CONTRIBUTION OF HEAT PUMPS TO ENVIRONMENTAL AND ENERGY SUSTAINABILITY

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Introduction

Climate change, namely global warming, is one of the main problems caused by the use of fossil fuels. The energy sector is, undoubtedly, one of the main contributors (75%) to the European Union's (EU) greenhouse gas (GHG) emissions [1].

EU has an energy dependency of around 50% [2], and for the particular case of Portugal, this value is even higher and near to 70% [3]. A high energy dependency leads to a significant country's vulnerability due to the instability of the fossil fuels market (supply and prices) like it has been happening with Ukraine – Russia war.

The building sector assumes an important role not only in the achievement of the EU sustainability targets but also in the decreasing of energy dependency. In 2020, buildings represented 40% [4] and 33% (residential 19,5% and services 13,5%) [5] of the final energy consumption in the EU and in Portugal, respectively.

Since the residential sector in Portugal represents more than two-thirds (70%) of the fossil fuel consumed in buildings [5], this study will be focused on this specific sector, namely the replacement of fossil fuel boilers by efficient heat pumps (HP) for Space Heating (SH) and Domestic Hot Water (DHW) production. HPs are three-to-five times more energy efficient than fossil fuel boilers [6] and use Renewable Energy Sources (RES), as defined in the Directive (EU) 2018/2001.

Objectives

The main focus of this study is to assess the energy and CO_2 emissions savings by switching fossil fuel boilers, used for SH and DHW production, to efficient electric air-water HP, in Portuguese residential buildings.

Methodology

Based on the total final energy consumption (2.75 Mtoe, without considering the RES used by HP), on the energy types breakdown (Figure 1) [5] and on the energy end uses breakdown (Figure 2) [7], in the residential sector for 2020, it was obtained the energy used for SH and DHW production based on fossil fuels boilers, which corresponds to 495 ktoe (Natural Gas (NG) – 40.9%, Liquefied Petroleum Gas (LPG) – 48.6% and Diesel – 10.5%).

To assess the energy and CO_2 emissions savings by switching fossil fuel boilers to HP, the following conditions were considered:

- An energy efficiency of 90% for fossil fuel boilers was used to determine the corresponding useful thermal energy.
- A Seasonal Coefficient Of Performance (SCOP) of 3.2 [8] for HP was used to determine the electricity needed to deliver the same amount of thermal energy.
- A conversion factor of 1.3 [9] was used for electricity primary energy calculations, considering the RES share higher than 50% in the electricity generation in the last 5 years [10].
- A conversion factor of 1 was used for fossil fuels' primary energy calculations.
- For CO_2 emissions calculations from fossil fuel boilers, the emission factors considered were those presented in Portuguese legislation [11] (NG - 2683.7 $kgCO_2$/toe, LPG - 2637.7 $kgCO_2$/toe, Diesel - 3098.2 $kgCO_2$/toe).
- For CO_2 emissions calculations from electricity, an average emission factor of 257 g CO_2/kWh (2988.9 $kgCO_2$/toe) from the last 5 years was used [12].

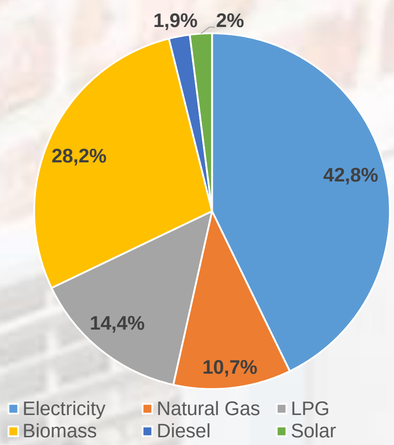

Fig. 1 - Energy breakdown by energy type in the Portuguese Residential Sector (2020).

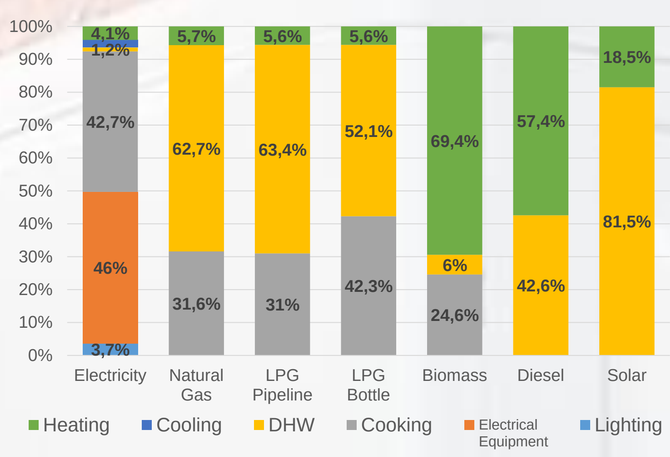

Fig. 2 - Energy breakdown by end uses for each energy type in the Portuguese Residential Sector (2020).

Results and Discussion

As can be observed in Table 1 and Figure 3, this strategy technology replacement allowed a reduction of 63.4% of primary energy and 71.9% of final energy, compared to the initial energy required for SH and DHW based on fossil fuels. These savings correspond to a significant reduction (12.9 %) of the total final energy consumed by the residential sector. At a global level, results show that primary energy consumption decreases by 1.5 %, also contributing directly to the reduction of Portuguese energy dependency. It is also observed that emissions savings are significant, corresponding to 68.9 % of the emissions based on fossil fuels, 41.7 % of the emissions of the residential sector, and 1.6 % of the total Portuguese emissions. In absolute terms, these emissions savings correspond to 922.9 kton CO_2/ year (Figure 4), which is the main contributor to the planet's global warming.

TABLE 1 - Energy and emissions data for SH and DHW and respective savings.

		Final Energy (ktoe)	Primary Energy (ktoe)	Emissions (kton CO_2)
General Data Year 2020 [5, 13]	Total Portugal	15407	20814	57600
	Residential Sector	2756	3109	2215
Current Situation - Fossil fuel boilers for SH+DHW	Natural Gas	202.3	202.3	542.9
	Liquefied Petroleum Gas	240.7	240.7	634.8
	Diesel	52.1	52.1	161.4
	Total Fossil Fuels	495.0	495.0	1339.1
Technology proposed for SH+DHW - Heat Pumps	HP electricity	139.2	181.0	416.2
Energy and CO_2 emissions savings	Savings	355.8	314.0	922.9
	Savings (%)	71.9 %	63.4%	68.9%
	Savings over Residential Sector (%)	12.9 %	10.1%	41.7%
	Savings over total (%)	2.3%	1.5%	1.6%

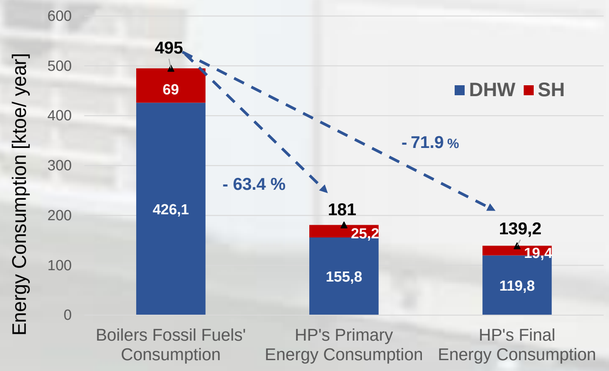

Fig. 3 - Energy savings from replacing fossil fuel boilers by heat pumps for SH and DHW.

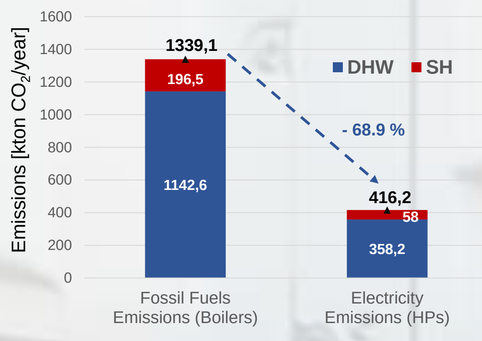

Fig. 4 - GHG emissions reduction from replacing fossil fuel boilers by heat pumps for SH and DHW.

Conclusions

Buildings continue to be a key sector for the achievement of the EU sustainability targets, having a high potential for energy and emissions savings. Besides the improvement of the building envelope to minimize the energy needs, efficient technologies using RES should be installed.

The results achieved in this study demonstrated that heat pumps for SH and DHW powered by electricity with a high share of RES electricity, which is the case of Portugal, bring very important benefits at energy and environmental levels when compared with fossil fuel boilers. Additionally, energy savings also reduce countries energy dependency making them less vulnerable to sudden changes in energy prices and to the risk of supply failure.

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