Abstract

The present dissertation is focused at the energetic and economic analysis of the industrial unit of the company Generis® Farmacêutica in Venda Nova, looking for improvements on the installation in terms of energy efficiency. In order to do that the building was modeled with a dynamic simulation program, HAP from Carrier, that allowed obtaining the energy and economical balance of the whole building for the year of 2013 and so it was estimated that 68% of the energy consumption of the plant was due to the HVAC system. The reports of the results are presented and analyzed in detail and the capacity for improvement using the dynamic simulation model. An application was also developed that allows, with the consumption values of the hot and cold water production plants of any building, perform an economical study for the implementation of any heat pump from the Market to improve the building’s energy efficiency. Using the application and the results of the company’s dynamic simulation the investment and implementation of the 30XWH254 Carrier’s heat pump was studied at the industrial unit. The savings are presented in detail based on the consumptions of natural gas and electricity and the savings on CO2 equivalent emissions and primary energy. It was concluded that with an investment of about 65 thousand Euros in the implementation of the heat pump, would have a small increase in the electrical consumption of the installation, but in return we could save a huge amount of natural gas, which would imply a reduction of approximately 40 thousand Euros in the Generis’ energy bill.

Keywords: Energetic efficiency; Buildings’ modeling; HAP; Heat pumps.
1. Introduction

Global consumption of primary energy has increased drastically and hence the world's dependence on fossil fuels.

In order to reduce this dependence and due to growing concern about the impact of emissions of CO2, NOx and CFCs in the environment, regulations have been created all over the world seeking to impose limitations on emissions and energy consumption. Thus, interest in environmentally friendly technologies and energy efficiency concepts, sustainable development and "green engineering" have been increasing quite significantly to the point of being invested several million Euros in the study and implementation of technologies for the production of either clean energy / renewable energy, either to improve efficiency in energy use.

Knowing that buildings are responsible for 40% of global energy consumption, mainly in electricity, heating, cooling and air conditioning, i.e., in HVAC systems, should be given special attention to the study of technologies to improve energy efficiency in this sector.

The main objective of the present work is to evaluate the energetic and economic impact of the integration of a heat pump at the HVAC system in an industrial unit - the company Generis in Venda Nova. The existing system already has a heating system based on natural gas boiler and a parallel Chilled Water Unit Producer aka chiller. This paper aims to analyze the feasibility of installing a water-water heat pump that transfers energy of the return line chilled water for the hot water circuit.

2. Methodology of analysis

The study was based on the modeling of the mentioned installation using a dynamic simulation model for buildings, the Carrier's HAP. Thereafter, the simulation of the year 2013 was made, and as the HAP still doesn't allow simulations with integration of a heat pump in the existing system for recovering dissipated heat into the chiller, an application was programmed in Visual Basic with capability of receive the data from the simulation and make all calculations relating to the validation of the implementation of a heat pump in the installation.

The application that was created allows to enter the energy delivered and released by the chiller and delivered and released by the boiler during the 8760 hours of the year, ie, the respective 8760 inputs and outputs for the production of heat and cold in the installation. These are the values simulated by the program HAP that enters directly to the table of the application (figure 1).

![Figure 1 – First window of the application to insert data](image-url)
The program also requires the user to enter the COP of the heat pump that is proposed to be implemented (the heat pump 30XWH254 of Carrier) as well as the increase of power that will be requested to the pumps, either in the hot zone, or in cold zone of the heat pump due to the pressure drop in the passage through the condenser and the evaporator, respectively (figure 2).

<table>
<thead>
<tr>
<th>COP</th>
<th>Consumo extra (máximo) da bomba da central quente (kW)</th>
<th>Consumo extra (máximo) da bomba da central fria (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.53</td>
<td>0.559</td>
<td>0.282</td>
</tr>
</tbody>
</table>

*Figure 2 – Second window of the application to insert data*

Entered these data, the program do the hourly calculation, with the heat pump integrated into the plant, and allows to know the saving of natural gas, electricity, Euros, CO$_2$ equivalent emissions and primary energy (toe), the consumption of the heat pump implemented and the time that the chiller and boilers could be stopped.

3. **Installation description and application of the model**

The industrial unit of the study has more than 3200 m$^2$ and is divided into three subunits as shown in figure 3: Production, Packaging; LQC - Laboratory of Quality Control.

*Figure 3 – Representative plant of the two floors of the factory*

The installation has two boilers (figure 4), which produce steam for the production process that goes directly to the factory and to warm water at 60 °C in heat exchangers which in turn feeds the HVAC system. Further the installation has a chiller (figure 5) which supplies cold water at 7°C to the several heat exchangers present in the building and to the HVAC system.
The equipment listed are the main constituents of the HVAC system that feed six air handling units (AHU) that are in operation 24 hours a day and have the following functions:

- Ensure that production temperatures and comfort are maintained with variations of ± 2°C.
- Maintain the relative humidity in most areas of production, packaging and quality control under 50%.
- Supply the air into the installation to ensure that the pressure differences are conducive at the non-contamination of the products, ie relative pressure of approximately 50 Pa in the "clean" chambers and corridors and lower, about 25 Pa, in the "dirty" zones and corridors, so it guides the air to be extracted to the atmosphere. (These pressure differences are checked regularly because of its significance, because weak pressure differences can cause contamination of the product and too high pressure differences can cause headaches to the employees).
- They remove thermal loads for lighting, all electrical equipment and those caused by employees. These values as well as information of air supply are shown in table 1.

<table>
<thead>
<tr>
<th></th>
<th>Area (m²)</th>
<th>Number of employees</th>
<th>Fresh air flow rate (l/s)</th>
<th>Illumination</th>
<th>Electrical equipments</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sensible</td>
</tr>
<tr>
<td>Production</td>
<td>1108,6</td>
<td>12</td>
<td>16.668</td>
<td>37,4</td>
<td>105,3</td>
<td>1,1</td>
</tr>
<tr>
<td>Packaging</td>
<td>973,3</td>
<td>17</td>
<td>9.847</td>
<td>28,8</td>
<td>83,5</td>
<td>1,9</td>
</tr>
<tr>
<td>LQC</td>
<td>317,1</td>
<td>22</td>
<td>2.971</td>
<td>9,9</td>
<td>41,6</td>
<td>1,9</td>
</tr>
</tbody>
</table>

*Table 1 – Flow values and load values per zones*
Some measurements of electricity consumption in sector were made and adjustments in order to calibrate the model. The air flow supply of each AHU was measured with a turbine anemometer and the values were introduced into the modeling program. Measurements were made in the electrical panels in order to find a load factor characteristic of electrical equipment to calibrate their consumption. Occupancy schedules were also inserted of all employees in order to control sensible and latent loads they cause.

4. Analysis of results

4.1. Simulation Results

With the simulation the year 2013 available for analysis and in order to have an idea of the weight that the power consumption of the HVAC system has in the company's energy bill, it was requested to HAP an annual simulation by component (figure 6).

As can be seen in the previous figure, 68.8% of the consumption is due to the HVAC system, so that about half of this value (32.6%) is due to heating, specifically, natural gas consumption in the boilers. These values are quite common in the pharmaceutical industry and validate the idea that the implementation of a heat pump may in fact be a viable investment.

To have a clear understanding of the consumption of the various components throughout the year, not only quantitatively, but also its variation with the weather, we made a detailed study of the annual consumption of the installation disaggregated (figure 7).
Analyzing figure 7 noticed that the consumption of electrical equipment, fans and lighting are practically constant throughout the year, and, as shown earlier, which mainly influences the variation in consumption of the company is the HVAC system, i.e. the needs of heating and cooling which in turn influences the consumption of the pumps.

The consumption for cooling is quite as expected with a small demand in winter and higher in summer, but the heating values obtained trigger some curiosity. In fact the majority of pharmaceutical industries do not need large power for heating in winter, because the industries are heavily insulated by external walls with high thermal resistance and usually have significant internal heat loads, as is the case with this installation. In the summer the heat requirements of the plant are extremely high, this is because the vast majority of the rooms have values of relative humidity below 50% and even 40% in some cases. In the warmer months, while the relative humidity is lower, the absolute humidity is quite higher, i.e., there is much more water vapor per kilogram of air. This is due to the saturation temperature increases and hence the air capacity to retain water vapour. Accordingly, although in percentage the air is closer to saturation it contains much less amounts of water. As in the industrial unit temperature is constant throughout the year, about 22°C ± 2°C, the amount of water in the air will be the same annually to meet the requirements relative humidity inside. Hence the high heat requirements of the HVAC system so it can make the continuous atmospheric air dehumidification.
What may raise some concern is the fact that, in the graph of figure 7, the "Heating" is greater than "Cooling" throughout the year, but it should be taken into account that the values in that figure refer to consumptions so the thermal energy generated for heating and cooling can be compared. These energy values are shown in figure 8, giving a clearer idea of what are the thermal needs of the installation.

![Graph showing annual needs of heating and cooling (kWh/month)](image)

**Figure 8 – Annual needs of heating and cooling (kWh/month)**

4.2. Proposal for Improvement

Based on the simultaneous need for heating and cooling in the same period it is quite evident that the implementation of a heat pump has potential for energy saving.

To choose the heat pump to be proposed the thermal power of the boilers throughout the year was analyzed and it is found that the maximum of this graph is about 240 kW. This is the output heat amount that must be supported by the equipment that will be implemented and therefore, as has been said, we opted for the heat pump Carrier 30XWH254.

Currently in the industry of Generis in Venda Nova, the plant of hot and cold water are independent as illustrated in figure 9, it is proposed the installation of the Carrier's heat pump (Red square in figure 9) in order to integrate it in one scheme a little more complex, but increasing the energy efficiency of the system, reducing costs and emissions.
The heat pump proposed would have two functions.

In the hot side, top of the scheme of Figure 9, the boilers supply steam for the heat exchangers to warm water coming from the installation to 60°C, whereby this water, now heated, go back to the factory and AHU to meet the heat requirements. The proposed heat pump would be to provide heat to the water that comes from the installation by avoiding, whenever possible, the operation of boilers for water heating, saving natural gas, i.e., the HP works simultaneously whenever it has a minimum of load and boilers work complementarily.

In the lower circuit of figure 9, the chiller is cooling the water to 7°C, this water will remove the installation's heat load and then go back to the reservoir to again be cooled by the chiller, and so, the second function of the HP would be to remove heat from the water that comes from the plant, the water become cooler and so it saves power of the chiller.
4.3. Validation of the proposed

The validation of the proposal is made by the programmed application performing the calculations needed to present the savings.

The main objective is clearly reached because the boilers are stopped 74.21% of the year and the remaining time would be in partial operation in favor of stopping the chiller. The values that result from the stop of the equipment in terms of energy savings, costs and decrease of emissions can be obtained in the application created and the information has been summarized in table 2.

<table>
<thead>
<tr>
<th>Saving</th>
<th>Boilers</th>
<th>849.953 kWh of natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chiller</td>
<td>120.527 kWh of electric energy</td>
</tr>
<tr>
<td>Cost Reduction</td>
<td></td>
<td>39.727 Euros</td>
</tr>
<tr>
<td>CO₂ equivalent emissions</td>
<td></td>
<td>135 tons</td>
</tr>
<tr>
<td>Tons of oil equivalent</td>
<td></td>
<td>63.74 toe</td>
</tr>
</tbody>
</table>

Table 2 - Summary of annual costs and savings of the implementation of Carrier’s HP 30XWH254 at Generis’s industrial unit in Venda Nova.

As can be seen in the table, with an increase of 221.518 kWh and a saving of 120.527 kWh of electricity provides a net increase of electricity consumption of 100.991 kWh and saves 849.953 kWh of natural gas resulting in annual savings of almost 40 thousand Euros. It should be reminded that the COP considered for the heat pump is 3.53 what explains that the energy saving of natural gas is (3.53/0.92) 3.83 times larger than the electricity consumption of the heat pump. In addition there has been a reduction of primary energy quite significantly of 63.74 toe and a decrease of 135 tons on CO₂ equivalent emissions. Based on these data was prepared a budget for the investment that would have a payback time of little more than 1 year and a half.
5. Conclusions

During the development of the present study some important conclusions were taken under the theme of energy efficiency.

It was seen that, globally, that there is an urgency at improve the energy use and also that investment and implementation of new technologies to combat this global deficit is undoubtedly a priority.

It was studied and stressed the added value of using modeling and simulation programs in order to face this problem effectively and competently and concluded that these programs, when properly accepted by the industry, will be a significant development in the study and integration of projects to improve energy efficiency.

Based on this thinking, the company's industrial unit of Generis in Venda Nova was modeled as accurately as possible and the results revealed that 68% of the energy was used for acclimatization, i.e., in the HVAC system and half of that value, was only due to burning natural gas for heating. Therefore, there is a great potential for improvement with the introduction of a heat pump.

As the inclusion of a heat pump with a conventional installation with boilers and chillers is not considered in the dynamic simulation program an application was prepared to evaluate the implementation of the heat pump. Based on the predicted heat and cooling requirements the installation of a heat pump was shown to originate annual savings of almost 40,000 Euros. This result was achieved as it is expected that the boilers were able to stop about 74% of the year. The consumption of electricity as an alternative to natural gas originates not only economic and energy savings, as well as a large decrease CO2 equivalent emissions.