Energy Rehabilitation of the Covered Pool of the Military Academy in Lisbon

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Abstract

Energy efficiency must be considered in both new and retrofitting buildings. The main objective is to obtain appropriate thermal behaviour and energy performance that prosecute building requirements coupled with reduced resource consumption.

This thesis focuses the implementation of different energy rehabilitation measures in a service building, more specifically the indoor pool of the Military Academy of Lisbon.

This building was opened in the 1980's and presents some degradation of building envelope and equipment due to the lack of maintenance and requalification which conducts to inefficient thermal performance and high energy consumption.

To mitigate the above mentioned undesirable effects a rehabilitation study based in the adoption of several energy rehabilitation measures was carried out, such as: application of thermal insulation on facades and on roof; implementation of glazed areas with double or triple glazing units with PVC window frames; adoption of LED lighting system; and change the operating hours of boilers, among others.

To achieve this, *in situ* measurements and building energy simulations, using the Hourly Analysis Program software, were performed to determine the energy needs of the building before and after the implementation of rehabilitation measures.

Furthermore, we performed an analysis of the economic viability of the four proposals for energy rehabilitation. We concluded that their implementation has a significant impact on reducing energy consumption and it improves the thermal and energy performance of the building.

Keywords: Energy rehabilitation, thermal behaviour, energy performance, thermodynamic simulation, Hourly Analysis Program, economic viability

1 Introduction

The concern with the consumption of energy resources worldwide is notorious and the future outlook shows that is mandatory to make a deep and complex intervention, cooperation and change in mentalities by all countries.

According to the US Energy Information Administration (2016), it is estimated that the primary world energy consumption will increase around 48% between 2012 and 2040, and the large portion of this increase in consumption will be caused by countries that are not part the Organization for Economic Cooperation and Development.

According to the Eurostat (2016) the global primary energy consumption of the different sectors of activity in the European Union has a significant and relevant weight in energy consumption worldwide, and the sectors relating to transport, industry and buildings account for the large share of consumption of primary energy.

In Figure 1.1 it can be observed statistics of the global consumption of primary energy from different sectors of the European Union in 2014.

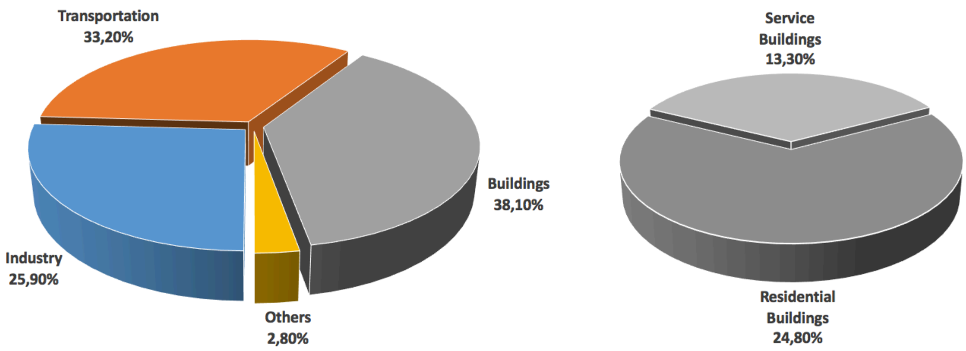

Figure 1.1 – Primary global energy consumption in the EU-28 in 2014 (adapted from Eurostat, 2016)

Looking at Figure 1.1, the sectors of the buildings presents the larger portion of consumption, totalling about 38.10% of global consumption, of which 24.80% correspond to primary energy consumption for residential buildings and the remaining 13.30% to the service buildings.

Therefore, the best way to minimize the excessive consumption of energy resources is by analyse the "energy trilemma" which features three main aspects to consider: energy security, energy equity and environmental sustainability, whose ultimate goal is to achieve energy efficiency, promoting policies of implementation of effective and sustainable measures, taking into account the environmental benefits due to the implementation of the measures and the associated costs (World Energy Council, 2013).

Therefore, contributing to the reduction of energy consumption in the indoor pool of the Military Academy through the implementation of rehabilitation measures to increase energy performance and thermal behaviour, it will promote the reduction of primary energy consumption in the service-level sector world. Despite being a small contribution it is on step in path that should be followed in order to fill the constant consumption of non-renewable energy sources.

2 Objectives and methodology

This master's thesis aims for the rehabilitation of an indoor pool of the Military Academy belonging to the Portuguese Army. This infrastructure presents a several degradations of its building materials, resulting in poor thermal performance and high energy consumption.

With this in mind, we have proceeded to an energy rehabilitation study based on the following main objectives: to proceed to a dynamic simulation of the current building for the evaluation of its thermal behaviour and energy performance; the implementation of the experimental monitoring campaigns in situ in order to calibrate the simulation model; evaluation of the implementation of energy rehabilitation measures and analysis of the economic viability of energy rehabilitation measures.

To achieve these objectives, we have followed the work methodology outlined in Figure 2.1.

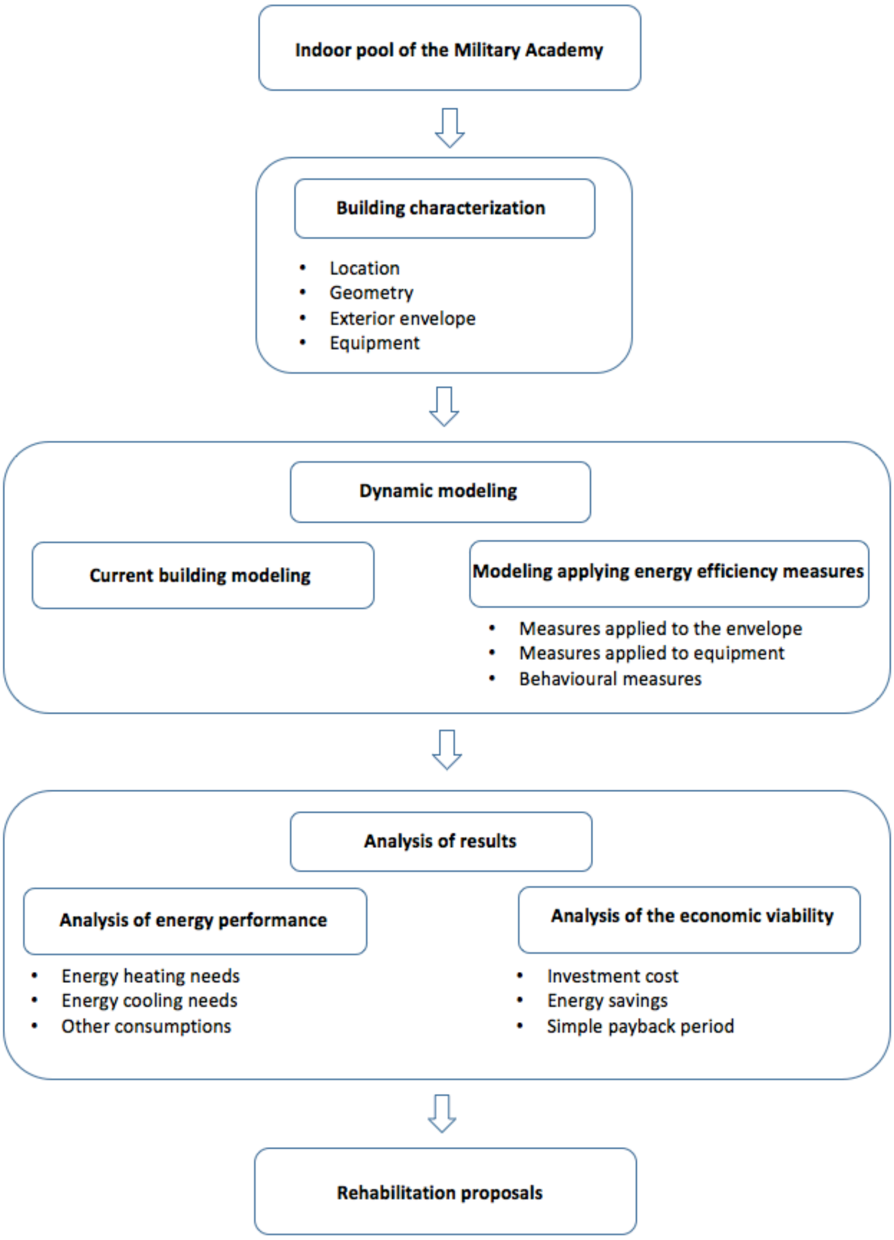

Figure 2.1 – General Methodology of Rehabilitation (scheme produced by the author)

In the characterization of the building we have determined the following data: Location of the indoor pool; geometric survey of the thermal zones; characterization of the constructive solutions of the exterior envelope and of the equipment.

Then, using the HAP simulation software, we performed the modelling of the building in initial conditions (current state of the building) and in the final conditions (building state after the implementation of energy rehabilitation measures).

The next step of the methodology consisted in the analysis of results, which was divided in the analysis of the energy performance (determination of energy heating needs, cooling and other consumption) and the analysis of the economic viability (the cost / benefit of implementation of each measure that is determined by the simple payback period- ratio between the investment cost and energy savings achieved).

Finally, we have defined the rehabilitation improvement proposals.

3 Case Study

3.1 Location

The indoor pool of the Military Academy is a service building that was built in 1986 in Lisbon and is inserted in the Military Academy complex that consists in several infrastructures. In Figure 3.1 it might be verified the location and orientation of the building. The complex of the Military Academy is bounded with an Orange line and the building of the indoor pool with a red line, which is located in the centre of the complex.

Figure 3.1 – Location of the indoor pool of the Military Academy (Satellite image taken from Google Maps, September 15, 2016)

3.2 Building Characterization

The characterization of the building is one of the most important steps in the study methodology, because it defines the actual conditions of the indoor pool of the Military Academy. In this regard, we have made several visits to the site in order to perform the survey and to proceed to a detailed analysis of all relevant aspects for the characterization of the building, since the location of the site; analysis of orientation and sun exposure of building facades; identification and characterization of materials and constructive solutions recommended in the opaque outer envelope (walls, roof, floors and doors) and

not opaque (windows, skylights and glass doors); and the identification and characterization of equipment and interior devices that perform the lighting, domestic hot water heating (DHW), water heating pool (DHP), water pumping, among others.
The envelope of a building is the separation between the outside environment and the interior, which is responsible for high energy exchanges. Therefore, its characterization should be done with accuracy. Table 3.1 shows the values of the heat transfer coefficient, U, of the building elements.

Table 3.1 – Characterization of building elements

Designation		U [W/m².◦C]
Wall	Exterior Wall	1,344
	Interior Wall	1,784
	Wall in contact with the ground	1,320
Floor	Ground floor (Z ≤ 0,5 m)	0,253
	Ground floor (Z ≥ 3,0 m)	0,187
	Interior floor	2,294
Roof	Flat roof (on the main nave)	0,626
	Flat roof (on remaining spaces)	2,801
Glazed areas	Window (with fixed opening system)	3,900
	Window (with opening system flag)	4,300
	Skylight	6,040
Doors	Tempered glass door	5,650
	Metal door (aluminium)	5,880

3.3 Thermodynamic Simulation Software

The software used for modelling the indoor pool was the HAP (Hourly Analysis Program). It is a dynamic simulation tool developed by North American Carrier company, accredited by ASHRAE Standard 140-2007. This thermodynamic simulation software allows you to perform many operations and model / simulate the various systems that make up a thermal area with a speed that is not achieved in the analytical calculation. In addition, most of the simulation software have a pleasant and intuitive graphical interface for the user, containing organized information whom provides a support system that displays information about the procedures to be taken in each modelling step (Carrier - United Technologies, 2016).
Therefore, through the correct input of the data on the software interface, more specifically the data point defined in the proceeding of the building characterization, is achieved a design dynamic model very similar to the actual building.

4 Energy efficiency measures

The efficiency measures analysed in this study are grouped into three categories: energy efficiency measures applied to the outer casing; energy efficiency measures applied to interior systems; and measuring energy efficiency resulting from behavioural changes.

Regarding the implementation of energy efficiency measures applied to the outer surrounding, these consisted of applying exterior thermal insulation (ETICS- External Insulation Composite Systems) with insulation thicknesses of EPS type (Expanded Polystyrene) and XPS (Extruded Polystyrene) 40, 60, 80 and 100 mm in the exterior walls and roof of the indoor pool, respectively; replacement of glazed surfaces with PVC window frames (Polyvinyl Chloride) and double or triple glazing; application of solar reflective films in glazed surfaces.

On the other hand, the energy efficiency measure applied to interior systems is characterized by the replacement of the current lighting system using fluorescent, incandescent tube lamps and sodium vapour high consumption of incandescent power for a lighting system using LED bulbs (Light Emitting Diode) low consumption.

At last, the measure of energy efficiency resulting from behavioural change is defined by changing the operating hours of boilers.

5 Results

5.1 Current energy needs

By modelling the building of the indoor pool of the Military Academy, using the HAP software simulation, the results from the thermodynamic simulation of three categories of annual energy needs were analysed and grouped: heating needs; cooling needs; and other consumptions corresponding to the energy requirements associated with pumping systems, lighting and equipment present in the control cabinet.

Figure 5.1 shows the annual energy needs of the indoor pool of the Military Academy.

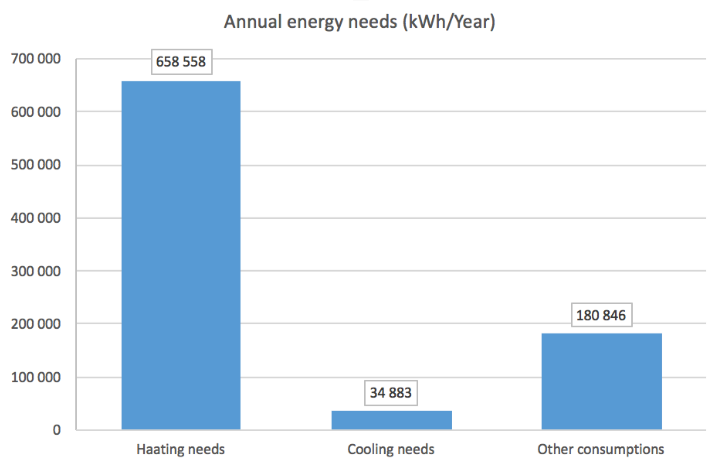

Figure 5.1 – Annual energy needs

The results obtained through the building thermodynamic simulation show that the annual primary energy needs are high, with a total of 874 287 kWh / year, of which approximately 75% correspond to the heating requirements; 4% to cooling requirements and about 21% is relative to the needs associated with the other inputs.

5.2 Validation of the simulation model

Model validation is a widely used procedure when you perform energy analysis using dynamic multizone simulation software, in order to verify and / or calibrate the model used.

To validate the simulation model it was necessary to compare the actual values of the consumption of electricity and fuel in a year (determined in situ) with the results from the simulation of the base model. The variation between the actual consumption and the simulation results should not be greater than 10%.

Table 5.1 shows the error associated between the consumption of electricity and fuel, obtained experimentally and through simulation.

Table 5.1 – Validation of the simulation model

Designation		Value
Electricity consumption - Real	[kWh/year]	170 942
Electricity consumption - Simulation	[kWh/year]	180 846
	Error [%]	-5,79
Heating oil consumption - Real	[liters/year]	72 000
Heating oil consumption - Simulation	[liters/year]	75 910
	Error [%]	-5,43

As it can be seen in Table 5.1, the simulation model is valid, since the errors associated between the consumption obtained experimentally and by simulation are less than 10%.

5.3 Analysis of the economic viability of the energy efficiency proposals

This study was performed combining the various energy efficiency measures constituting four proposals for implementation. Each proposed implementation features: a rehabilitation measure that consists in the adoption of thermal insulation EPS applied to exterior walls; a rehabilitation measure consisting in the implementation of XPS insulation applied to the roof; the measure of glazed areas with PVC window frames and triple glazing; the measure to replace the current lighting system for a LED lighting system; and a change in measurement of operating hours of boilers.

Therefore, in each proposal to implement the solutions that refer to the adoption of thermal insulation EPS and XPS type, are being analysed for thickness of 40 mm, 60 mm, 80 mm and 100 mm while the remaining three rehabilitation measures were previously chosen because they have a good energy performance.

In the Table 5.2 is described the four rehabilitation proposals.

Table 5.2 – Framework Summary: Rehabilitation Proposals

	Rehabilitation Proposals
Proposal 1	Thermal insulation application EPS of 40 mm on the outer walls Thermal insulation application XPS 40 mm on the flat roof Replacement and application of glazed surfaces of triple-glazed with PVC window frames Replacement and application of lighting system with LED Technology Changing the operating hours of boilers
Proposal 2	Thermal insulation application EPS of 60 mm on the outer walls Thermal insulation application XPS 60 mm on the flat roof Replacement and application of glazed surfaces of triple-glazed with PVC window frames Replacement and application of lighting system with LED Technology Changing the operating hours of boilers
Proposal 3	Thermal insulation application EPS of 80 mm on the outer walls Thermal insulation application XPS 80 mm on the flat roof Replacement and application of glazed surfaces of triple-glazed with PVC window frames Replacement and application of lighting system with LED Technology Changing the operating hours of boilers
Proposal 4	Thermal insulation application EPS of 100 mm on the outer walls Thermal insulation application XPS 100 mm on the flat roof Replacement and application of glazed surfaces of triple-glazed with PVC window frames Replacement and application of lighting system with LED Technology Changing the operating hours of boilers

Replacement and application of glazed surfaces of triple-glazed with PVC window frames Replacement and application of lighting system with LED Technology Changing the operating hours of boilers.

In the Table 5.3, it can be seen, for each proposed rehabilitation, the results of changes in global demand due to the simulation of the base model; annual savings in electricity and heating oil; the investment cost of implementing the proposals and the simple payback period (PRS) that defines if a proposal is economically viable.

Table 5.3 – Framework Summary: Rehabilitation Proposal.

Designation	Variation of global needs owing to the base de simulation [kWh / year]	Savings Electricity [€/year]	Savings Diesel Heating [€/year]	Total savings [€ / year]	Investment cost [€]	Payback Period [years]
Proposal 1	-289 996	2 320	25 338	27 658	66 344	2,4
Proposal 2	-292 313	2 378	25 493	27 872	73 667	2,6
Proposal 3	-293 799	2 415	25 593	28 010	80 244	2,9
Proposal 4	-294 862	2 444	25 663	28 107	95 256	3,4

We can verified, by looking at Table 5.3 that all four rehabilitation proposals present an acceptable economic viability, as the simple payback period of each bid is below the regulatory maximum in Order No. 15793-L / 2013 (3 December 2013) which states that the measures that are conditional on the economic viability, are of mandatory implementation when the respective study demonstrates that there are no obvious constraints or technical limitations, legal or administrative installation and that the PRS is equal to or less than 8 years.

Overall, the PRS of the four proposals analysed are substantially reduced because of the economic savings from changing the operating hours of boilers totalling about 85% to 90% of total savings and, as they present no investment cost associate, the return is immediate. Therefore, only 10% to 15% of total economic savings are related to the application of thermal insulation exterior walls; coverage; replacement of glazed surfaces and replacement of the lighting system.

If it were not possible to implement the change in hours of operation of the boilers, the PRS of the four proposals analysed would increase significantly for the period from 20 years to 26 years, which would not allow its implementation in a perspective of cost benefit.

The implementation of the proposal 1, presents a PRS of 2,4 years, resulting in an investment cost of € 66 344 and annual financial savings of € 27 658, which stems from the reduction of global energy needs in 289 996 kWh / year compared to current consumption.

Regarding the implementation of the proposal 2 what differs from the proposal one is the increasing of the thickness of insulation EPS and XPS to 60 mm, which provides a higher performance and comfort of the environment inside the indoor despite annual economic savings increase € 214 from the previous measurement, the cost associated with investment increases about € 7 323, resulting in a PRS 2,6 years.

The proposals 3 and 4 presents PRS 2,9 and 3,4 years, which shows an increase PRS caused by the steeper rise of variations in investment costs compared with the gradual and small increase in economic savings.

In short, the adoption of any of the four proposals presented in Table 5.3 is economically viable, ensuring an effective energy performance and a more efficient thermal comfort, given the current state of the indoor pool of the Military Academy.

6 Conclusions and future developments

This master's thesis consisted in the study for the implementation of energy efficiency measures to improve the conditions of a sports infrastructure belonging to the Portuguese Army, and in particular, the building of the indoor pool of the Military Academy.

Therefore, after the identification of the problem, it was requested by the Military Academy, the study of the implementation of the rehabilitation measures in the indoor pool which ultimate goal was to reduce energy consumption and improve the thermal and energy performances of the indoor pool.

For such purpose, various inspections were performed to the site in order to proceed to the lifting and to made detailed analysis of all relevant aspects to characterize the building.

These data were then entered into the dynamic simulation software HAP and analysed the results of the base of the building modelling.

In this regard we have analysed several rehabilitation measures that have been applied to the outdoor environment, to internal systems and behavioural changes, and then combined with each other, resulting in the final four rehabilitation proposals.
Due to the incorporation of alternative measures of lighting and changing the hours of operation of the boiler in conjunction with the application of external thermal insulation in the walls and roof of the envelope and replacement of glazed surfaces, the simple payback period ranges from 2, 4 to 3.4 years, which can be translate into total investment costs between € 66 344 to € 95 256 and energy savings of € 27 658 to € 28 107.
Therefore, the adoption of any of the four energy rehabilitation proposals is economically viable, ensuring effective energy performance and a more efficient thermal comfort, given the current state of the indoor pool of the Military Academy.
It should be noted that the choice of the type of intervention depends solely on the consumer's decision, since he decides whether to make an economically more advantageous rehabilitation intervention or to present a more efficient energy performance.
As future prospects we suggest the study and application of energy efficiency measures based on ideology "nZEB - Nearly Zero Energy Buildings", whose main objective is based on the reduction of energy consumption of a building to values close to zero. For this purpose, we can weigh the projection of a central of photovoltaic panels; the replacement of heating oil boilers with biomass boilers; the implementation of devices that aimed increasing the performance and efficiency of equipment, such as electronic variable speed drives, batteries, capacitors, crepuscular lighting sensors, air conditioning and ventilation systems, among others. Other aspects that can be analysed in detail are the existing heat exchange between the outside environment and the interior, to determine the planar and linear thermal bridges or heat losses associated with swimming tank.

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