. Energy analysis of the school buildings showed that electric energy consumptions was between 15% and 25% due to non-A/C sources, while thermal consumption contributed up to 80% of the total annual energy consumptions. By comparing the electric energy consumptions and thermal energy consumptions per unit volume, they shown that thermal energy saving could reach up to 38% and electric energy consumption could be reduced by 46%, if the minimum optimal energy consumption is reached.

Santamouris et al. [6] carried out energy audits on 238 schools buildings in Greece for construction, heating, cooling, lighting, and mechanical and electrical systems, in order to verify the energy-consumption indicators and the energy-saving opportunities. The annual average total energy consumption is 93 kWh/m2, of which approximately 72% is consumed for space heating. The implementation of various energy-conservation techniques shows a potential for 20% overall energy conservation.

The success of a building retrofit programme does not depend only on retrofit technologies. It also depends on: policies and regulations, client resources and expectations, building specific information, human factors and other uncertainty factors [3]. The optimization of an energy efficient building needs a holistic integrated approach including the analysis of several processes: planning, building design, systems design, environmental system operation and management.

Concerning school buildings, large investments are required to improve their energy performance. Thus, for a good choice of the best business it is necessary to study a few characteristics which directly affect their adoption. Initial cost of the retrofit solution, payback return, energy savings, lifetime of the new solution and its compatibility with building lifetime and financial contract lifetime, are some of the most relevant parameters that should be taken into account.

The recent Directive 31/2010 [7], named "EPBD (Energy Performance Building Directive) recast", promotes the energy efficiency of buildings (for new buildings and also for existing buildings when undergoing major renovation). Thus, it is clear that the objective of the Directive is to reduce the gap between the energy performance of existing buildings and that of new buildings.

The EU's interest in the energy upgrade of public buildings is confirmed by the Directive 2012/27/UE. In this Directive [8] it is stated that Member States shall ensure that, as from 1 January 2014, 3% of the total floor area of existing public buildings is renovated each year, in order to meet at least the minimum energy performance requirements.

The necessary funds for investments in sustainable energy measures at a local level are mainly promoted by the European Commission and the European Investment Bank. They established the European Local Energy Assistance (ELENA) financed through the Intelligent Energy-Europe program. Thus, ELENA can share the costs of the technical support implementation of the investment program [6]. JESSICA is also being developed by the European Commission and the EIB, in collaboration with the Council of Europe Development Bank (CEB). JESSICA operations has also significant potential for the financing of urban energy efficiency and renewable energy projects which are typically considered to be medium to high risk and can have long payback periods
Thus, it is necessary the knowledge of the different financial mechanisms and current support systems available to successfully implement energy efficiency actions.

. From the above considerations it is clear that improving the energy performance of public school buildings is a topic of current interest, especially since the implementation of Directive 2012/27/EU [8]. According to this, Member States must define strategies and decide the energy retrofit actions to undertake on their existing public building stock.

2. Objectives and motivation

This study presents an integrated approach for building rehabilitation conducted on a school building complex located in Moita, Portugal. The goal was to collect data concerning its actual energy consumption for space heating, occupants' behaviour and the technical and architectural characteristics of the buildings. On the basis of these data, an action plan concerning different energy retrofit scenarios was studied with different performance and cost-effectiveness targets.

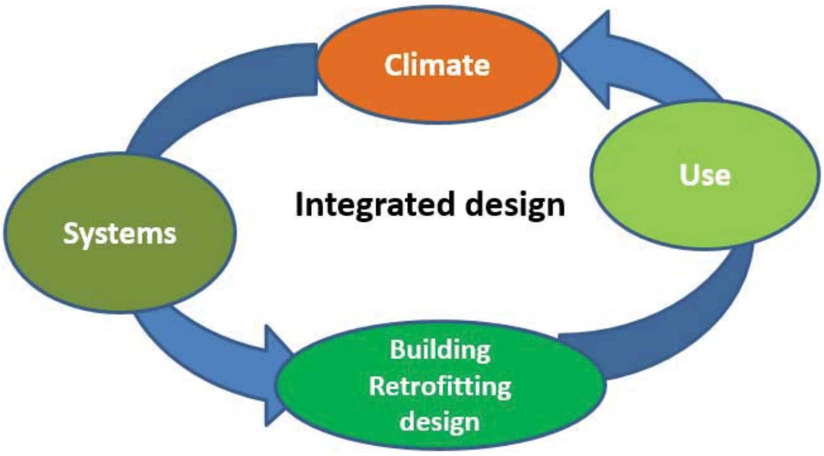


Fig. 2: Integrated design approach for school buildings retrofitting.

The following approach was used:

- Integrated approach for school building rehabilitation – analyse of constructive typologies to define an action plan;
- Energy audit was conducted (occupants behavior, systems use, operation energy, constructive characteristics);5 energy retrofit scenarios were studied with different cost-effectiveness targets (targets (0- repair of the existing external plaster, 1- improving thermal behaviour of vertical envelope, 2- roof insulation, 3- improving windows frames effectiveness 4- combo of scenarios 1+2);
- Technical and economic evaluations taking into account payback analyses and life cycle cost analyses to minimize environmental impact;
- Energy retrofit scenarios compatible with European available financial mechanisms.

3. School building data collection

3.1. Building location and specification

The school buildings were constructed in the 80's, in Moita in the southern suburbs of Lisbon, Portugal. The original building (composed by two symmetric blocks) is compact with one floor above ground. Single brick wall without thermal insulation was used in the construction of the vertical opaque envelope of the building, covered with an external ordinary cement rendering. This construction typology adopted for the building envelops has proved to be the cause of great thermal loss and condensation effects, contributing to the observed increasing number of flu and lack of health detected in this specific community of students.

Fig. 3 presents the general view of the school buildings and their orientation. The buildings are located in an isolated area, having no adjacent structures/buildings. They are oriented east-west, each block consisting of two floors with 8 classrooms, two director rooms, one staff room, one storage room and four toilets. Figs. 4 and 5 present the ground and first floor of the building. Fig. 6 and 7 show, respectively, the west and east views of the buildings.

Fig. 3: General view of the school buildings and their orientation [10].

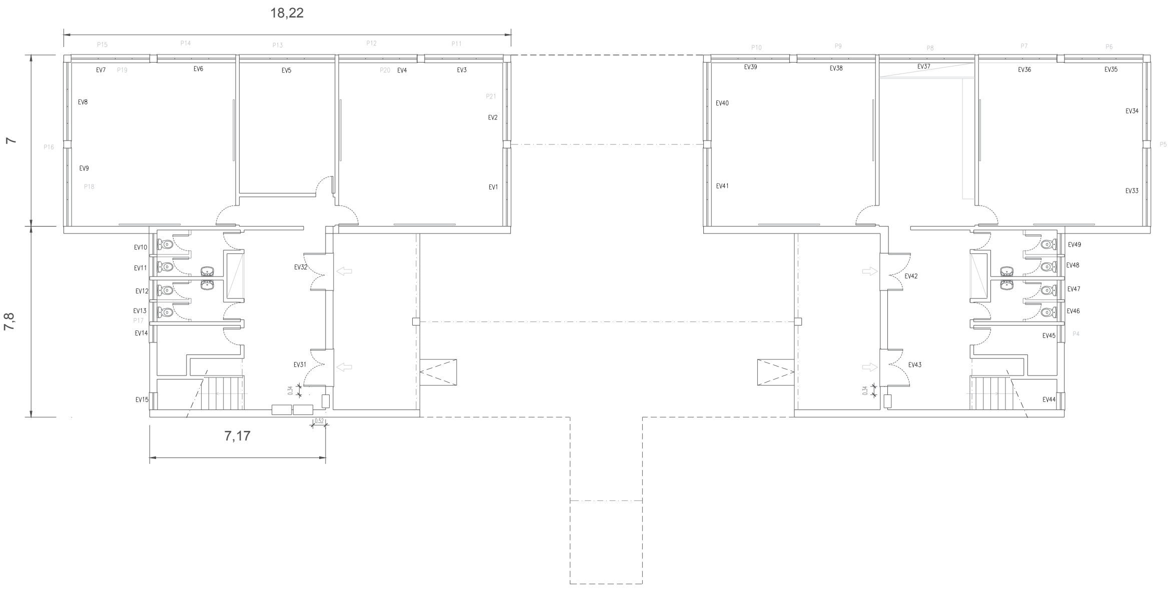


Fig.4: Ground floor of the school.

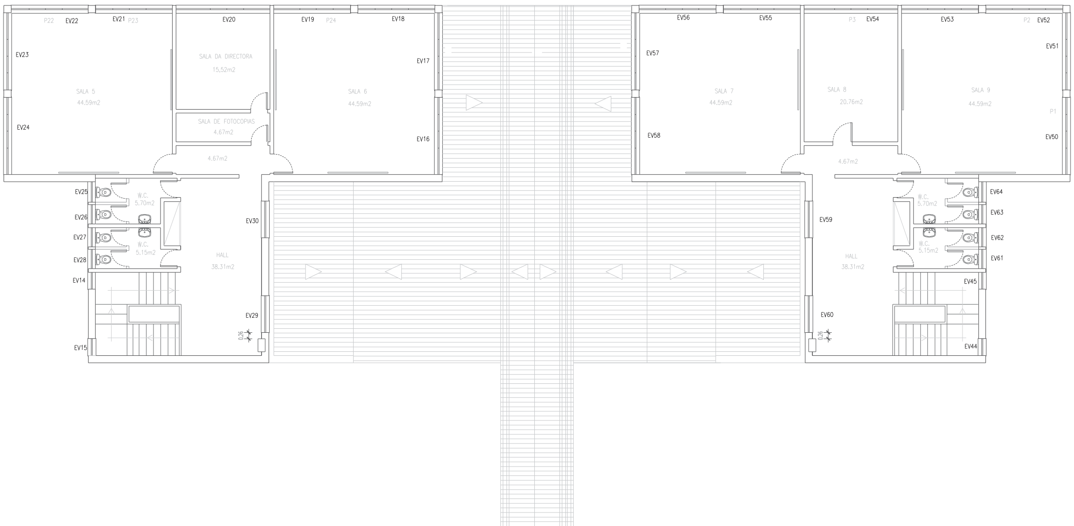


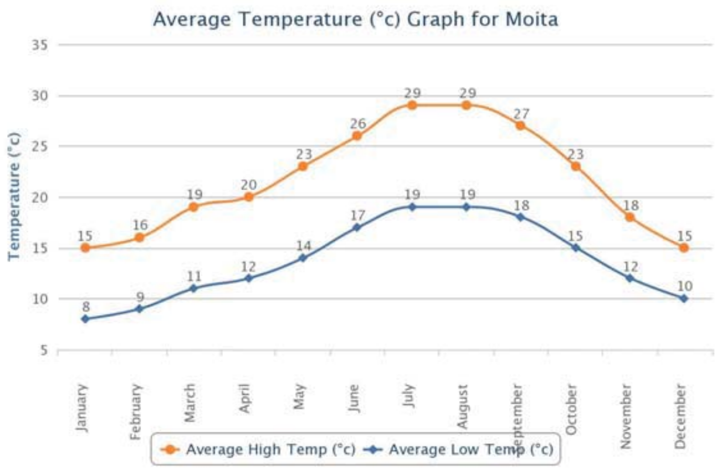
Fig.5: First floor of the school.

Fig.6: West view of the school.

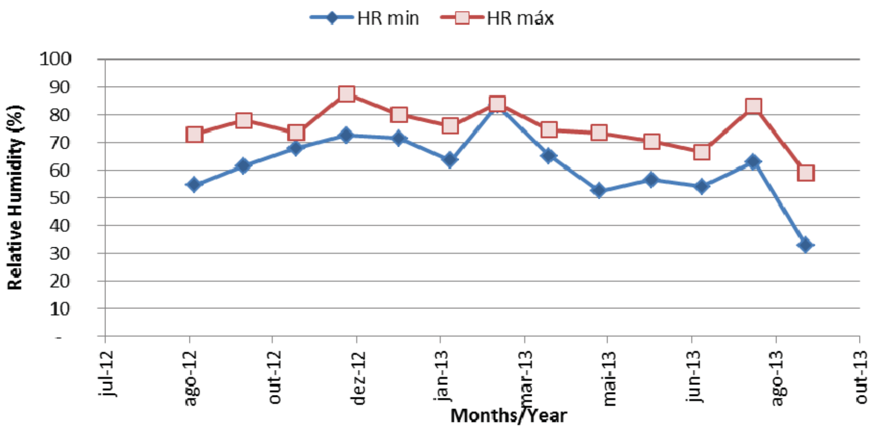
Fig.7: East view of one of the buildings.

3.2. Building climate zone characterization

Moita is located near Lisbon, in the south side of Tagus river, at the Longitude of 9ºW and Latitude of 38ºN.The following figures (Fig.8 (a) and (b)) present the average monthly maximum and minimum temperature and relative humidity distribution from September 2012 to September 2013.



(a)



(b)

Fig.8: Monthly average: (a) temperature and (b) relative humidity [11].

It is clear from Fig. 8 that the hottest months are July and August with the lowest relative humidity. It also shows the lowest temperature occurs from November to March with the highest relative humidity.

Table 1 presents the values of solar insolation per month [12].

Table 1: Solar insolation (average values per year).

Months	Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Total (h)	144,5	151,1	208,2	235,0	291,0	302,5	352,0	342,8	260,4	212,9	158,6	142,2

3.3. Building construction characterization

The main structural details of the buildings that were used for simulation studies are summarized in Table 2. Vertical opaque envelopes and support frames represent more than 30% of the total construction area (Table 3), which underlies a detailed analysis concerning energy evaluation of building vertical opaque envelopes.

Table 2: 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
Roof	Small attic covered by asbestos	No thermal insulation
Openings	Extruded aluminium system with simple glazing	Extruded aluminium system: simple glazing
Floor construction on ground	Reinforced concrete (RC)	No thermal insulation

Table 3: Area of structural elements for each school building.

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

An *in situ* inspection was carried out in order to enable a detailed thermal analysis of the buildings. Thus, 24 samples were collected from the building walls (Fig. 9 (a), (b), (c) and (d)) which confirmed the thickness of both renderings and walls.

(a) (b) (c) (d)

Fig.9: *In situ* inspection carried out in order to enable a detailed thermal analysis of the school buildings - (a) to (d).

Results show that renderings present 4 cm thick and internal bricks present an average thickness equal to 11 cm. Fig. 10 presents the external envelope of the school building.

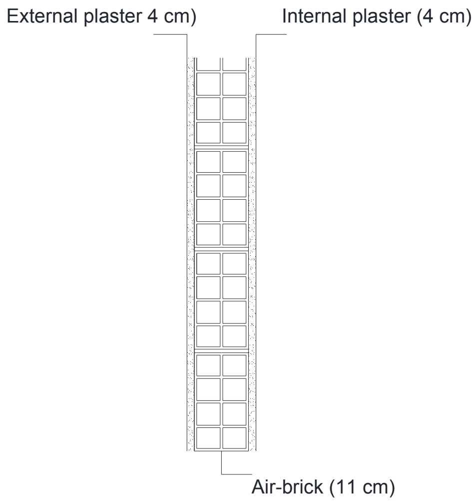


Fig.10: Single brick wall used in the external envelope of the school building.

3.4. Thermal performance of the building

In order to save energy in the building, its total thermal performance should include:

- ✓ Analysis of construction materials, colour of external walls and thermal insulation.
- ✓ Analysis of solar orientation of the building, and its geometric shape.
- ✓ Analysis of number of stories for a given floor area requirement.
- ✓ Analysis of shading or reflections from adjacent structures.
- ✓ Opportunities for natural ventilation; wind direction and speed.
- ✓ Air infiltration and efficiently sized mechanical equipment.

The buildings under investigation have a free space almost from all sides except from the south, in which there exists another similar school building. The two buildings are 7 m to 18 m apart. Due to these factors, their shading effect and the reflection on each other are relatively low.

Open windows represent 60% of all windows typologies of each building (Table 4), which means that natural ventilation into the building is an option. However, concerning the air renovation, no air inlet devices where found in facades but air infiltration was detected on windows.

The wind in this region comes normally from the north and west. Since the building is located in an open area, the wind effect should be considered especially in heat loss of classrooms placed in the North side.

Table 5 shows average wind speed in Moita region, for 12 months used in the analysis of the energetic invoicing period (September 2012 to 2013). Wind speed ranges from 10 to 23 km/h.

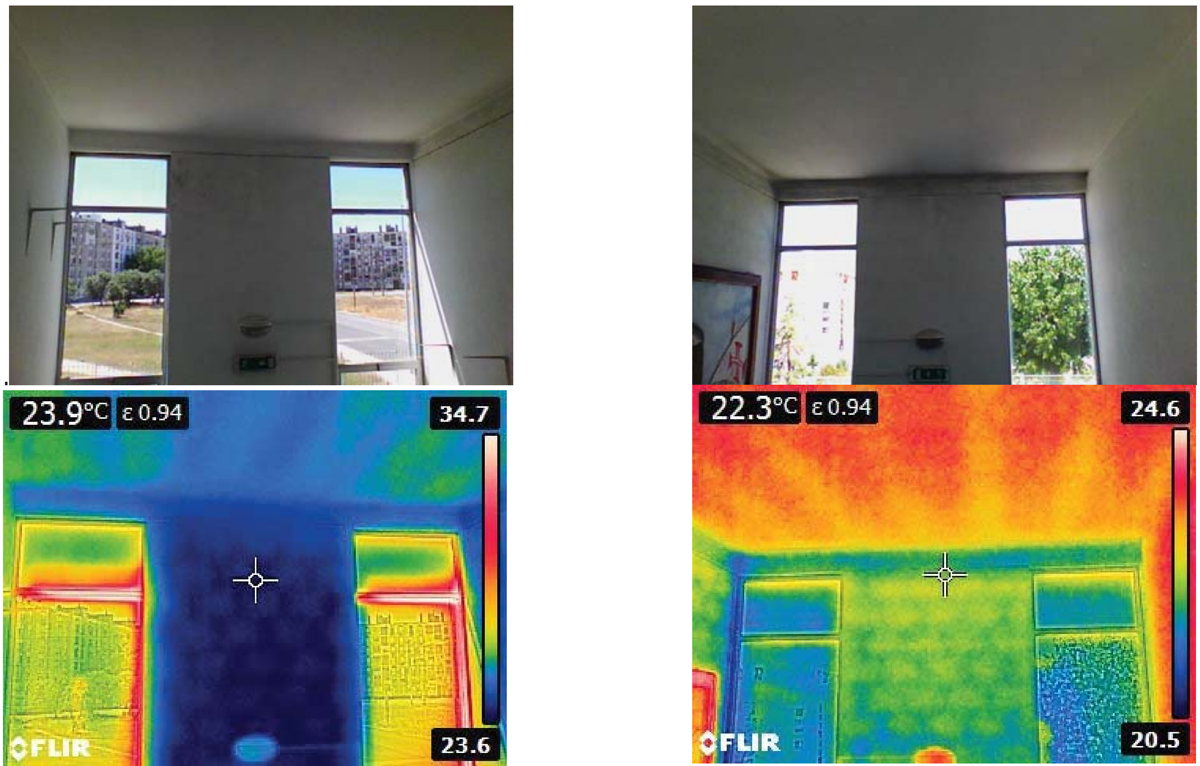
Table 4: Thermal characteristics of windows and doors of the buildings.

Elements		Construction characterization	Thermal characteristics	Area (m^2)
Glass windows	Sliding window	Sliding frame in anodized aluminum, 2 sheets of simple glass without protection	Uwdn=5,20 W/(m2.ºC)	89,26
	Fixed window	Fixed frame in anodized aluminum, 1 sheets of simple glass without protection	Uwdn=4,9 W/(m2.ºC)	77,88
	Rotating window	Rotating frame in anodized aluminum, 1 sheet of simple glass without protection	Uwdn=5,00 W/(m2.ºC)	31,88
Entry doors		Door in anodized aluminum 4mm thick and EPS 30mm thick between aluminum sheets and partially with colorless simple glass	3 cm of EPS	14,88

Table 5: Predominant wind direction and speed in Moita, from September 2012 to 2013 [12].

	2012				2013								
Month/ year	Sept	Out	Nov	Dec	Jan	Feb	Mar	Apt	May	June	July	Augoust	Sept
Velocity (km/h)	11,3	12,9	10,5	10,5	10,5	11,3	22,5	17,7	12,1	14,5	11,3	13,7	4,8
Direction	WNW	NNW	NNW	SSE	N	NW	W	N	N	NNW	NW	NNW	WNW

In order to analyse the effect of the orientation of the building, thermal images of the windows located in various rooms of the school building were captured. Due to the use of the building, the measurement through thermal images was only possible in June. Nevertheless, from all thermal images it is clearly shown that the temperature of the metal frame of the windows is higher than the surrounding wall. In fact, the temperature reaches a mean value of 33 ºC as shown in Fig. 11, which is almost 10 ºC higher than the indoor temperature. It is also possible to visualize the hot and cool air losses from the windows, which indicates air infiltration, which in turn means that more heating flow is required in classrooms to compensate the excessive heat loss.
Fig. 12presents a thermal image of the class room located at the North side of the school buildings. It also indicates the presence of thermal bridges with condensation problems (during winter season).



(a) (b)

Fig.11: Thermal Images of windows located the East side at the ground floor (a) and 1nd floor (b).

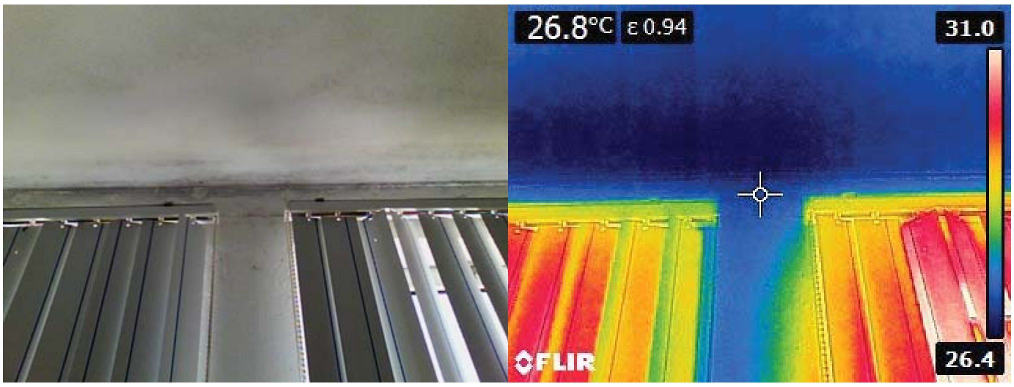


Fig.12: Thermal Images of thermal bridge in a classroom located the North sideat the ground floor.

3.5. Energy audit of the school building

The total power requirement and its percentage for various types of electrical equipments (the single source of energy used in the school building), are shown in Table 6. Potentiometers were used for the analysis of the electrical consumption. The electric load for the climatization system represents about 90% of the total installed power. In fact, most of the electric energy consumption is due to electrical heaters. The electric load for lights is of approximately 1%, which is low, since all lights of the building are of the florescent type, consuming very low electricity and producing a fair level of illumination. Other electrical loads for the building are still low.

Table 6: School building electrical load (W) (the analysed building is the one from the left side presented in Fig. 4 and 5)

		Power (W)	% Power
Lighting	Lights	180	0,8%
Climatization	Electrical heaters	18990	88,0%
	Dehumidifier	300	1,4%
	Fan	225	1,0%
Electrical appliances	Microwaves	157,3	0,7%
	Fridge	50,1	0,2%
Office equipmnet	Printer/Copier/Scanner	1500	6,9%
	TV	110,1	0,5%
	Stereo music player	48,1	0,2%
	Overhead projector	30,3	0,1%
TOTAL		21590,9	

Most buildings have an electric load due to thermal load between 70% and 80%, as indicated by Umberto and Stefania 13]. In the case of the existing building, the excessive electric load is due to the lack of thermal insulation of the building. In fact, the use of electrical heaters in each class room (working 8h/day during heating season) leads to a maximum temperature of 23ºC, due to the significant heat loos inside the buildings (Table 7).

Table 7: Consumed electrical load (kWh) for each building partition, per year (values for the left school building).

School building	Lighting (kWh)	Cooling (kWh)	Heating (kWh)
Class rooms	236,2	53,28	12862,56
Director rooms	69,04	13,32	3528
Bathroom	59,04	0	0
Halls	49,03	0	0
TOTAL (kWh/m2.yr)	1,3	0,2	50

The previous table allows 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 (50 kWh/m2.yr), while lighting and cooling needs are negligible.

Fig. 13 shows the total energy consumption for the building for nineteen months starting from September 2012 to March 2014. The highest energy consumption was verified in the coldest months, especially between October 2013 and March 2014, where consumption exceeds 3000 kWh. During these months, the outside temperature and solar radiation are smaller than during the cooling season from the year before (2012/2013), leading to the need of improving heating comfort in classrooms (see Fig 8, Table 1 and Fig. 14) by using electrical heaters. It is also noticed that the electric consumptions from June to August are lower than the remaining months, which is due to the non-use of the buildings during summer holidays.

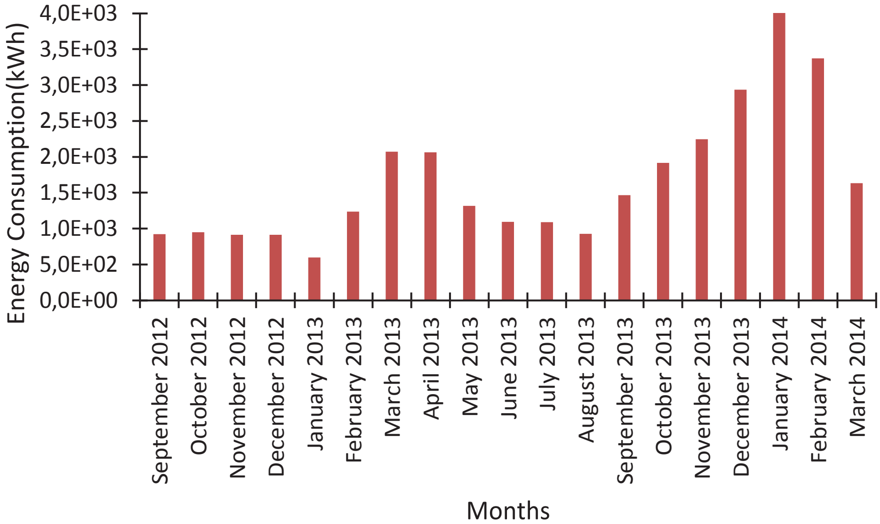


Fig. 13: Monthly Energy Consumption in Engineering Building starts from September 2012 to March 2014.

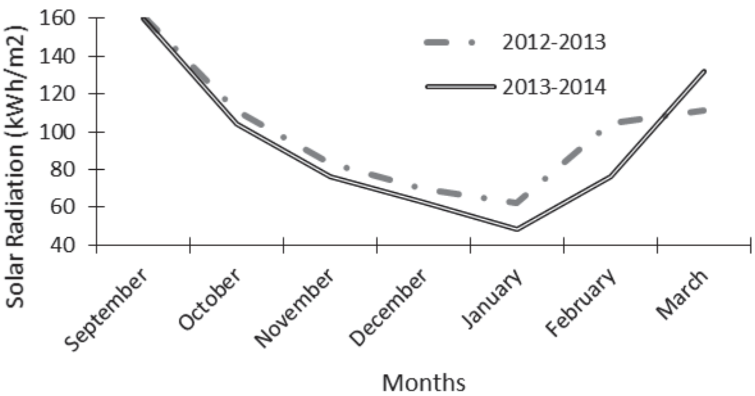


Fig. 14: Solar Radiation (kWh/m2) at Moita from September 2012 to March 2013 and from September 2013 to March 2014 [12].

On “non-working months” (from middle June to August), the school buildings consume 10% of the total load , which means that energy saving cannot significantly be achievedby modifying equipment behaviour - lighting, electrical appliances and office equipment.

According to the energy audit information, the total operational energy (OE) consumed in each building is equal to 51,5 kWh/m2.yr, where heating needs represent 97% of the total OE, emphasizing the importance of building construction quality and the influence of comfort requirements and occupancy regimes.

4. Thermal analysis of the school building

4.1. Original situation

The analysis of the specific energy consumption for heating of the school was carried out according to the Portuguese Legislation [14].Based on the previous information, the analysis of the specific energy consumption for heating of the buildings was carried out according to the ISO 13790 [9]. The goal was to correlate particular structural and engineering situations to the high/ low consumptions of the building and identify possible improvements to energy management.

The following figure (Fig. 15) presents the heat losses for the school building presented in the left side of Fig. 4 and 5 (due to its several conditions when compared to the one of the right side) in the winter season.

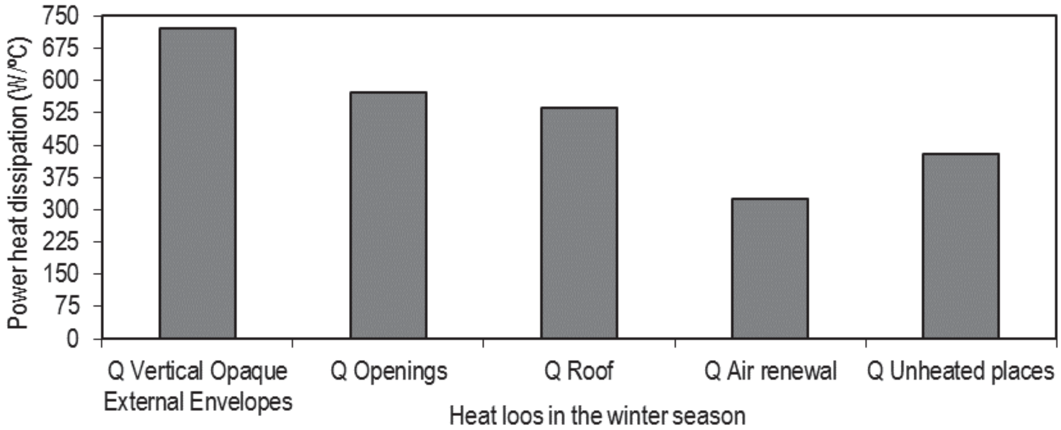


Fig. 15: Heat losses in one of the buildings school – original condition (winter season).

It is shown that the power of heat dissipation (Q) in the walls (vertical opaque external envelopes) is the most important one in the heating phase (Fig. 15), followed by the heat loss in openings and roof. The total thermal energy need is calculated and used to assess the energy efficiency performance of the architectural design (without any systems information).

In order to evaluate the standard energy performance of the buildings, the Decree Law 118/2013 procedure was adopted [14], which is largely based on EN 13790 2008 [9] and the other standards approved and published by the CEN (European Committee for Standardisation). The authors have used a more simplified approach in the energy evaluations of the school building because the collected data are not very detailed. The calculation of the energy balance for space heating was, therefore, performed on a seasonal basis. According to the calculation carried out, the annual energy needs in the original situation correspond to 123 kWh/m2.yr for heating and 29kWh/m2.yr for cooling, which increases the importance of controlling heating needs.

The system energy consumption of the school buildings – in order to meet the thermal energy demand for thermal comfort - is determined based on the data obtained in the energy audit of the building. Based on audit results, measured energy needs for heating correspond to 50 kWh/m2.yr (Table 7). The measured energy consumption is 60% lower than the predicted consumption (123 kWh/m2.yr), which is far from the expected results.

Thermal hygrometers where placed inside classrooms during winter season (from December 2013 to April 2014), in order to detect the maximum room temperature when electrical heaters where switch on. Those results are presented in table 8.

Table 8: Maximum room temperature when electrical heaters where switch on in two classrooms (North and East side).

Fraction		RH (%)	Max Internal Temperature (ºC)	External Temperature when maximum Internal Temperature was achieved ºC)
Classroom at North side	Heating season	64	21,4	22,5
Classroom at East side	Heating season	62	22,0	17,0

The previous results show that classrooms at the North side are more exposed to external conditions than those in the East side. Besides this, thermal comfort is not achieved easily since it is evident that building heat loss (from walls and openings mainly due to

air infiltration) together with a low building thermal inertia (Fig.10) are the main reason to disable electric heating of reaching the predicted energy consumption during winter season.
Capital-intensive measures such as the insulation of facades, replacement of windows or upgrades of ventilation systems might not be viable projects or may involve payback periods that are too long for a private investment. Thus, an understanding of financial mechanism and European policies is necessary to ensure the best decision for renovation.

4.2. Financing the energy renovation of buildings

The rate of building renovations depends not only on the development of suitable methodologies for energy audits aimed at the energy retrofit [15,16], but also in the knowledge of the different financial mechanisms and current support systems available to successfully implement energy efficiency actions.

Concerning school buildings, large investments are required to improve their energy performance. The economy over the next few years and the Stability and Growth Pact [17] which is now mandatory for the public administration of European countries, especially in Portugal to reduce the national debt, will limit direct investments and enhance the knowledge of those financial mechanisms (especially third party financing).
In the programming period 2014-2020, the European Commission has foreseen to introduce an alternative to the traditional grant funding – innovative financial instruments. These would create a multiplier effect for the EU budget by facilitating and attracting other public and private financing for projects of EU interest. EU funds can be used in partnership with the private and banking sectors, particularly with the European Investment Bank (EIB) [18].
There are several financial mechanisms (Table 9) and each main advantages and disadvantages should be identified in order to enable local authorities and other stakeholders to choose the most suitable mechanism for each situation [19, 20].

Table 9: Available financial mechanisms to promote buildings energy efficiency measures.

Financial mechanism	What is it?
Grants	A non-reimbursable financial support for the implementation of energy efficiency actions (usually partially covering their cost), chosen by the beneficiary from a set of eligible measures.
Preferential loans	A lender provides a loan to a borrower for a specific use over a predefined period of time.
Guarantees	Mechanism through which risk is shared, where the guarantor entity assumes a debt obligation in case a borrower fails to repay.
Energy Performance Contractors with ESCO finance	In an Energy Performance Contract (EPC), the contracting partner (ESCO) design and implement energy efficiency measures guaranteeing a minimum performance achieved during the contract duration for an end-user and a financial institution. The payments are based on the fulfilment of energy efficiency improvements and/or on meeting predefined agreed criteria
Energy Performance Contractors with owner finance	In the case of EPC with owner finance, the main difference with EPC with ESCO finance is that the building owner is the one who finances the energy efficiency measures with his own capital or through a bank loan. Buildings owners might be eligible for preferential loans or other mechanisms, different from the ESCO solutions, to facilitate access to finance.

The following table (Table 10) is an adaptation of [17] and summarizes the main advantages and disadvantages of each financial mechanisms.

Table 10: Main advantage and disadvantage of each available financial mechanisms to promote buildings energy efficiency measures (based on [17]).

Financial mechanism	Main advantages	Main disadvantages
Grants	They are quite versatile, as they can be targeted to different technologies or focused to achieve a particular policy objective. They are suitable to impulse proof-of-concept and demonstrative displays as well, fostering the adoption of beyond cost-optimal actions. They are the most efficient way to promote energy performance actions identified as priority by policy makers. Their characteristics make them particularly convenient for economically depressed areas or areas where conventional financial mechanisms are constrained.	They generally have limited control mechanisms for transparency and performance They might lead to overpriced solutions
Preferential loans	These financial mechanism generally target the most appropriate and cost-effective measures. As money borrowed is paid back, it can be reinvested into more projects. Its administration is not particularly complex. It is a well understood mechanisms for all stakeholders involved.	In some situations, energy savings are not considered as a cash flow by financial intermediaries which means that the payback period for the measure is extended. This mechanism is less advantageous for final recipient compared to grants and they are generally less motivated to take part. This mechanism is not suitable for poorer house-owners who do not have enough income to repay the loan.
Guarantees	This mechanism helps overcome the gap between the risk perceived by a financial institution and the actual risk. Guarantees also provide comfort for financial institutions in relation with technologies or approaches where they are inexperienced. They ease the access to finance and reduce the cost of capital for borrowers. They increase debt-to-equity ratios, increasing return for borrowers. When public entities back guarantees, they enhance direct flow of private funds towards energy efficiency actions by mitigating the risk.	Guarantees are not suitable for every market situation, as they would be of little use when the main constrain of financial flow is the lack of liquidity of a financial institution. When project investor has insufficient capital, partial guarantees schemes do not provide a proper solution.
Energy Performance Contractors with ESCO finance	This mechanism guarantees a minimum level of performance and avoid for end users any risk related to performance. From the end-user side, a cost, energy and financial savings and equipment performance protection exist. Due to their business model, ESCO have a deep knowledge of technical requirements, support schemes, and related legislation. They are eligible for many support mechanism, which reduce the payback period.	It is a complex arrangement. Designing an Energy Performance Contract is a time and resource consuming task, as it need to be individually assess in order to estimate realistically potential energy saving. During the contract period, the end-user is tied to the one vendor. ESCOs tend to low risk solutions with a short payback period. Therefore long-term engagements and deep renovations are not common.
Energy Performance Contractors with owner finance	Clients are protected from performance risk as a minimum level of energy saving is guaranteed by ESCOs. The ESCOs provide their expertise in the field, including legislative, technical and financial advice. Building owners benefit of a bigger share of the savings derived from energy efficiency measures. Building owners can tailor an energy performance contracts based on their own experience, making them more suitable for their particular situation. When building owners have a high credit-rating, being able to borrow more money, they might be in the position to get lower interests rates than an ESCO. This is particularly appropriate for public authorities (such as municipalities) as building owners.	For a building owner, financing an energy efficiency measure with a loan implies that it will be capitalized in the owner's balance sheet, what might reduce its ability to access further credit for new projects. Energy efficiency measures are generally financed with the energy cost savings achieved during 10 years.

In order to select the best financial mechanism (presented in Table 9) it is necessary to know the relevant financial programs in the European Union level concerning sustainable energy [19, 21, 22]. Five relevant programs were identified: ELENA, SEFF, EEEF, EU Structural and Cohesion Funds and PF4EE:

- European Local ENergy Assistance (ELENA): it is a European Investment Bank initiative developed to fund up to 90 per cent of technical support cost to prepare, implement and finance investment programs to implement large energy efficiency and renewable projects. Local and regional authorities or other public bodies are eligible beneficiaries of this program.
- Sustainable energy financing facilities (SEFF): it is an initiative of the European Bank for Reconstruction and Development (EBRD). Potential beneficiaries of this mechanism are commercial and household energy efficiency projects.

- European Energy Efficiency Fund (EEEF): it focuses on financing energy efficiency, small-scale renewable energy and clean urban transport projects targeting municipal, local and regional authorities as well as public and private entities acting on behalf of those authorities. The fund is supported by the European Investment Bank (EIB), Cassa Depositi e Prestiti SpA (CDP) and Deutshe Bank. EEEF is a Public-Private Partnership (PPP).
- European Structural and Investment Funds (ESI Funds): ESI Funds operate under shared management between the Commission and the Member States. In the 2014-2020 period, the term European Structural and Investment Funds refers to the following five funds: (1) European Regional Development Fund (ERDF), (2) European Social Fund (ESF), (3) Cohesion Fund (CF), (4) European Agricultural and Development Fund (EARDF), (5) European Maritime and Fisheries Fund (EMFF). Under new procedures, Member States are being given the option of using some of their Structural Funds, to make repayable investments in projects forming part of an integrated plan for sustainable urban development. The Joint European Support for Sustainable Investment in City Areas (JESSICA) is being developed by the European Commission and the EIB, in collaboration with the Council of Europe Development Bank (CEB). These investments, which may take the form of equity, loans and/or guarantees, are delivered to projects via Urban Development Funds and, if required, Holding Funds. [23]. As a general rule, JESSICA operations focus on projects that would not attract sufficient finance through normal market mechanisms. Therefore JESSICA has significant potential for the financing of urban energy efficiency (EE) and renewable energy (RE) projects which are typically considered to be medium to high risk and can have long payback periods [21].

- Private Financing for Energy Efficiency instrument (PF4EE): The goal is to increase debt financing to the final recipients from private financial institutions for energy efficiency projects in order to meet EU energy efficiency directives requirements and help in making energy efficiency related loans a more sustainable activity across the European financial sector. Financial institutions and SMEs are some of the potential beneficiaries of this financing instrument.

The analyzed financial mechanism (presented in Tables 9 and 10) show that most of them tend to be adopted for low risk solutions with a short payback period, which means deep renovations are not common. However, energy efficiency projects have a significant competitive advantage comparing to other investments – they generate financial savings which are a guarantee that the loans will be paid back. Based on EIB experiences with innovative financing and technical assistance initiatives (e.g. ELENA, JESSICA), Energy Cities sees the EIB as a European leader in financial innovation and capacity building, able to boost the implementation of local sustainable energy projects at a large scale all over Europe.

In the period 2014-2020, EIB will be responsible to invent, test and promote the most successful innovative financing schemes (e.g. local or regional saving schemes, guarantee funds, cooperatives, etc.) in order to help overcome current barriers for financing sustainable energy projects, in particular high up-front investment costs, and problems of local and regional authorities with the cash-flow and long payback periods of energy investments. The EIB should promote these schemes at national level and encourage local, regional and national banks to follow its example [18].

According to the analyses made by EIB concerning the best practice from the leading cities, the selection criteria for EE and RE projects include the following six dimensions [21]:

1. Economic viability;
2. GHG emission reduction;
3. Economic impact;
4. Social impact;
5. Technical feasibility;
6. Deliverability and readiness.

Investment in the energy efficiency of public buildings often have difficulties in attracting sufficient finance through normal market mechanisms because of information asymmetries and the fact that public buildings are generally considered to be a public good. However, energy efficiency in public buildings can generate stable returns that are relatively risk-free and therefore could benefit greatly from an Energy Focused Urban Development Funds.

EE retrofits do not have a standard project typology; the recommended investments vary based on the characteristics of each individual project. At a project level, a suite of recommendations is tailored and optimized based on costs, benefits and risks.

4.3. Energy retrofit measures for the Portuguese school buildings

4.3.1. Technical and economic evaluations – payback analyses

Holistic and integrated approaches to building renovation are needed in order to achieve the EU's ambitious EE objectives. Such approaches should aim to combine a certain number of measures (such as retrofitting insulation and installing RE heating systems). Deploying single measures will generally be insufficient. Besides this, the fact that once some basic energy efficiency measures have been implemented, it becomes less cost effective to fit more comprehensive measures in the future.

Thus, for a good choice of the best business it is necessary to study a few characteristics which directly affect their adoption. Initial cost of the retrofit solution, payback return, energy savings, lifetime of the new solution and its compatibility with building lifetime and financial contract lifetime, are some of the most relevant parameters that should be take into account. Based on each solution, the specifications [19, 22] classifies the obtained energy saving in three topics:

- ✓ low effect (when energy savings are <10%);
- ✓ medium (energy savings are between 10% and 30%);
- ✓ high (energy savings >30%).

Concerning payback period:

- ✓ very long (>8 years);
- ✓ long (between 5-8 years);
- ✓ medium (2-4 years);
- ✓ short (<2 years).

With renovation cycles for existing buildings of at least 25 years, managing authorities should ensure that each renovation maximizes the savings potential of the building. Building retrofits approach usually adopts a process that involves doing the most cost- effective, least invasive measures, which tend to have quick payback periods and yield energy savings of up to 20-25% (called "low-hanging fruit"). However, much higher energy savings are required if the full economic and technical potential is to be realized. Here, it should be mentioned that those energy savings will also depend on the success of other factors such as changes in behaviour by consumers once improvements have been made.

Based on the previous recommendations of the European Bank of Investments (EIB), it is essential that the average payback period for the energy retrofit measures should be shorter than 8 to 14 years [19, 20, 21, 24].

Thus, the technical and economic evaluations of strategies for the energy retrofit of the school building are considered in five different scenarios. All of them take into account an intervention in the construction system since this represents the main cause of electrical energy consumption and lack of thermal comfort. The choice of these remedial tasks, however, does not neglect the economic aspects: the objective is to identify measures that could be financed over a period of time compatible for example with European funding promoted by the EIB.

- In scenario 0 it is intended to represent small maintenance actions that are going to occur in the school buildings. It corresponds to the repair of the existing external plaster (original situation).
- In scenario 1, the objective is to provide walls thermal improvement by using 4cm of thermal enhanced mortars for thermal rehabilitation (with thermal conductibility equal to 0,1 W/mºC), developed by the authors [25,26,27].
- In scenario 2, the objective is to significantly increase the energy performance of the horizontal building envelope by placing a thermal insulation on the roof (4 cm of Expanded Polystyrene).
- In scenario 3, the purpose is to increase the energy performance of the school building by replacing window frames by extruded aluminium system: double glazing 4 (12) 4.
- Combo 1+2 corresponds to the combination of scenario 1 and 2.

An economic evaluation was carried out concerning the electric energy cost and its annual growing rate in the Portuguese school building, taking into account the previous tested scenarios. The objective is to choose the best solution from a technical and economical point of view, taking into account the initial investment costs, the maintenance and the energy costs for operational (mainly heating cost):

$$C_{g,n} = C_0 + C_{man,n} + C_{\exp,n} \qquad (4)$$

Where: Cg,n – Global cost in the year n (in €/m²); C_0 – Initial cost in €/m²; $C_{man,n}$ – Maintenance cost (in €/m²); $C_{exp,n}$ – Operational cost in €/m².

The initial cost was estimated using the prices data of the construction materials and the necessary manpower to remove the existing external plaster by a new optimized mortar, using the original thickness (Table 11).

Table 11: Initial cost of an intervention on field concerning the analysed scenarios.

Scenario	Situation	Inicial cost (€/m2)
0	Original situation: repair of the existing external plaster	27
1	Thermal mortar [19, Brás A., Gomes V (2015), LCA	52

	implementation in the selection of thermal enhanced mortars for energetic rehabilitation of school buildings, Energy and Buildings (already accepted)]]	
2	Roof thermal improvement	10
3	New windows frame	375
Combo 1+2	Scenario 1+2	62

The maintenance cost adopted took into account the necessary cleaning work, small repair operations and application of a new wall painting each 7 years (C_{man} = 5.8 €/m2). Since these prices are a function of the inflation rate, the prediction of the maintenance cost is also a function of that.

The methodology adopted for the determination of the energy costs for heating and cooling (operational cost) is based on the Portuguese legislation [14]:

$$C_{gx} = C_0 + \sum_{x=1}^{n} (C_{manx}(1+\alpha)^x + (0{,}1\frac{N_{ic}}{\eta_i} \times C_{exi} + 0{,}1\frac{N_{vc}}{\eta_v} \times C_{exv}) \times (1+\alpha')^x) \times (1+i)^x \qquad (5)$$

Where: α = inflation rate (0,6% in 2014); α' = electricity cost rate per year (4%); *i* = Discount rate (for this public investment, it was used the rate =6.0%); $C_{ex,i}$ = $C_{ex,v}$ = price of Kwh (the mean value in the two last years is 0,30 €). *Nic*= Annual energy needs for heating (kWh/m2.yr); Nvc= Annual energy needs for cooling (kWh/m2.yr); Nominal efficiency of electrical heaters (the only energy source used for climatization).

For each scenario, Nic and Nvc was calculated. Those results are presented in table 12.

Table 12: Annual energy needs for heating and cooling of the school building for different scenarios (according to [14]).

	Annual energy needs for heating (kWh/m2.yr)	Annual energy needs for cooling (kWh/m2.yr)	Nominal efficiency of electrical heaters
Scenario 0	122,9	28,7	1
Scenario 1	104,0	27,0	
Scenario 2	97,3	28,7	
Scenario 3	103,6	32,1	
Combo 1+2	74,5	25,8	

The prediction of the global cost of the three energy retrofit scenarios was done taking into account the previous data (Fig.16). This kind of analysis is fairly simple and gives an overview of the state and possibilities for the school building stock. A detailed analysis is necessary for the proper planning phase.

The aim is to obtain data concerning the investment required expressed as €/m2 of the net floor area, the percent energy reduction and the simple payback period of the investments for the school building per each scenario.

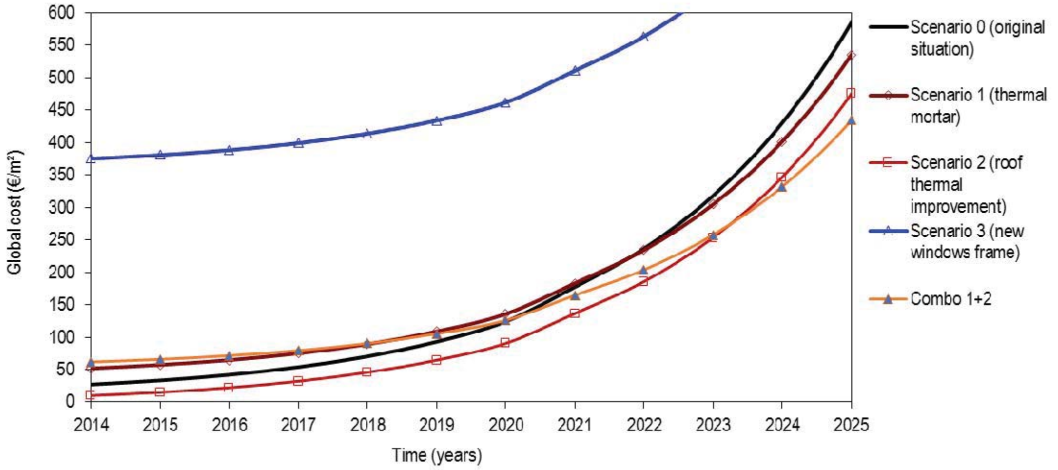


Fig. 16: Prediction of the global cost evolution using three energy retrofit scenarios and comparison with original situation.

In Scenario 1 (retrofitting with thermal enhanced mortar on the external walls) the achievable energy savings are 15%, with an investment of 52 €/m2. Under these conditions, the payback period is 7 years, which may be considered a good scenario, as the investment required is affordable, the payback period is compatible with third party financing solutions proposed by the ESCOs (Energy Service Company) that works under the ELENA programmes. This sort of choice can be justified if there are outsourcing contracts for energy management made with ESCOs for no long than 8 or 9 years duration. Besides this, the implementation of scenario 1 will improve the thermal behaviour of the external wall, minimizing the condensations effects and contributing to a better insulation against external weather conditions.

The achievable energy saving with Scenario 2 is 21% - roof thermal improvement. This scenario represents a typical situation of low-profile maintenance actions without any ambition to obtain a substantial improvement in building maintenance conditions or energy efficiency. However, the global cost of this solution is always smaller than the repair according to scenarios 0 or 1, which enhances the benefit of using this scenario together with another one.

"Combo 1+2" is an interesting solution since it leads to 40% of energy savings and a reduction of the payback period to 6 years, which is compatible with third party financing solutions proposed by the ESCOs or JESSICA operations [21]
Considering the replacement of all windows by extruded aluminum system replacing also single by double glazing 4 (12) 4 - Scenario 3- the achievable energy saving is 16% with an investment required of 375 € /m2. Under these conditions, the payback period is 18 years. The economic effort to support this scenario is much higher than the previous solution. Furthermore, the payback period (very long) is not easily compatible with third party financing solutions. Once again, JESSICA operations seems to fit this type of projects, which are typically considered to be medium to high risk and can have long payback periods.

4.3.2. Technical and economic evaluations – life cycle cost analyses to minimize environmental impact

The use of different solutions for building envelops may cause significant environmental impacts not only because they are generally formed by non-renewable raw-materials, but also because they could present possible reduction of their service life. This reduction could happen due to solar exposure, rain, thermal movements, among others, which increases the civil construction environmental onus. Thus, in order to understand what could be the influence of a reduction of each scenario service life in choosing the best solution for energetic rehabilitation, life cycle cost method (LCC) was used [28].

The LCC method is the most commonly accepted method to assess the economic benefits of energy conservation projects over their lifetime. The basic procedure of the LCC method aims to determine the relative cost-effectiveness of the various alternatives. For each alternative, the total cost is computed over the project lifetime. In most energy-efficiency projects, the annual cash flow remains the same after the initial investment [28, 29]. In this case, LCC can be estimated based on the initial cost and the annual cost using eq. 5.

LCC of each scenario was estimated for different service life equal to: 5 years, 10 years and 15 years. Fig. 17 present the evolution of LCC as a function of energy savings using for scenario 0, 1, 2, combo 1+2 and 3, for different service life.

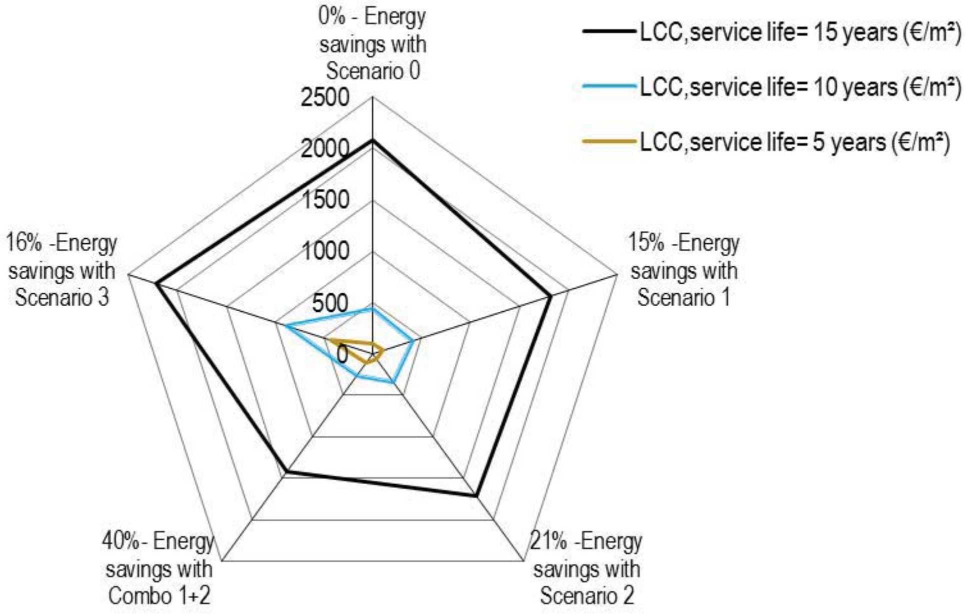


Fig. 17: Evolution of LCC as a function of energy savings using for scenario 0, 1, 2, combo 1+2 and 3, for different service life (5, 10 and 15 years).

For the analysed solutions, Fig. 17 show that each scenario service life presents an important effect in LCC. The differences in LCC values are only obvious if the service life is at least of 15 years – here it could be seen that scenario 3 is the one that significantly presents higher LCC. Below that, different scenarios (except scenario 3) start to become less relevant. The improvement of walls with thermal mortar together with roof thermal improvement (Combo 1+2), leads to faster benefits concerning the reduction of heating needs and reduction of LCC, when compared to other scenarios contribution. Therefore, Combo 1+2 will become the most effective economically and will be the recommended option to the managing authorities, as long as the solution presents a service life higher than 15 years.

5. Conclusions

The aim of the present work was to assess the energy performance of a building school and to achieve beneficial solutions for the educational organizations / managing authorities in order to improve indoor comfort for students and professors, manage the electric usage and reduce the electric bills. Detailed auditing was done in the building including: the construction materials used; energy consumption; cooling load and lighting. Based on these data, 5 different energy retrofit scenarios were studied with different performance and cost-effectiveness targets. Afterwards, an analysis was carried out using European available financial mechanisms to promote energy efficiency measures on buildings and the compatibility of these measures with previous scenarios.

According to the energy audit information and thermal analysis:

- Energy saving in this specific school building cannot significantly be achieved by modifying equipment behaviour in non-working months (from middle June to August): lighting, electrical appliances and office equipment.
- Heating needs represent 97% of the total OE (51,5 kWh/m2.yr), emphasizing the importance of the construction quality.
- Thermal comfort is not achieved easily since it is evident that building heat loss (from walls and openings, mainly due to air infiltration) together with a low building thermal inertia are the central reason to disable electric heating devices of reaching the predicted energy consumption during winter season.

Thus, in order to take into account what current building changes on field may imply, as regards energy consumption, different scenarios were investigated in the thermal performance simulation, namely:

- Scenario 0: Repair of the existing external plaster;
- Scenario 1: Provide walls thermal improvement by using 4cm of thermal enhanced mortars for thermal rehabilitation
- Scenario 2: Increase the energy performance of the horizontal building envelope by placing a thermal insulation on the roof
- Scenario 3: Replacing windows frames by extruded aluminium system: double glazing or;
- Combo 1+2: Combination of scenario 1 and 2.

The combination of scenario 1 and 2 ("Combo 1+2") is an interesting solution since it leads to 40% of energy savings and a reduction of payback period to 6 years which is compatible with third party financing solutions proposed by the ESCOs that works under the ELENA programmes and JESSICA operations.

The achievable energy saving with scenario 3 (replacing windows frames) is only of 16%. Under these conditions, the payback period is 18 years, which means that the economic effort to support this scenario is much higher than previous solution. Furthermore the very long payback period is not easily compatible with third party financing solutions.

The use of different solutions for building envelops may cause significant environmental impacts because they could present possible reduction of their service life. It was also detected that different scenarios service life present an important effect in LCC. The improvement of walls with thermal mortar together with roof thermal improvement (Combo 1+2), leads to faster benefits concerning the reduction of heating needs and reduction of LCC, when compared to other scenarios contribution, specially the worse one (scenario 3). Therefore, Combo 1+2 will become the most effective economically and will be the recommended option to the managing authorities, as long as the solution presents a service life higher than 15 years.

This study demonstrates that reaching better levels of energy performance and improving building conditions (namely concerning minimization of air infiltration and condensations effects to enhance indoor air quality) might be very difficult or not cost-effective in some cases. From a generalized point of view, this analysis should be carried out for each typology of school buildings, taking into account the specific energy cost per user (including students, teachers, etc.).

An integrated approach to building rehabilitation is necessary in order to achieve the EU's ambitious EE objectives. Deploying single measures of building rehabilitation will generally be insufficient. Besides this, the fact that once some basic energy efficiency measures have been implemented, it becomes less cost effective to fit more comprehensive measures in the future. Thus, an understanding of financial mechanism and European policies is necessary to ensure the best decision for renovation.

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Integrated approach for school buildings rehabilitation in a Portuguese city and analysis of suitable third party financing solutions in EU

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HIGHLIGHTS

Integrated approach for school building rehabilitation► Energy audit conducted the school in the suburbs of Lisbon ► 5 energy retrofit scenarios were studied with different cost-effectiveness targets ► Energy retrofit scenarios compatible with European available financial mechanisms ► Service life presents an important effect in LCC ► Results show it is possible to reduce the electric energy consumptions up to 40%