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Efficient space heating in a Portuguese Public Building Replacement of a Liquefied Petroleum Gas Boiler by Heat Pump

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Abstract. Buildings are responsible for approximately 40% of the total world annual energy consumption, putting them among the largest end-use sectors. Especially important has been the increase of energy consumption in HVAC systems, which has become essential in the demand for thermal comfort. The introduction and recent amendments to the European Energy Performance of Buildings Directive demonstrate growing recognition among the policy community of the importance of energy efficiency in the building sector. The implementation of energy efficient measures, without compromising comfort level of building's occupants, can significantly reduce energy consumption in buildings, the energy bills and the correspondent greenhouse gas emissions. In the building sector there are several energy conservation measures that can be implemented to reduce building energy consumption, namely four main areas: space heating, space cooling, domestic hot water and artificial lighting. This paper presents a simple case study used to compare an efficient electric heat pump with a conventional system for a public building space heating purposes. The study has been performed using two software tools: *Cype* and *EnergyPlus*.

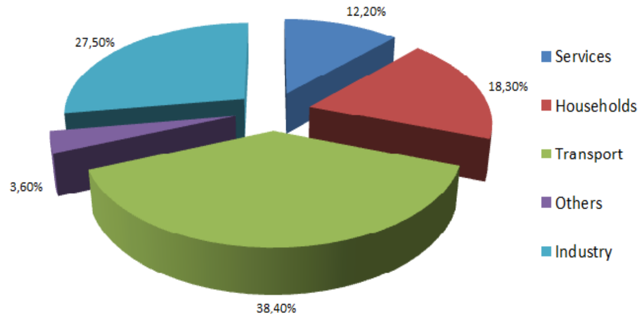
Key words

Building energy efficiency, Heat pumps, Space heating, Boilers

1. Introduction

The contribution of the building sector towards global energy consumption has been increasing and nowadays buildings (households and services) account for 40 % of total energy consumption in the European Union (EU) and are an equally important source of CO_2 emissions. The breakdown of final energy consumption by sector during 2009, showed that transport and industry consume more than half of the total final energy in the EU, while a quarter of final energy is consumed by households [1].

In Portugal, during 2009, the building sector was responsible for more than 30% of the total consumption of final energy (18.3 % in households and 12.2% in services) [2] - see in Figure 1 the breakdown of final energy consumption by sector.



Source: DGEG [2]
Fig. 1. Final energy consumption by sector

The improvement of the energy efficiency in buildings has become a prime objective and an essential instrument in the energy policies at regional, national and international levels, to ensure the energy supply in the mid to long term, and to meet the targets stated in the Kyoto Protocol.

The main legislative instrument at EU level to achieve common goals of sustainable development and use of energy resources is the European Directive on the Energy Performance of Buildings (EPBD) (2002/91/EC). Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings. The recast of Directive 2010/31/EU [3] on the Energy Performance of Buildings, amending Directive 2002/91/EC, introduces for the first time a European-wide definition of 'nearly zero energy buildings'. Up until now, only a handful of Member States had definitions for low energy/plus energy or zero carbon buildings, and these were all different. The recast introduces for the first time a European-wide definition of nearly zero energy buildings. Nearly zero energy buildings are now defined in the EPBD as constructions that have a very high energy performance. All Member

States are also required to actively promote buildings in which both carbon dioxide emissions and primary energy use are very low or equal to zero. National plans should be made with clear definitions of these types of buildings and targets for their uptake.

The transposition of the European Directive 2002/91/EC to the Portuguese regulation includes three main laws, which are in force since the 4 April 2006: SCE (National Energy Performance Certification System and Indoor Air Quality in Buildings, law 78/2006, 2006). RSECE (Regulations on HVAC Systems in Buildings - law no 79/2006) and RCCTE (Regulations on Thermal Behaviour of Buildings, law 80/2006)

Energy performance of buildings is a key to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the Greenhouse gases emissions by 2020 and a 20% energy savings by 2020. The International Energy Agency (IEA) has identified the building sector as one of the most cost-effective sectors for reducing energy consumption [4].

To achieve the objective set by European Union to reduce the energy consumption of buildings by the year 2020, effective measures for increasing energy efficiency have to be implemented.

The promotion of Energy Efficiency is one of the main axis in which the main political guidelines and measures to the energy sector defined by the new National Strategy for Energy (ENE 2020) are based [5]. ENE 2020 aims at promoting energy efficiency by targeting a 20% reduction in final energy consumption by 2020, based on a set of measures, as well as promoting innovative projects, namely by the optimization of public lighting models and the energy management of public, residential and services buildings.

In public buildings, the implementation of energy efficient measures can significantly reduce energy consumption, the energy bill and greenhouse gas emissions, while maintaining or improving human comfort, health and security. In the building sector there are several energy conservation measures that can be implemented to reduce building energy consumption, namely four main areas: space heating, space cooling, domestic hot water and artificial lighting.

This paper presents a simple case study used to compare an efficient electric heat pump with a conventional system for a public building space heating purposes. The building under study is a Departmental building from the College of Engineering of Coimbra and the study has been performed using two software tools: *Cype* [6] and *EnergyPlus* [7] for obtained building's thermal loads and thermal energy demand, respectively.

2. Space heating technologies

There are several technologies for space heating. However, here are only referred the two technologies involved in the study: Liquefied Petroleum Gas boilers and heat pumps.

A. LPG Boiler

The Liquefied Petroleum Gas (LPG) boiler is the device where propane gas is burned. Through a heat exchanger, the heat that results from the combustion is transferred to the water that circulates around the heating system. This one, transfers the heat to the space at a lower temperature. When the water absorbs enough heat, it flows through the installation to the end-points, which can be radiators installed in the space to heat as shown in Figure 6 (section 3 – Case study).

Boiler performance is based on the efficiency of heat transfer and highly dependent on boiler size/output and emitter size/output. To achieve a good performance of the installation it is recommended to keep controlled pressure values and a good isolation [8].

B. Heat Pump

A heat pump is an electrical device that extracts heat from one place and transfers it to another. Heat pumps for heating and cooling buildings are described by the medium from which they extract energy (air, water or ground), the heat transport medium they use (air or water) and the service they provide (cooling, space heating and/or water heating) [9].

Heat pumps for heating and cooling buildings can be divided into four main categories depending on their operational function and needs. The categories include: (1) heating-only heat pumps, providing space heating and/or water heating; (2) heating and cooling heat pumps, providing both space heating and cooling; (3) integrated heat pump systems, providing space heating, cooling, water heating and sometimes exhaust air heat recovery and (4) heat pump water heaters, fully dedicated to water heating [10].

The heat pump is not a new technology. Heat pump has evolved to become a mature technology over the past two decades. However, it is not applied as widely as it should or could be. Initial costs, system design and integration remain to be challenging problems, since few major vendors of refrigeration systems offer large-scale heat pumps [10].

Heat pumps are highly efficient, although their overall primary energy efficiency depends on the efficiency of electricity production (or other energy source) they use [9]. The performance of the heat pump is designated coefficient of performance (COP). COP is a measure of a heat pump's efficiency and it is determined by dividing the energy output of the heat pump by the electrical energy needed to run the heat pump, at a specific temperature. The higher the COP, the more efficient the heat pumps. This number is comparable to the steady-state efficiency of oil- and gas-fired furnaces.

Electrically driven heat pumps achieve good efficiencies for space heating. The use of electricity for heat pump operation is clearly more efficient than direct electric space heating [11].

3. Case Study

The main objective of this study is the comparison of an efficient electric heat pump with a conventional system for a public building space heating purposes. The public building is a Departmental building from the College of Engineering of Coimbra, in Portugal. The study has been performed using two software tools: *Cype* and *EnergyPlus* for obtained building's thermal loads and thermal energy demand, respectively.

A. Building Characterization

With an area of about 2341 square meters, the school is a three floor building, as illustrated in Figure 2. This area involves classrooms, several laboratories, offices, computer rooms, administrative services, sanitary facilities and circulation spaces.

The building is a reinforced concrete structure with reinforced reticular floor slabs. The exterior walls are double brick construction with a 5cm or 6cm air-box, insulated with extruded polystyrene. The interior walls are 11cm thick brick construction. The coverage of the building consists of two aluminium plates (interior and exterior) with 2cm thick each and insulated with a 5cm with extruded polystyrene. Sills and thresholds are in natural stone with white lacquered aluminium frames and double glazing.

Fig.2. Main façade of the departmental building.

B. Thermal loads calculation

To calculate the thermal loads with the software *Cype*, the building has been designed, taking into account the construction parameters, location and building orientation. Figure 3 shows a 3D view of the building obtained with *Cype* after inserting all these parameters.

The interior (compartments) of the Ground Floor of the building, obtained with *Cype*, is presented in Figure 4.

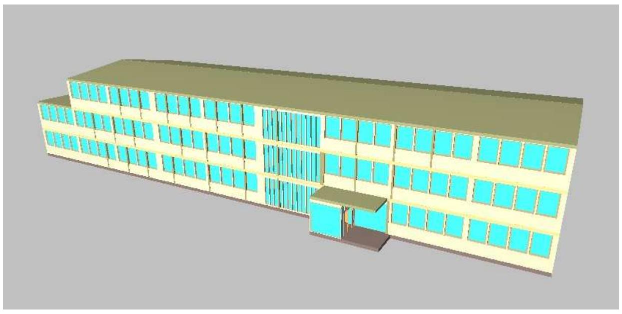


Fig.3. A 3D view of the building obtained with *Cype*

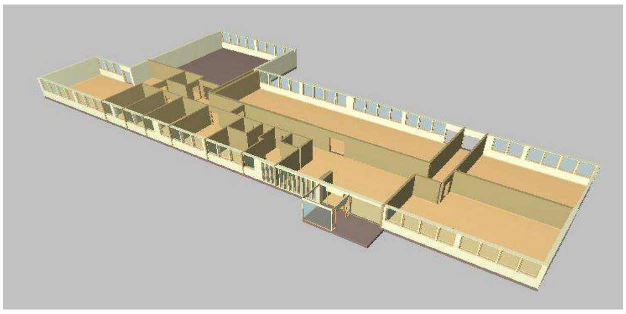


Fig.4. The interior of the Ground Floor obtained with *Cype*

The simulation with software *Cype* allowed obtaining a total power for heating of approximately 167 kW. Applying a safety factor of 20%, we can conclude that to meet the building's heating requirements it is necessary to install a power of about 200 kW.

C. Energy needs calculation

The exportation of the 3D plants to *EnergyPlus* (see Figure 5) allowed obtaining the building's energy needs, according to the pre-defined whether parameters for the city of Coimbra.

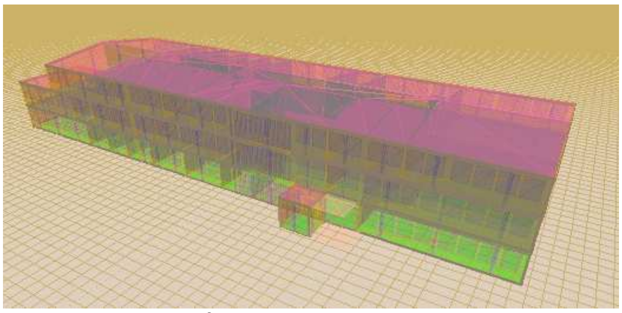


Fig.5. Exportation of the 3D plants to *EnergyPlus*.

The results from the simulation are present in a monthly basis in Table I.

Table I. – Energy Needs

Space	Area (m^2)	Months (kWh/m^2)												Total (kWh/m^2)
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
DEE	2341.76	7.99	4.48	3.55	2.20	0.67	0.01	-	0.00	-	0.25	4.06	4.94	28.13

From the analysis of the values presented in Table I, it appears that for the months of May to October the energy requirements for heating are very few or non-existent, while November to March are the months with greater needs for heating.

The nominal energy needed is determined by the formula (1).

$$E_n = 28{,}13 \times 2341{,}76 = 65873{,}7\ kWh/year \quad (1)$$

D. Performance comparison

Once we consider the same heat distribution system (the existing system – see Figure 6) for the two space heating technologies, the efficiency of the hydronic heat distribution systems was not taken into account for the comparison analysis of boiler and heat pump's performance.

Fig.6. Existing heat distribution system.

1) LPG Boiler.

The performance of the installed LPG boiler is 90.9%, registered in its control panel (see the right side from the Figure 7).

Fig.7. Existing boiler and control panel.

Considering for the LPG the price of 1.505 € per kg and a greenhouse gas emission factor of 63 kgCO2e/GJ [12], we obtain for annual values of consumption, costs and greenhouse gas emissions, respectively: 5591.7 kg; 8371.2 €; 16433.7 kgCO2e.

2) Heat Pump.

Heat pump's electricity consumption and indirect greenhouse gas emissions are related with the Coefficient of Performance of the machine.

Figures 8 and 9 depict the variation of electricity consumption, cost, and emissions for different COPs, taking into account the heat pump's operation schedule, the cost per kWh (according to the contract of electricity supply) and the emission factor associated with electricity production of 0,47 kgCO2e/kWh [12].

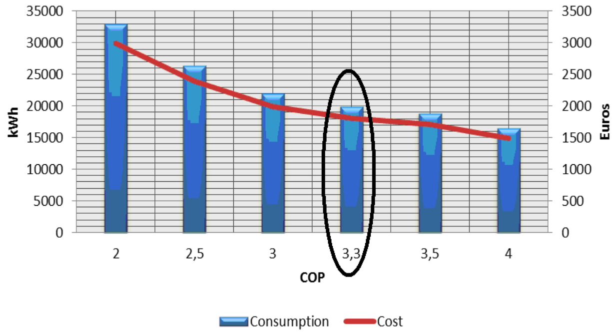


Fig.8. Electricity consumption and cost for different COPs.

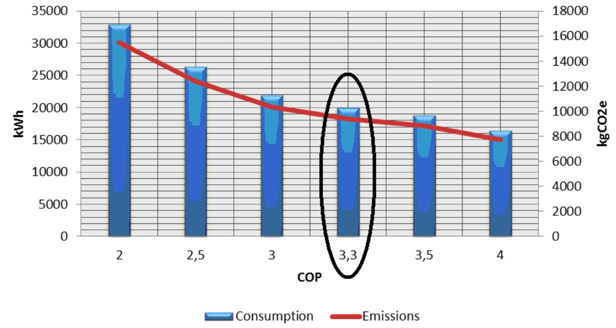


Fig.9. Electricity consumption and GHG emissions for different COPs.

E. *Evaluation of the replacement of the existing LPG Boiler by a Heat Pump*

For replacing existing LPG boiler, a heat pump with three modules (one main module and two auxiliary modules) in a total of 207 kW and with a nominal Coefficient of Performance of 3.3 has been chosen (see figures 8 and 9).

The evaluation of the measure related with the replacement of the existing boiler by a heat pump is presented in Table II. This evaluation took into account the characteristics of new and existing equipment, the investment costs of new heat pump [13], operation and maintenance costs and the operation schedule.

Table II. – LPG boiler replacement

Existing boiler	Performance 90.9%
Heat pump	COP 3.3
Total investment cost	37319.2 €
Annual maintenance costs	Boiler – 300 € Heat pump – 100 €
Annual operation costs	Boiler – 8671.2€ Heat pump – 1922.6 €
Annual cost reduction	6748.6 €
Payback period	5.5 years

4. Conclusions

To achieve the objective set by European Union to reduce the energy consumption of buildings by the year 2020, effective measures for increasing energy efficiency have to be implemented.

In public buildings, the implementation of energy efficient measures can significantly reduce energy consumption, greenhouse gas emissions and the energy bill, without compromising comfort, health and security levels.

Since the energy required for space heating represents a large fraction of the total energy consumption in a building, particular attention is need for this area.

Thermal insulation of buildings will reduce annual energy consumption for space heating, by lowering heat losses through the building's envelope. Energy-efficient equipments for heat production can replace old /obsolete existing boilers to reduce annual energy consumption for space heating, due to increased efficiency of the heat production system.

Highly efficient technologies like heat pumps for cooling and space and water heating will have a great impact in building's energy consumption.

From the comparative analysis of the two systems presented in this study: LPG gas boiler and heat pump, we concluded that the use of heat pump will bring economic and environmental benefits, particularly in terms of direct emissions.

Despite of its high initial cost, heat pump offers a great reduction in building's energy consumption and consequently a great reduction in annual bills, with payback period less than six years for the installation in the building under study.

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