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EFFICIENCY, AND ENVIRONMENTAL ASSESSMENT OF GROUND-SOURCE HEAT PUMPS IN INDUSTRIAL BUILDINGS

G. DRAGOMIR[1] **A. BREZEANU**[1] **I. BOIAN**[1]
V. CIOFOAIA[1] **N. IORDAN**[1]

Abstract: *This paper discusses the suitability of heat pump systems into industrial applications and analyses the energy needed by a ground source heat pump system to heat, cool and to produce DHW for a building in Bucharest. The energy used, and thermal comfort factors were monitored for a year. Using these values we were able to determine the energy savings, the GHG emissions and the payback period compared to a hybrid system of fuel-oil heat and electric cooling.*

Key words: *heat pump, greenhouse emission gases, efficiency.*

1. Introduction

Geothermal energy is usually associated with steam extracted from underground and used to produce electric energy. Today, a better and more convenient way to use geothermal energy is usage of the ground-coupled heat pumps (GCHPs) in commercial and residential facilities.

GCHP systems exchange heat with the ground, and maintain a high level of performance even in colder climates. This results in a more efficient energy ussage, this beeing the reason why many countries support this type of equipment [4].

Traditionally, boilers based on fossil fuels (solid, liquid and gaseous) and electrical driven air conditioning systems have been used for heating and for cooling spaces. Heat pumps offer the same comfort level, being more sustainable and having less greenhouse gasses emissions (GHG).

The heat pump systems represent a proven technology, capable of significant energy use savings even in summer peak electrical demand in buildings is reduced.

Usually, in Romania, GCHP have been used in residential area and because of the advantages they bring, and the continuous rise of the energy price for space heating and cooling these systems started to be implemented in comercial and industrial buildings too.

The potential for significant energy savings of GCHP systems results from a lower electricity consumption necessary only for its operation, the main energy use being extracted from the earth.

2. Building and HVAC facilities

The 6669 m^2 building houses offices, truck service, restaurant and training rooms. The mission of the new building is to provide new facilities for trucks servicing, along with dealer activities and technology integration.

[1] Centre “Research Building Facilities”, *Transilvania* University of Braşov.

The new building was especially designed to have low environmental impact by using LED lighting technology, and also heat pump systems.

The building's envelope features exterior walls constructed of insulated panels, achieving additional energy savings. Their overall U-value of 0,48 W/m^{2}K reduces heat losses. The roof is constructed of white EPDM membrane, insulation and concrete, having an overall U-value of 0,28 W/m^{2}K. The exterior windows consist of low-e glazing with a U-value of 1,33 W/m^{2}K.

Fig. 1. *Image of the studied building*

Each of these features is factored into the performance of the building, and is part of a comprehensive system design that provides 56% savings compared to the industrial buildings code's requirements for the envelope.

To meet the low environmental target impact and to comply with the comfort standards, a heat pump system was implemented, and the building was divided into two separate functionality zones:

Zone 1- Service and Warehouse, where heating and cooling are provided by underfloor radiant surfaces.

Zone 2- Offices and Restaurant are serviced by fan coils.

Thermal comfort is met in the building by supplying hot water to the above mentioned separate thermal zones:

A) The first one is served by an industrial radiant surface, made of peroxide cross linked polyethylene pipes 20×2,0 mm mounted on a 20 cm slab. The operating parameters of the system are: flow temperature 50º C, return temperature 40º C, the floor temperature 29,7° C. All these conclude to a 127 W/ m² heat flow transferred to the thermal zone.

The cooling process: flow temperature 17º C, return temperature 20 º C , floor temperature 21,5° C. The designed internal temperature was 26 º C and the specific flux was 29 W/m².

B) The second thermal zone is served by a fancoil system working simultaneously with a ventilation system for fresh air supply.

The energy needed to operate the heating/cooling systems is provided by two ground- water heat pumps Vitocal 300 G Pro-240 kW each, operating in a master-slave system, each of them being equipped with two compressors [7]. The system has been designed for operation temperatures of 50 to 40°C for heating periods, and 12 to 16° C for cooling time. Technologically, the system allows a passive cooling operation, but active cooling is used only when peak loads occur. During transition periods (warm to cold and vice-versa) and according to each zone demand the system can operate simultaneously both on cooling and on heating. To achieve this, and to avoid cycling of the heat pump the system is equipped with two 10,000 liter tanks.

DHW is produced through a 240 kW-plate heat exchanger being connected to the master heat pump, with priority over the heating and cooling procedures.

The primary flow for the heat pumps is achieved with 80 vertical earth loops, 100 meter deep, placed at 6 m from one another and arranged into two fields.For the first field two pieces of equipment have been used simultaneously, considering the drilling of one bore lasts about one day and for the second field only one equipment was used, as can be seen in Figure 2.

Fig. 2. *The drilling process for the vertical earth loops.*

3. Energy efficiency of a heat pump system

The cost efficiency depends on various parameters such as:

-Coefficient of performance (COP)of the heat pump;

-Number of working hours during a year;

-Cost of the investment;

-The cost of the electricity;

-Additional expenses;

Efficiency of a heat pump increases as the annual operating hours are higher and as the coefficient of performance of the heat pump increases. Unfortunately, no general predictions are possible. For this reason, each case must be analyzed separately by comparing costs involved in various heating systems.

The Seasonal Performance Factor, SPF defined as the ratio of heat supplied to the total energy used for the heat pump operation is taking into consideration factors as the variable heating/cooling load, the temperature variation of the source and of the consumer throughout the year. SPF is useful to compare different heat pumps with conventional heating systems such as boilers, in terms of primary energy savings and CO_2 emission reductions.

SPF values are usually lower than the instantaneous COP as results from field measurements. To determine the efficiency of the system we used the data provided by the equipment's internal software as shown in Table 1. During the past heating season, the two heat pumps have provided 1333 MWh energy for space heating, 63MWh energy for DHW and 108 MWh energy for active space cooling, the rest of the cooling load being achieved by means of passive cooling. To obtain a real and concrete efficiency of the heat pump system we compared it with a traditional gas-fired boiler for heating and with a conventional chiller for cooling. The seasonal efficiency of typical fuel gas boilers throughout the heating period is evaluated between 75 and 80 %. Using these data and considering the average price for natural gas of 0.31 Euro/m^3 and 0.15 Euro/kWh for electricity we were able to calculate the savings in thermal energy costs during the year as shown in Figure 3.

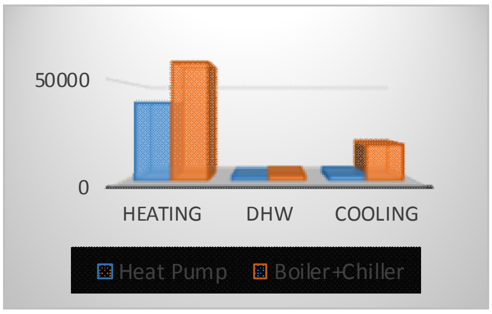

Fig. 3. *Comparison of the cost of heating, cooling, and DHW between heat pump system and the classic one*

The energy costs for the two thermal zones heating during the winter was 34 % lower, and the DHW savings are about 22% lower.

During the summer time when passive cooling was mostly used, a significant reduction was achieved, about 85%. All these lead to a 66.000 Euro savings

Working hours, COP and SPF for the two Vitocal 300 G Pro Heat Pumps Table 1

		Working Hours-Heating	***Working Hours-DHW***	***Working Hours-Cooling***	***COP DHW***	***SPF Heating***
Heat Pump-Master	Compressor 1	3474	245	303	4,4	**5,2**
	Compressor 2	2513		240		
Heat Pump-Slave	Compressor 1	2514		241		
	Compressor 2	**2612**		**201**		

To evaluate whether the lower energy costs of the ground-source heat pump system are worthwhile, we estimated the costs of each system over a period of ten years, assuming that electricity cost is increaseing 5% per year , and gas cost 10% every year.

The difference of the initial investment cost between the heat pump system and a conventional one for this building was about. 300.000 Euro. The recovery can be archived in approx. 8.5 years. The rate of price increase for natural gas is twice the electricity, leading to a recovery of initial investment in a much shorter period of time, approx. 6 years.

4. Greenhouse gas emissions

The drop of the greenhouse gas emissions (GHG) is essential for limiting the global warming. This leads to the replacement of the existing solutions for heating/cooling based on fossil fuels with heat pumps, especially those that use ground as a source of energy [2]. The overall potential for GHG reductions is determined by lifecycle emissions of each energy source, and the efficiency of energy conversion used to meet heating/cooling [1].

The reduction of the greenhouse gases can be determined by using:

$$GHG = C_e \cdot \left(\frac{I_f}{\eta_{sources}} - \frac{I_e}{3{,}6 \cdot COP} \right) \cdot 10^{-3} \quad (1)$$

I_f - the intensity of the greenhouse gases production, specific for every fossil fuel (natural gas 50 kg CO_2/GJ);

COP - coefficient of performance for heating, DHW and cooling.

η_{source}- conventional boiler efficiency (for a gas fired boiler is 0,75 ÷ 0,8)

C_e-energy used for heating, DHW and cooling;

I_e- emission intensity, specific for the efficiency of the electricity production. An important role in reducing GHG is the share of renewables in the electricity production-mix for the heat pump system. In Romania they have a pronounced variation throughout the day, months and year (Figure 4).

GHG emissions by energy type Table 2

Fuel Type	**g_{CO2}/kWh**
Coal	800-1000
Oil	400
Wind	8-32
Photovoltaic	43-73
Biomass	35-99
Nucear	2,8-28
Hydro	0,35-30

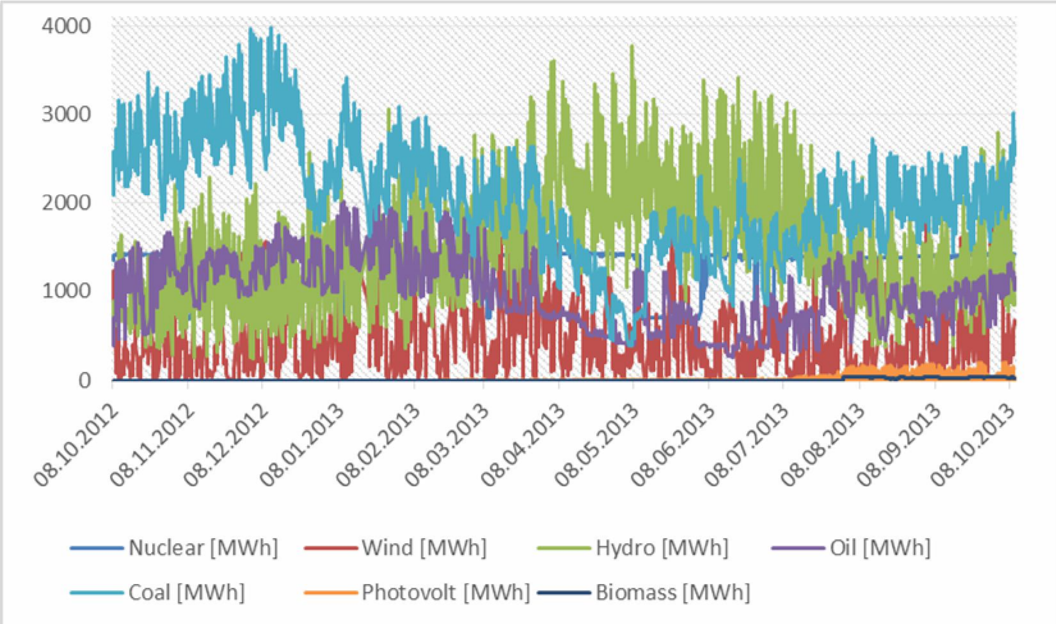

Fig. 4. *Electric energy production in Romania for different production types during the last year* [6]

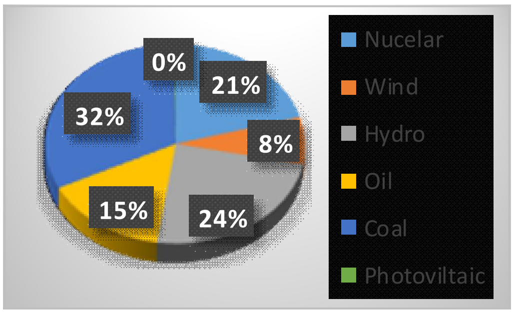

Fig. 5. *Total electricity production by share type (oct.2012-oct.2013).*

All energy systems emit greenhouse gases (GHG) and contribute to anthropogenic climate change. It is now widely recognized that GHG emissions resulting from the use of a particular energy technology need to be quantified over all stages of the technology and its fuel life-cycle [5].

Emission intensity, specific for the efficiency of the electricity production for Romania is 326 g_{CO2}/kWh, the calculation used for the average data of the share type electricity producers. This ratio is shown in Figure 5.

Based on the data obtained by monitoring the heat pump system through last year, it can be expected to reduce greenhouse gas emissions, in comparison to conventional gas boiler and chiller with the values shown in Figure 6.

Due to high values of heat pump's COP and the large share of the total electricity produced in Romania from renewable sources (hydro, photovoltaic and wind), greenhouse gas reduction in our case has a significant value.

Relative to natural gas and heating oil, the threshold of electric CO_2 intensity at which heat pumps become environmentally feasible varies with the efficiency levels of both conventional and GSHP systems.

Unlike the comparison to natural gas or heating oil, emission reductions available through ground source heat pump systems relative to electric heating increase substantially in regions where electricity

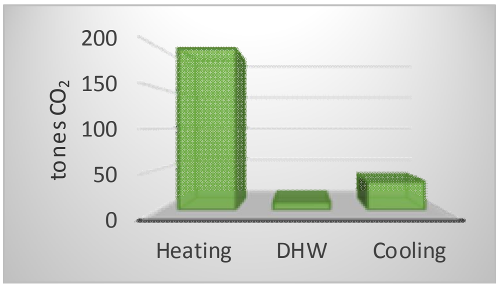

Fig. 6. GHG reduction due to the heat pump usage.

5. Conclusions

Heat pumps are an economical, and sustainable method for energy, independent of fossil fuel price fluctuations, being also a measure of consumption and greenhouse gases emissions reduction.

Energy savings and CO_2 emission reductions that will result from the expansion to industrial area of the heat pump systems are substantial. Improved green electricity generation systems will lead to lower emissions and improved heat pumps (higher SPF) will increase the share of energy taken from environment renewable energy.

Heat pumps have the potential to lower both average and peak energy costs for homeowners and industrial customers.

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